Onions in Tropical Regions (NRI Bulletin No. 35)

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ONIONS IN TROPICAL REGIONS

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ONIONS IN TROPICAL REGIONS

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ABBREVIATIONS

AADF	Associated Agricultural Development Foundation
ABA	abscisic acid
a.i.	active ingredient
BR	bulbing ratio
°C	°Celsius
Ca	calcium
CA	controlled atmosphere
CaO	calcium oxide
cm	centimetre
CO_2	carbon dioxide
CTIFL	Centre Technique Interprofessionel des Fruits et Légumes
cv.	cultivar
d	deci
E	Einstein
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
EMPASC	Empresa Catarinense de Pesquisa Agropecuária
FAO	Food and Agriculture Organization of the United Nations
FUSAGRI	Fundación Servicio para el Agricultor
g	gramme
GA	gibberellic acid
h	hour
ha	hectare
IARI	Indian Agricultural Research Institute
IHR	Institute of Horticultural Research
IIHR	Indian Institute of Horticultural Research
INVUFLEC	Institut National de Vulgarisation pour les Fruits, Légumes et Champignons
K	potassium
K_2O	potassium oxide
kg	kilogramme
LAI	leaf area index
LR	leaf ratio
m	metre
MAFF	Ministry of Agriculture, Fisheries and Food, United Kingdom
MG	Minas Gerais
Mg	magnesium
MgO	magnesium oxide
MH	maleic hydrazide
min	minute

mmho	millimho
N	nitrogen
Na	sodium
NRI	Natural Resources Institute
O	oxygen
ODNRI	Overseas Development Natural Resources Institute (now NRI)
P	phosphorus
PE	Pernambuco
P_2O_5	phosphorus pentoxide
ppm	parts per million
PR	Parana
RS	Rio Grande do Sul
RH	relative humidity
RJ	Rio de Janeiro
s	second
S	Siemen
SC	Santa Catarina
SP	São Paulo
t	tonne
TDRI	Tropical Development and Research Institute (now NRI)
TPI	Tropical Products Institute (now NRI)
UV	ultra violet (radiation)
VAM	vesicular-arbuscular mycorrhiza

INTRODUCTORY NOTES

This study was undertaken by Dr Lesley Currah on a Special Research Contract to the Institute of Horticultural Research, Wellesbourne, United Kingdom, funded by the Natural Resources Institute (NRI), the scientific arm of the Overseas Development Administration, United Kingdom.

The study forms part of a programme to improve onion production and storage in the tropics, co-ordinated by Felicity J. Proctor of the Natural Resources Institute. Questionnaires on onion production and storage were circulated by NRI in 1986-89 and the report was written in February–September 1989.

The views and opinions expressed in this study are those of the authors.

The authors hope that this publication will stimulate interest, and advance understanding of the problems of onion growing and storing in the tropics. Readers are invited to respond with comments, corrections and additional information to Felicity Proctor at NRI, Central Avenue, Chatham Maritime, Chatham, Kent ME4 4TB, United Kingdom.

Bibliographic note: some extension literature is referred to in the text by the acronym of the originating agency and the date of publication, and can be found in the main list of references under this heading. In addition, Appendix 4 also lists extension literature under countries, with the full names of the agencies and the authors of the publications if known.

Whilst this publication was in press, the Yemen Arab Republic, referred to as Yemen (North), and the People's Democratic Republic of Yemen, referred to as Yemen (South), merged. The new state is called the Republic of Yemen.

Summaries

SUMMARY

Onions in tropical regions

The bulletin reviews the particular problems of producing and storing onions in tropical and subtropical regions, presents the results of a survey by questionnaire, draws a series of conclusions and makes recommendations for future work.

Structure of the bulletin

The bulletin is presented in three parts, with five appendices. In Part I, the review section, Chapter 1 outlines the wordwide importance of the onion as a vegetable crop, the quantities involved in world trade, and its food and culinary value. The aims and scope of the study are defined. Chapter 2 describes the main types of short-day onions grown in the tropics and their chief characteristics, including storage behaviour. Chapter 3 outlines the life cycle of the onion and how it responds to environmental stimuli during the vegetative stage of growth. Chapter 4 describes tropical agronomic systems and suggests research topics which might contribute to improving yields. In Chapter 5 the pre-harvest factors which contribute to onion storage quality are discussed; harvesting and drying techniques and onion storage technology at low and high temperatures are described, and the environmental requirements of storage pathogens are defined briefly. Chapter 6 reviews onion seed production in the tropics.

Part II of the bulletin presents the results of the NRI questionnaire. The information is given in the form of tables, summaries of answers to individual questions, and comments from correspondents. The storage performance of cultivars grown and the storage structures used are described.

Part III suggests areas for future research and extension work on onions and shallots in the tropics: the references follow. Appendix 1 contains the English text of the NRI questionnaire; Appendix 2 lists the questionnaire informants and the addresses of the organizations where they work; Appendix 3 lists the code numbers used to identify informants in the tables in Part II, and their names and countries; Appendix 4 is a selected bibliography of extension literature on onions; Appendix 5 is a list of seed firms and the short-day onion cultivars which they sell. The bulletin concludes with an index.

Part I A selective review of the literature

Onions as a world crop

Trade and production figures are cited to show how widespread is the production of onions and the fact that many tropical countries are substantial importers. The food uses and value of onions are indicated. The onion is physiologically a 'long-day' plant, of which some cultivars are adapted to bulb at day-lengths of about 12 hours: these are the so-called 'short-day' onions which can be grown at low latitudes. High-temperature dormancy in onions is discussed, with reference to a seasonal life cycle in which bulbs for storage are grown during the cooler, drier season in the tropics. Techniques developed recently for cold storage of onions in temperate climates are compared with ambient storage in the tropics. The need for information on the onion cultivars which are grown in the tropics and the storage problems encountered there resulted in the NRI survey: this and the other information sources used are described briefly.

The chapter concludes with a diagrammatic scheme of the onion's life cycle, showing what factors can limit normal development at the various stages of growth, and what the consequences are in terms of the plant's reactions. This diagram can be used as a key to the location of discussions of particular onion problems in the bulletin.

The onions grown in the tropics

Onion (*Allium cepa*) cultivars and land-races are described on a regional basis, starting with the Indian region, where many red-brown and white cultivars are grown, and continuing with southern India, Sri Lanka and Indonesia, where multiplier onions and shallots are more widely grown than bulb onion, then moving to the Arabian Peninsula and East Africa, where both red varieties from India and also United States (US) short-day onion cultivars are found. In West and north-east Central Africa a number of mainly red and white, little improved onion races with long-storage properties exist: they are usually named after their localities of origin. The development of the yellow-brown US short-day cultivars of the Bermuda, Early Grano and Granex types from the onions grown in Spain for bulbing when the day-length is approximately 12 hours is described; these high yielding onions are grown in many parts of the tropics, particularly in the Caribbean region, but under ambient storage in the tropics they do not keep well. The Creole group of onions from Louisiana have high dry matter and long dormancy at high temperatures: cv. Red Creole is another cultivar grown widely in the tropics, and has better storage qualities than the previous group. The recent development in Brazil of tropically adapted onions from the Baia Periforme stocks originating in the south of the country is described.

The onion and the environment

The importance of factors other than photoperiod (day-length), such as temperature, nutrition and spacing, in regulating development and bulbing in onions in the tropics is outlined. Examples are given of work which may help to explain phenomena such as premature bulbing, elongated or bottle-neck bulb formation, thick-necking and splitting in onions grown in the tropics. The importance of timely application of nitrogen fertilizer and its role at different stages in the growth of the onion are discussed. Water relations in onions and the effect of salinity in reducing onion growth are reviewed briefly.

Agronomy of onions in the tropics

A traditional growing system in northern Nigeria, a more recent system in Guatemala, and extension work from Venezuela, Brazil and India are described, to exemplify onion production methods in a wide variety of climates, and to indicate the pest and disease problems commonly found in tropical environments. Shallot agronomy in the tropics is reviewed. Seed priming, solarization as a means of improving seed-beds, vesicular-arbuscular mycorrhizae, reduction of transplant pruning and nutritional studies are discussed in terms of their potential for onion yield improvement in the tropics.

Harvesting, drying and storing onions

Pre-harvest factors such as the timing of fertilizer application and of the last irrigation can influence the storage quality of onions. Emphasis is laid on the care needed to avoid damage during lifting, harvesting and drying in the field or under cover, as many storage pathogens enter the bulbs through wounds. Timely harvesting can be used to avoid skin loss from bulbs and the spread of disease inoculum in the field during the final stages of bulb maturation. The genetic factors of high dry-matter content and high pungency are usually associated with good storage quality, while onions of low dry-matter content are normally difficult to store even under ideal conditions. Onions can be dried efficiently by short periods of heating at 25°C or over with air at a relative humidity (RH) below 80%: rapid high-temperature drying (at about 30°C) also suppresses neck rot development, an important factor if cold storage is later used. The environmental requirements for the development of common storage pathogens found in the tropics are briefly described. Storage at either high (> about 25°C) or low (0–2°C) temperatures suppresses bulb sprouting, but control of humidity (RH *ca.* 60–75%) is necessary to prevent the development of fungal disease on bulbs in warm ambient storage. Temperatures of 25°C and above tend to favour the development of soft rot bacteria. Experiments in the tropics on the use of maleic hydrazide to suppress sprouting are reviewed. The modification of ambient storage conditions for onion storage by heated air ventilation to discourage sprouting and to reduce humidity in stores, suggested by recent work in Brazil, is discussed.

Seed production

Methods of seed production reported from the tropics are reviewed and some possible methods of improving seed yields are suggested. Timing of mother-bulb planting so that bulbs receive the necessary low night temperatures during early growth, particularly after warm ambient storage, is emphasized. Pollinators must be provided when large-scale onion seed production is attempted. The maintenance of onion seed viability is particularly difficult in hot damp climates; improvements in the control of seed storage conditions, and efficient drying and packaging are needed if seed quality is to be maintained.

Part II The onion questionnaire results

The questionnaire response and the analysis of results are described. Results of 72 replies from 46 countries showed that most informants considered onions to be a major crop, and that onions are stored every year in many tropical countries. Considerable onion importation by tropical countries was also reported. Information was obtained on seasons of production, cultivars grown and their relative importance, their physical and storage characteristics and yield; sources of seed and planting material; the amount of bolting in the bulb crop; the stage at which onions are harvested; methods of drying; who in the marketing chain stores onions; methods of storage; storage structures; degree of loss during storage; main causes of loss during storage (disease > sprouting > shrivelling > rooting); and other *Allium* crops grown. Correspondents' comments on the onion situation in their countries are quoted. Needs for improved onion seed (and better storing cultivars) and for better storage technology were strongly expressed. Very few informants reported any controlled temperature onion stores in their countries (7), and even fewer, stores with humidity management (3).

The storage performance of the cultivars named by informants is summarized as mean months survival in store and is discussed in relation to the main groups of onions grown in the tropics. Storage structures and methods are described.

Part III Conclusions and recommendations

Genetic resources

Collection and preservation of onions are needed in regions where local seed sources are still used. Development of local material either by selection within existing strains or by crossing with other tropically adapted lines is recommended to create varieties which will be more homogeneous for size, shape and maturity date; selection for good storage quality should also be done. New or improved cultivars must be maintained by continued selection pressure. Desirable characters for inclusion by breeding in onions for the tropics are listed.

Physiology

Field studies on the timing of bulbing in relation to well-recorded weather and day-length data are recommended for new cultivars or new onion-producing areas. Controlled environment studies on tropical varieties of onion should be undertaken where possible. Onion growth response to different natural light intensities also needs study.

Work on the control of bolting also requires careful environmental recording and plant growth measurement in successional trials within production regions; the influence of nitrogenous fertilizer application early in growth on bolting during the vegetative stage should also be studied. The influence of temperature on splitting in onions and the genetic control of this phenomenon need to be better understood.

Agronomy

Full use should be made of the available extension literature on onion growing. Economic constraints on farmers' inputs may be more limiting in many areas than lack of agronomic skills; availability of credit, group purchasing facilities and co-operative marketing should be encouraged where appropriate. When increased inputs are possible, herbicides can be used to reduce hand labour requirements, and pesticides to protect vegetative growth, which must be as uninterrupted as possible to produce well-matured bulbs. Limiting factors to onion growth such as excessive salinity of irrigation water, soil-borne pathogens which attack the roots, and excessively high soil temperatures which may lead to the production of elongated bulbs should be investigated locally. Fertilizer recommendations should also be based on local trial results. Extension work at district level is therefore essential to support onion growers and improve yields.

Innovations such as soil solarization of seed-beds, slow release fertilizer use, and prediction of pest and disease build-up are also of potential benefit and could be tested at a limited range of sites before being more widely recommended. Shallot and multiplier onion agronomy has been little studied and more published work is needed in this area. For existing lines of shallots, tissue culture methods should be used to free them from virus infection and multiply the clean lines for distribution. The use of true seed of shallots and the possibility of producing hybrid shallot seed should be investigated.

Pre-harvest factors affecting onion storage

Onions with long dormancy must be grown if they are expected to survive for months in ambient stores. Traditional long-storing cultivars often lack homogeneity and freedom from doubling and splitting. Genetic improvement by breeding and selection is needed to improve storage quality and yield of onions within the tropics.

Careful regulation of fertilizer timing and irrigation in the later stages of bulbing are needed to ensure good storage quality. Avoidance of pest and disease damage to the foliage, which encourages late resumption of leaf production and hence thick-necking, justifies continuing control measures throughout the growing season; late fungicide treatment may also reduce storage losses by cutting down the level of inoculum on bulbs and should be further studied.

Harvesting and drying

Timing of harvesting must be decided in relation to local weather conditions, but lifting should preferably take place before all the tops of the bulbs have fallen, to encourage drying off without excessive skin loss. Care in all the operations of lifting, topping and transport is essential to avoid mechanical damage to the bulbs which allows pathogens to enter. The events of skin drying and curing are little understood and should be studied at both anatomical and biochemical levels.

Solar driers for drying onions before storage should be investigated further. Length of drying time and the safest temperatures to use in artificial driers need study in relation to different onion genotypes and their physical characteristics, such as skin thickness.

Low-temperature storage

Cold storage in the tropics can prolong the life of onions, if temperatures of 0–2°C can be maintained: the chief objections to its use are that it is expensive to install and run, and needs reliable supplies of power. RH must be < 80%, otherwise rooting is likely to take place, particularly in cultivars of low dormancy, and diseases such as neck rot may develop if latent infection is present. The storage pathogens black mould, basal rot and *Penicillium* fungi and soft rot bacteria should be controlled by low temperatures, so storage losses should be greatly reduced. Problems of condensation on cold-stored bulbs when they are taken out of stores for sale should be solved by arrangements for warming and drying the bulbs.

High-temperature storage

The optimum temperature range for storage of onions using their high-temperature dormancy character needs to be defined for the chief cultivars grown in the tropics. Dormancy temperature may be susceptible to change by selection in onion populations. High-temperature storage is cheap but many storage pathogens can attack bulbs at temperatures of 25°C and over, particularly where the humidity is uncontrolled and ventilation is poor. Studies are needed on the sources of inoculum of the diseases and on their control by chemical means; where the identity of pathogens is uncertain, study by trained pathologists is needed.

Store design

Minimizing water loss from bulbs while maintaining an adequately dry atmosphere requires improved store design. Improvements already being introduced in stores in some parts of the tropics, such as increasing ventilation by using more shelves or layers, forced air circulation, the introduction of heating to reduce humidity in stores and to keep the temperature above the critical level for sprout induction, deserve to be studied in practical experiments; if these methods are successful in reducing storage losses, they should be more widely publicized. More information is needed on a national scale on the economics of onion store construction and use in relation to price fluctuations and the prices of imported onions.

Treatments to prevent sprouting in store

Where maleic hydrazide has been used at effective concentrations and timed correctly, it has given good results in preventing onions sprouting in the tropics; where its use is permitted, it could be valuable particularly for onions for cold storage. It does not prevent pathogen growth at high temperatures. Irradiation affects both sprouting ability and pathogen loading, so it may be of greater utility for ambient stored onions. Work to define irradiation doses appropriate for cultivars adapted to the tropics and assessment of effects on bulb quality may be warranted.

Seed production

Onion cultivar quality could be improved if seed from bolting plants were not saved, and if bolters were never allowed to cross with the seed crop grown from bulbs. Seed production techniques from countries such as India and Brazil could be used more widely within the tropics and information on these methods should be disseminated elsewhere. Efficient pest and disease control in the seed crop is needed to raise seed yields, and fungicide treatment of bulbs for seed production should be developed. The optimum temperatures and duration of bulb vernalization treatments should be established for tropical varieties of onions and shallots; their requirements are likely to differ from those of onions of temperate regions.

The need for simple variety maintenance in the production area is emphasized. Techniques such as roguing in the bulb and seed crop, selection for bulb shape and against doubling and splitting can be used to maintain quality; without attention of this kind, even improved cultivars will deteriorate. Training in seed production techniques may be needed where onion seed production is not traditionally practiced. Pollinators must be provided if seed production is attempted on a large scale.

Information

Sources of information of onion growing and storage are summarized and the need for more extensive and rapid exchange of information between workers in different countries and in different languages is emphasized. It is hoped that this bulletin will promote such interchange, and that it can become the basis for an information network for onions in the tropics.

Suggestions are made for writers on onion topics with the aim of making publications more useful internationally by the inclusion in scientific papers of data on site location, weather and agronomic practices during field trials. The use of the term 'seed' only for true seed, and the standardization of terms for other propagules are recommended.

RESUME

L'oignon dans les régions tropicales

Ce bulletin passe en revue les problèmes particuliers de la production et du stockage des oignons dans les régions tropicales et sub-tropicales, présente les résultats d'une enquête par questionnaire, trace une série de conclusions et formule des recommandations pour du travail ultérieur.

Structure du bulletin

Le bulletin est présenté en trois parties, avec cinq appendices. Dans la partie I, la partie de revue, le chapitre premier indique l'importance mondiale de l'oignon comme culture légumière, les quantités qui figurent dans les échanges mondiaux et sa valeur alimentaire et culinaire. Les buts et la portée de l'étude sont définis. Le chapitre 2 décrit les types principaux d'oignons 'de jours courts' cultivés sous les tropiques et leurs caractéristiques principales, y compris leur comportement en stockage. Le chapitre 3 décrit le cycle vital de l'oignon et comment il répond aux stimulants de l'environnement pendant l'étape végétative de la croissance. Le chapitre 4 décrit des systèmes agronomiques tropicaux et suggère des angles de recherche qui pourraient contribuer à améliorer le rendement. Au chapitre 5, les facteurs prérécolte qui contribuent à la qualité du stockage de l'oignon sont examinés: techniques de récolte et de séchage et technologie du stockage de l'oignon à températures basse et haute et les demandes d'environnement des pathogènes du stockage, y sont brièvement décrites. Le chapitre 6 passe en revue la production de semences d'oignons sous les tropiques.

La partie II du bulletin présente les résultats du questionnaire du NRI. Les informations sont fournies sous la forme de tableaux, de résumés des réponses à des questions individuelles et de commentaires des correspondants. La performance en stockage de cultivars produits et les structures de stockage utilisées sont décrites.

La partie III suggère pour l'avenir des sujets de recherche et de travail de vulgarisation sur les oignons et les échalotes sous les tropiques. L'appendice 1 contient le texte anglais du questionnaire du NRI; l'appendice 2 indique les personnes qui ont fourni des informations en réponse au questionnaire et les adresses des organisations pour lesquelles elles travaillent; l'appendice 3 contient une liste de numéros de codes employés pour identifier les répondants dans les tableaux de la partie II, avec leurs noms et pays; l'appendice 4 est une bibliographie sélectionnée de littérature sur la vulgarisation des oignons; l'appendice 5 est une liste de fermes semencières et des cultivars d'oignons à 'journée courte' qu'elles vendent. Le bulletin contient enfin un index.

Partie I Revue

L'oignon, culture mondiale

Des chiffres des échanges commerciaux et de la production sont cités pour montrer à quel point la production de l'oignon est répandue, ainsi que le fait que bien des pays tropicaux en importent de grosses quantités. Les usages alimentaires et la valeur de l'oignon sont indiqués. L'oignon est physiologiquement une plante 'à journée longue', dont certains cultivars sont adaptés pour bulber à des longueurs de journée d'environ 12 heures: ce sont ce qu'on appelle des oignons 'de jours courts' qui peuvent être cultivés à des latitudes basses. La dormance des oignons à forte température est examinée, en ce qui concerne un cycle vital saisonnier au cours

duquel les bulbes à entreposer sont cultivés pendant la saison plus fraîche et plus sèche sous les tropiques. Les techniques mises récemment au point pour le stockage à froid d'oignons dans les climats tempérés sont comparées avec le stockage ambiant sous les tropiques. C'est en raison du besoin d'informations sur les types d'oignons qui sont cultivés sous les tropiques et sur les problèmes de stockage qui y sont subis que l'enquête du NRI a été entreprise: cette source d'informations et d'autres sont brièvement décrites.

Le chapitre conclut sur un schéma du cycle de vie de l'oignon, indiquant les facteurs qui peuvent limiter le développement normal aux diverses étapes de croissance et quelles en sont les conséquences du point de vue des réactions du plant. Ce diagramme peut servir de clé pour repérer des discussions des différents problèmes sur les oignons dans le bulletin.

Les oignons cultivés sous les tropiques

Les cultivars et les races locales d'oignons (*Allium cepa*) sont décrits sur une base régionale, en commençant par la région des Indes, où l'on exploite bien des cultivars bruns-rouges et blancs et en continuant avec l'Inde du sud, Sri Lanka et l'Indonésie, où les oignons à bulbilles et les échalotes sont plus largement cultivés que les oignons à bulbes, passant ensuite à l'Arabie et à l'Afrique orientale, où l'on trouve tant les variétés rouges de l'Inde que les cultivars d'oignons des Etats-Unis de jours courts. En Afrique de l'ouest et du nord-est, il existe un certain nombre de variétés d'oignons surtout rouges et blanches, peu améliorées, qui se prêtent à un stockage prolongé: elles portent généralement le nom de leur localité d'origine. Le développement de cultivars des Etats-Unis, bruns-jaunes de jours courts des Bermudes, des types Early Grano et Granex à partir d'oignons cultivés en Espagne pour bulber lorsque la longueur de la journée est d'environ 12 heures: cela est décrit. Ces oignons à fort rendement sont cultivés dans bien des parties des tropiques et particulièrement dans la région des Caraïbes, mais ils ne se conservent pas bien lorsqu'ils sont stockés dans l'air ambiant. Le groupe Créole d'oignons de Louisiane ont une forte quantité de matières sèches et une longue dormance à forte température: le cultivar Red Creole est un autre type largement produit sous les tropiques et qui a de meilleures qualités de stockage que ceux du groupe précédent. Le développement récent au Brésil d'oignons adaptés aux tropiques à partir de souches de Baia Periforme, dont l'origine est le sud du pays, est décrit.

L'oignon et l'environnement

Il s'agit de décrire l'importance de facteurs autres que la photopériode (longueur de la journée), par exemple la température, la fertilisation et l'espacement, pour régler le développement et la bulbaison des oignons sous les tropiques. Des exemples sont fournis de travaux qui peuvent aider à expliquer des phénomènes tels que la bulbaison prématurée, la formation de bulbes fusiformes ou à col de bouteille, ou à gros collet et de division des oignons cultivés sous les tropiques. L'importance d'un apport effectué à temps d'engrais azoté et son rôle à différentes étapes de la croissance de l'oignon sont examinés. Le bilan hydrique des oignons et l'effet de la salinité pour réduire leur croissance sont examinés brièvement.

Agronomie des oignons sous les tropiques

L'article décrit un système traditionnel de culture au Nigéria du nord, un système plus récent au Guatémala et des travaux de vulgarisation du Vénézuela, du Brésil et de l'Inde, pour fournir des exemples des méthodes de production d'oignons dans une grande variété de climats et pour indiquer des problèmes d'ennemis et de maladies que l'on trouve couramment dans les environnements tropicaux. Bref coup d'oeil sur l'agronomie de l'échalote sous les tropiques. Traitement des semences; solarisation en vue d'améliorer les planches de semis; mycorhizées vésiculaires-arbusculaires; réduction de la taille de transplantation; et études nutritives: ces aspects sont examinés sous l'angle de leur potentiel pour l'amélioration du rendement des oignons sous les tropiques.

Récolte, séchage et stockage des oignons

Des facteurs prérécolte, comme le moment de l'apport d'engrais et de la dernière irrigation, peuvent influer sur la qualité des oignons en stockage. On insiste sur les soins nécessaires pour éviter de causer des dommages pendant l'arrachage, la récolte et le séchage sur le terrain ou sous couvert, car bien des pathogènes du stockage pénètrent dans les bulbes à travers les lésions. Une récolte opportune peut servir à éviter la perte des tuniques externes des bulbes et la diffusion de l'inoculum de maladie sur le terrain pendant les dernières étapes de la maturation des bulbes. Les facteurs génétiques: une forte teneur en matière sèche et un goût très piquant sont généralement associés à une bonne qualité en stockage, tandis que les oignons qui ont une faible teneur en matière sèche sont normalement difficiles à stocker, même dans des conditions idéales. Les oignons peuvent être séchés efficacement par de brèves périodes de chauffage à 25°C ou davantage, au moyen d'air à une humidité relative inférieure à 80%: un séchage rapide à forte température (à environ 30°C) supprime également le développement de pourriture grise du collet, facteur important si l'on doit ensuite stocker à froid. Les conditions de l'environnement pour le développement de pathogènes communs du stockage qui se trouvent sous les tropiques sont brièvement décrites. Le stockage à des températures soit élevées (> environ 25°C) ou faibles (0-2°C) supprime la formation de pousses mais le contrôle de l'humidité (humidité relative *ca.* 60-75%) est nécessaire pour empêcher le développement de maladies fongiques sur les bulbes dans un stockage ambiant chaud. Des températures de 25°C et au-dessus tendent à favoriser le développement de pourriture bactérienne qui provoque le ramollissement de l'oignon. Des expériences faits sous les tropiques quant à l'usage d'hydrazide maléique pour supprimer la formation de pousses sont examinées. La modification des conditions de stockage ambiant pour le stockage des oignons par ventilation d'air chaud afin de décourager la formation de pousses et de réduire l'humidité dans les magasins, comme l'ont suggéré des travaux récents au Brésil, font également l'objet d'un examen.

Production de semences

Les méthodes de production semencière signalées sous les tropiques sont examinées et des méthodes qui permettraient d'améliorer les rendements semenciers sont suggérées. Les auteurs soulignent l'utilité de planter les bulbes mères au moment opportun, afin qu'ils bénéficient de basses températures nocturnes qui sont nécessaires pendant le début de la croissance, particulièrement après un stockage en air ambiant chaud. Il faut fournir des pollinisateurs lorsqu'on cherche à produire de grandes quantités d'oignons de semences. Le maintien de la viabilité semencière de l'oignon est particulièrement difficile sous les climats chauds et humides: l'amélioration du réglage des conditions de stockage des semences et de l'efficiacité du séchage et de l'emballage sont nécessaires pour le maintien de la qualité des semences.

Partie II Résultats du questionnaire sur les oignons

La réponse au questionnaire et l'analyse des résultats sont décrites. Les résultats de 72 réponses de 46 pays ont montré que la plupart des répondeurs considéraient les oignons comme une importante culture et des oignons sont stockés tous les ans dans bien des pays tropicaux. On a également signalé des importations considérables d'oignons par des pays tropicaux. Des informations ont été obtenues sur les saisons de production, les cultivars utilisés et leur importance relative, leurs caractéristiques physiques et en stockage et leur rendement; les sources de semences et de matériel de plantation; l'importance de la montée en graine dans la récolte de bulbes; le stade de croissance où les oignons sont récoltés; les méthodes de séchage; qui, dans la chaîne de commercialisation stocke des oignons; les méthodes de stockage; les structures de stockage; le degré de pertes pendant le stockage; les causes principales de pertes en stockage (maladie > pousse > rabougrissement > enracinement); et autres cultures de la famille des *Allium*. Les commentaires des correspondants sur la situation des oignons dans leurs pays sont cités. Ils ont vigoureusement proclamé la nécessité d'améliorer les semences d'oignons (et d'obtenir meilleurs cultivars pour le stockage) et d'améliorer la technologie due stockage. Très peu de personnes qui ont répondu ont signalé l'existence dans leurs pays d'entrepôts à températures contrôlées (7) et encore moins d'entrepôts à humidité contrôlée (3).

Le comportement en stockage des cultivars indiqués par les réponses au questionnaire est résumé comme étant la survie pendant un nombre moyen de mois dans des stocks et ce comportement est discuté en fonction des groupes principaux d'oignons cultivés sous les tropiques. Ils décrivent les structures et les méthodes de stockage.

Partie III Conclusions et recommandations

Ressources génétiques

La collecte et la préservation des oignons sont nécessaires dans les régions où l'on continue à se servir des bulbes locaux comme semences. Le développement de matériels locaux, soit par sélection au sein de souches existantes ou par hybridisation avec d'autres lignées adaptées aux tropiques est recommandé pour créer des variétés qui soient plus homogènes quant à la dimension, à la forme et à la date de maturité: la sélection devrait également se faire pour maintenir la qualité en stockage. Des cultivars nouveaux ou améliorés doivent être maintenus par une pression sélective continue. Une liste des caractéristiques désirables qui devraient être incluses pour l'amélioration génétique des oignons pour les tropiques est indiquée.

Physiologie

Des études sur le terrain quant au moment de la bulbaison en fonction des conditions climatiques bien connues et de données sur la longueur de la journée sont recommandées pour les nouveaux cultivars ou pour les zones où la production oignonnière est nouvelle. Des études contrôlées sur l'environnement quant aux variétés tropicales d'oignons devraient être entreprises dans la mesure du possible. La réponse de croissance de l'oignon à différentes intensités de lumière naturelle mérite également d'être étudiée.

Les travaux sur la maîtrise des plants montant à graine comprennent également une étude approfondie des conditions de l'environnement et de la croissance des plantes pendant des essais à dates decalées sur les résultats obtenus dans les régions de production: l'influence sur la formation des hampes florales de l'apport précoce d'engrais azoté pendant le stade végétatif doit également être étudiée. L'influence de la température sur la production de caïeux et le contrôle génétique de ce phénomène méritent d'être mieux compris.

Agronomie

Il faut tirer pleinement parti de la littérature disponible sur la vulgarisation de la culture de l'oignon. Des contraintes économiques sur les intrants des cultivateurs peuvent être plus limites dans certaines régions que le manque de dextérité agronomique: disponibilité des crédits, possibilité d'achats en groupe et de commercialisation coopérative, devraient également être encouragées lorsque cela paraît approprié. Lorsqu'il est possible d'accroître les intrants, on peut utiliser des herbicides pour réduire le travail manuel du sol et des pesticides pour protéger la croissance végétative, qui doit être aussi ininterrompue que possible pour produire des bulbes à bonne maturation. Les facteurs limites de la croissance de l'oignon, comme la salinité excessive de l'eau d'irrigation, des pathogènes contenus dans le sol, qui attaquent les racines et des températures excessives du sol qui peuvent mener à la production de bulbes fusiformes, conviennent d'être etudié localement. Des recommandations sur les engrais doivent également être basées sur des résultats d'essais locaux. Le travail de vulgarisation au niveau du district est donc essentiel pour appuyer des producteurs d'oignons et améliorer leurs rendements.

Des innovations comme la solarisation du sol dans les planches de semis, l'usage d'engrais à dégagement ralenti et la prédiction de l'accumulation d'ennemis et de maladies, présentent également des avantages potentiels et devraient être mis à l'épreuve sur une gamme limitée de sites avant d'être plus largement recommandées. L'agronomie de l'échalote et de l'oignon à bulbilles n'a guère été étudiée et il faudrait publier davantage de travaux à cet égard. En ce qui concerne les lignées existantes d'échalotes, on devrait se servir des méthodes de culture de tissus pour les libérer de l'infection virale et multiplier des lignées saines pour la distribution. L'usage de semence vraie d'échalote et la possibilité de produire des semences d'échalote hybridge devraient également être étudiés.

Facteurs prérécolte qui affectent le stockage des oignons

Les oignons à longue dormance doivent être cultivés si l'on s'attend à ce qu'ils survivent pendant desmois dans des stockages ambiants. Les cultivars traditionnels à long stockage manquent souvent d'homogénéité et sont enclins à doublement internal et au clivage. L'amélioration génétique par la sélection est nécessaire pour améliorer la qualité en stockage et le rendement des oignons sous les tropiques.

La régulation attentive du moment de l'apport d'engrais et de l'irrigation pendant les dernières étapes de la bulbaison sont nécessaires pour assurer une bonne qualité en stockage. La nécessité d'éviter les dégâts causés par les ennemis et les maladies au feuillage, provoquant une reprise tardive de la production foliaire et donc aux gros collets, justifie la prise de mesures de surveillance continue pendant toute la campagne de culture: un traitement fongicide tardif peut également réduire les pertes en stockage en réduisant le niveau d'inoculum sur les bulbes et il convient de l'étudier davantage.

Récolte et séchage

Le moment de la récolte doit être déterminé en fonction des conditions climatiques locales mais l'arrachage doit de préférence se faire avant que toutes les feuilles soient couchées, pour encourager un séchage sans perte excessive des tuniques externes. Il est essentiel de faire avec grand soin toutes les opérations d'arrachage, d'effeuillage et de transport pour éviter les blessures mécaniques des bulbes, qui ouvrent la voie aux pathogènes. Les événements du séchage complet des tuniques extérieures sont trop mal compris et devraient être étudiés au niveau anatomique aussi bien que biochimique.

Les séchoirs solaires pour sécher les oignons avant le stockage devraient faire l'objet d'études ultérieures. La durée du temps de séchage et des températures à recommander pour usage dans des séchoirs artificiels devraient être étudiées davantage en fonctions des différents génotypes d'oignons et de leurs caractéristiques physiques, telles que l'épaisseur de la tunique.

Stockage à faible température

Le stockage à froid sous les tropiques peut prolonger la vie des oignons, si l'on peut maintenir des températures de 0 à 2°C: les principales objections contre son usage sont que ce système est coûteux à installer et à faire fonctionner et qu'il exige une alimentation fiable en énergie électrique. L'humidité relative doit être < 80%, sinon, le racinement risque de se produire, particulièrement chez les cultivars de faible dormance, et des maladies telles que la pourriture du collet peuvent se développer si une infection latente est présente. Les pathogènes de stockage qui provoquent l'*Aspergillus niger*, la fusariose, la pourriture bactérienne et les champignons de la famille *Pénicillium* doivent être maîtrisés par des températures basses, afin de pouvoir réduire sérieusement les pertes en stockage. Les problèmes de condensation sur les bulbes stockés à froid, au moment où on les retire des stocks pour la vente, doivent être résolus en prévoyant le réchauffage et le séchage des bulbes.

Stockage à température élevée

La gamme optimum de températures pour les stockage des oignons en se servant de leur caractéristique de dormance à fortes températures doit être définie pour les cultivars utilisés sous les tropiques. La température de dormance doit être apte à un changement par sélection des populations d'oignons. Le stockage à forte température est meilleur marché mais bien des pathogènes de stockage peuvent attaquer les bulbes à des températures de 25°C et audessus, particulièrement lorsque l'humidité n'est pas contrôlée et que la ventilation est mauvaise. Des études sont nécessaires sur les sources d'inoculum des maladies et sur leur maîtrise par des moyens chimiques: lorsque l'identité des pathogènes n'est pas certaine, il faut que des pathologues expérimentés les étudient.

Conception des entrepôts

Pour réduire au minimum les pertes d'eau des bulbes tout en maintenant une atmosphère assez sèche pour leur convenir, il faut améliorer la conception des entrepôts. Des améliorations déjà introduites dans des entrepôts de certaines parties des tropiques, comme une ventilation accrue en se servant d'un nombre plus important d'étagères ou de clayettes, une circulation d'air sous pression, l'introduction de chauffage pour réduire l'humidité dans les stocks et pour maintenir la température au-dessus du niveau critique pour la formation de pousses, tout cela mérite d'être étudié par des expériences pratiques: si ces méthodes réussissent à réduire les pertes en stockage, il conviendrait de les faire connaître plus largement. Davantage d'informations sont nécessaires à l'échelle nationale quant à l'économie de la construction d'entrepôts d'oignons et quant à leur usage en fonction des fluctuations de prix et du coût des oignons d'importation.

Traitements pour empêcher la formation de pousses en stockage

Lorsqu'on se sert d'hydrazide maléique à des concentrations efficaces et au moment correct, les résultats sont bons pour empêcher la formation de pousses sous les tropiques: lorsque son usage est autorisé,il peut être utile, particulièrement pour les oignons en entrepôt froid. Cela n'empêche pas la croissance des pathogènes à des températures élevées. L'irradiation affecte tant l'aptitude à la germination que la multiplication des pathogènes et elle peut donc être plus utile pour les oignons stockés à température ambiante. Des travaux seraient justifiés pour définir les doses d'irradiation appropriées pour des cultivars adaptés aux tropiques et pour évaluer leurs effets sur la qualité des bulbes.

Production de semences

La qualité des cultivars d'oignons pourrait être améliorée si l'on ne gardait pas les semences des plants montant en graine et si ces plants montant en graine n'étaient jamais laissés faire des hybrides avec la récolte semencière cultivée à partir de bulbes. Les techniques de production semencière de pays comme l'Inde et le Brésil pourraient servir plus largement sous les tropiques et des informations sur ces méthodes devraient être distribuées partout. Un contrôle efficace des ennemis et des maladies est nécessaire pour relever le rendement semencier et il faudrait développer le traitement par fongicide des bulbes destinés à la production semencière. La température optimum et la durée des traitements de vernalisation des bulbes devraient être déterminées pour les variétés tropicales d'oignons et d'échalotes: leurs besoins diffèrent probablement de ceux des oignons des régions tempérées.

Il convient de souligner l'importance d'un simple entretien de variétés dans la zone de production. Des techniques comme l'épurage de la culture à l'étape des bulbes ou de production de semences, la sélection de la forme de bulbes et contre le double-nez et la production de caïeux peuvent servir à maintenir la qualité: si on ne s'en préoccupe pas, même les cultivars améliorés se détérioreront. La formation aux techniques de production semencière pourra être nécessaire lorsque la production semencière n'est pas une pratique traditionnelle. Des pollinisateurs devront être fournis si l'on veut produire sur grande échelle.

Informations

Les sources d'informations sur la culture et le stockage des oignons sont résumées et il est à souligner qu'il faut procéder à des échanges d'informations plus étendus et plus rapides entre les collègues qui travaillent dans des pays différents. Il est à espérer que ce bulletin pourra susciter de tels échanges et qu'il fournira la base d'un réseau d'informations sur les oignons sous les tropiques.

Des suggestions sont faites en vue d'inviter des écrivains sur les questions relatives aux oignons de préparer des publications plus utiles internationalement en y faisant figurer dans les communications scientifiques de données sur l'emplacement, le climat et les façons agronomiques pendant les essais sur le terrain. Il est à recommander de réserver l'usage du terme 'seed' ('graine' en anglais) à la semence vraie et de standardiser les termes pour d'autres propagules.

RESUMEN

Cebollas en regiones tropicales

El boletín pasa revista a problemas específicos relacionados con la producción y almacenamiento de cebollas en regiones tropicales y subtropicales, presentando los resultados de un estudio realizado mediante cuestionario, junto con las conclusiones deducidas y recomendaciones para trabajos futuros.

Estructura del boletín

El boletín se presenta en tres partes, con cinco apéndices. En el Capítulo 1 de la Parte I (parte de revisión), se presentan las líneas generales de la importancia mundial de la cebolla como verdura, cantidades del producto en el mercado mundial y valor culinario y alimenticio del mismo. En este capítulo se definen los objetivos y alcance del estudio. En el Capítulo 2 se presentan los tipos principales de cebollas 'de día corto' cultivadas en los trópicos, junto con sus principales características, entre las que se cuentan su comportamiento en almacenamiento. El Capítulo 3 presenta el ciclo de desarrollo de la cebolla y su respuesta a estímulos ambientales durante su etapa vegetativa de crecimiento. En el Capítulo 4, se describen los sistemas agronómicos tropicales y se sugieren aspectos de investigación que podrían contribuir a una mejora del rendimiento. En el Capítulo 5 se estudian los factores anteriores a la recolección, que contribuyen a la calidad de almacenamiento de la cebolla. Se estudian aquí las técnicas de recolección y secado y se ofrece una descripción de la tecnología de almacenamiento de cebollas a bajas y altas temperaturas, presentándose además una breve definición de los requisitos ambientales de los patógenos quien las atacan durante el almacenamiento. Finalmente, en el Capítulo 6 se pasa revista a la producción de semillas de cebolla en los trópicos.

La Parte II del Boletín se dedica a los resultados del cuestionario producido por el NRI. La información se proporciona en la forma de tablas, resúmenes y respuestas a preguntas individuales y comentarios de los corresponsales. También se describen los resultados de los cultivares desarrollados en almacenamiento y las estructuras de almacenamiento utilizadas.

En la Parte III se sugieren sectores para investigaciones futuras y trabajos de extensión sobre cebollas y chalotes en los trópicos, siguiendo a ello la bibliografía. El Apéndice 1 contiene el texto en inglés del cuestionario del NRI. En el Apéndice 2, se enumeran los informantes del cuestionario y las direcciones de las organizaciones para las que trabajan. En el Apéndice 3 se indican los números de códigos utilizados para la identificación de informantes en las tablas de la Parte II, junto con sus nombres y países. El Apéndice 4 se halla constituido por una bibliografía seleccionada de los trabajos de extensión sobre cebollas. El Apéndice 5 es una lista de compañías semilleras y de los cultivares de cebollas 'de día corto' por ellas vendidos. El Boletín termina con un indice.

Parte I La revista

La cebolla como cultivo mundial

El texto presenta las cifras de producción y comercio para mostrar lo generalizado de la producción de cebollas y apuntar el hecho de que un gran numero de países tropicales son importantes importadores. También se indican los usos y valor alimenticio de las cebollas. Fisiológicamente, la cebolla es una planta de 'día largo', existiendo algunos cultivares adaptados para producción de bulbos con longitudes de día de unas 12 horas. A estas plantas se les ha dado el nombre de cebollas de 'día corto', que pueden ser cultivadas en latitudes bajas. El estudio examina la latencia de las cebollas a altas temperaturas con referencia a un ciclo estacional en el que los bulbos para almacenamiento se cultivan en los trópicos durante la temporada más fresca y seca. También se lleva a cabo una comparación entre las técnicas recientemente desarrolladas para el almacenamiento refrigerado de las cebollas en climas templados y las temperaturas ambiente de los trópicos. El estudio del NRI se debió a la necesidad de adquirir información sobre el tipo de cebolla cultivado en los trópicos y sobre los problemas de almacenamiento encontrados, presentándose una breve descripción de éstas y de otras fuentes informativas utilizadas.

El capítulo concluye con un diagrama del ciclo de la cebolla, presentándose los factores que pueden limitar el desarrollo normal del producto en las distintas etapas de su crecimiento, así como sus consecuencias por cuanto respecta a las reacciones de la planta. Dicho diagrama podrá ser utilizado a manera de clave para la identificación de discusiones sobre problemas espicíficos de las cebollas en el Boletín.

Cebollas cultivadas en los trópicos

Se describen las razas y cultivares de cebollas (*Allium cepa*) de acuerdo con una distribución regional, comenzando con la región del Océano Indico – en donde se producen numerosos cultivares blancos y rojos-marrones – para seguir después con la región meridional de la India, Sri Lanka e Indonesia, en donde se cultivan chalotes y cebollas de multiplicación de manera más generalizada que las cebollas bulbo. A continuación, se examina la situación en Arabia y Africa Oriental, en donde se encuentran variedades rojas procedentes de la India, junto a cultivares de cebollas de día corto procedentes de los Estados Unidos. En las regiones occidental, central y nororiental de Africa, existen diversas razas de cebolla, principalmente rojas y blancas apenas mejoradas, con propiedades de almacenamiento prolongado que, por regla general, reciben el nombre de sus localidades de origen. También se describe el desarrollo de los cultivares amarillos-marrones estadounidenses de día corto de las Bermudas, tipos 'Early Grano' y 'Granex' de las cebollas cultivadas en España para producción de bulbos cuando la longitud del día es de unas 12 horas. Estas cebollas de alto rendimiento se cultivan en multitud de regiones de los trópicos, particularmente en el Caribe, si bien sus características de almacenamiento a temperatura ambiente en los trópicos no son buenas. El grupo de cebollas Creole de Luisiana posee un elevado contenido de materia seca y latencia prolongada a altas temperaturas. La variedad 'Red Creole' es otro cultivar muy generalizado en los tropicos, con mejores características de almacenamiento que el grupo anterior. También se describe el reciente desarrollo en Brasil de cebollas tropicalmente adaptadas procedentes de Bahía Periforme, originarias del sur del país.

La cebolla y el medio ambiente

Se presenta la importancia de factores distintos del fotoperíodo (longitud del día), tales como la temperatura, nutrición y espaciado por cuanto respecta a la regulación del desarrollo y producción de bulbos en la cebolla. También se presentan ejemplos de trabajos que tal vez puedan explicar fenómenos tales como la aparición temprana de bulbos, formación de bulbos alargados o en forma de cuello de botella, o de cuello grueso, y de división en las cebollas desarrolladas en los trópicos. Otro aspecto examinado es la importancia de la aplicación de fertilizantes nitrogenados en el momento adecuado y su papel en las distintas etapas del desarrollo de la cebolla. Finalmente, se pasa brevemente revista a las relaciones del agua en las cebollas y el impacto de la salinidad en la reducción de su desarrollo.

Agronomía de las cebollas en los trópicos

Se presentan un sistema tradicional de desarrollo utilizado en la región septentrional de Nigeria, otro sistema aplicado más recientemente en Guatemala y trabajos de extensión realizados en Venezuela, en Brasil y en la India, a manera de ejemplos de métodos de producción de cebollas en climas diversos y para indicar los problemas de plagas y enfermedades normalmente encontrados en medios ambientales tropicales. También se pasa una breve revista a la agronomía del chalote en los trópicos. Se discuta la preparación de semillas de cebollas; solarización como método de mejora de las camas de siembra; micorrizas vesiculares-arbusculares; reducción de la poda de transplantes; y estudios nutritivos; en relación con su potencial para la mejora del rendimiento de las cosechas en los trópicos.

Recolección, secado y almacenamiento de cebollas

Las características de almacenamiento de la cebolla pueden verse influenciadas por factores de prerrecolección tales como el momento de la aplicación de fertilizantes y del último riego. Se pone un énfasis particular sobre el cuidado requerido para evitar que se produzcan daños durante el levantamiento, recolección y secado en el campo o bajo cubierto, ya que son numerosos los patógenos de almacenamiento que entran en los bulbos por las heridas. Será posible utilizar una recolección en el momento apropiado para evitar pérdida de túnicas en los bulbos y la propagación del inóculo en los campos durante las etapas finales de la maduración de bulbos. Por regla general, los factores genéticos, alto contenido de materia seca y acritud se hallan asociados con buenas características de almacenamiento, mientras que las cebollas con un bajo contenido de materia seca son, por regla general, difíciles de almacenar, aun bajo condiciones ideales. Resulta posible secar eficientemente las cebollas utilizando cortos períodos de calefacción a 25°C en adelante, con una humedad relativa del aire inferior al 80%. La aplicación de un secador rápido a temperaturas elevadas (unos 30°C) contribuye también a eliminar el desarrollo de la podredumbre del cuello, factor de importancia cuando se utiliza ulteriormente el almacenamiento en frío. El trabajo describe brevemente los requisitos ambientales para el desarrollo de patógenos comunes de almacenamiento encontrados en los trópicos. Si bien el almacenamiento a una temperatura elevada (> 25°C, aproximadamente) o baja (0 – 2°C) suprime la germinación de los bulbos, será necesario un control de la humedad

(humedad relativa aproximada de 60–75%) es necesario para impedir el desarrollo de enfermedades fungales en los bulbos bajo condiciones ambientales cálidas de almacenamiento. Temperaturas de 25°C en adelante tienden a favorecer el desarrollo de bacterias productoras de la podredumbre blanda. El trabajo pasa revista a experimentos realizados en los trópicos sobre el empleo de la hidracida del ácido maleico para suprimir la aparición de brotes. También se examina la modificación de las condiciones ambientales de almacenamiento para las cebollas mediante ventilación de aire calentado para impedir la aparición de brotes y reducir la humedad en los almacenes, de acuerdo con recientes trabajos realizados en Brasil.

Producción de semillas

Se lleva a cabo un examen de los métodos de producción de semillas encontrados en los trópicos, junto con posibles métodos de mejorar el rendimiento de la semilla. Se subraya la importancia del momento del plantío de bulbos madre, de manera que los bulbos reciban las bajas temperaturas nocturnas necesarias durante su desarrollo temprano, particularmente después de un almacenamiento en medios ambientales cálidos. En todo intento de producción de semillas de cebolla en gran escala deberá contarse con polinizadores. El mantenimiento de la viabilidad de las semillas de cebolla resulta particularmente difícil en climas cálidos y húmedos, requiriéndose mejoras en el control de las condiciones de almacenamiento de la semilla, junto con un secado y envasado eficientes, para que pueda mantenerse la calidad de las semillas.

Parte II Resultados del cuestionario sobre las cebollas

En esta sección se describen las respuestas al cuestionario y se analizan los resultados obtenidos. Los resultados de 72 respuestas procedentes de 46 países mostraron que la mayor parte de los informantes consideraban que la cebolla era un importante cultivo y que su almacenamiento tiene lugar anualmente en numerosos países tropicales. También se puso de relieve el considerable índice de importación de cebollas por parte de los países tropicales. El cuestionario proporcionó información sobre temporadas de producción, cultivares desarrollados e importancia relativa de los mismos, características físicas, almacenamiento y rendimiento; fuentes de semilla y material de plantío; frecuencia de floración prematura en el cultivo de bulbos; etapa en la que se produce la recolección de la cebolla; métodos de secado; quiénes son los almacenistas de cebolla en la cabena de comercialización; métodos de almacenamiento; estructuras de almacenamiento; grado de pérdida durante el almacenamiento; principales causas de las pérdidas observadas durante el almacenamiento (enfermeded > germinación > desecación > aparición de raíces); y otros cultivos de la familia *Allium*. También se citan los comentarios de los corresponsales sobre la situación de la cebolla en sus países, expresándose enfáticamente la necesidad de mejorar la semilla de la cebolla (y de cultivares más apto para el almacenamiento), junto con una mejora de la tecnología de almacenamiento. Fue muy reducido el número de informantes que indicó la presencia de almacenes de cebollas con temperatura regulada en sus países (7), habiendo sido un número todavía menor quienes comunicaron la existencia de almacenes con gestión de humedad (3).

En esta parte se presenta asimismo un resumen de la situación de los cultivares nombrados por los informantes durante su almacenamiento. Esta información se ofrece a manera de media de los meses de supervivencia en almacén, examinándose los principales grupos de cebollas cultivados en los trópicos. También se describen las estructuras y métodos de almacenamiento.

Parte III Conclusiones y recomendaciones

Recursos genéticos

Se hace necesaria la recolección y preservación de cebollas en regiones en donde siguen utilizándose fuentes locales de semilla. Se recomienda el desarrollo de material local, bien mediante selección dentro de las variedades en existencia o mediante cruce con otras variedades adaptades a los trópicos, con objeto de crear variedades con mayor homegeneidad de tamaño, configuración y fecha de madurez. También debería realizarse su selección con respecto a algunas características de almacenamiento. Se hace imprescindible el mantenimiento de cultivares nuevos o mejorados, mediante una selección continuada. El trabajo enumera características deseables a incluir genéticamente en las cebollas para los trópicos.

Fisiología

Para nuevos cultivares o para nuevas zonas productoras de cebollas se recomienda la realización de estudios sobre el terreno relacionados con el momento de la aparición de los bulbos en relación con información meteorológica y de longitud del día bien registradas. Dentro de lo posible, deberían realizarse estudios ambientales controlados sobre variedades tropicales de cebollas, así como sobre el desarrollo de las cebollas en respuesta a distintas intensidades de luz natural.

Otros trabajos que requieren asimismo datos ambientales cuidadosamente obtenidos se hallan relacionados con la floración prematura y con la medición del desarrollo de las plantas en pruebas sucesivas dentro de las regiones productoras. También debería investigarse la influencia de la aplicación temprana de fertilizantes nitrogenados sobre la aparición de tallos florales durante la etapa vegetativa. Otro aspecto que requiere una mayor comprensión es la influencia de la temperatura sobre la división en las cebollas, así como el control genético de este fenómeno.

Agronomía

Debería aprovecharse al máximo la bibliografía de extensión disponible sobre el cultivo de cebollas. En muchas zonas, las restricciones económicas sobre los ingresos de los agricultores pueden ser un factor límite más importante que la carencia de pericia agronómica, por lo que deberían fomentarse la disponibilidad de crédito, posibilidad de compras en grupo y medidas de comercialización cooperativa, en casos apropiados. En aquellos casos en que mayores ingresos son posibles, podrán utilizarse herbicidas para reducir los requisitos de mano de obra y pesticidas para proteger el desarrollo vegetativo, que deberá ser, en lo posible, ininterrumpido para producir bulbos con buena madurez. Será necesario investigar a nivel local factores límite del crecimiento de las cebollas, tales como una salinidad excesiva del agua de riego, patógenos existentes en la tierra que atacan las raíces y temperaturas del suelo excesivamente elevadas, que pueden resultar en la producción de bulbos alargados. Las recommendaciones relativas a los fertilizantes deberían estar basadas también en resultados de pruebas locales. En consecuencia, se considera como esencial la labor de extensión a nivel de distrito, para apoyar al agricultor dedicado al cultivo de la cebolla y mejorar su rendimiento.

Dados sus posibles beneficios, podrían probarse también en un reducido número de ubicaciones, antes de su empleo más generalizado, innovaciones tales como la solarización de las semilleras, empleo de fertilizantes de acción lenta y predicción de la acumulación de plagas y enfermedades. La agronomía relativa a los chalotes y a las cebollas de multiplicación apenas si ha sido estudiada, requiriéndose mayor bibliografía en este sector. Para variedades de chalotes en existencia, sería necesario utilizar métodos de cultivo de tejido que eliminaran las infecciones virales a que se ven sometidas y multiplicaran las variedades limpias para su distribución. Sería necesario investigar el empleo de semilla auténtica de chalotes y la posibilidad de producir chalotes híbridos.

Factores anteriores a la recolección que afectan el almacenamiento

Por cuanto respecta a los factores anteriores a la recolección que afectan el almacenamiento de la cebolla, será necesario cultivar bulbos con prolongada latencia, cuando se requiera que sobrevivan durante meses en almacenes a temperatura ambiente. A menudo, los cultivares tradicionales con características de almacenamiento prolongadas carecen de homogeneidad y se hallan sometidos a doblaje y división, requiriéndose la introducción de mejoras mediante técnicas fitogenéticas y de selección para mejorar sus características de almacenamiento y rendimiento dentro de los trópicos.

Una regulación cuidadosa del memento de aplicación de fertilizantes y del riego en las etapas finales de la producción de bulbos resultarán en buenas características de almacenamiento. El evitar los daños foliares producidos por las plages y enfermedades, que fomenta la reanudación tardía de la producción de hojas y, en consecuencia, el desarrollo de cuellos gruesos, justifica el mantenimiento de medidas de control durante la entera temporado de desarrollo. Un tratamiento tardío de fungicida podrá reducir también pérdidas de almacenamiento, al disminuir el nivel de inóculo en los bulbos, por lo que deberia ser estudiado más a fondo.

Recolección y secado

El momento oportuno para la recolección deberá decidirse en relación con las condiciones climáticas locales, si bien su levantamiento debería tener lugar, a ser posible, antes de que se hayan caído las hojas de los bulbos, para fomentar su secado sin pérdida excesiva de las túnicas.

Con objeto de evitar lesiones mecánicas en los bulbos, que permitan el ingreso de patógenos, es esencial que todas las operaciones de levantamiento, de cortar las hojas secas y de transporte se realicen con gran cuidado. El proceso del secado de la piel y su 'curado' son poco comprendidos, por lo que deberían ser estudiados a nivel anatómico y bioquímico.

Un punto a investigar más a fondo es el empleo de secadores solares para el secado de cebollas antes de su almacenamiento. Será necesario realizar un estudio de la longitud del tiempo de secado y de las temperaturas más seguras a utilizar con los secadores artificiales, en relación con los distintos genotipos de cebolla y de características físicas de los bulbos, tales como el espesor de la piel.

Almacenamiento hipotérmico

En los trópicos, el almacenamiento refrigerado podrá prolongar la vida de las cebollas, cuando sea posible mantener la temperatura entre 0–2°C. Los principales obstáculos son los costes de instalación y funcionamiento y la necesidad de un suministro energético confiable. La humedad relativa deberá ser de < 80%, ya que, de otro modo, es probable que se produzca la aparición de raíces – particularmente en cultivares con baja latencia – y el desarrollo de enfermedades tales como la pudrición del cuello, cuando exista una infección latente. Dado que el almacenamiento hipotérmico debería controlar micropatógenos de almacenamiento tales como la moho negro, podredumbre basal y *Penicillium*, así como las bacterias productoras de la podredumbre blanda, las pérdidas en almacén deberían quedar considerablemente reducidas. Los problemas presentados por la condensación en los bulbos mantenidos bajo almacenamiento refrigerado, cuando se sacan de almacén para su venta, deberían resolverse mediante el empleo de métodos que permitan su calentamiento y secado.

Almacenamiento a alta temperatura

La gama óptima de temperaturas para el almacenamiento de cebollas utilizando sus características de latencia a alta temperatura deberá ser establecida para los principales cultivares desarrollados en los trópicos. Es posible que la temperatura de latencia sea susceptible a alteración, mediante selección en las poblaciones de cebollas. Si bien el almacenamiento a alta temperatura es económico, son numerosos los patógenos que pueden atacar a la cebolla a temperaturas de 25°C en adelante, particularmente en aquellos casos en que la humedad no se halla regulada y la ventilación es pobre. Se necesitan estudios sobre fuentes de inóculo de las enfermedades y sobre su control por medios químicos. En aquellos casos en que los patógenos no se encuentren claramente identificados, deberá llevarse a cabo su estudio por patólogos especializados.

Diseño de almacenes

La reducción al mínimo de la pérdida de agua en los bulbos, manteniendo al mismo tiempo una atmósfera adecuadamente seca, requiere mejoras en il diseño de los almacenes. Deberán realizarse experimentos prácticos relacionados con las mejoras que se están llevando ya a cabo en almacenes existentes en algunas partes de los trópicos, tales como el aumento de la ventilación mediante el empleo de un mayor número de estantes o capas, circulación forzada de aire, introducción de calefacción para reducir la humedad en los almacenes y para mantener la temperatura por encima del nivel crítico para la inducción de brotes. Caso que estos métodos consigan reducir satisfactoriamente las pérdidas en almacén, debería tratarse de generalizar su uso. Se necesita mayor información a nivel nacional sobre los factores económicos de la construcción de almacenes para cebollas y de su empleo en relación con fluctuaciones de precios y con el coste de las cebollas importadas.

Tratamientos para le prevención de la aparición de brotes en almacén

En aquellos casos en que se ha utilizado la hidracida de ácido maleico en concentraciones eficaces y en el momento apropiado, los resultados obtenidos en la prevención de la aparición de brotes en las cebollas en los trópicos han sido buenos. En aquellos países en que su uso está permitido, su empleo podría ser particularmente valioso para cebollas mantenidas en almacenamiento refrigerado, ya que dicho producto no impide el desarrollo de patógenos a altas temperaturas. Dado que la irradiación afecta no solamente el proceso de aparición de brotes sino la cantidad de patógenos, puede que sea de gran utilidad para cebollas almacenadas a temperatura ambiente. Es posible que se halle justificada la realización de trabajos que permitan definir las dosis de irradiación apropiadas para cultivares adaptados a los trópicos y para la evaluación de su impacto sobre la calidad de los bulbos.

Producción de semilla

La calidad de los cultivares de cebolla podrían mejorarse si no se guardara la semilla procedente de plantas de floración prematura y si no se permitiera que las plantas con floración prematura se crucen con otras producidas a partir de bulbos. Sería posible la extensión de las técnicas de producción de semilla utilizadas en países tales como la India y Brasil dentro de los trópicos, por lo que debería diseminarse información relativa a dichos métodos. Se necesita un control eficaz de plagas y enfermedades en el cultivo para semilla, de manera que sea posible incrementar el rendimiento, debiendo desarrollarse un tratamiento fungicida de bulbos para producción de semillas. Las temperaturas y duración óptimas de los tratamientos de vernalización de bulbos para variedades tropicales de cebollas y chalotes deben establecerse, siendo probable que sus requisitos difieran de los establecidos para las cebollas de los climas templados.

Se subraya la importancia de la necesidad de un sencillo mantenimiento de variedades en la zona de producción, siendo posible el empleo de técnicas tales como le eliminación de bulbos y semillas defectuosos, selección de la configuración de los bulbos y métodos contra el doblaje y división para mantener la calidad. Sin este tipo de cuidados, aun los cultivares mejorados sufrirán deterioro. Es posible que se requiera capacitación en técnicas de producción semillera en aquellos lugares en que la producción de semilla para cebolla no ha sido tradicionalmente practicada. Cuando se intente la producción de semilla en gran escala, será necessario contar con polinizadores.

Información

Se presenta un resumen de fuentes informativas sobre el cultivo y almacenamiento de cebollas y se subraya la necesidad de incrementar y acelerar el intercambio de información entre cuantos trabajan en este sector en distintos países e idiomas. Se espera que este boletín sirva para promover dicho intercambio y que pueda constituir la base para una red informativa sobre la cebolla en los trópicos.

También se presentan sugerencias para escritores sobre materias relacionadas con la cebolla, de manera que sus publicaciones posean una mayor utilidad internacional mediante la inclusión en toda comunicación científica de datos sobre ubicación, condiciones climáticas y prácticas agronómicas durante las pruebas sobre el terreno. Se recomienda el empleo del término 'seed' exclusivamente para semilla auténtica, así como la normalización de términos relativos a otros propágulos.

RESUMO

Cebolas em regiões tropicais

O boletim faz uma revisão dos problemas especiais de produção e armazenagem de cebolas em regiões subtropicais e tropicais, apresenta os resultados de um levantamento por questionário, tira uma séries de conclusões e faz recomendações para trabalhos futuros.

Estrutura do boletim

O boletim é apresentado em três partes com cinco apêndices. Na Parte I, parte de revisão, o Capítulo 1 delineia a importância mundial de cebola como uma cultura vegetal, as quantidades envolvidas no comércio mundial e o seu valor alimentício e culinário. Estão definidos os objetivos e escopo do estudo. O Capítulo 2 descreve os tipos principais de cebolas de 'dia curto' cultivadas nos trópicos e suas principais características inclusive o seu comportamento na armazenagem. O Capítulo 3 delineia o ciclo de vida da cebola e como ela responde aos estímulos ambientais durante o estágio do crescimento vegetativo. O Capítulo 4 descreve os sistemas agronômicos tropicais e propõe as tópicos para pesquisa que podem contribuir para aumentar a produção. No Capítulo 5 são discutidos os fatores de précolheita que contribuem para a formação de boas características para armazenagem da cebola: descrevem-se as técnicas de colheita e secagem, a tecnologia de armazenagem de cebola a temperatures baxias e altas e os requisitos ambientais dos patógenos da armazenagem são definidos resumidamente. O Capítulo 6 faz uma revisão de prdução de sementes de cebolas nos trópicos.

A Parte II do boletim apresenta os resultados do questionário NRI. A informação é dada na forma de tabelas, resumos das respostas às perguntas individuals e os comentários dos correspondentes. São descritos o desempenho das cultivares na armazenagem e as estruturas de armazenagem usadas.

A Parte III propõe os campos para pesquisa futura e trabalhos de extensão com cebolas e cebolinhas nos trópicos: seguem as referências. O Apêndice 1 contém o questionário NRI em inglês; o Apêndice 2 relaciona os informantes do questionário e os endereços das organizaçēs para as quais trabalham; o Apêndice 3 relaciona os números dos códigos usados para identificar os informantes nas tabelas na Parte II, seus nomes e países; o Apêndice 4 é uma bibliografia selecionada de literatura de extensão sobre cebolas; o Apêndice 5 é uma lista das firmas fornecedoras de sementes e as cultivares de 'dia-curto' que vendem. O boletim conclui com un índice.

Parte I Revisão

A cebola como cultura mundial

Citam-se cifras de comércio e produção para mostrar como é difundido o cultivo de cebolas e o fato de muitos paises tropicais serem importadores substanciais. Estão indicados os usos e valor alimentício das cebolas. A cebola é fisiologicamente uma planta de 'longo-dia', sendo umas cultivares adaptadas a formação de bulbos pela duração de umas 12 horas: estas são as chamadas cebolas de 'dia-curto' que podem ser cultivadas em baixas latitudes. Discute-se a dormência das cebolas em altas temperatures com referência a um ciclo de vida sazonal no qual os bulbos para armazenagem são plantados durante a estação mais fria e mais seca nos trópicos. As técnicas desenvolvidas recentemente para armazenagem frigorífica de cebolas em climas temperados são comparadas com as de armazenagem à temperatura ambiental nos trópicos. A necessidade de informações sobre como as cebolas são cultivadas nos trópicos e os problemas lá encontrados com armazenagem resultaram no levantamento NRI: estas e as outras fontes de informações usadas são descritas resumidamente.

O capítulo encerra-se com um diagrama do ciclo de vida da cebola, mostrando quais os fatores que podem limitar o desenvolvimento em vários estágios de crescimento, e quais são as consequência em termos de reação de planta. Este diagrama pode ser usada como uma chave para localizar as discussões de problemas particulares das cebolas no boletim.

Cebolas cultivadas nos trópicos

As cultivares de cebola (*Allium cepa*) e as raças de países são descritas numa base regional, a começar pela região da Índia, onde são cultivadas muitas cultivares vermelho-castanho e branca, e continuando com o Sul da Índia, Sri Lanka e Indonésia, onde o cultivo das cebolas e cebolinhas para multiplicação é mais difundido do que bulbo de cebola, passando, então, para a Arábia e África Oriental, onde ambas as variedades vermelhas da Índia e também a cebola de dia curto americana são encontradas. No Oeste, Nordeste e na região Centro-oriental africana há diversas raças de cebolas pouco melhoradas, principalmente vermelha e branca, com propriedades de longa armazenagem: normalmente recebem o nome dos seus locais de origem. O desenvolvimento das cultivares americanas de dia curto amarelo-castanho dos tipos Bermudas, Early Grano e Granex produzidas de cebolas plantadas na Espanha para a formação de bulbinho quando a duração do dia é de aproximadamente 12 horas está descrito: essas cebolas de alto rendimento são cultivadas em muitas partes dos trópicos, especialmente na região do Caribe, mas sob armazenagem à temperatura ambiente nos trópicos elas não se conservam bem. O grupo de cebolas Creole da Louisiana tem alto teor de matéria seca e longo período de dormência a temperaturas altas: a Red Creole é outra cultivar de cultivo muito difundido nos trópicos e possui melhoes características de armazenagem do que o grupo anterior. Descrevese aqui o desenvolvimento recente no Brasil de cebolas tropicalmente adaptadas derivadas dos estoques Baia Periforme, originados no sul do pais.

A cebola e o ambiente

A importância dos fatores que não sejam o fotoperiodo (duração do dia), tais como temperatura, nutrição e espaçamento para regular o desenvolvimento e a formação de bulbos nas cebolas nos trópicos está delineado. São dados exemplos de trabalhos que podem ajudar a explicar os fenômenos tais como formaçáo prematura de bulbos, formação de bulbos alongados ou pescoço de garrafa, pescoço espesso e divisão em cebolas plantadas nos trópicos. A importância de precisar a época de aplicação de fertilizante de nitrogênio e o seu papel em diferentes estágios do crescimento das cebolas são discutidos. Há uma revisão resumida das relações com a água nas cebolas e o efeito da salinidade na redução do crescimento da cebola.

Agronomia de cebolas nos trópicos

São descritos um sistema tradicional de cultivo no norte da Nigéria, um sistema mais recente na Guatemala e trabalhos de extensão de Venezuela, Brasil e Índia para exemplificar os métodos de produção de cebolas numa grande variedade de climas, e para indicar os problemas de pragas e doenças comumente encontrados em ambientes tropicais. Há uma revisão resumida da agronomia das cebolinhas nos trópicos. Preparação de sementes; solarização como um meio de melhorar os leitos de sementes; micorriza vesicular-arbuscular; redução da poda para transplante; os estudos nutricionais são discutidos em termos do seu potencial para melhoria do rendimento das cebolas nos trópicos.

Colheita, secagem e armazenagem de cebolas

Fatores pré-colheita como época de aplicação dos fertilizantes e da última irrigação podem influenciar as boas características para armazenagem das cebolas. Dá-se ênfase ao cuidado necessário para evitar danos ao arrancar, colheita e secagem no campo ou sob cobertura porque muitos patógenos penetram nos bulbos através das lesões. Fixar a época certa para colheita pode ser utilizada para evitar perdas de casca dos bulbos e a disseminação do inóculo de doenças no campo durante os estágios finais de maturação dos bulbos. Os fatores genéticos, alto teor de matéria seca e alta pungência são normalmente associados às boas características para armazenagam enquanto cebolas de baixo teor de matéria seca são normalmente difíceis de armazenar mesmo sob condições ideais. As cebolas podem ser secadas eficazmente por curtos periódos de aquecimento a 25°C ou acima com o ar a uma umidade relativa abaixo de 80%: secagem rápida a alta temperatura (a cerca de 30°C) também suprime o desenvolvimento da podridão do pescoço, fator importante se for mais tarde usada armazenagem frigorífica. Estão descritos resumidamente os requisitos ambientais para o desenvolvimento de patógenos comuns da armazenagem encontrados nos trópicos. Armazenagem a temperaturas altas (>cerca de 25°C) ou baixa (0-2°C) suprime o brotamento dos bulbos, porém, controle da umidade (Umidade Relativa cerca de 60–75%) é necessário para impedir o desenvolvimento de fungos nos bulbos em armazenagem à temperatura do calor ambiental. Temperatures a 25°C e acima tendem a favorecer o desenvolvimento da bactéria da podridão mole. São revistos os experimentos nos trópicos com hidrazina maléica para suprimir o brotamento dos bulbos. Discute-se ainda a modificação das condições ambientais de armazenagem para armazenagem das cebolas por ventilação a ar quente a fim de impedir o brotamento e reduzir a umidade nos armazéns, sugestão feita por um trabalho recente no Brasil.

Produção de sementes

São revistos os relatórios dos métodos de produção de sementes dos trópicos e sugerem-se alguns métodos proáveis de melhorar os rendimentos das sementes. Dá-se ênfase à fixaçâo da época do plantio do bulbo-mãe de modo que os bulbos recebam as temperaturas noturnas baixas necessárias durante o crescimento inicial especialmente após armazenagem ao calor ambiental. Deven-se fornecer os polinizadores quando-tenta-se uma produção em larga escala de semente de cebola. A viabilidade de conservação da semente de cebola é especialmente difícil em climas quente-úmidos: melhorias no controle de condições de armazenamento de sementes, secagem e ensacagem eficazes são necessárias desejando-se manter a qualidade da semente.

Part II Resultados do questionário sobre cebolas

Estão descritas as respostas do questionário e a análise dos resultados. Os resultados das 72 respostas provenientes de 46 países demonstraram que a maior parte dos informantes consideravam a lavoura de cebolas importante e que as cebolas são armazenadas anualmente em muitos países tropicais. Reportou-se também uma considerável importação de cebolas de países tropicais. Obteve-se informação sobre as estações de produção, cultivares plantadas e sua importância relativa, suas características físicas e de armazenagem e produtividade; fontes de sementes e material para plantação, quantidade de florescência prematura na lavoura de bulbos; estágio no qual as cebolas são colhidas; métodos de secagem; quem armazena cebolas nas redes de comercialização; métodos de armazenagem; estruturas de armazenagem; grau de perda durante a armazenagem; causas principais de perdas durante a armazenagem (doenças> brotação> murcha> enraizamento) e outras lavouras de família *Allium* cultivadas. Os comentários dos correspondentes sobre a situação da cebola nos seus própios países estão citados. A necessidade de melhorar a semente de cebola (e melhores cultivares para armazenagem) e para melhor tecnologia de armazenagem foram expressos com veemência. Muito poucos informantes relataram qualquer controle na temperatura da armazenagem das cebolas nos seus países (7) e menos informantes ainda, armazenam monitorando a umidade (3).

O desempenho da armazenagem das cultivares denominadas pelos informantes está resumido numa média de meses de sobrevivência em armazenagem e está discutido em relação aos grupos principais de cebolas plantadas nos trópicos.

Parte III Conclusões e recomendações

Recursos genéticos

A coleta e preservação das cebolas faz-se necessário em regiões onde fontes de sementes locais ainda são usadas. Recomenda-se o desenvolvimento de material local por seleção dentro das raças existentes ou por cruzamento com outras linhagens tropicalmente adaptadas para criar variedades mais homogêneas em tamanho, forma e data de maturação: deve-se fazer também seleção daquelas com boas características para armazenagem. Devem-se manter cultivares novas ou melhoradas fazendo-se pressão contínua para selação. Estão relacionadas as características desejáveis para inclusão na fitogenética de cebolas para os trópicos.

Fisiologia

Estudos de campo sobre a época da formação de bulbos com relação a bem registrados dados climáticos e sobre a duração do dia são recomendados para as novas cultivares ou novas áreas de produção de cebolas. Onde possivel, devem-se realizar estudos ambientais controlados sobre variedades tropicais de cebolas. A reação do crescimento de cebolas a diferentes intensidades de luz natural também precisa ser estudada.

O trabalho do controle de florescência prematura também exige registro ambiental cuidoso e medida do crescimento da planta em experimentos sucessivos dentros das regiões de produção: a influência da aplicação de fertilizante de nitrogênio no início do crescimento sobre a florescência prematura durante o estágio vegetativo deve também ser estudada. A influência da temperatura sobre divicsão nas cebolas e o controle genético sobre esse fenômeno deve ser melhor compreendido.

Agronomia

Deve-se utilizar plenamente toda a literature disponível sôbre a cultura de cebolas. As restrições econômicas sobre os insumos dos agricultores podem ser elementos de maior de limitação em muitos áreas do que a falta de capacidade agronômica: disponibilidade de crédito, facilidades de compra em grupos e comercialização por cooperativa devem ser fomentados onde convenientes. Quando for possível um aumento de insumos, podem-se usar herbicidas para reduzir os requisitos de mão-de-obra e pesticidas para proteger o crescimento vegetativo o qual deve ser tão ininterrupto quanto possível para produzir bulbos bem maduros. Devem-se investigar localmente os fatores de restrição ao crescimento da cebola tais como salinidade excessiva da água de irrigação, patógenos do solo que atacam as raízes e temperaturas excessivamente altas do solo que podem levar à produção de bulbos alongados. Devem-se fazer recomendações sobre fertilizantes baseadas nos resultados dos experimentos locais. Trabalhos de extensão dentro do distrito é portanto essencial para dar apoio aos cebolicultores e aumentar os rendimentos.

Inovações como solarização do solo do leito da sementeira, uso de fertilizantes de ação lenta, e previsão do desenvolvimento das pragas e doenças são também de benefício potencial e poderiam ser testadas em uma gama limitada de locais antes de serem mais geralmente recomendadas. A agronomia de cebolinhas e cebolas para multiplicação tem sido pouco estudada e necessita-se publicar mais trabalhos neste campo. Devem-se usar os métodos de cultura dos tecidos para as linhas existentes de cebolinhas para livrá-las de infecção de virus e multiplicar as linhagens puras para distribuição. O uso de sementes de cebolinhas verdadeiras e a possibilidade de produzir sementes de cebolinhas híbridas deve ser investigado.

Fatores pré-colheita que afetam a armazenagem de cebolas

Devem-se cultivar cebolas com características de longa dormência se elas são para ser armazenadas por meses em armazéns de temperatura ambiente. As cultivares tradicionais boas para longa armazenagem sempre deixam de ter homogeneidade e não estão livres de duplicação e divisão. Necessita-se melhoramento genético por reprodução e seleção para melhorar a boa característica para armazenagem e rendimento das cebolas nos trópicos.

Necessita-se fixar com cuidado a época certa de aplicação de fertilizantes e irrigação nos estágios posteriores de formação dos bulbos para assegurar boas características de armazenagem. Evitar danos causados à folhagem pelas pragas e doenças que incentivam a retomada tardia da produção de folhas resultando daí em pescoço espesso justificam a continuidade das medidas de controle durante toda a estação de cultivo: tratamento tardio com fungicidas pode também reduzir as perdas em armazenagem através da diminuição dos níveis de inóculo nos bulbos e deve ser estudado mais.

Colheita e secagem

Deve-se decidir a época da colheita em relação às condições climáticas locais, mas o arrancamento, preferivelmente, deve ser realizado antes do tombamento de todas as folhas dos bulbos para incentivar o secamento sem perda excessiva de pele. É essencial em todas as operações de arrancamento, corte das folhas e transporte para evitar danos mecânicos aos bulbos que permitem a penetração de patógenos. Entende-se pouco sobre secagem da casca e cura, devendo-se estudar sua anatomia a bioquímica.

Secadores solares para a secagem de cebolas antes da armazenagem devem ser mais investigados. A duração do tempo de secagem e as temperaturas próprias a usar em secadores artificais precisam ser estudadas com relação aos diferentes genotipos de cebolas e suas caracteristicas físicas tais como espessamento da casca.

Armazenagem à baixa temperatura

A armazenagem em frigorífico nos trópicos pode prolongar a vida das cebolas se temperaturas de 0-2°C puderem ser mantidas: as principais objeções ao seu uso são que a sua instalação e operação são dispendiosas e precisam de fornecimento de energia confiável. A Umidade Relativa deve ser < 80% de outra maneira realiza-se o enraizamento particularmente em cultivares de baixa dormência e doenças tais como podridão do pescoço podem desenvolver-se se estiver presente uma infecção latente. Os patógenos de armazenagem *Apsergillus niger*, podridão basal e fungos *Penicillium* e a bactéria da podridão mole devem ser controladas por temperaturas baixas de modo que as perdas em armazenagem sejam significantemente reduzidas. Os problemas de condensação em bulbos de câmaras frigoríficas quando retirados para venda devem ser resolvidos arranjando-se aquecimento e secagem para os bulbos.

Armazenagem à alta temperatura

A gama de temperatura ótima para armazenagem de cebolas usando suas características de dormência em altas temperaturas precisa ser definida para as principais cultivares plantadas nos trópicos. A temperatura de dormência pode ser suscetível à mudança por seleção nas populações de cebolas. A armazenagem a alta temperatura é barato mas muitos patógenos de armazenagem podem atacar os bulbos das cebolas a temperaruras de 25°C e acima, especialmente onde a unimdade não é controlada e a ventilação precária. Necessita-se realizar estudos das fontes de inóculo das doenças e sobre o seu controle químico: onde a identidade dos patógenos for incerta, necessita-se realizar estudos por patologistas treinados.

Projecto dos armazéns

Minimizar a perda de água dos bulbos enquanto mantémse uma atmosfera seca adequada requer melhoria no projeto do armazém. Os melhoramentos que já estão sendo introduzidos em armazéns em certas partes dos trópicos tais como aumento de ventilação com o uso de mais prateleiras ou camadas, circulação de ar forçada, introdução de aquecimento para reduzir a umidade em armazéns e manter a temperatura acima do nível crítico para induzir o brotamento, merecem ser estudados em experimentos práticos: se esses métodes forem bem sucedidos na redução de perdas na armazenagem, deve-se lhes dar mais ampla publicidade. Precisa-se de mais informação em escala nacional sobre os aspectos econômicos da construção de armazéns para cebolas e o uso em relação às flutuações dos preços e os preços de cebolas importadas.

Tratamentos para impedir o brotamento na armazenagem

Onde hidrazida maléica foi usada a concentrações eficazes e a época da sua aplicação corretamente fixada, houve bons resultados na prevenção do brotamento de cebolas nos trópicos: onde o seu uso é permitido, poderia ser de valor especial a cebolas para armazenagem frigorífica. Ele não impede o desen volvimento de patógenos a altas temperatures. A irradiação afeta tanto a capacidade de brotar quanto a quantidade de patógenos, assim, pode ser de grande utilidade para cebolas armazenadas à temperatura ambiente. Os trabalhos para definir as doses adequadas de irradiação para as cultivares adaptadas aos trópicos e a avaliaçaõ dos efeitos sobre a qualidade dos bulbos talvez sejam justificados.

Produção de sementes

A qualidade das cultivares de cebolas poderiam ser melhoradas se as sementes de plantas que floresceram prematuramente não fossem guardadas e que nunca se permitisse o cruzamento das sementes da florescência prematura com as sementes da safra de bulbos. As técnicas de produção de países como a Índia e Brasil poderiam ser mais amplamente empregadas nos trópicos e a informação sobre esses métodos deveriam ser disseminadas noutros lugares. Necessita-se um controle eficaz das pragas e doenças na cultura das sementes para incrementar os rendimentos das sementes e o tratamento do bulbos com fungicidas para a produção de sementes deve ser desenvolvido e a duração dos tratamentos de vernalização dos bulbos estabelecidos para as variedades tropicais de cebolas e cebolinhas: os requisitos das mesmas provavelmente diferem dos daqueles das cebolas das regiões temperadas.

A necessidade para uma simples manutenção das variedades no campo de produção é enfatizado. As técnicas de eliminação dos espécimes inferiores na lavoura dos bulbos e sementes, a seleção do formato dos bulbos e técnicas contra duplicação e divisão pode ser usadas para conservar a qualidade: sem esse tipo de atenção, mesmo as cultivares melhoradas vão deteriorar. O treinamento das técnicas de produção de sementes pode ser necessário onde a produção de semente de cebolas não é tradicionalmente practicada. Os polinizadores devem ser fornecidos se a produção de sementes for tentada em grande escala.

Informação

Estão resumidas as fontes de informação do cultivo de cebolas e armazenagem e enfatizada a necessidade para informação mais extensa e rápida troca de informação entre os trabalhadores de diferentes países e em línguas diferentes. Espera-se que este boletim promova tal intercâmbio e que se torne a base para uma rede de informação sobre cebolas nos trópicos.

Fazem-se sugestões aos autores de tópicos sobre cebolas tropicais com o objetivo de tornar as publicações mais úteis internacionalmente através da inclusão de documentos científicos sobre dados no local do cultivo, clima a práticas agrícolas durante os experimentos de campo. Recomenda-se o use do termo 'seed' somente para sementes verdadeiras e a padronização dos termos para outros tipos de propagação.

Part I A selective review of the literature

Chapter 1 Introduction

ONIONS AS A WORLD CROP

Onions (*Allium cepa*) and shallots (*A. cepa* var. *ascalonicum*) are popular vegetables with most of the world's population. They are valued for their distinctive pungent or mild flavours and form essential ingredients of the cuisine of many regions. Onions are naturally packaged vegetables consisting of fleshy, concentric scales which are enclosed in paper-like wrapping leaves, connected at the base by a flattened stem disc. They are produced in large quantities in many countries (*see* Table 1) and are traded within and between countries on a significant scale (*see* Table 2). However, there are specific problems which occur when onions are grown and stored in the tropics, and this bulletin will attempt to define the causes of these problems and suggest some ways in which they might be overcome.

ONION PRODUCTION IN THE TROPICS

A high proportion of world onion production takes place in tropical regions (*see* Table 1). However, many tropical countries import large volumes of onion bulbs, and producers and merchants would like to develop onion or shallot

Table 1

Statistics of dry onion production, from *FAO Production Yearbook* for 1987

	Developed	Developing	Total
Areas harvested (ha)	518,000	1,248,000	1,766,000
Production (million t)	10.6	14.7	25.3
Yields (tonnes/ha)	20.5	11.8	14.3

Major producers: Production in thousands of tonnes

>1000		*500–1000*		*250–500*		*100–250*	
China	3,600	Brazil	856	Italy	485	Burma	226
India	2,790	Iran	740	Colombia	473	France	184
Soviet Union	2,000	Poland	615	Romania	420	South Africa, Rep. of	175
USA	1,993	Pakistan	585	Korea	400	Algeria	174
Turkey	1,500	Netherlands	540	Egypt	395	Australia	171
Japan	1,260			Argentina	296	Thailand	171
Spain	1,104			Indonesia	294	Greece	154
				United Kingdom	275	Hungary	150
				Yugoslavia	273	Vietnam	150
				Morocco	270	Czechoslovakia	146
						Syria	142
						Bangladesh	135
						Chile	135
						Canada	130
						Niger	125
						German Democratic Republic	105
						Iraq	100

Note: Mexico does not appear in the FAO Production figures, but exports of 141,000 t are shown in the FAO Trade figures, *see* Table 2.

Table 2

Trade in dry onions, from *FAO Trade Yearbook* for 1987

Countries/territories which exported >1000 t of dry onions	
Burkina Faso	3,700
Egypt	41,168
Morocco	6,300
Niger	6,000
South Africa, Republic of	7,500
Africa, total	66,677
Canada	16,099
Guatemala	5,000
Mexico	141,000
USA	93,836
N. and C. America, total	256,183
Chile	29,001
S. America, total	29,478
China	22,660
Gaza Strip	3,000
Hong Kong	3,888
India	210,000
Indonesia	4,642
Iran	4,000
Israel	5,000
Japan	3,744
Jordan	1,529
Korea	1,203
Lebanon	7,200
Malaysia	2,000
Pakistan	48,942
Philippines	10,145
Saudi Arabia	2,700
Singapore	34,510
Syria	12,656
Thailand	6,300
Turkey	135,339
Asia, total	520,346
Europe, total	1,063,055
Australia	43,713
New Zealand	29,274
Oceania, total	73,007
Developed	1,262,221
Developing	746,525
World	2,008,746

Countries/territories which imported >1000 t of dry onions	
Botswana	1,400
Cameroon	2,668
Congo	1,400
Côte d'Ivoire	21,000
Gabon	2,200
Gambia	1,300
Liberia	3,100
Mauritania	1,300
Mauritius	2,000
Reunion	1,456
Senegal	16,586
Sierra Leone	4,300
Zaire	5,300
Africa, total	66,710
Barbados	1,500
Canada	98,151
Cuba	7,000
El Salvador	5,054
Guadeloupe	2,508
Martinique	2,776
Mexico	2,500
Neth. Antilles	1,500
Panama	5,300
Trinidad and Tobago	5,848
USA	168,055
N. and C. America, total	303,756
Surinam	1,900
S. America, total	2,523
Bahrain	10,000
Bangladesh	5,600
Brunei Darus	1,800
China	7,840
Hong Kong	16,946
Indonesia	5,086
Iraq	18,000
Japan	35,855
Jordan	38,000
Kuwait	43,800
Lebanon	9,000
Macau	4,000
Malaysia	105,017
Nepal	6,000
Pakistan	22,999
Qatar	4,000
Saudi Arabia	42,000
Singapore	53,099
Sri Lanka	34,403
United Arab Emirates	85,000
Yemen (South)	2,500
Asia, total	550,955
Europe, total	1,028,881
Australia	2,014
Fiji	4,876
New Caledonia	1,172
Papua New Guinea	2,600
Oceania, total	11,793
Soviet Union	71,367
Developed	1,404,338
Developing	631,647
World	2,035,985

production within these countries to supply local demand for as much of each year as possible. Some countries, such as Brazil and India, which are only partly situated within the tropics, have several onion production regions and seasons, so they can achieve this ideal and also develop onion exports. Onion production in other countries may be possible only during specific seasons, or it may be continuous (*see* Part II, Table 4). Some countries, for example certain of those of the Sahel in West Africa, already have a well-established onion export trade, though this may not always appear in official statistics.

ADAPTATION DURING DOMESTICATION

The onion has a long history of domestication. Onions are now grown in regions which vary from the tropics to the north of Europe, and this dispersal by man from the ancestral centre of origin, which is thought to be south-west Central Asia, has been accomplished through thousands of generations of conscious and unconscious selection by farmers for adaptation to specific local conditions. In particular, onions have become adapted over the centuries to grow at different latitudes. Adaptation to latitude in the onion has chiefly entailed adaptation to specific lengths of the period of daylight, known as the photoperiod, which are required for bulbing to take place. The nature of the response of onions to day-length, and to the other aspects of the environment which interact with it to influence growth and bulb formation will be discussed in Chapter 3.

FOOD USES

Onions can be eaten raw or cooked. Raw onions are consumed as young green plants, sometimes called 'spring onions' or 'scallions', or as bulbs, which are usually sliced or chopped. Mild flavoured or colourful bulb onions are often chosen for salads. For cooking, bulb onions and, less frequently, green onions are used. Consumers often have very strong local preferences for colour, size, shape and pungency of bulb onions. These consumer preferences must be respected, for they form part of the culture of a region and cannot lightly be altered.

SHALLOTS AND MULTIPLIER ONIONS

Shallots, although they are sometimes distinguished botanically from bulb onions, appear to be types of bulb onions which have been selected for their ability to be maintained vegetatively. They tend to flower less readily than bulb onions, though this character is variable. Shallots are grown widely in areas of the tropics where the climate is unfavourable for the growth of bulb onions, and also because for some purposes, such as preparing certain sauces, cooks prefer shallots to bulb onions. Shallots may contain higher levels of fats and soluble solids, including sugars, than bulb onions.

Another apparent variant of *A. cepa* is the multiplier onion, (*A. cepa* var. *aggregatum*) which forms a number of bulbs within an outside sheath; both multiplier onions and shallots, if they flower, are fully crossable with bulb onions and may simply be vegetative variants of the species which have accumulated large numbers of genes for the splitting habit.

JAPANESE BUNCHING ONIONS

A. fistulosum, the 'stem onion' or Japanese bunching onion, is one of the related *Allium* species which is crossable with *A. cepa*. A wide variety of cultivars of bunching onion have been developed in the Far East, and are used in cooking there; spring onions (*A. cepa*) can be used in oriental dishes if bunching onions are not obtainable, though the flavour of the two species is not identical.

PRESERVATION

In parts of West Africa, fermented preparations are made from crushed or ground green onion leaves and tops; these products are used to flavour food at times when fresh onions are not available. Onion scales may be sun-dried for the same purpose. Commercially prepared onion products include dehydrated flakes and powders, usually made from white cultivars with high dry-matter content, and onion oil, which is produced by distillation. Dried onion products are much used by the food processing industry. Frozen onion products include rings and small whole bulbs. Pickled onions are prepared from small bulb onions, though some very small silverskin or pearl onions are of a different species of *Allium, A. ampeloprasum* or great-headed garlic.

ONIONS AND HEALTH

Onions have many uses as folk remedies, and, recently, research has suggested that onions in the diet may play a part in preventing heart disease and other ailments. This aspect of the use of onions was reviewed by Hanley and Fenwick (1985) and Augusti (1990) and will not be elaborated here. However, if the suggestion that onion consumption is beneficial to the health becomes firmly established in the public consciousness, it may cause an increase in the demand for the vegetable, as has recently happened with garlic, on similar grounds, in India. Both onions and garlic are known to contain substances with antibiotic properties.

DEMAND AND THE NEED FOR STORAGE

Onions are valued as a food largely because of their flavour and texture. Their strong and appetizing taste makes a particularly welcome addition to monotonous cereal diets, even though from the purely nutritional point of view, onions rank relatively low among foods because of the large proportion of water which they contain. They are valuable in the diet for their content of sugars, vitamins and minerals. Among vegetables on a world scale, they rank second only to tomatoes in the quantities produced. In most countries there is a constant, but relatively inelastic, demand for onions. The fact that markets cannot suddenly absorb supplies of large quantities of onions, and the stability of demand for the vegetable throughout the year, has led to the development in many parts of the world of onion cultivars which can be stored for several months, if environmental conditions permit. This allows the marketing period to be extended for most of the year in exceptionally favoured regions such as Egypt (*see* Part II, Table 6, p. 111).

DORMANCY AND THE ONION'S LIFE CYCLE

The capacity to remain dormant is one which onions share with many other bulbs. It is a mechanism by which many perennial plants withstand periods of the year which are unfavourable for growth. In central Asia, where the ancestor of the onion grew as a perennial, this period was probably the hot summer. Growth from the bulb would have been resumed when temperatures declined and rains fell in the autumn, allowing flowering to take place in the spring before the onset of the next dry season, when the seed would ripen and scatter.

In the course of domestication and geographical dispersal, other seasonal time-tables have been adopted in onion-growing areas which are far distant from the home of the crop. Onions to be sold as bulbs are usually grown as annuals, and produce the bulb at the end of the first season of growth. Seed production from bulbs therefore requires a biennial cycle, because flowers are not produced or desired during the first growing season. In temperate regions, the active season for onion growth is the summer, and the storage period is the winter, when growth is prevented by low temperatures, which keep the onions dormant. In areas such as eastern Europe, onions were more or less consciously selected for good storage qualities under this regime, simply because the mother-bulbs, which were needed to produce the seed crop, had to survive several months of storage before they were replanted in the spring to flower and produce seeds. Bulbs which perished during storage therefore did not enter the breeding population.

In many parts of the tropics, however, the onion's life cycle may be more like that in its geographical centre of origin; the main crop intended for storage is often grown under irrigation in the cooler, drier 'winter' season, while the staple cereal or root crops are grown under rain-fed conditions in the hotter, wetter 'summer' season. To extend the bulb onion marketing period in these tropical regions therefore calls for types of onion which remain dormant, without sprouting, for several months during a hot and humid season. To produce seed from such tropically adapted cultivars, the mother-bulbs themselves also have to be stored for a long time, probably under high temperature and humidity, for at least some of the storage period. In Côte d'Ivoire, for example, onions must be stored for eight months, from February until November, in order to produce a seed crop (*see* Chapter 6). For consumption in the seasons unfavourable for bulb growth, short-term crops of green onions or the tops of shallots may be used as leafy vegetables.

STORAGE AND DETERIORATION AT HIGH AMBIENT TEMPERATURES

Onion bulbs are naturally dormant at temperatures of approximately 22-25°C or over. If the relative humidity (RH) is fairly low (below about 75% RH), healthy, undamaged onion bulbs of cultivars which have high dry-matter content, and which have been dried and cured before storage, can be kept for some months in dry, well-ventilated stores. Bulbs which are damaged, immature or uncured are however likely to be attacked by a range of storage pathogens which are flavoured by high temperatures and high relative humidity. Damaged or immature onions which are deteriorating in an unventilated store release water, which leads to local increases in relative humidity; this enables rooting and sprouting to start in neighbouring bulbs, and allows pathogens present on the bulbs to attack. Bulbs of cultivars with low dry-matter content which were not developed for long storage are particularly susceptible to early sprouting and rooting and to storage rots. Chapter 5 contains a discussion of the characteristics of onions which affect their storage ability and of the environmental requirements for the development of storage pathogens.

Once the wet season begins, usually after a dry period of rising temperatures under tropical conditions, the temperature falls and humidity rises, both factors which favour dormancy breaking and disease development; under these conditions, very large proportions of a stored onion crop may be lost. Heavy losses of bulbs stored at ambient temperatures have been reported in studies from Sudan and India, for example (*see* Chapter 5). Seed-mother bulbs, which must be stored before replanting in the next cool season, are also difficult to keep in a healthy state through the rainy season. An additional physiological problem for the production of onion seed in the tropics is the need to satisfy a cold requirement in some cultivars before flowering can take place, that is, the stored bulbs or growing seed-mother plants must be vernalized before they can produce seed. For certain cultivars, artificial cold treatment may be required for efficient seed production, but for some well-adapted cultivars, the cold requirement may be satisfied by a relatively small number of cool nights during growth in the seed field. This aspect will be discussed further in Chapter 6.

CONTROLLED LOW-TEMPERATURE STORAGE

Storage technology for onions has been the subject of intensive research in temperate countries, and has resulted in the development of sophisticated computer-controlled storage systems which are now used in northern Europe and the US (*see* Chapter 5). These systems use ventilation with forced air at high temperatures to remove surface water and dry the outer skins of the bulbs, then the store temperature is allowed to drop gradually until it is low enough (using the cold ambient air of the northern winter) to preserve onion dormancy. Automatic controls incorporate sensing equipment and can monitor and regulate the temperature and relative humidity in store, with the result that the marketing period for the crop can be extended throughout the winter. For a proportion of the crop, refrigeration can be used late in the storage season to extend the dormant period into the spring months.

SPROUT SUPPRESSANT TREATMENT

Pre-harvest treatment with a shoot inhibitor, maleic hydrazide (MH) is also a common practice for onions intended for storing in temperate regions (*see* Chapter 5). Maleic hydrazide is applied late in the growing season, while the foliage is drying off. It is taken up by the green leaves which are drying gradually and translocated to the growing points in the bulbs, where it prevents cell division, so that no new sprouts are formed. The timing of MH application to the mature foliage is critical: if it is applied too early, the onion bulb quality is impaired, and if too late, it is ineffective in prolonging storage life. The onion foliage must also remain dry for at least 24 hours after the chemical is applied. Pathogens of stored onions can develop on MH-treated bulbs if the storage conditions favour them. The future use of MH may be in doubt in temperate countries because of resistance by consumers to the use of such chemicals on crops; legislation limits its use in some countries. Results on its use as a sprout suppressant in the tropics have been conflicting (*see* Chapter 5).

ONION STORAGE IN THE TROPICS

The onion storage methods outlined above have been developed for large-scale production systems in temperate countries. They have needed large-scale investment in storage facilities by groups of farmers or large individual businesses. In contrast, vegetable farming in the tropics is often comparatively small scale on family holdings, even when it involves co-operative farms or centrally organized irrigation projects. Marketing infrastructures are not yet well developed in many tropical countries: packaging and transport must rely on local resources, often in remote areas, and refrigerated storage is too expensive in many countries of the tropics to be considered financially viable for crops of comparatively low value. For onions, ambient temperature storage is almost universally used in the tropics (*see* Part II). In recent years, many research reports have been produced in the tropics on the behaviour of cultivars of onion under ambient storage conditions (*see* Chapter 5). However, very little seems to be known of the nature or physiological basis for high-temperature dormancy in onions, and little has been added recently to the works on this topic which date from thirty or forty years ago.

THE NRI PROGRAMME: DEFINING THE PROBLEMS

One aim of NRI's onion storage programme is to collect and collate information from those who are actively involved in research and development on onion growing and storage in the tropics. There is a need to find out which onion cultivars are actually grown and where, what kinds of onion storage facilities are used, and how well the currently available cultivars withstand storage. Another aim is to identify the main factors which limit onion yields in tropical countries. Improvements in crop agronomy or the use or development of better adapted cultivars in certain regions may help to increase productivity. Good onion yields are achieved in some tropical countries and can be emulated in others if the methods used are known more widely. The same may also apply to improvements in the technology of onion storage which are being developed in several parts of the tropics and subtropics.

Between 1986 and 1989 a questionnaire (*see* Appendix 1) was circulated from the Natural Resources Institute (NRI), in the United Kingdom. Its purpose was to obtain direct information on onion growing and storage in the tropics. A detailed analysis of the replies received is given in Part II of this bulletin, but the general findings were also used as the background for the review chapters which form Part I. Information was received from 46 countries, and in most of these the onion was regarded as a major crop. The facts established by the NRI survey should help to provide a basis for future decisions on work on onions in the tropics.

Part III, which concludes the bulletin, suggests some possible research and extension approaches to increasing onion production and improving storage in the tropics.

INFORMATION SOURCES

Besides the sources mentioned above, information for this bulletin has been drawn from books, reviews, published and drafted articles, extension literature from both temperate and tropical countries, and the personal observations of many experienced workers with onions in the tropics. Because so much interesting local advisory literature was received from correspondents, a list of some of these publications has been included in the appendices (*see* Appendix 4). Some extension publications are straightforward instructions on how to grow onions in a particular country or region, and others are more specialized studies of topics such as storage technology, which deserve to reach a wider audience, as they may include methods which can be applied elsewhere. Where extension publications are referred to in the main body of the text, either the author, if known, or the publishing body, for anonymous or collective texts, will be cited, together with the date of publication; some of these texts therefore appear both in the main bibliography (*see* p. 165) and in the list in Appendix 4. Reference books of particular value on aspects of onion work are also included in Appendix 4, even though not all of them are cited in the review.

DIAGRAMMATIC SCHEME OF ONION GROWTH, ITS LIMITING FACTORS AND THEIR CONSEQUENCES

The scheme follows the onion's normal life cycle from seed through vegetative growth to bulbing, dormancy, flowering and seed production, and indicates briefly at each stage what are the factors (mostly environmental) which can interfere with development, and their consequences for the plant. The final column also shows the page numbers in the bulletin where the symptoms noted are discussed. The diagram can thus be used as a guide for tracking down the immediate causes of various onion defects. However, the ultimate reason for many particular reactions will probably be governed by the population's genetic constitution and breeding history.

Diagrammatic scheme of onion life cycle

Optimum conditions	Operation	Stage of development	Limiting factors	Consequences of limiting factors
Fresh or well-stored, treated seed		Seed	held too long too hot too damp	Dies (*see* pp. 58, 60-1, 97-8, 130)
			infected seed	Carries fungal diseases or nematodes (*see* pp. 58, 61, 96, 98, 155)
	Sowing			
Moist, pathogen-free soil		Seedling	weather too cold	Fails to germinate/emerge (*see* p. 61)
Favourable: temperature day-length nutrients water			weather too hot	Fails to germinate/emerge (*see* pp. 53, 55, 57)
			soil capping	Fails to emerge (*see* pp. 53, 57)
			sown in infected soil	Damping off, other soil-borne diseases (*see* pp. 55, 58, 61-2)
			too hot or dry	Bulbs prematurely (*see* pp. 47-8, 54, 58, 62) or bulbing retarded (*see* pp.46-7)
			day-length too long	Bulbs prematurely (*see* pp. 47-8)
			poor nutrition	Grows slowly, leaf scales thicken (*see* p. 50)
			weed competition or overcrowding	Grows slowly or dies, or bulbs prematurely (*see* pp. 47, 50, 54)
			infected soil	Roots attacked by disease, plant grows slowly or dies: infected plants transmit disease to bulb production field (*see* pp. 55, 62)
			excessive salinity	Poor germination and growth (*see* p. 52)

Optimum conditions	Operation	Stage of development	Limiting factors	Consequences of limiting factors
	Transplanting or sets produced			
Favourable: temperature day-length nutrients water crop protection		Leafy plant	weed competition	Bulbs prematurely (*see* p. 50)
			infected soil	Growth poor, transplant survival poor (*see* pp. 62, 79-80)
			leaf diseases	Growth poor, later storage disease (*see* pp. 54, 79-80, 155)
			insect attack	Growth poor, disease may enter through wounded tissue (*see* p. 155)
			overcrowding	Plant size reduced, early bulbing or bolting (*see* pp. 50-1, 151)
			excessive salinity	Growth reduced (*see* p. 52)
			sets too large, stored too cool (5°-20°C)	Bolting
			plants too large, cool nights	Bolting (*see* pp. 64, 151)
			lack of N during early growth	Bolting (*see* pp. 64, 151)
			spacing too close	Bulbs too small, bolting (*see* pp. 50, 151)
Favourable: temperature day-length nutrients water crop protection		Bulbing plant	leaf damage (e.g. hail, herbicide)	Late maturity, failure to mature (*see* pp. 51, 54, 155)
			growing season too long before bulbing induced	Split or doubled bulbs (*see* p. 48)
			too hot	Split or doubled bulbs (*see* p. 48)
			too hot	Bottle-shaped bulbs (*see* p. 48)
			leaf diseases	Leaf growth resumes, bulb size reduced (*see* p. 51)
			declining day-length (some cvs.)	Leaf growth resumes, bulb size reduced (*see* p. 51)
			lack of water during early and mid-bulbing	Bulb size limited (*see* p. 64)
			excess water during late bulbing	Poorly matured bulbs, thick necks (*see* pp. 67, 156)
			late fertilizer application	Poorly matured bulbs, thick necks (*see* pp. 67, 156)

Optimum conditions	Operation	Stage of development	Limiting factors	Consequences of limiting factors
Favourable: temperature day-length dry weather		Bulb maturity	wrong cv. for latitude	Premature or delayed bulbing, failure to bulb (*see* p. 51)
			weather wet	Infection by disease organisms, re-rooting (*see* pp. 67, 70)
	Harvesting		harvest too early	Storage quality reduced, bulbs not fully dormant (*see* pp. 67, 70)
Careful handling			harvest too late	Storage quality reduced, dry skins lost, desiccation (*see* p. 69)
	Drying Curing			
			exposure to sun	Sunscald injury, allows diseases to enter (*see* p. 70)
Sorting only mature, dormant healthy bulbs for storage			damage during lifting, including topping too low	Unhealed wounds allow diseases to enter (*see* pp. 68, 71, 157)
	Storage			
Ventilated storage		Dormant bulb	infected bulbs stored	Neck rots develop (*see* p. 79)
			too cool (5°-20°C)	Dormancy ceases early, sprouting (*see* pp. 72-4)
temperature high enough to maintain dormancy OR temperature low enough to prevent growth			too hot and dry	Bulbs desiccate, skins lost (*see* pp. 76-8)
			too hot and damp	Storage rots (*see* pp. 78-81, 84-8)
			too cool and damp	Rooting and sprouting, storage rots (*see* pp. 72-4, 79, 83)
RH 60-75%			rotted bulbs left in store	Rooting and sprouting of sound bulbs (*see* pp. 24, 89)
			stacked too deep	Crushing and deformation (*see* p. 71)
			wrong cv. for storage	Rapid sprouting in store, susceptibility to storage diseases (*see* pp. 66-7, 70, 73, 75-6, 79-80, 83-4, 136-9)

Optimum conditions	Operation	Stage of development	Limiting factors	Consequences of limiting factors
	Replanting			
Favourable: temperature, day-length, nutrients, water, crop protection		Seed-mother plant	too hot when planted	Bulbs grow and split rather than flower (if already vernalized, buds abort) (*see* pp. 93-4)
			planted too late	Insufficient vernalization, reduced flowering (*see* pp. 94-5)
			too hot during flowering	Seeds fails to set (*see* p. 96)
			no crop protection	Flower stalks lodge, seed lost (*see* p. 96)
Pollinators			systemic disease	Poor seed crop, seed infected
			poor pollination	Poor seed crop (*see* p. 95)
			pest attack	Lowers seed yield (*see* p. 96)
			too hot during seed maturation	Seeds abort (*see* p. 96)
			wet weather	Fungal diseases on seed heads, seed infected (*see* pp. 79, 96)
Harvest seed when 10% capsules open	Harvesting seed heads		harvested late	Seed lost in field (*see* p. 97)
		Seed	seed left in damp, hot conditions	Loses viability rapidly (*see* p. 97)
Stored in cool dry conditions			seed collected from bolted plants	Poor genetic quality (*see* p. 161)

Part I A selective review of the literature

Chapter 2 The genetic base and the cultivars grown in the tropics

THE GEOGRAPHICAL ORIGIN OF THE ONION AND RELATED SPECIES

Onions (*Allium cepa*) are no longer known as a wild species, though other, closely related species still exist in the area which is regarded as the botanical centre of origin for the crop: the south-western part of Central Asia, largely covered by the countries of Iran, Afghanistan, Pakistan and the southern republics of the Soviet Union (Jones and Mann, 1963). Here wild alliums such as *A. vavilovii, A. oschaninii* and *A. galanthum* can still be found. These species look very similar to the common onion and share with it the features of hollow leaves and hollow flower stalks. They can be crossed with *A. cepa*, though the interspecific hybrids are usually highly infertile. In several breeding schemes in temperate countries, attempts are being made to introduce valuable characters present in other *Allium* species into *A. cepa*; for example, *A. fistulosum* is being crossed with *A. cepa* with the aim of improving cold tolerance and resistance to pink root rot (*Pyrenochaeta terrestris*) and *Botrytis* diseases (Peffley, personal communications; Currah *et al.*, 1984). In the Netherlands, breeders are crossing *A. roylei* with *A. cepa* with the aim of bringing resistance to downy mildew (*Peronospora destructor*) into the bulb onion (de Vries, in preparation). Some breeders are using fertile tetraploid interspecific hybrids, obtained by chromosome doubling with colchicine, to try to speed the process of genetic introgression. However, as far as is known, no commercial bulb onion cultivar containing genetic material from another species has yet been released.

During the onion's long period of co-existence with the human race, it has become adapted to a variety of climates and growing systems. Vegetatively propagated variants of *A. cepa* which are grown in many parts of the tropics are shallots and multiplier onions.

SHALLOTS: TERMINOLOGY, HABIT AND USES IN THE TROPICS

The term 'shallot', as used in this bulletin, refers to the vegetatively propagated forms of *A. cepa* var. *ascalonicum* which were included in the *aggregatum* group of the species *A. cepa* by Jones and Mann (1963). Shallots of this type appear to have been derived by selection from naturally occurring variants within *A. cepa*. (The old botanical name *A. ascalonicum*, formerly used for shallots, was originally applied to a distinct wild species from the Near East: Hanelt, 1990). Several other cultivars which are referred to in US literature as shallots are actually derived from *A. cepa* × *A. fistulosum* crosses (e.g. cv. Delta Giant); they should not be confused with the shallots of the *A. cepa aggregatum* group. *A. cepa* shallots are distinguished from normal bulb onions by their habit of multiplying vegetatively by lateral bud growth; a single shallot bulb usually contains several shoot initials, and after the bulb is planted, several leafy shoots grow out from it. Each shoot then rapidly produces a small bulb so that a cluster forms which remains attached to the original base plate. The bulbs can be separated and the process repeated in the next growing season. In the tropics, shallots are often grown in areas where bulb onions culture is difficult, either because the climate is humid and bulb onions are badly attacked by leaf diseases which the local shallots can withstand, or because onion seed is difficult to produce. They may also have special culinary value, for example, the Indonesian shallot variety 'Sumenep' is said to have a high 'fat' content (Turral, personal communication). Another advantage of tropical shallots is their very short growing season of only two or three months, which allows them to be grown between other crops or during a short dry season. The green tops are often eaten.

Where temperatures are high all the year, onion bulbs may never become vernalized, that is, no flower initials form within the bulb. In the lowland tropics lack of a distinct cool period can prevent onions from flowering for this reason. Vernalization in onions requires a certain period of cool or cold temperatures, though cultivars differ in the amount of cold treatment necessary (*see* Chapter 6). In some areas where onion seed production is difficult, such as south India and Sri Lanka, two distinct types of *aggregatum* onions are grown: shallots and multiplier onions (Wijeratnam, personal communication). Multiplier onions are larger than tropical shallots and form fewer bulbs in each compound cluster (varying from 4-8 up to 8-11, compared with up to 16 in the shallot); the individual bulblets are larger and flatter in shape, the multiple bulb forms underground and the bulblets remain more closely packed inside an encircling sheath than do shallots, which are connected only at the base when the bulbs are mature (Jones and Mann, 1963). In Sri Lanka both flowering and non-flowering lines of multiplier onion and shallot are known (Kuruppuruachchi, personal communication). In other countries such as Indonesia, shallots are a major crop and substantial quantities are exported; a large number of varieties are distinguished for use in highland and lowland zones (*see* Part II, Table 6). It is possible that a genetically controlled reaction to temperature may be implicated in the tendency to split found in tropical onions and shallots. If bulb onions are planted out in hot seasons, they may produce several shoots and then split like shallots, a characteristic which can allow out-of-season multiplication (*see* Chapter 3).

ONION COLOURS AND THEIR INHERITANCE

Before discussing the current range of onion cultivars grown in the tropics, and speculating on how their distribution has come about, the question of colour in onions will be discussed briefly (colour being one potential means of classification). Colour in onions is mainly under the control of a series of genes which are inherited in a simple Mendelian fashion, (Clarke *et al.*, 1944; El-Shafie and Davis, 1967). White bulb colour can be due either to a dominant colour inhibitor gene, which suppresses other onion skin colours, or to a recessive white skin colour gene. Within a geographical area, therefore, onion varieties can often be found which differ by little except their skin colour; indeed, white segregants which occur in red, yellow or brown onion populations have been selected from the parent population and used as the basis for new white varieties (Nabos, 1976; discussed by Currah, 1985). Within this comparatively simple framework, however, there are other, less well understood factors, such as the appearance of complementary red colours which may occur when yellow or recessive white cultivars of different origins are crossed (Jones and Peterson, 1952). There are also genetic colour-intensifying factors which are probably quantitatively inherited: these may account for some of the variation found in shades of reds and browns in onion skins. Depth of colour development in onion skin is also controlled to some extent by curing treatment: high temperature curing results in darker skin colours developing (Bleasdale and Thompson, 1966).

ONIONS AND THE REGIONS WHERE THEY ARE GROWN

The onions currently grown in the tropics can be grouped or classified in several ways. For the purpose of this review, a historical/geographical approach will be used. It will be assumed that the region which is the nearest to the supposed centre of origin in a southerly direction, namely India, Pakistan and Bangladesh, is the area where it is most likely that the onion started its tropical domesticated existence. From there the most probable route or routes taken by onions to reach other parts of the tropics where they are now grown will be followed, using a process of guesswork and deduction. The questionnaire analysis in Part II of this bulletin presents the information from correspondents on the onion races or cultivars grown today in their countries.

ONIONS IN INDIA, PAKISTAN AND BANGLADESH

A huge variety of different onion cultivars or named land-races, that is, locally adapted but highly heterogeneous populations, exists today in India. Thomas and Dabas (1986), reported that 2000 accessions were collected for the Indian National Bureau for Plant Genetic Resources Gene Bank in New Delhi. Of these, 950 accessions were grown in trials and the bulbs stored: approximately half of the lines had reasonably good ambient (i.e. high) temperature dormancy, as shown by their failure to sprout when held in store for six months.

Thomas and Dabas (1986) listed 54 of the most important varieties or selections grown in India, including some introduced cultivars, and gave brief descriptions of each with indications of their yields in trials. Our questionnaire findings show that the most widely grown bulb onion cultivars in India at present are Pusa Red, Pusa Ratnar, Nasik Red, Patna Red, N 404, N 207-1, Agrifound Light and Dark Red, White Patna, N-53 and N-2-4-1. Bellary Red or Bellary Big onion is an important type grown in Karnataka, south India; shallots grown in southern India are often referred to as small onion. Other Indian cultivars which are mentioned in recent extension literature from the Associated Agricultural Development Foundation, New Delhi (AADF, undated) are Udaipur 101, Udaipur 103, Punjab Selection (Ludhiana), Hissar-2, Kalyanpur Red Round, Arka Pragati, Arka Niketan, Arka Kalyan, Bangalore Rose, and the white cultivars Punjab 48, Udaipur 102, Pusa White Round and Pusa White Flat. The account by AADF gives the total soluble solids content, a brief description of each cultivar and notes on where it was bred or selected, and on where in India it is grown. In Pakistan the cvs. Phulkara, Faisalabad Early and Desi Red, and a local white variety in Kashmir, were listed (M.N.A. Chaudhry, personal communication). In Bangladesh, several local varieties exist, (five were used in trials by Husain, 1985), but cvs. Faridpur Vati and Taherpuri were mentioned in particular by our informant (Mondal, personal communication). Without a knowledge of the local situation in these countries, it can be difficult to distinguish land-races or populations named after place of origin, from selected varieties which may have been developed at a research station or university farm, and which will have a narrower genetic base. An unpublished AADF report however explains that the Pusa cultivars originate from the work of the Indian Agricultural Research Institute (IARI), which released Pusa Red prior to 1960, and later produced Pusa Ratnar and the white varieties listed; the Arka series of cultivars was bred at the Indian Institute of Horticultural Research (IIHR), Bangalore, and N-53 and N-2-4-1 were developed by the Maharashtra State Department of Agriculture before 1960. Nasik Red is a generic term used for onions grown in the Nasik district of Maharashtra state, and selections within this stock by the AADF have produced the recently developed Agrifound Dark Red and Agrifound Light Red varieties (Gupta, personal communication).

MULTIPLIER ONIONS IN SOUTHERN INDIA

Multiplier onions are grown in the southern India states of Tamil Nadu and Karnataka and in Sri Lanka. Improved lines of multiplier onion have been bred at Tamil Nadu Agricultural University by crossing with bulb onion: the CO-1 to CO-4 series of cultivars developed there, and breeding work is continuing. In cultivars where flowering can be induced, a cool period of 40 days at 14°C is required; though seed can be produced from some lines, vegetative multiplication is usually practised (Irulappan, personal communication). The CO cultivars are described in the AADF booklet *'Onion Production in India'*. The bulb colour is pink or red. The multiplier onions typically split into a few daughter bulbs, the numbers of which range from 4-8 up to 8-11 in the different CO cultivars (AADF, undated), whereas the smaller tropical shallots flower less freely and split into more daughter bulbs, typically about 16 (Wijeratnam, personal communication). Both multiplier onions and tropical shallots take only 60 to 75 days to multiply and die down again, and the bulbs can be stored for considerable periods (over 5 months in some trials). Individual clusters or multiplier onions in the CO series have average weights which range from about 25 g up to 85 g (AADF, undated; Vadivelu and Muthukrishnan, 1982).

CURRENT ONION IMPROVEMENT IN INDIA

Many onion farmers in India save their own seed, so that genetic diversity is maintained or even increased locally. Recently, co-operative organizations, such as the AADF and the All-India Coordinated Vegetable Improvement Project run from IARI, are encouraging the culture of improved, selected onion cultivars in India. This will result in better quality and homogeneity for India's onion crop and make it more competitive in world markets. India already has a considerable export trade in onions to Sri Lanka, Malaysia and the Arabian Gulf countries.

Research on the development and breeding of new onion cultivars, including F1 hybrids, in India, is done at universities and research institutes and by the AADF. There are active breeding programmes in universities at Varanasi, Rahuri and Tamil Nadu, for example. University breeding schemes are often allied to biometrical studies (e.g. Vadivelu *et al.*, 1982; Patil and Kale, 1985). The IIHR at Bangalore maintains another onion germplasm collection and reports variety and storage trials on onions annually. Attention is being given to the suitability of onion varieties for processing in the All-India Coordinated Research Project for Post-Harvest Technology of Horticultural Crops.

Although a tremendous variety of onion types is to be found in India, Pakistan and Bangladesh, it is probably true to say that the most characteristic onions to be found there are pungent, round-to-flattish in shape and are deep red, light red, reddish-brown, or white in colour. Thomas and Dabas (1986) state that the deep red Indian cultivars do not store as well as the light red or brown ones. The introduced US yellow/brown Texas Early Grano/Granex types are also grown, and are valued for salad uses, but they cannot be stored in the Indian climate for more than a month or two. The local cultivars however, as already noted, include a large proportion which have good storage potential.

Indian growers and merchants are currently aiming to produce better quality onions for storage, and are also searching for brown cultivars which could be grown for export to Europe, where red onions are less in demand than brown types. There is also a need to find more cultivars for growing in the wet Kharif (late summer or monsoon: approximately July to November) season, for which only cv. N-53 (a selection from the Niphad area) is widely used at present: the recent selection Agrifound Dark Red can also be grown during Kharif, when temperatures are decreasing. The main crop for storage is grown during the drier Rabi, or winter season (approximately October to April). In Maharashtra state, inland from Bombay, onions are grown all the year round and the majority of the export crop is produced there; the red onions exported from India are known generically in Sri Lanka as Bombay Red or Poona Red onion. Within Sri Lanka, the traditional area for shallot and multiplier onion production was the Jaffna peninsula, but since the disruption of this area's economy by political troubles, onion growing is being developed on the west coast of the island, using seed imported from India (Kuruppuruachchi, personal communication). Selections have also been made from red onion material probably originating from Ethiopia (Eavis, personal communication). Multiplier onions grown in Sri Lanka are known by the Tamil name of their south Indian town of origin, 'Vedala Vengayam', that is, Vedala onion; there are two distinct types, only one of which produces seeds ('Mal lunu' or 'flower onion' in Sinhala). These can be used to raise sets (single dry bulbs) which farmers use as propagating material to produce the saleable crop (Kuruppuruachchi, personal communication).

ONIONS AND SHALLOTS IN SOUTHERN ASIA AND EAST AFRICA

Areas to which the Indian types of bulb onion have spread directly are Yemen (South), Kenya and Tanzania, where a cultivar or type referred to as 'Bombay Red' is often grown from Indian seed. Shallots which are grown in Mauritius, Rodrigues, Sri Lanka, Indonesia, Thailand and other countries with humid equatorial climates may have spread there from southern India. In Ethiopia, small local red shallots grown in the highlands are highly valued in the traditional 'wat' sauce to accompany 'injera' bread made from tef or wheat flour. Attempts are now being made in Ethiopia to develop a shallot-growing system making use of true seed in a two-stage process similar to that used for the multiplier onions in Sri Lanka. Seedlings are grown into sets which are then planted to produce the shallot crop. This system allows farmers to multiply their own planting materials and avoid storage losses (Jackson, personal communication; *see* Chapter 4).

SUDANESE ONIONS

In Sudan there are many local land-races of onions, most commonly red, but also white, yellow and brown. Usually they are simply named after their district of origin. Many of these local races contain mixtures of colours and also vary in the degree of splitting, doubling and bolting which they exhibit. The brown and yellow varieties grown in the north of the country may have come from Egypt originally. The white cv. Nasi was selected for dehydration. Mild white onions are grown in the western district of Zalingi, where a smaller, mainly red type known as 'Fer' is also grown and is preferred for cooking (Mohamedali, Hamad and Abdalla, unpublished report). Many of the local red types found in central Sudan are pungent, have high dry-matter content (15-18%) and good dormancy, but suffer heavy losses in store from deterioration caused by pathogens (Musa *et al.*, 1973; *see* Chapter 5). Considerable breeding and selection work is in progress in Sudan, but up to the present Sudanese farmers usually save their own onion seed. Research on seed production in Sudan was reviewed by Nourai (1984; *see* Chapter 6).

In Ethiopia, some Sudanese onion varieties have been selected for the local highland conditions, though leaf disease resistance of bulb onions was less than that of the local red shallots (Jackson, 1987). The onion cultivars Adama Red and Mermiru Brown were developed by selection at Nazret in Ethiopia during the 1970s and 1980s (Jackson, personal communication). An interesting export trade in onion flowers has developed: many thousands are sent yearly to the Amsterdam markets by air (Jackson, 1987).

THE LONG-STORING ONIONS OF WEST AFRICA

Sahelian West Africa is a region where, as in India, a variety of red, purple, pink and white onions are found. These onions are grown mostly in the

Savannah belt between the Sahara and the wetter equatorial coasts, and evidently have a long, though largely undocumented history. Bulb onions are grown under irrigation in the dry season in northern Nigeria, Ghana, Mali, Niger, Burkina Faso and Senegal. It is difficult to know whether these onions first arrived overland by caravans trading across the Sahara, or via the sea coast when this was first explored and exploited by the Mediterranean navigators, but in view of their evident adaptation to the region, it seems most likely that they spread to the Sahel by trade within Africa. The photoperiodic responses of West African cultivars have been little studied, and they are notable for their tendency to bolt (that is, flower in the first season of growth), a feature which tends to counteract their inherently excellent storage qualities. Among the named cultivars or races of this region are Violet de Galmi and Blanc de Soumarana (both originally from Niger, but now selected in a number of other locations); Bawku from Ghana; and Gindin Tasa, Wuyan Bijimi, Wuyan Makorowa and Kano Red from Nigeria (*see* Part II, Table 6,). These onions can be grown to a very large size when well spaced: their shapes are round to flat. Sinnadurai (1970) noted that in northern Ghana the bolting rate of cv. Bawku was 96%, and that the flower stalks are nipped off by the growers to encourage bulb growth.

Onions from West Africa have many of the qualities which are needed for growing in the drier tropics, and by selection the percentage of bolters can be substantially reduced, as Nabos (1976) has shown. However, the recent history of attempts to improve these onions has demonstrated above all the need for continued, unremitting selection pressure to maintain quality in the selected strains. If left to cross freely with neighbouring, freely-bolting populations, improved populations soon revert to the level of the local population (Turner, personal communication).

SHALLOTS ON THE WEST AFRICAN COAST

Shallots are grown in the coastal regions of West Africa and have been studied in Ghana by Sinnadurai (1973) and Sinnadurai and Amuti (1971). The Ghanaian shallots are grown in the Anloga area on the lower Volta River and were brought there from Anecho in Togo, reputedly from plants given to the local people by Europeans in about 1800 (Sinnadurai, 1973). New shallot cultivars are now being developed at the University of Legon, Ghana by crossing with bulb onions (Johnson, personal communication).

ONIONS OF THE MEDITERRANEAN REGION

Moving towards more temperate zones, the areas around the Mediterranean have contributed to the development of fast-bulbing, short day-length responsive onions which are now frequently grown in the tropics. This area was regarded by Vavilov as a secondary centre of onion variation; several ancient civilizations of the Middle and Near East are known to have grown them. Egypt's involvement with the onion's history has been recorded since the time of the Pharaohs, and until very recently this country was one of the world's major onion exporters, producing high quality, reddish-brown onions with exceptionally good keeping quality in the hot dry climate. Now, since the disturbance of earlier agricultural practices by the changes which followed the construction of the Aswan High Dam, the soil-borne disease white rot *(Sclerotium cepivorum)* has spread in recent years through the traditional onion-growing regions of middle and upper Egypt, where previously it was kept in check by seasonal inundation. The area cultivated for onion growing has decreased substantially as a result. The best known cultivars from Egypt are Giza-6, which was developed by the Ministry of Agriculture from the Sahidi type of upper Egypt, and Beheri, the onion of the Delta region, which needs a slightly longer day-length to bulb (Meer, 1986). In the dry climate of Egypt, these onions can be stored for 8-10 months (*see* Part II, Table 6). In Israel, some cultivars have been developed from the Egyptian types, for example, cv.

Haemek; hybrid cultivars with long storage life are now being bred there, such as cv. Moab (Rabinowitch, personal communication).

Further west, in Tunisia, white onions are favoured; many farmers produce their own onion seed there. Yellow varieties are also grown (*see* Part II, Table 6). Local onion races are to be collected and evaluated for resistance to bolting (premature flowering) and for good storage characteristics (N. Hamza, personal communication). Imported cultivars grown are of US, French, Spanish and Italian origin.

EARLY-BULBING SPANISH ONIONS IN THE AMERICAS

Like the Indian peninsula, the countries of the northern Mediterranean shores have an astonishing variety of types of onion. Italy, France and Spain all list red, pink, white, brown and yellow cultivars. From the area, the two types which have now spread most widely, notably into the Americas, are the Spanish early-bulb onions from the coastal regions, and the later maturing, long-keeping, deeper brown cultivars which are grown in Spain as the storage crop. The first of these groups contains onions which are sown in September in the Valencia region, and are adapted to bulb early in the spring as the day-length increases in February, March and April. They are known by the names Babosa and Valenciana Temprana in Spain itself. This is probably the group of cultivars which gave rise to the flat yellow onions of the Atlantic Islands (for example, Amarela Chata das Canarias, long grown in tropical Brazil, and the Bermuda cultivars). These early flat onions became popular for growing in the southern regions of the USA in the late 19th and early 20th century. Later, in the 1920s, the New Mexico Agricultural Experiment Station in the USA developed an improved selection which was named New Mexico Early Grano, from seed imported as 'Valencia Grano 9452'. From this variety, which was deeper in shape than the Bermuda varieties, the first Texas Early Grano was developed by the Texas Agricultural Experiment Station and released in 1944, superseding the flatter Bermuda onions for early onion production from over-wintered plants in the Rio Grande valley of south Texas (Magruder *et al.*, 1941a; Corgan, 1984). The Early Grano varieties have a distinctive top-like shape and are notable for their ability to bulb rapidly and for a relative indifference to day-length as long as it is about 11 to 13 hours (*see* Chapter 3). An improvement made to the original type was the introduction of pink root resistant (PRR) strains, obtained by crossing and selection from cultivars of the Bermuda type, which carry improved resistance or tolerance, usually expressed as more vigorous root growth, to the soil-borne disease *Pyrenochaeta terrestris* (Jones and Perry, 1956).

In recent years the open-pollinated Texas Early Grano stock has been the subject of intensive breeding effort. By crossing with the slightly later cv. Ben Shemen, a Sweet Spanish type, L.M. Pike of Texas A. and M. University and his associates have developed a series of cultivars intended for a succession of defined sowing dates in the autumn, and aimed at supplying an extended harvest season during the months of March through to May in the Rio Grande Valley and later from more northerly locations in Texas (Pike *et al.*, 1988a-d). The names of these selections indicate their recommended sowing dates, for example, Texas Yellow Grano 1015Y is intended for sowing on 15 October in the Rio Grande valley (the US-style date gives month before day). In New Mexico, with a slightly cooler climate and more northerly location, J.N. Corgan has also successfully bred new onion varieties with improved pink root resistance, for example, NuMex BR1, NuMex Sunlite (Corgan, 1984; 1988). White variants of both New Mexico and Texas Granos are available. The Early Grano type of onion also provided the parent material for a range of internationally successful hybrid cultivars, the Granex series (Call, personal communication), which gives some of the highest onion yields in the tropics (*see* Part II, Table 6). H.A. Jones developed the Yellow Granex in the mid-1950s, using the genic/cytoplasmic male sterility system which he had first noted in cv. Italian Red in 1925 (Jones and Clarke, 1943). Yellow, Red and White Granex varieties are now available (*see* Appendix 5). The shape of the Granex varieties tends to be more round than that of the Early Granos, which are somewhat top-shaped.

CHARACTERISTICS OF THE US SHORT-DAY ONIONS

Because of their origins as spring fresh market bulb onions, intended for growing in the USA's earliest production region in the far south of Texas, the Bermuda and Texas Early group of cultivars as developed and selected in the USA, was not until comparatively recently selected for keeping qualities. The essential characteristic of this group was its ability to bulb rapidly, at the expense of few and thin skins and low dry-matter content; because of their softness, Early Grano onions are still mainly harvested by hand in the USA. Recently, early Texas onions have been packed for sale in cartons in order to reduce injury by crushing during transport (O'Higgins, 1988a). These onions are also renowned for their sweetness and lack of pungency, qualities which are highly valued in North America.

Lack of understanding of the nature and intended use of the US short-day cultivars which are derived from early season Spanish sources has often led to disappointment with their lack of durability and pungency when they have been grown in the tropics. Because of their high yield potential and the ready commercial availability of seed, the Early Grano and hybrid Granex varieties are however grown in many tropical countries, as shown by the results of the survey in Part II. Texas Early Grano, Granex hybrids and the Bermuda cultivars are sometimes the only short-day types to be found in the seed lists of international commercial companies, though others offer a much greater choice (*see* Appendix 5). Informants from areas such as Central America, the West Indies and northern South America, where onion seed production is difficult because of the hot, humid climate, and where there is not such a choice of locally adapted material as in India and West Africa, sometimes listed only the US short-day cultivars (*see* Part II, Tables 5 and 6). Some of the Caribbean islands, such as Guadeloupe and Haiti, do however have red shallots, which resemble those of the Old World tropics, and a shallot breeding programme has been in progress there (Anais, 1977; Messaien and Beyries, 1986).

SPANISH ONIONS FOR STORAGE

The second major Spanish group of cultivars, known outside Spain by names such as Brown Spanish, Sweet Spanish or Valenciana de Exportación, is the traditional Spanish onion of the export trade: large, round and brown, resistant to transport damage and to storage diseases. It still commands a premium price because of its high quality and reliability on markets throughout the world. Onion varieties of this type, and their modified descendants, are grown less than the Early Grano and Bermuda group in the true tropics, because they need a longer bulb maturing period, and require a Mediterranean summer day-length of over 13 hours to complete their bulbing. Hence they are grown as a summer crop in Spain and also in the dry, irrigated production regions of mid- and western USA from Colorado northwards, and in the Mediterranean climatic area of Chile. Pukekohe Longkeeper from New Zealand probably contains genetic elements of the same Spanish type (Grant and Carter, 1986), and in Australia cv. Creamgold, which is derived from NZ Pukekohe Longkeeper, is another, more distant descendant. Other southern hemisphere, brown, thick-coated onion cultivars such as Caledon Globe from South Africa, and the Gladalan and Lockyer Brown and White cultivars from the Brisbane region may also ultimately derive from the same source, late Spanish onions. Members of this group may well be worth crossing with onions grown in the tropics, with the aim of improving their dry-matter content and storage quality, and of developing more brown-skinned onion cultivars for growing in tropical conditions. South African and Australian brown onions are grown in the southern and central African countries from Swaziland to Malawi, where US short-day onions of the Grano/Granex type are also used (*see* Part II, Tables 5 and 6).

In Spain itself the long-storing onion is called a late Valencia Grano or 'De Grano de Valencia'. It is potentially confusing that the name Grano (which simply means 'seed' in Spanish), has in the Americas, and in the international vegetable seed trade, become firmly attached to a group of early, or short-day onions which have probably diverged substantially from the type now commonly called Grano in Spain itself.

ONIONS OF SOUTHERN AFRICA

The onion cultivars grown in the Republic of South Africa are thought to have been brought to the Cape area by the early settlers from the Netherlands. Since then, selection has resulted in increases in earliness which have produced cultivars suitable for growing in more northerly parts of the country such as the Transvaal. Such cultivars are also suitable for growing in other southern African countries and seed is found on the market in Zimbabwe and Malawi, for example (*see* Part II, Tables 5 and 6). Joubert (1986) gave an account of the development of several South African cultivars and their characteristics, from which the following information was taken.

Pyramid, the earliest maturing cultivar, was released in 1968 from the Horticultural Research Institute (HRI), Pretoria, where it was produced from cv. De Wildt by inbreeding and selection. The shape is flat-round and the bulbs of a brown straw colour; the cultivar has superseded cv. De Wildt because it has better uniformity, and fewer bolters and split bulbs. Pyramid is used for the early bulb crop and also for sets. The progenitor De Wildt is said to be a selection from cv. Early Cape Flat (van Zijl, personal communication).

Two somewhat later South African cultivars are Bon Accord (which like De Wildt and Pyramid are named after districts near Pretoria) and Hojem. Bon Accord was bred at the HRI, Pretoria from a cross between cvs. Excel (a Bermuda selection) and Hojem (a South African cultivar). The bulbs are round and straw brown and are said to store well. The maturity date is 2-3 weeks later than that of cv. Pyramid. Bon Accord is said to have good bolting resistance and also to split only rarely. It was released in 1968. The cultivar Hojem is deep-round in shape and can produce large bulbs; it is a good seed producer with vigorous seedling growth. An improved strain has been released by the HRI. Maturity date is 3-4 weeks later than that of cv. Pyramid.

Texas Grano seed produced in South Africa is said to be a selection which matures 12 to 14 days earlier than the strain originally imported from the USA (Joubert, 1986). In the Republic of South Africa, the large bulbs produced by this cultivar are kept down to a more marketable size for local tastes by decreasing the spacing: yields of 60 t/ha or more are reported. Joubert (1986) reports that it is resistant to downy mildew, and notes that the leaves are of a brighter green than those of the other cultivars listed. In the Republic of South Africa, cv. Texas Grano (local strain) is not regarded as being as early as cv. Pyramid, perhaps because early sowing results in a fairly high percentage of bolting.

Late onion cultivars grown in the Republic of South Africa at latitudes greater than 28°S are Caledon Globe, an export and long-storage variety grown in Cape Province and the Orange Free State, (Caledon is an area near Cape Town) and Australian Brown, a variety also noted for its excellent keeping properties, with thick, leathery outer scales which are dark to red-brown in colour. The latitude adaptation is slightly farther south, 29°S or more, for this variety, which is harvested in mid- to late summer in the Republic of South Africa (Joubert, 1986).

ONIONS IN CENTRAL AMERICA

Although wild alliums are found in the Americas, all the *A. cepa* onions now grown there are descendants of onions brought over the Atlantic by European settlers. While many countries in and around the Caribbean grow mainly the onions of the Bermuda and Early Grano group, in some countries which have well-populated highland regions, such as Mexico and Guatemala, a variety of local onion races exists in remote areas. These may have been developed in isolation since the early Spanish settlers arrived in the sixteenth century; genetic resource co-ordinators in these countries are now conscious of the need to preserve these onion populations (Hernadez and Orozco, personal communication). Mexico increasingly exports white and yellow onions from the Tampico area to the USA, and has an all-year-round production area south of Mexico City in the Celaya region which was described by Jones and Mann (1963). Cojumatlan is a well-known white Mexican cv. or local race of onion which was shown in Brazil to have some resistance to pink root disease (Noda, 1981). Onion germplasm from Mexico has been used by US seed firms to develop selections such as the white cv. El Toro, which are grown in the tropics. In Costa Rica, Panama and Venezuela the onions grown are mainly of the Granex, Yellow Bermuda and Dessex types (*see* Part II, Tables 5 and 6).

THE CREOLE GROUP OF ONION CULTIVARS

Another interesting and distinctive group of onions from the Gulf of Mexico area is the Creole type (Red, White and Yellow Creole cultivars) which was maintained and developed in the region around New Orleans in Louisiana (Magruder *et al.*, 1941a). Creole onions are grown there during the winter and form bulbs during the spring, and they are noted for their good high-temperature dormancy, which enables them to withstand storage during the hot, humid Gulf Coast summer before being replanted in the autumn for seed production. This characteristic may indicate that these onions, so different from the other southern US varieties, originate from West Africa. Possibly they may also include some admixture of older French or Italian onion germplasm. In areas of the New and Old World tropics where red onions are acceptable and seed production locally is difficult, Red Creole or selections from it are often found to be valuable. Selections are currently being made from it for improved quality in the Philippines (Groot, personal communication) and in Cuba (Muñoz de Con *et al.*, 1985) and a number of improved cultivars based on it are listed by seed firms in Appendix 5. Its distribution and storage characteristics are discussed further in Part II. Red Creole been noted for its resistance to purple blotch (*Alternaria porri*), a damaging leaf disease in the tropics, and the existing resistance is being improved by selection in Cuba (Muñoz de Con *et al.*, 1985).

BRAZIL: A COUNTRY AIMING AT SELF-SUFFICIENCY IN ONION SUPPLY

Brazil is probably the tropical country where research and development work has been done on the largest scale on onion breeding, agronomy and storage. Because of the language barrier, (most of this work has been reported in Portuguese), little of this interesting work is known outside Brazil itself. The vast size and spread of latitudes within the country's boundaries have allowed the Brazilians to develop recently a marketing strategy for onions which includes storage of the main crop in the southern regions, and supply from the tropical north-east of the country during the off-season (Zaidhaft, 1984). In the lower mid-São Francisco valley, in the state of Pernambuco in north-east Brazil, onions can now be grown under irrigation all year round, at a latitude of approximately 9°S. This has been achieved by a deliberate investment, over a 25-year period, of considerable research and breeding effort (Costa, personal communication). The starting material which has been used as the basis for improvement in several breeding programmes in Brazil is a highly variable group or land-race of light brown or reddish-skinned, medium storage quality onions known under the generic name of Baia Periforme. Their name refers to their pear-like shape, that is, they are round with a tapered neck. These onions were originally brought from Portugal and the Azores by settlers who arrived in the south of Brazil in the 19th century (Melo and Ribeiro, personal communication). Other characteristics of the group are the waxy, dark green leaves, thin neck, and a tendency to produce double-centred bulbs. The group shows tolerance to pink root rot and to purple blotch disease, and selections have been made from it in São Paulo with improved resistance to anthracnose or 'mal-das-sete-voltas' (*Colletotrichum gloeosporioides* in Brazilian literature: Costa and Melo, 1984). Skins are typically thin and few in number, a characteristic which is more suited to humid climates or to growing under sprinkler irrigation (Costa, personal communication).

Baia Periforme onions were first grown well outside the tropical zone, in the states of Rio Grande do Sul and Santa Catarina, and improved strains were selected by growers there. The first advance towards the tropics was made by selection in São Paulo state, Brazil's major onion producer, for use as sets (small dry bulbs), to give a crop in the months of May and June. Other strains of the same group were selected in São Paulo for the transplanted or direct-drilled crop which matures in October/November. Much of the selection work was done at the University of São Paulo by Costa and his associates.

In the late 1960s, further selections were made further north in Brazil by Wanderley *et al.*, (1986), and this work has led to the development of a series of cultivars which are adapted for growing in the lower mid-São Francisco valley, a comparatively recently developed irrigated production area: these are the IPA series (IPA 1, 2, 4, 5, 6 and 7). The Pira series, which includes Pira Ouro and Pira Tropical, which was developed by onion breeding at the University of São Paulo, is also suitable for the tropical north-east region. Formerly, cv. Amarela Chata das Canarias, one of the Atlantic Island flat yellow onion cultivars, was grown in the north-east from imported seed, but the Canary Island cultivar was found too soft to withstand transport to markets in the cities further south, whereas the Baia Periforme-derived lines have higher dry-matter content and sustain less damage during transport and marketing.

The US short-day onion variety Texas Grano 502 is currently the most widely grown cultivar in north-east Brazil, but the newer selections from the Baia Periforme type are being increasingly used there and in the more humid northern States, and are now offered by national seed companies (*see* Appendix 5). In the São Paulo state onion production region, the US hybrid Granex cvs. are popular for over-wintering because they are less susceptible to bolting (premature flowering in the bulb crop) than the Baia varieties. Melo and Ribeira (personal communication) estimated in 1988 that 10% of Brazilian onions are hybrids and 90% open-pollinated variaties, which include both the Baia selections largely grown in the southern states and cv. Texas Early Grano in the tropical areas.

Part of the success of the Brazilian breeding programmes based on indigenous (that is, long-ago introduced) material is undoubtedly due to the very variable nature of the Baia Periforme onion populations. It seems likely that this group itself may have been created by the genetic combination in Brazil of onions from a wide range of sources, reflecting the Portuguese nation's trading history throughout the tropics as well as its Mediterranean origins. The Baia Periforme group seems to provide an inexhaustible genetic resource for its country's onion breeders, and demonstrates the genetic plasticity of the species under selection pressure.

MULTIPLIER ONIONS IN ECUADOR

Another country where multiplier onions are grown is Ecuador. About half of the crop of these onions, which have red, or sometimes white bulbs, are sold as large green immature plants, before bulbing is complete. The individual bulbs are quite large: 3-4 cm in diameter. As well as the multiplier type of onion, which may have been grown in Ecuador since Spanish colonial times, imported US short-day onions are also grown from seed. (Yepez, personal communication).

THE NRI SURVEY

The information gathered together by the recent NRI survey is presented in Part II. It amplifies the overall picture given in this chapter and provides details of the cultivars grown in the tropical countries from which information was received. Because no replies were received from some countries, the survey does not give a complete account of the onions currently grown in the tropics, but in general it shows that the US short-day cultivars are very widely grown, especially in the Americas, while some countries in the Old World tropics use only local selections, and other tropical countries, such as Brazil, use both imported and local onion varieties for different purposes. Possibilities for onion improvement by breeding in the tropies will be discussed further in Part III of this bulletin.

Part I A selective review of the literature

Chapter 3 The onion and the environment

THE LIFE CYCLE OF THE ONION

The normal life cycle of the onion has been described by many authors (for example, Hayward, 1938; Jones and Mann, 1963). The sequence of events is as follows. The onion seed, which contains a small, coiled embryo and an endospermic food reserve, imbibes water when wetted in the soil and the cells rehydrate. The embryo starts active growth, drawing on the nutrients in the endosperm, to which it is attached by a haustorium-like structure at the tip of the cotyledon or seed-leaf. When the seed germinates, first the radicle or rootlet emerges and starts to become anchored in the soil. The cotyledon itself then emerges and by elongating it forms a looped structure which breaks the surface of the ground while the seed is still below ground level. The seed leaf continues to elongate at the base until eventually the remains of the seed from which it has grown are carried up above ground level, still attached to the tip of the cotyledon. The meristematic growing point of the seedling remains below ground, within the area where the cotyledon joins the radicle. This area is crucial to the organization of the onion plant throughout its life. From the growing point the seedling develops a succession of leaves, which grow from the flattened stem or base plate which forms around the growing point. Each foliage leaf is made up of a hollow green photosynthetic blade and a cylindrical sheath which connects the blade to the base plate of the onion plant. Cell division takes place near the base of the leaf, so that the oldest part of each leaf is the tip, and the youngest the base of the leaf sheath. Each leaf is produced inside the encircling leaf sheaths of older ones and grows up through them, so that a neck or 'pseudostem' is formed from the concentric leaf sheaths. Each new leaf blade emerges through a small hole or pore at the junction of the blade and sheath of the previous leaf. The hollow, tapering leaf blades are carried in two rows arranged opposite each other.

Roots are also produced from the base plate. New roots form in irregular rings above and around the older ones and emerge through the corky outer tissue. Each successive ring contains more roots than the previous one all the time that active vegetative growth continues.

The leafy plant eventually ceases to form leaf blades, and instead the apex begins to initiate a number of bladeless, concentric, thickened leaf sheaths: these form the bulb scales. Together with the swollen lower leaf sheaths of the older leaves, they make up the fleshy part of the onion bulb. Studies on movement of assimilates during bulbing have shown that most of the dry matter in the green leaves is transferred down to the bulb at this stage, contributing to both the swollen leaf sheaths and to the bladeless fleshy scales. The papery outer bulb scales are formed from the expanded, dried out bases of older leaf sheaths; the events of the process have not yet been described in detail.

Once no further leaf blades are being produced to support it from the inside, the onion's neck becomes hollow and the top of the plant falls down under the weight of the leaf blades: the green blades gradually senesce and die, but during this period nutrients from the leaf blades are still being exported into the bulb, which continues to store them. When this process is complete the onion ceases to grow and is ready for harvest. If it remains in the ground, root regrowth may start again, particularly if the soil is damp.

Lancaster and Gandar (1986) found that mature bulbs of cv. Spartan Sleeper grown in New Zealand had 9 to 12 scales, and that all of these were formed after the onset of bulbing, which began at about the 8-leaf stage. There was a burst of rapid leaf production just before bulb expansion began. It seems likely that these last-formed foliage leaves are those of which the leaf bases later form the dry outer scales of the bulb; clearly, considerable lateral growth takes place in between the vascular elements of the sheaths of these leaves to allow the onion bulb to expand to its final size while still remaining fully enclosed by the leaf bases.

During the period of apparent external dormancy, the main and usually several lateral growing points on the upper surface of the base plate continue to grow slowly and form shoot initials consisting of bladed leaves and flower stalk primordia (Abdalla and Mann, 1963). When the onion is replanted, roots start to grow from initials present in the base plate, and soon one or more leafy shoots emerge, followed by the floral scapes or stalks. Individual plants can produce several scapes. The scape is a stoutly formed green, hollow structure which becomes rather inflated at about one-third of the way up; it carries the flower buds at its tip. At first the buds are hidden by a thin outer spathe or sheath, which splits and peels away to allow the buds to develop and open into flowers, which are carried in a more or less spherical inflorescence known as an umbel. Each flower has a perianth of six white tepals with central green veins, six stamens with green or yellow anthers, and an ovary of three locules each containing two rather large ovules; the style is only 1-2 mm long when the flower opens and reaches its full length of 4-7 mm over the next 3-6 days; the stigma is a simple or slightly trilobed knob which only develops when the style has reached its full length, when the stigmatic surfaces exudes a sticky liquid to which pollen can adhere (Currah and Ockendon, 1978). Nectar is produced from glands on the outer walls of the ovary and is held inside the expanded filament bases of the inner whorl of three stamens. When the stigma is at the receptive stage, the tepals (petals and sepals) open widely so that the nectar is displayed to pollinators: the nectar fluoresces in the UV spectrum which insects can perceive (Waller and Martin, 1978).

The onion is insect pollinated and each individual flowers is protandrous, that is, it releases the pollen before the stigma is receptive. The onion is largely out-breeding, but as hundreds of flowers are produced on one umbel over a period of 3-4 weeks, there is usually a proportion of self-pollination within plants caused by pollinators moving between flowers on the same plant. If pollination and fertilization are successful the ovules start to develop: the seed capsules mature in a few weeks and split open to release the black, somewhat angular seeds. The parent plant may survive by producing one or more new bulbs from shoots at its base, but often dies from rotting at ground level.

ONION BULBING AND ITS CONTROL

The brief descriptive sketch of the onion's life history given above has hardly referred to its physiology. Many of the transitions between phases of the onion's life cycle, and in particular the onset of bulbing, have been extensively investigated during the last fifty years in attempts to define the environmental and internal signals which control them. Jones and Mann (1963) summarized what was known from earlier work, and more recently Brewster (1977; 1990a) has reviewed the whole area of onion physiology and productivity in detail. In this chapter, therefore, an attempt will be made to focus on physiological studies which are specifically relevant to the behaviour of onions growing in the tropics.

Physiologically, the onion is classed as a long-day plant. This concept means that for a particular onion population, a certain length of day can be determined which must be attained before bulbing will take place, no matter what the other environmental conditions. Within this concept, factors such as temperature, nutrition and spacing play important parts in accelerating or slowing down the bulbing process. Internal factors such as plant age or size also have a strong influence on the readiness of onion plants to respond to external stimuli (Jones and Mann, 1963).

The lengths of day to which different onion cultivars respond by forming bulbs vary greatly. Onions adapted to latitudes far away from the equator start to initiate bulbing when day-lengths of 14 to 16 hours are reached, and often complete the bulbing process under declining day-lengths in the autumn or fall season. The onions adapted to these regions are commonly referred to as long-day onions. They are sown or planted as sets (small dry bulbs) in the spring so that they can grow during the warm summer.

PHOTOPERIOD IS LESS IMPORTANT AT LOW LATITUDES

In the tropics, however, well-adapted onion populations are found in regions where the day-length varies very little, or not at all, throughout the year. Evidently, photoperiod must carry less importance as an environmental signal in tropical parts of the world; at the equator itself the days are all very nearly 12 hours long, and in regions within the tropics the variation over the year in day-length is within a narrow range (approximately 11 to 13 hours). The onions which can be grown in tropical regions are often referred to as short-day cultivars. (This does not mean that these onions are 'physiologically short-day' plants, a term which has a different and specific meaning: they are still physiologically long-day plants, but ones which respond to days which are short). Short-day cultivars can initiate and form bulbs under photoperiods of 13 hours or less, equivalent to those found in latitudes which are $<24°$ from the equator. Within the tropics, therefore, short-day onions may go through their whole life cycle under a photoperiod which, in theory, is sufficiently long to permit them to form bulbs. In these circumstances, environmental factors such as temperature, nutrition and spacing, and internal factors such as the age, or stage of development of the plants themselves, apparently control the onset and progress of bulb formation. The relative importance of the environmental and internal factors which control bulbing in 'short-day' onions are not yet fully understood. Little detailed physiological research has yet been done on onions which are adapted to growing in the tropics, therefore it is important to analyse and attempt to understand the control factors from the small amount of existing data.

THE SHORT-DAY ONIONS

The group known as short-day onions includes not only populations which have been developed within the tropics themselves, in regions such as the Sahel of West Africa and in India, but also the group of Mediterranean, Atlantic and southern USA 'early season' bulb onion cultivars such as Babosa (Spain), the Bermuda cultivars and the Early Grano group (USA). As discussed in Chapter 2, these varieties were developed well outside the tropics as over-wintered crops to provide the first fresh bulb onions of the new season. To do this, they must begin to bulb early in the spring, when the day-length increases to 11 or 12 hours, (February–March in the northern hemisphere outside the tropics), and at a time when the weather is rapidly becoming hotter and drier, factors which favour fast bulb development. The reason why they can also be grown in the tropics, therefore, is because they are adapted to bulbing at approximately equinoctial day-lengths which are within the normal photoperiodic range for the tropics (*see* Chapter 2).

However, some of the physiological responses of the onions of Mediterranean origin may differ from those of truly tropically adapted onions; for example, in north-east Brazil, flowering and seed production of cv. Texas Early Grano after artificial cold treatment of the bulbs to vernalize them, was less successful than that of similarly treated Brazilian lines selected from cv. Baia Periforme and other Brazilian stocks (Aguiar *et al.*, 1983). It seemed that even if cv. Texas Grano was vernalized successfully (that is, the bulbs contained flower initials after cold treatment), it was unable to produce inflorescences at the high ambient temperatures which prevailed in the seed fields after the bulbs were planted out. Probably the strong bulbing stimulus which the high temperature gave to the plants competed strongly enough to cause scape abortion (Kampen, 1970). Evidence from work at the University of Nigeria, Nsukka, (6° 52'N) was that the West African cvs. Bawku and Red Kano responded better to vernalization when stored at a comparatively high temperature, 20°C, than when kept at 10°C, which led to complete failure to flower after they were planted out (Uzo, 1983). Differences of this kind in response to temperature may differentiate the tropically adapted from the Mediterranean or US short-day onion groups. Selection of cv. Red Creole for seed production within Cuba shows that as lines become better adapted to the tropical environment over several generations, seed yields increase (Muñoz de Con *et al.*, 1985).

Onion physiology has been the subject of several classic studies in the past. In the 1920s and 1930s, Magruder and Allard (1937) in the USA, and in the 1940s and 1950s Heath and Holdsworth (1943; 1948) in the UK, investigated the day-length and temperature responses of onion varieties which were mainly long or intermediate day-length sensitive. Because these studies were made in temperate regions, where photoperiod was the most obvious, and possibly the major factor controlling the initiation of onion bulbing, this aspect may have been overemphasized in discussions of the topic until recently. The very strong influence of temperature on bulbing once an inductive day-length was reached was however noted in the early studies.

In the 1930s, Magruder and his associates made thorough experiments on the behaviour in the field and in storage of the best known current US onion varieties, including the short-day Creole, Bermuda and Early Grano types. Growth trials were made at several locations in the USA, and clearly showed that the US short-day onions only gave satisfactory yields when grown as over-wintered crops in the southern states (Magruder *et al.*, 1941a). The storage trials distinguished between the good storage characteristics of cv. Australian Brown and the Creole group compared with the Bermuda and Early Grano types, which were classed as being poor keepers (Magruder *et al.*, 1941b).

TEMPERATURE AND ONION GROWTH: EXPERIMENTS IN THE TROPICS

The interaction between day-length and temperature in controlling onion bulbing was noted many years ago (Thompson and Smith, 1938). In temperate climates, year-to-year differences of some weeks in the dates of onion bulb maturity are often associated with the type of weather experienced during the period when the bulbs are forming and maturing. Abdalla (1967) studied onion bulbing in Sudan and first proposed that under arid tropical conditions, temperature was the more important controlling factor, as it was relatively more variable than day-length locally. In the Khartoum area (15°N) day-lengths vary from 13 hours in June to 11.25 hours in December, whereas the respective temperature ranges were 25-42°C and 13-30°C. In trials on 12 cultivars which were sown at 2-month intervals from June to December, mean number of days to bulbing varied from 77 days for the June-sown crop to 110 days for the October-sown crop, which made most of its growth during the coolest period of the year. Abdalla also noted that where temperatures reached 40-

45°C in a glasshouse, bulbing was retarded in 10 out of 12 cultivars, though leaves were still produced at these temperatures. However, bulbing of the local cv. Hilalia and of cv. Red Tropicana was not affected by the very high temperatures, suggesting that these two varieties were better adapted to Sudanese growing conditions than the others (Abdalla, 1967).

In the 1960s Robinson (1971; 1973) grew several US and South African onion cultivars in Zimbabwe and described in detail their responses from successive sowings during the cooler part of the year in the lowveld region of the country. Onions were sown at monthly intervals from February until June (northern hemisphere equivalents August to December) and their yields, bulb quality and growth were recorded. Mean temperatures were high at the first sowing date, then fell and rose again during the successive sowings. The mean monthly temperatures during the trials were: February 28.3°C; March 24.4°C; April 23.1°C; May 19.2°C; June 17.8°C; July 17.0°C. By the time the crop from the last sowing date was at the leafy stage, mean temperatures were again as high as 25°C and bulbing was then induced rapidly, before the plants had reached their optimum leaf area; bulb yields from the last harvest were therefore the lowest of the five (Robinson 1971, 1973).

Plants from Robinson's first two sowings had a greater tendency to split or form double bulbs than those sown at the third and fourth dates, when the mean temperatures were lower. Marketable yields were highest from the three middle sowing dates, and the time from transplanting to bulb maturity (defined as 75% of tops down) decreased by approximately 10 days for each successive sowing date, from 128 days for February sowing to 80 days for June (mid-winter) sowing. In contrast with the work of Abdulla (1967), the temperatures experienced were not high enough to inhibit bulbing in the range recorded. The Zimbabwe winter temperatures were low enough to allow the onions a long vegetative growing season at mean temperatures of about 17°C to 23°C, which resulted in the greatest yields of good quality bulbs (Robinson, 1971).

PREMATURE BULBING IN THE SEED-BED

Robinson (1971) noted high levels of premature bulbing in the seed-bed in some of the cultivars sown at the earliest date; cvs. Dessex, de Wildt and Pyramid had 72%, 35% and 40% respectively, while cv. Texas Grano only had 7% and Bon Accord 17%. 'Precocious' or premature bulb formation is a problem which is often mentioned in literature on onions from the tropics. The small bulbs are produced by seedlings, sometimes with only 3 or 4 leaves or even fewer, which become totally dormant for a time after the leaves have died down. They resume growth only weeks or even months later, so they are not worth transplanting (Robinson, 1971). In fact, they can be likened to the deliberately produced sets of North America or northern Europe. Sets are also small, dormant bulbs. They are produced by thickly sowing onion seed of long-day varieties in the spring, they form bulbs early in growth and are stored in a dormant state for use as planting material in the following year (Jones and Mann, 1963). In the case of sets, the factors which induce early bulbing are overcrowding, and the high temperatures and long days under which they mature. Bearing in mind that short-day onions may be growing all the time under potentially bulb-inductive day-lengths, it may well be that excessively high temperatures at the time of early growth, particularly when allied to overcrowding in the seed-bed, can induce this behaviour in a proportion of the onion population.

In onion breeding schemes in Brazil, selection in the nursery bed and field against precocious bulbing was one of the techniques used to improve the adaptation of populations to ever hotter areas and seasons (Melo *et al.*, 1978; Menezes *et al.*, 1979). The fact that the level of premature bulbing could be reduced by selection shows that to some extent it must be under genetic control.

Another interesting aspect of the work of Robinson (1971) was his observation that growth at high temperatures resulted in increased bulb splitting. Splitting, and to a lesser degree, doubling of onions occurs following the formation and substantial growth of more than one growing point from a bulb in a single season, and it leads to the production of unmarketable bulbs, which if stored do not normally keep well. In appearance, these resemble European shallots (that is, they are larger than typical tropical shallots). Steer (1980a) noted in experiments made under controlled environment conditions that one cultivar out of four in the trial, cv. Braeside Golden Globe, when grown at a range of temperatures above 18/10°C (day/night) at an 11-hour day, reacted by producing numerous lateral buds which continued to grow rather than bulbing. The other three Australian cultivars however did not react thus. This reaction, and that of the onions in Robinson's earliest sowing, described above, suggest that compound bulb variants of *A. cepa* such as multiplier onions and tropical shallots may be selections from bulb onion populations which respond to short days and high temperatures by increased lateral bud formation and growth. Slightly different timing of lateral bud formation might then account for the different numbers of daughter shoots in multiplier onions and shallots and for their final degree of separation. More information is needed on the genetics of doubling and splitting, and on the influence on it of the environment. It may be relevant to note here that within the species *A. fistulosum* a wide variety of splitting habits exists, so that some cultivars are virtually single-centred and others split profusely.

CONTROLLED ENVIRONMENT STUDIES OF AUSTRALASIAN ONIONS

Steer (1980a) compared Australasian varieties of onions adapted to different latitudes, using five temperature regimes ranging from 18/10°C up to 34/26°C day/night, and three day-lengths: 10, 14 and 17 hours. In general, bulbing was more rapid the higher the temperature and the longer the day-length, confirming the earlier results of Thompson and Smith (1938). One cultivar, Creamgold, could not be induced to bulb at all at the lowest temperature; the others bulbed if given sufficient time. Steer (1980b) also found that night temperatures which were comparatively warm (5°C below day temperature) accelerated bulbing more than those which were cool (15°C below day temperature).

SOIL TEMPERATURE AFFECTS BULB SHAPE AND PUNGENCY

An interesting effect of soil temperature on bulb shape was found by Yamaguchi *et al.* (1975) in glasshouse experiments in California, using three white onion cultivars, two of which were selections grown for dehydration. Comparisons were made at soil temperatures of 13°C, 18°C, 24°C and 29°C, and it was found that the higher the soil temperature, the more elongated was the resulting bulb. The height of the bulb increased while the diameter remained the same, except at the highest soil temperature, 29°C, at which bulb diameter was slightly reduced. High soil temperatures may therefore contribute to the occurrence of bottle- or cigar-shaped onion bulbs which are reported from hot countries (for example, 'charutos', the term used in Brazil). Yamaguchi *et al.* (1975) also found that onion pungency and flavour volatiles increased significantly as soil temperature rose, though dry weight and total sugars were not affected.

TEMPERATURE AND DAY-LENGTH EXPERIMENTS IN THE UNITED KINGDOM ON SHORT-DAY ONIONS

The US and South African short-day onion cultivars which are grown in Botswana and Swaziland are being studied by Wiles (1989) in a Ph.D. project entitled 'The effect of light and temperature on bulb initiation and development in tropical cultivars of onion', which is being made under glasshouse and controlled environment conditions at Wye College, University of London. The day-lengths studied range from 10 to 15 hours. When cv. Granex was grown in a glasshouse at ambient temperatures, its response to a range of day-lengths, in terms of days to onset of bulbing, was negative and almost linear: that is, the longer the day, the more quickly the plants started to bulb. When a series of controlled temperature treatments from 14/6°C up to 34/26°C were compared at a 14-hour day-length, cv. Granex bulbed most rapidly at 30/22°C (day/night) and more slowly at lower temperatures; interestingly, it also bulbed more slowly at 34/26°C, suggesting that growth was reduced by stress to an extent which delayed bulb growth (Wiles, 1989; compare with Abdallam, 1967, discussed earlier).

When plants of different ages, which had been raised in a short, non-inductive day-length (10 hours) for 8, 12 and 16 weeks previously, were given 11- and 13-hour day treatments, cultivar responses varied within the short-day group. In cv. Texas Grano, plants of all ages bulbed in 13-hour days, but only the oldest plants could be induced to bulb in 11-hour days (Wiles, 1989). This demonstrates the relatively strong influence of plant age on readiness to bulb in cv. Texas Grano, and helps to explain how it can be grown successfully all the year round in many tropical regions (for example, in Lara and Falcon States, Venezuela; Flores, personal communication).

Wiles found a tendency for bulbing to take place after the same number of leaves has emerged, at non-stressful temperatures between 22/14°C and 30/22°C, in the short-day cultivars which he studies. This work, which amplifies the earlier field observations by Robinson, shows how onion cvs. such as Texas Grano can produce a bulb crop in areas like Zimbabwe when the day-length is as short as 11 hours, provided that the plant has reached a sufficiently mature size. This feature of the response of Texas Early Grano has led to it being described sometimes as 'day-length insensitive', or 'day-neutral'. However, these terms only apply when it is grown in day-lengths of near 12 hours; growing the variety at day-lengths of longer than 14 hours will result in very rapid bulbing. Of the other cultivars tested by Wiles, cvs. Ori and Yodalef bulbed at both 11- and 13-hour day-lengths within 3 to 5 weeks of transfer, except for the youngest plants in the 11-hour day treatment, while in cvs. Hojem and Bon Accord only the older two classes of plant in 13-hour days had started to bulb by 5 to 6 weeks after transfer.

Plant age was also an important factor affecting bulbing in the experiments of Wright and Sobeih (1986) and Sobeih and Wright (1986), who studied light intensity and photoperiod effects on bulbing of long-day onions under controlled environment conditions in the UK.

MEASURING ONION BULBING

The work of Brewster over the last 15 years in the UK has not been directly concerned with short-day onion cultivars, but has contributed greatly to a general understanding of the factors controlling bulbing and flower production by onions, and also of the theoretical limits to bulb productivity. Brewster has used two main indicators of bulbing in his studies:

(i) bulbing ratio (BR) (Clark and Heath, 1962):
bulb diameter at widest point divided by neck diameter. BR >2 is often taken to indicate that bulbing has begun. (The reciprocal measurement, neck diameter divided by bulb diameter, was used by Abdalla and Mann, 1963: a ratio of 0.4 indicated onset of bulbing.) Non-destructive; and

(ii) leaf ratio (LR) (Heath and Hollies, 1965):
measured on leaves which are still inside the bulb. Leaf blade length divided by sheath length. LR <1 indicates bulbing has begun. Destructive.

Bulbing ratio, when used alone, may sometimes be misleading, because in certain circumstances, thickening of the bulb region can occur which is not followed by cessation of leaf blade growth, particularly in cultivars which are not fully adapted to the region where they are being grown (de Bon, 1988): this can result in the production of thick-necked bulbs in which BR >2 but which do not mature fully. Leaf ratio is used to distinguish bulbs where leaf blade initiation has ceased, and only bulb scales are being formed. The two measurements are complementary. In making field studies on time of bulbing, it may also be useful to record the time of cessation of leaf appearance (Mondal *et al.*, 1986a). Maturity of the individual bulbs is usually taken to be the date at which the neck of the bulb weakens enough to allow the foliage to fall down ('tops fallen', 'flopover', 'lodging' and other terms are variously used to describe this). For a particular crop the date of a defined percentage of tops fallen can be used as a measure of crop maturity or as an indicator of readiness for harvest. Mondal *et al.* (1986a) used 80% tops fallen; it should be noted, however, that bulbs may continue to gain in weight even after 100% of tops have fallen, as the remaining assimilates in the leaf blades continue to be translocated into the bulbs through the vascular system of the neck until it dries out.

SPACING, LIGHT WAVELENGTH AND BULBING

The influence of spacing and plant competition on bulb formation was investigated using measurements of BR and LR (Mondal *et al.*, 1986a-c; Brewster, 1987) in experiments in the field in the UK at different spacings and using different forms of shading, and also in experiments under controlled conditions where the amount of incident light and its spectral quality could be adjusted. Bulbing was promoted by close spacing, even under conditions where nutrition and water supply were non-limiting. Shading of leafy onion plants, either by other onions or by other green plants, also promoted bulbing. To understand why this occurs, it is necessary to know that the wavelength of light is modified by a canopy of green leaves; the ratio of red to far-red wavelengths decreases, and this gives a signal, detected by the onion plant via the phytochrome system, which hastens the onset of bulbing (Mondal *et al.*, 1986b). Young leaves were the most sensitive to this change in wavelength (Sobeih and Wright, 1986). Onions are well known to be very adversely affected by weed competition, particularly during the stage of rapid vegetative growth (Shadbolt and Holm, 1956; Hewson and Roberts, 1973), and the work of Mondal *et al.* (1986a-c) helps to explain why they bulb early, with consequent loss of yield, when growing in a competitive situation and particularly when shaded by other plants. Premature bulbing in the seed-bed under hot conditions may also be partly explained by these findings, because it is known that the phytochrome system is sensitive to temperature; therefore, a degree of seedling competition which might be tolerated at moderate temperatures could result in bulbing in hotter weather.

NITROGEN SUPPLY AND ONION BULBING

The effect of nitrogen (N) supply on onion bulbing has also been reviewed and investigated recently by Brewster (1988; 1990a) and Brewster and Butler (1989). Many agronomic studies have been made on onions in the field on the timing and quantity of nitrogen application, but results on onion yield have often been difficult to interpret, frequently because the original N level in the soil and its changes throughout the growing season were not quantified. From Brewster's recent nutrient experiments, in which only N levels and lengths of photoperiods were varied, it was found that bulb scale initiation was delayed by limiting the supply of N. This was in spite of the fact that early in the experiment, young vegetative plants showed comparatively high bulbing ratios; this was caused by thickening of the leaf sheaths, and occurred at a time when the rate of growth was being kept at a low level by N shortage. These plants however continued to initiate foliage leaves. Later in the experiment, onions growth in the adequate N treatments initiated internal bulb scales as expected in the photoperiod treatment given, but in plants in the low N treatments, bulb scale formation was delayed. This may explain why, even if a nitrogen shortage is remedied late in the growing season, the bulbs formed tend not to mature normally, but often show a high proportion of thick-necked bulbs. The reason for this is that foliage leaves continue to be initiated later in plants which have been through a period of nitrogen shortage, compared with those which were well supplied throughout the vegetative growth period.

THE THICK-NECK SYNDROME AND ITS CAUSES

Thick-necked bulbs are those in which late foliage leaves emerging through the neck prevent it from collapsing at harvest time. They can be regarded as 'lagging' members of the population which have failed to produce mature bulbs by the target harvest date. There can be several different causes of this condition: defective nutrition as discussed above; lack of inter-plant competition, as sometimes seen in large isolated plants; slower overall growth rate, which is shown by inbred plants within an open-pollinated population; or prolonged cool, overcast weather, at a time when onions in which bulbing has been induced are completing the process under day-lengths which are marginal for the population. Another way of explaining the last-mentioned reason for the thick-neck syndrome is to say that it is shown by onions which are not fully genetically adapted to the climate in which they are being grown, in that they require a longer day-length or higher temperature than the prevailing one to bulb efficiently. In climates such as those of northern Europe, where there is great year-to-year variation in the amount of heat and light received during the onion bulbing period, considerable seasonal variation is common in both date of harvest and degree of thick-neck formation, even in supposedly well-adapted onion cultivars. In the tropics, reasons such as regrowth following leaf damage by disease or pests, or growing in a season of declining temperatures are likely causes of this condition.

LIGHT INTERCEPTION AND ONION YIELD

The importance of adequate nutrition of onions early in their growth cycle was emphasized by the experiments of Mondal and Brewster discussed above. If a relatively rapid rate of growth can be established during the juvenile phase of rapid leaf production, it allows the plants to develop without checking through to early and complete bulb maturity. Brewster *et al.* (1986) investigated the potential yield of onion in the UK and found experimentally that it was highly dependent on the Leaf Area Index (LAI) of the crop during the period between onset of bulbing and harvest in the UK, a period known as 'duration of bulbing'. LAI is a measure of the amount of leaf surface area of the crop per unit area of land. The onion converts most of the plant's dry matter into harvestable product (harvest index 70-80%), but because of the shape and arrangement of the leaves, it is inefficient at intercepting incoming radiation (Brewster, 1982), hence the need to encourage as much leaf growth as possible early in the season, so that total light interception is maximized.

Work by Lercari (1983) has shown that the photoperiodic aspect of the control of bulbing is a 'high irradiance response' of the phytochrome system: this may explain why bulbing in onions occurs more rapidly in seasons or areas of high light intensity than in seasons, or regions, where the weather is more cloudy, and may also help to explain differences in bulbing behaviour of onions at different altitudes but at similar latitudes, which have been reported by observers in the tropics.

WATER RELATIONS

The water status of the crop is another important factor which can potentially limit growth. Plants respond to water stress by closing their stomata, which cuts down water loss by transpiration but also imposes limits on gas exchange within the leaf and so slows down photosynthesis and growth. The onion is comparatively sensitive to water stress, and its growth can be inhibited well before the leaves wilt visibly from high temperatures or drying winds, even when the roots seem adequately supplied with water (Millar *et al.*, 1971). There appears to be a fairly narrow window of water conditions at which the onion functions efficiently by both transpiring and photosynthesizing freely. Measurements made in seed onion fields in Idaho, where the air temperatures were as high as 43°C, showed that stomatal resistance was least at 30°C (that is, at this temperature gas exchange was least limiting to photosynthesis), but that stomatal resistance increased at higher and lower temperatures (Goltz and Tanner, 1972). In trials on young leafy onions, it was found that as the leaves lost water and their turgor pressure went down, a rapid change took place in stomatal conductivity, and leaf growth rate slowed down correspondingly (Darbyshire *et al.*, 1979).

SALINITY EFFECTS ON GROWTH

Onion yields can be reduced by high salinity, particularly when this is accompanied by high evapotranspiration (Bernstein and Ayers, 1953). The onion seems to have only a limited capability of adjusting its internal osmotic regime to compensate for outside salinity, with the result that its rate of photosynthesis and hence of growth is much more severely reduced in saline conditions compared to that of beans or cotton (Gale *et al.*, 1967). The effect in onions was thought to be due to the stomata closing when leaf turgor pressure fell under saline conditions, however, the effect was easily reversible once water which was less saline was supplied. Reduced yields were reported from plants grown under slightly saline conditions (Bernstein and Ayers, 1953), and this may be one reason for some of the low yields of irrigated onions in the tropics, where irrigation water may carry salts which can reach damaging concentrations each time the soil dries out. Wannamaker and Pike (1987) found that young onions were particularly sensitive to salinity at the emergence stage, but became less sensitive as the plants grew older, though growth was reduced and tip-burn symptoms appeared on the older plants at salinity levels above 1.6 dS.m.

This brief survey of the extensive literature on onion physiology has included work from both temperate and tropical regions in an attempt to explain the reasons behind some of the problems found in onion growing in the tropics. Some of the methods and approaches used might be taken as models for future work on tropical onions in the field. The physiology of dormancy, vernalization and flowering in the onion in tropical environments has been even less investigated than growth and bulbing in tropical environments. These tropics will be treated in the next chapters in connection with the agronomy, storage and seed production of the crop.

Chapter 4 Onion agronomy in the tropics

INTRODUCTION

More work has been done on onion agronomy in the tropics than on the physiology of short-day onions. Many experiments on onion production techniques have been made by extension and research services in different countries, and much of the information obtained has been incorporated into local advisory literature. Some of the extension literature published in the tropics is listed in Appendix 4. Naturally, some of the recommendations in the extension publications are of relatively local application, for example, when they refer to pests and diseases found in particular areas. In this chapter, some examples of onion growing systems in different parts of the tropics will be summarized from descriptive and advisory publications, then some detailed aspects of onion agronomy will be discussed, in particular some aspects of recent research work which may be potentially useful for improving onion production in the tropics.

Although there are many local publications describing onion agronomy in the tropics, as yet there have been few attempts to review the topic on a larger scale. Baradi (1971) first brought together some of the earlier literature, and the TDRI (1986) manual *Pest Control in Tropical Onions*, which reviewed pest, disease, nematode and weed control fully, also contained a general chapter on methods of onion growing in the tropics. Three chapters of a new multi-authored book, *Onions and Allied Crops* (Rabinowitch and Brewster (eds.), 1990), are on onion agronomy. Brewster deals with temperate systems, Corgan and Kedar with largely mechanized production methods in subtropical regions, which have much potential relevance to future developments in tropical regions, and Uzo and Currah with agronomy of onions in the tropics, in a chapter which draws on some of the sources also used here.

A TRADITIONAL ONION GROWING SYSTEM IN NORTHERN NIGERIA

Inyang (1966) gave a detailed account of how onions are grown in northern Nigeria, and Bednarz (personal communication) has recently confirmed that the practices described are still used in the region. The crop is grown in dry areas in the north of the country, and three crops are produced per year: two rain-fed and one irrigated. Transplants are produced by sowing seed broadcast, or in rows 10-15 cm apart, in a 120 cm-wide seed-bed prepared by incorporating compost or poultry manure. Seeds are sown at a depth of 12 mm or less, and if the weather is dry the beds are watered once or twice a week. Dry grass is used as a light mulch on top of the seed-beds to protect the seeds from being disturbed by the watering, (and also from overheating in the ground) and is removed when the seedlings emerge. The seedlings are ready to transplant after 6-8 weeks. In the seed-bed they are weeded and watered by hand. It is always necessary to add compost or manure to the land to grow onions (Inyang, 1966).

When grown during the wet season, the onions are transplanted onto ridges at a spacing of 15-20 cm apart, with 2 rows per ridge. Seedlings which are too small and those which have started to bulb precociously are discarded. The two rain-fed crops are sown in late April and June and harvested in August–September and November–December respectively. These onions are sold immediately and they do not crop well, both because farmers are too busy to attend to them while growing their main food crops,and also because the wet season favours the disease *Alternaria porri* (blast or purple blotch) (Inyang, 1966).

To produce the main or dry season crop in northern Nigeria, seeds are sown in October–November and transplanted in December–January. This crop is grown in flat beds 60 cm in width with plants 15-20 cm apart, and is supplied with water by a system of channels. It is irrigated once or twice a week. The onions are harvested in March–May. Local cultivars are described. Two of them showed different rates of precocious bulbing in the seed-bed: cv. Wuyan Makwarwa showed this tendency while cv. Wuyan Bijimi did not, but the latter tended to have a thicker neck (Inyang, 1966). These observations indicate that the two varieties probably have slightly different physiological responses to the environment, perhaps due to being selected originally at different latitudes. Wuyan Makwarwa appears to have a shorter day-length requirement or less tolerance to high temperatures compared with Wuyan Bijimi, which needs a longer day or higher temperature to complete the bulbing process.

Crickets, a leaf-eating moth and purple blotch were the chief pests and diseases attacking the crop. Yields were described as variable, and estimated at approximately 7-9 t/ha. The need to select only dry, healthy bulbs for storage was emphasized (Inyang, 1966).

To produce seed, sprouted axillary shoots, referred to as sets or bulbils by Inyang (1966) are produced from old bulbs, by a method which allows the top half of the bulb to be cut off for selling or eating, while the lower half is planted in a pot or seed-bed and watered every second day; a bulb 75 mm across can produce 15-20 sets. After the shoots from the cut bulbs have reached a length of 15-20 cm (Green, 1972) they are separated and planted in the field in the dry season, where they flower and produce seed in 3-4 months (Inyang, 1966). This system of seed production was investigated by Green (1972) in northern Nigeria. He found that the practice did not give more or better quality seed than planting whole bulbs, although more inflorescences per mother-bulb were produced following the cutting treatment; Nabos (1976), who made similar experiments in Niger also found no advantage for seed yield in the practice. However, from the breeding point of view, separating the inflorescences physically in the field may have the advantage of increasing the proportion of crossing between plants, compared with leaving the seed parent plants intact. If a higher level of heterozygosity (i.e. less self-fertilization) is achieved by this means, in the next generation of plants higher vigour and survival rates may be found (Currah and Ockendon, 1983), even though no immediate seed yield improvement can be detected: the advantage, if any, would be the increased genetic mixing within the population. This is an important factor in the out-breeding onion (Currah, 1981a), and it is not unlikely that the effects have been noted by West African farmers. Possible effects of bulb wounding on the breaking of dormancy will be discussed in Chapter 5.

The onion-growing methods described by Inyang (1966) resemble those used in many areas of the drier tropics where onions are grown on a small scale. The use of transplants is preferred in systems using hand labour, since it saves on weeding and watering effort during the early weeks of onion growth and enables the farmer to attend to the seedlings in a compact area, besides saving on land which may still be in use for another crop. In many parts of the wetter tropics, for example, the main onion or shallot crop is grown after rice, which is harvested after the end of the rainy season.

ONIONS IN THE AMERICAN TROPICS: GUATEMALA

Medina (1980) described briefly the onion growing methods recommended for Guatemala, in a popular article which is quoted as an example of the recommendations made to growers in the American tropics, where onions tend to be grown over a wider range of terrain and altitude than in West Africa. Medina (1980) in Guatemala made use of more research findings than Inyang (1966) who described the traditional onion-growing practices in Zaria, Nigeria.

Medina began by emphasizing the need to use pure seed with good germination, in order to get good plant establishment. He stated that seed germinates best at a soil temperature of 24°C, though it can grow between 1.6°C and 35°C if water is adequate. The influence of market requirements on the likely demand for the produce was pointed out; the grower needs to bear in mind what type of onion is required locally.

While the onion can be grown in climates ranging from cool to hot, it is best suited to moderate temperatures early in its development and higher ones at maturity. Temperatures of 12°C to 24°C are considered the most suitable for vegetative growth, though the onion can grow in temperatures from 8°C to 30°C. The influence of day-length is mentioned and some short-day cultivars are listed as being suitable for growing in Guatemala: Bermuda and Canary (Canarias) types and US and Mexican cvs. such as L-36, Louisiana Red Creole, Texas Grano, Crystal Wax, Granex Hybrid, Tropicana, Cojumatlan and Yellow Granex (Medina, 1980).

On soils, the advice is to use a well-prepared, well-drained and fertile site, preferably a sandy loam or other friable soil with a good level of organic matter and a pH of between 6.0 and 6.8. Raising the seedlings in seed-beds is recommended, using either raised or sunken beds (that is, according to the season). Three pounds (1.36 kg) of seed are used per 'manzana' (0.782 ha) of final transplanted field. The seed-bed should be prepared with a mixture of one-third each of 'black earth' (possibly peat), organic manure and fine sand. Various organo-chlorine insecticides are recommended for use on the seed-bed at a rate of an ounce (28 g) per square metre. Seed-bed pests are cutworms and other caterpillars, and ants. To prevent damping-off, pre-treatment of the seed-bed with methyl bromide is recommended, 15-20 days before sowing, using 1 pound (0.453 kg) per square metre, after which seed-beds should be covered with plastic sheets to retain the gas. A fungicide treatment of the beds 5 days before sowing is given as an alternative.

The seed should be sown in small furrows 1 cm deep and 8-10 cm apart and covered with fine earth, with the seeds 1 cm apart in the furrows. A seed-bed mulch of dry grass is used, as in Nigeria, but Medina added that the grass is left between the lines of seedlings after they emerge, to conserve water and suppress weeds. Seedlings are transplanted 6-10 weeks after sowing, and should be given a foliar feed 3-6 days before transplanting to prepare them to withstand the move: at the same time, irrigation is halted.* The leaves and roots should not be cut at transplanting, as this has a bad effect on the eventual yields (*see* below, p. 62 where this is confirmed).

No definite recommendations are made by Medina as to spacing of the transplants, as this depends very much on local growing conditions, including soil fertility, availability of irrigation and degree of mechanization of the growing system. Distances varying from 5 cm to 12 cm between plants and 15 cm and 45 cm between rows have been used successfully. Soil analysis is recommended in order to decide how much fertilizer to apply. (Onion fertilizer needs are discussed later on pp. 62-4.)

**Authors' note:* Presumably the intention is that the seedlings should be slightly wilted at transplanting time.

The need to keep onions well weeded, whether by hand, mechanically or by using herbicides, is emphasized. The high cost of hand weeding is pointed out and recommendations are given for the application of herbicide pre-emergence and when the plants are 15 cm to 20 cm high, with instructions to avoid spraying the crop itself, presumably by using a shielded nozzle. Medina (1980) advised growers to follow strictly the makers' recommendations for application of chemicals.

Among insect pests in Guatemala, thrips (*Thrips tabaci*) are the most serious; the damage which they cause is described and a number of insecticides, to be used with the addition of wetters, are recommended for use against them. It is suggested that the same insecticide should not be used more than four times in succession because of the danger of the development of resistance by the thrips.

The second most important pest in Guatemala is onion fly (*Delia antiqua*), for the control of which organochlorines were recommended in 1980. The treatments were also used to control other soil pests such as cut-worm caterpillars (*Noctuidae*). Other, less environmentally damaging chemicals would probably be advisable now.

Serious diseases for which treatments are described are damping-off, caused by *Rhizoctonia solani, Pythium* and *Fusarium*; downy mildew (*Peronospora destructor*); purple blotch (*Alternaria porri*); and bacterial soft rot (*Erwinia carotovora*) which attacks the bulbs, starting in the field.

For onions to be stored, a curing period of 3-10 days is recommended, to consist of 3 days in the field and then a period in the shade, to avoid excessive water loss. For drying in the field, the bulbs, particularly white ones, should be protected from the sun by their leaves.

The above account by Medina (1980) shows heavy reliance on commercial chemicals for pest and disease control. In this it demonstrates the need for crop protection measures on onions in the cooler, more humid climate of the highlands of Guatemala where many of the country's onions are grown. Such a climate is more favourable to disease development than that of the dry tropics, and also allows some temperate pests to flourish: onion fly, for example, is rarely encountered in hot dry environments. Details of the chemical treatments recommended by Medina are omitted, as recent crop protection measures for onions are described in the TDRI (1986) publication.

AN ONION GROWERS' GUIDE FROM VENEZUELA

Other extension publications describe methods of onion culture in greater detail: in Venezuela, for example, the Fundación Servicio para el Agricultor (FUSAGRI) organization publishes a comprehensive illustrated guide to onion and garlic growing (*Cebolla y ajo*, FUSAGRI 1986). An earlier edition of 1975 described how onion production in Venezuela was moving from the cooler mountainous regions to the hotter lowlands; the average yield was 20.25 t/ha. Growing systems using transplants and sets were described, and substantial information was given on fertilizer requirements and methods of application, and on irrigation, which is applied with serpentine furrows within large beds, with long furrows on level ground, or by sprinkler irrigation on more sloping fields.

The FUSAGRI (1986) publication contains descriptions and illustrations of the onion pests found in Venezuela. They include thrips, slugs, four types of cut-worms (*Noctuidae*), crickets (*Gryllus assimilis*) and mole-crickets (*Gryllotalpa hexadactyla*), leaf-miners (*Liriomyza trifolii* and *L. huidobrensis*), red spider mites (*Tetranychus urticae* and *T. cinnabarinus*), a bulb mite (*Rhizoglyphus echinopus*), a subterranean plant bug (*Cyrtomenus bergi*) and leaf-eating caterpillars (*Trichoplusia ni, Spodoptera frugiperda* and other *Spodoptera* spp.). The general discussion of pest control mentions the possibility of using mechanical, cultural and biological methods as well as chemicals. Also described are the onion diseases *Botrytis* leaf spot, pink root rot (*Pyrenochaeta terrestris*), white rot (*Sclerotium cepivorum*), and the nematodes occurring on onions in Venezuela; treatments are recommended. Research work on onion storage in Venezuela, which is discussed in Chapter 5 of this bulletin, is used to give up-to-date advice on storage techniques and realistic expectations for storage performance of the varieties grown, under both ambient and cold storage conditions.

Similar comprehensive accounts of onion growing and its problems are given in publications from Chile, Colombia and Panama (*see* Appendix 4).

RESEARCH AND EXTENSION WORK ON ONIONS IN BRAZIL

Onions are second in value only to tomatoes among vegetables in Brazil. Onion research is reported yearly at meetings of the Brazilian Vegetable Society, (Sociedade de Olericultura do Brasil) and published in national and regional journals. From a compilation of the abstracts of many years of onion research in Brazil (*Cebola: resumos informativos*, EMBRAPA, 1980) an idea can be obtained of the relative importance of various pests and diseases of onions there. *Colletotrichum gloeosporioides*, anthracnose or 'seven curls disease' (mal-das-sete-voltas) as it is called in Portuguese, is a very important onion disease in Brazil. This malady is reported from other parts of the tropics under the name of *Glomerella cingulata* (for example, from Nigeria and India). Other diseases on which numerous reports exist in Brazilian literature are *Alternaria* (also called *Macrosporium*) *porri, Botrytis* sp., *Sclerotium cepivorum* and *S. rolfsii*, pink root rot, and several storage pathogens including a number of bacteria. *Thrips tabaci* is by far the most frequently mentioned onion pest.

Several states in Brazil produce onion advisory literature for their own growers, among them Acre, Rondônia, Pernambuco, São Paulo, Santa Catarina and Minas Gerais. *Sistema de produção para cebola, Santa Catarina* (Empresa Catarinense de Pesquisa Agropecuaria (EMPASC), 1983), for example, summarizes the production seasons of the major onion-producing regions in Brazil and their relation to the market price for onions in the country throughout the year, then describes the production system recommended for Santa Catarina, one of the southern onion-growing states. Other technical circulars deal with onion-growing problems specific to the more tropical states of Brazil, such as the timing of crops to avoid periods of heavy rainfall, or the need to shade or protect the seed-bed with cloth, leaf or plastic shelters raised about 1 m above the ground while the young transplants are growing. Topics investigated extensively in Brazil include onion fertilizer requirements, production methods for different areas, performance of cultivars, treatment with sprouting inhibitor (maleic hydrazide), irradiation of bulbs, and storage methods. Brazilian storage work is discussed further in Chapter 5.

A production technique described for producing an out-of-season onion crop in Pindaré region in north-eastern Brazil is the 'soquiera' method which involves replanting small bulbs left over from the previous season, weighing about 35 g, in December–January, for harvest in April–May (Regina, 1986). Onion sets are used to extend the growing season in São Paulo state, where direct drilling (sowing) of onions (usually Granex hybrids) is also becoming more popular (Melo and Ribeiro, personal communication). In the tropical north-eastern production region of Brazil, onions are produced all the year round under furrow irrigation in shallow beds or by sprinkler irrigation. Seed production was investigated in this region, and a 90-day cold treatment of the mother-bulbs before replanting was found to result in maximum seed yields of local cultivars (Aguiar, 1984). Irrigation methods in the São Francisco valley of Pernambuco were compared by Soares and Wanderley (1985), who found that onions gave better yields when grown on raised beds inside irrigated basins than in level basins which were flood irrigated, on ridges, or on the flat under sprinkler irrigation. Trials on green manuring (that is, growing a rapid leafy crop from seed which is then ploughed in to act as a fertilizer) of onion fields with a forage legume, *Styzolobium atterimum*, in north-east Brazil, with sprinkler irrigation, gave yields as high as 60 t/ha of cv. Texas Grano on experimental plots, while Brazilian IPA cultivars produced 45-48 t/ha: high levels of fertilizer were also used. These yields represented 4-5 times the local average of 12 t/ha (Araújo *et al.*, in preparation).

ONION GROWING PRACTICES IN INDIA

To promote the improvement in onion, garlic and other crops with export potential in India, the Associated Agricultural Development Foundation (AADF) was set up in 1977 by the National Agricultural Co-operative Marketing Federation of India (NAFED) and Associated Shippers. The AADF now organizes research and development work on a large scale, and produces a quarterly newsletter and an annual report. Much work is done in collaboration with the All-India Co-ordinated Vegetable Improvement Programme and the All-India Co-ordinated Research Post-Harvest Project for Technology of Horticultural Crops, co-ordinated by the Indian Agricultural Research Council. The comprehensive advisory booklet entitled *Onion Production in India* (undated), was recently published and summarizes many of the findings of the first ten years of the work of the AADF. The booklet lists the production seasons for the various major onion-growing areas in India and describes in detail how agronomic practices should be varied to suit the different seasons of production. For example, seedlings raised in December–January (the Rabi crop) can be left for 8-9 weeks in the seed-bed, whereas those sown in May–June (Kharif crop) are transplanted at 6-7 weeks to avoid the danger of premature bolting which is stated to occur if the plants are left too long in an overcrowded condition (that is, they become starved because of excessive competition). Onion sets are used to give an early summer (Kharif) crop in Gujarat and other northern and central states.

The agronomy of the multiplier onion is also described. These can be propagated from seeds, but earlier and heavier crops are obtained by using sets which grow into large bulbs and then split to give from 3 to 8 bulblets per cluster. The quantity of sets or multiplier onions needed for planting 1 ha is 1-1.2 t; to raise enough onion transplants for 1 ha, 8-10 kg of seed are required. The large quantities of seed recommended may be a reflection of the generally low levels of onion seed germination in India. The AADF is currently working on improved methods of seed packaging to try to overcome this problem.

Seed dressing with thiram at 2-3 g per kg seed is recommended against damping-off in the seed-bed, and seed-beds can also be treated with thiram/captan at 4-5 g per square metre. Transplants are moved when they reach a thickness of 6-9 mm. The fields themselves are laid out in beds about 1.8 m wide. Multiplier onions and sets are spaced at 45 cm between ridges and 10 cm in double rows on the ridges.*

Irrigation is used for the winter (Rabi) crop which is grown for storage, and is used to supplement rainfall in the summer (Kharif or wet season) crop, which is usually sold immediately. Irrigation may be by furrow, by flooding in shallow beds or by sprinklers.

Diseases which are serious in India, and have not already been noted here include *Stemphylium* blight (*S. vesicarium*), which is particularly damaging to the seed crop, onion smudge (*Colletotrichum circinans*), neck rot (*Botrytis allii*), black mould (*Aspergillus niger*) which is a serious storage disease, onion yellow dwarf virus and the mycoplasma or virus-like aster yellows. These and the other onion diseases and their control are described by Gupta and Pandey (1986) and with the exception of *Stemphylium*, in the TDRI manual (TDRI, 1986). *Thrips tabaci* is again the most damaging pest, but others described

**Authors' note:* Onions grown on ridges in hot climates are often placed on the sides of the ridges so that if salts accumulate at the top of the ridge, the onion roots avoid contact with the highest concentrations.

include the head borer caterpillar (*Heliothis [Helicoverpa] armigera*) which is particularly troublesome in the seed crop; a leaf-miner, *Chromatomyia horticola*; the storage beetles *Anthrenus ocenicus*, *A. jordanicus* and *Alphitobius laevigatus*; and a mite, *Rhizoglyphus* sp., which attacks onions both in the field and in store (AADF, undated). Other pests and diseases are noted in the AADF Annual Reports.

The AADF bulletin also discusses packaging, marketing and transport aspects of onions, including the export trade from India. Onion yields are stated to average 20-25 t/ha in India, with 10-15 t/ha for multiplier onions. Thomas and Dabas (1986) however gave a more conservative estimate of mean yields in India at 7.5 t/ha. Onions in India may be intercropped with garlic, turmeric and sugar-cane; intercropping of Bellary Red onion with tapioca (that is, cassava, *Manihot esculentum*) is practised in Karnataka (Thomas and Dabas, 1986). The intercropping of onions with *Rauwolfia serpentina* was more profitable than growing *R. serpentina* alone (Maheshwari *et al.*, 1985). More investigation is needed on this topic.

SHALLOT GROWING IN THE TROPICS

Shallot agronomy in the tropics has been a comparatively neglected topic. Sinnadurai (1973) described the growing system used around Anloga in the coastal area of Ghana, where shallots are raised for the Accra markets. The shallots are planted on raised beds in sandy soil at a rate of approximately 4 t/ha. Expected yields were 10-11 t/ha; most farmers however had less than half a hectare of shallots. Three crops were grown a year, the major season being April–August, and the others January–March and September–December. The bulbs were planted at a distance of 7 cm apart. Crop yields were increased by 50% when the crop was fed three times at weekly intervals, starting at the time of planting, using a 10-10-10 NPK mixed fertilizer. Farmers added organic manures of various kinds to the shallot beds, and also needed to import soil at intervals because it was gradually washed away in the sandy site. The crop was labour intensive; hand labour was used for all the operations of growing and harvesting the crop, including watering, and considerable labour was also needed to grade and bunch the dry shallots for sale. The farmers' families were usually called on to do this (Sinnadurai, 1973).

In Ethiopia, red shallots are more popular than onions for cooking, but are susceptible to virus diseases and difficult to store between growing seasons. Farmers often have to buy in planting material from other areas of the country, which is expensive. Recently, a system of raising virus-free propagating material of shallots from true seed, to provide a crop which can then be multiplied vegetatively during the main growing season, was developed. By this two-stage process, farmers can grow their own propagating stock and avoid buying-in. The shallot seed is obtained from plants which are left in the field and irrigated again after the normal bulb crop has been harvested (Jackson, personal communication). A similar system can be used for raising the seeding type of multiplier onion known as Vedala Vengayam in Sri Lanka (Kuruppuruachchi, personal communication). With this method, the seed is sown in February–March in a nursery bed, and the single sets are harvested in June–July. After a period of storage they are replanted and then produce several bulblets per plant. Shallot growing in Indonesia has been described in the local language but is not yet available in an English version (*see* Appendix 4). Turral (personal communication) and his associates in Madura, Indonesia, supplied the following information on shallot agronomy: yields are 6-11 t/ha, and to establish a field of 1 ha, 900-1000 kg of planting material is needed. Plants are spaced at 15×15 to 20×20 cm, according to the cultivar and its habit. Yield gains are expected if fertilizer practice, including trace element nutrition, can be improved.

Grubben (personal communication) commented that the multiplication of shallots from true seed in Indonesia has promising benefits in terms of size and productivity of plants, and may solve some of the problems of obtaining and storing the propagating material. From local sources, Grubben (personal communication) supplied further information on shallot agronomy: 71% of the crop is grown at an elevation below 450 m; all soil types of pH>5.6 are used, but preferably well drained alluvial clays or andosols; average day temperature is 25–32°C; average fresh shallot yield is 7 t/ha in the dry (more favourable) season, maximum 18 t/ha. Planting material is harvested from healthy, well-matured crops at least 70 days after planting, and that from medium elevations (200-700 m) is preferred; bulbs are then stored for 2.5 (highland) to 4 (lowland) months in order to break dormancy: a weight loss of 15% occurs. At planting, the tops of the bulbs are cut if they are still dormant. Shallots are often cultivated after paddy (wet-land rice), which discourages soil-borne onion diseases. The crop is grown on beds measuring from 1.2 m to 1.8 m wide, with ditches up to half a metre wide and 50-60 cm deep between the beds. Organic manure is used in the uplands, and chemical fertilizer in the lowland areas. The crop is given a base dressing of fertilizer, a mixed fertilizer 10-15 days after planting, and then fertilized at two week intervals, until two weeks before harvest, with 200 kg/h or more of urea on each occasion. Watering may be done twice a day during the dry season, using a scoop from the irrigation ditches. To control *Spodoptera* sp. caterpillars and also thrips, twice weekly sprays of kuinalfos, monocrotofos or other insecticides are used. A variety of diseases, the most serious of which are *Alternaria porri* and *Colletotrichum* sp. are controlled with sprays of Maneb, Dithane or Difolatan.

Grubben's information continued: harvest takes place when 70-80% of the leaves have turned yellow, i.e. 65-70 days after planting in the lowlands, and 80-100 days in the highland areas. The shallots are pulled and tied into 1 kg bunches: they dry for 5 to 14 days in the field, covered by plastic if it rains. Eighty per cent of the crop is sold from the field, and 20% stored, mainly for propagation. Differences in disease resistance between cultivars are noticeable.

Subijanto (1988) noted that Indonesian national yield of shallots averaged 5.1 t/ha and that four selected varieties recently released by the Lembang Horticultural Research Institute (LEHRI) produce 7 to 11 t/ha. Shallots are exported to Malaysia, Singapore and Taiwan on a considerable scale from Indonesia. It is also interesting to note that garlic production in Indonesia was increased from 11,300 t in 1981 to 49,000 t in 1985 by the use of improved cultivars which were distributed through the extension service and farmers' co-operatives, together with measures to demonstrate techniques on farms and assistance in marketing: special credit was also available through the government bank (Subijanto, 1988).

The information on onion and shallot agronomy summarized above was mainly taken from descriptive accounts and extension publications prepared for farmers in tropical countries. Some agronomic topics on which research could potentially benefit onion growers in tropical areas will now be reviewed, and the chapter will conclude with a brief discussion of onion fertilizer requirements.

RESEARCH TOPICS IN ONION AGRONOMY

Seed treatments

Onion seed is well known to be highly perishable (Ellis and Roberts, 1981). One of the problems of onion production in the tropics is to obtain onion seed which is true to type and of high germination and vigour. Storing onion seed at high temperature and high humidity results in a rapid decline in its viability, and farmers are often advised not to try to use seed which is over a year old, and to test seed for germination before sowing. However, seed which is carefully dried to a low moisture content (6%) and then packed in a moisture-proof container such as a sealed tin or a foil packet, can be expected to remain viable longer, even at relatively high temperatures. A method of magnetic separation of leek seeds of low germination from commercial seed lots was described by Krishnan and Berlage (1986) and might give useful results on onions. Grubben (1978) recommended a method for the small-scale storage of vegetable seed in the tropics using silica gel at a proportion of not more than 1:10 of the seed quantity in an airtight jar. This technique might possibly be further developed for use on a village scale with larger containers and desiccant chemicals which can be regenerated easily by heating when they are saturated with moisture. This method would also be useful for preserving small seed samples in the early stages of a breeding scheme, if few facilities are available for controlled drying and cold storage. Grubben (1978) noted that fungi cannot develop on seeds if the RH of the air is <65%, and gave charts which allow the equilibrium moisture content of seeds to be calculated from the RH of the atmosphere.

Treatment of seed with fungicide to lower the rate of transmission of pathogens from one generation to the next has been practised with success for several years in temperate climates, particularly with the aim of reducing the incidence of neck rot in the stored onion crop (Maude and Presly, 1977b). Seed is treated with 1 g a.i. benomyl per kg of seed, sometimes in a mixture with thiram to control damping-off in the seed-bed. The AADF advisory recommendations for seed and seed-bed treatment were quoted earlier. Seed-bed drenches can also be used, with 2 g of thiram/captan mixture per litre of water at 7-10 day intervals, while the seedlings are growing. Gupta *et al.* (1984) isolated eleven species of fungi present on seed produced in India, of which the majority could cause serious pre- or post-emergence losses of seedlings. Benomyl was the most effective of the chemical seed dressings compared, while *Aspergillus flavus* was the most resistant of the seed-infesting fungi.

Seed priming, the treatment of seeds before sowing with an osmotic solution strong enough to prevent germination but which allows them to imbibe water, is being studied in onion seed in temperate climates as a way to encourage faster and more even germination and to forestall and delay ageing damage (Dearman *et al.*, 1986). The technique usually involves the soaking of the seeds in an aerated solution with a high, controlled osmolarity which allows the seeds to imbibe water but prevents actual germination. Primed seeds can be dried down again to a moisture content which allows them to be stored like untreated seed (<8%), and when sown they show benefits in speed and rate of germination compared with unprimed seed. The reason for the advantage conferred by priming is thought to be connected with repair processes at the cellular level which can take place when the seeds are in the imbibed state (Burgass and Powell, 1984). Primed seeds might be particularly useful in highland areas of the tropics where low temperatures may lead to slow onion seedling emergence and establishment.

Three methods of hydration followed by dehydration of onion seeds which succeeded in improving their storage qualities, but which did not involve osmotic control of during the process, were described by Choudhuri and Basu (1988) in West Bengal. They dried onion seed back to a moisture content of 7.8% after hydrating them either with water or with a number of mineral or organic solutions, (of which monosodium hydrogen phosphate (10^{-4} M) or sodium sulphate (10^{-4} M) were the most effective,) and tested germination and other growth parameters after accelerated or natural ageing of the seeds. Their work suggests that further developments of this kind on a larger scale could be undertaken by seed companies.

Soil solarization

Solarization is a technique for heating damp soil over a period of weeks to temperatures which are lethal for weed seeds and pathogens such as *Fusarium* and pink root rot disease. It is carried out by covering the soil with sheets of clear plastic, under which high temperatures are attained in dry, sunny climates.

The soil must be wet at the start for the treatment to work effectively. Solarization has been used successfully in Israel and elsewhere to improve the hygiene of seed-beds, with a consequent increase in survival and vigour of seedlings (Katan, 1981; Katan *et al.*, 1987). In experiments in which soils were solarized before onions were sown, damage by pathogens including pink root rot was reduced (Katan *et al.*, 1980). Weed seeds and soil pests are destroyed or reduced to low levels if the soil temperatures attained are high enough over a sufficiently long period (Katan, 1981). Promising results on disease reduction and higher yields were found in agronomic experiments using the technique by Rabinowitch *et al.* (1981). Soil solarization probably merits research in areas of the tropics where losses of transplants in seed-beds are severe because of limited land available for rotation and there is a build-up of onion pathogens and nematodes in the soil.

Vesicular-arbuscular mycorrhizae on onions

Another area of potential interest for onion agronomists is that of vesicular-arbuscular mycorrhizae (VAMs). These are largely beneficial fungi which often naturally infect onion roots in the field and have been shown to improve the nutrition of the host plant. The topic has been reviewed by Stribley (1990) and research results from temperate climates show that in soils where low phosphate availability limits onion growth, plants with VAM on their roots grow better than others without the fungus, which is usually *Glomus mosseae*. It is not yet certain how the fungus acts to make phosphorus more available to the plant; there may be a simple explanation based on the increase in the volume of soil on which the roots can draw, or possibly the VAM fungus may render the soil phosphate more soluble: this is discussed by Stribley (1990). Glasshouse experiments suggested that the presence of VAMs on onion roots gives some protection against the deleterious effects of salinity (Poss *et al.*, 1985) and drought (Nelsen and Safir, 1982). Field experimentation on VAMs is difficult, but techniques are being developed whereby plots can be treated with fungicides such as benomyl to eliminate the natural VAMs population and allow comparisons to be made between crops with and without the addition of mycorrhizae (Fitter and Nichols, 1988). Although there are considerable practical difficulties in culturing and inoculating VAMs, their potential benefits may merit research effort in tropical regions. The possibility that VAMs help onions to withstand environmental stresses makes them particularly interesting, and research in the hotter parts of the USA on this topic may provide useful information for use elsewhere.

Transplant pruning

The trimming of transplants resulted in reduced final bulb yield in work in the USA on cv. White Grano (Sabota and Downes, 1981). Roots and leaves of transplants are often cut to make the plants easier to handle and so to reduce the time taken to transplant them, but this practice results in the plants suffering a check to growth from which they do not recover, and particularly affects top growth, that is, the leaf area, which is closely related to final yield. Unpruned transplants produced 4.17 t/ha more onions than pruned (mean of all pruned treatments), which was attributable to their having twice the top growth and a third more bulb growth than the trimmed plants (Sabota and Downes, 1981). In another US study, bulbing ratio (BR) was used to identify those transplants which had bulbed too much in the seed-bed to be worth transplanting, that is, which transplants failed to resume leaf growth after they were moved. Transplants which had a $BR > 3.37$ were those which did not continue to grow (Ramtohul and Splittstoessner, 1979).

Onion nutrition

Zink (1966) studied the amounts of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) removed from the soil during the onion growing season. The trials were made on crops of cv.

Southport White Globe onions in the Salinas Valley, California, USA, under furrow irrigation in commercial growing conditions. The mean percentage of dry matter in the bulbs produced was 15.8%, which is a relatively high level. Based on the results, graphs were prepared which showed what quantities of the main nutrient elements (N,P and K) were removed by onion crops at fresh-weight yields of 8-26 tons per acre (equivalent to 20.1-65.3 t/ha). For N, the figures were from 48-159 kg/ha; for P, 9-29 kg/ha, and for K, the figures were 32.5–106.5 kg/ha for the respective extremes of the graph (approximate conversions).

Graphs made by Zink (1966) of the nutrient level changes in the onions over the season's growth showed that the quantity of N taken up by the crop increased throughout the growing season until the time of harvest; that K was taken up at most rapidly at the time of maximum vegetative growth prior to bulbing, and sometimes showed another rise during the last month of bulb growth; and that there was a steady increase in the amount of P used throughout the growing season although the actual quantity taken up by the crop was relatively low. The approximate ratio between the three major nutrients was 6:1:5 N:P:K in the onion crops studied. Calcium was more heavily used than P but the pattern of Ca usage varied in the seasons compared; less Ca was required than K, and it tended to be most rapidly taken up during maximum leaf growth. Mg and Na were absorbed in small quantities which increased slightly throughout crop growth.

Zink (1966) found that nutrients were removed from the soil only slowly during early growth, but that during the bulbing period, when two-thirds of the crop fresh weight was accumulated, plants used approximately 68% of their total N, 75% of P, and 47% of total K. At harvest, a crop calculated at 56 t/ha had removed approximately 160 kg N, 26 kg P, 127 kg K, 97.5 kg Ca, 14.6 kg Mg and 11.2 kg Na per hectare.

The conclusions drawn as to the timings of fertilizer application were that an adequate N supply was vital throughout growth, and particularly during bulbing; that P should be applied before planting for maximum benefit; and that K should only be applied if needed on the mineral soils on which the trials were made.

Tremblay (1988) advised that onions need only 10-12 p.p.m. of nitrate N in the 0-30 cm root zone to take them to the 3-leaf stage: this is the soil layer where N is most accessible to the plants, as few roots are found at lower levels. Heavy irrigation, root diseases and nematodes lead to onions needing more N in order to crop well. Recent trials on N fertilizer placement in the USA have shown benefits from putting a slow-release N fertilizer, sulphur-coated urea (SCU), in pre-plant bands below the root region in direct-sown crops grown with furrow irrigation in Idaho (Brown *et al.*, 1988). One aim of this work was to avoid the problem of toxicity of high levels of N to young onion plants in conditions which encourage salt accumulation within the ridges; another was to reduce the amount of leaching of nitrate into the ground-water. The SCU treatment was as good as a split application of urea and superior to one pre-plant urea application. This type of fertilizer, combining slow release with placement, might be useful for onions grown in the tropics with similar irrigation systems. Novel methods of P placement are being developed in the UK which may also show benefits when applied particularly to direct-drilled onions (Rowse, personal communication). P is less mobile in the soil than N so placement directly below the root zone is likely to be highly advantageous for this element.

Numerous reports of fertilizer trials on onions in the tropics exist. In general, they tend to show marked responses to the application of N and less clear-cut reactions to P and K fertilizers. Hassan and Ayoub (1978) in the Sudan Gezira, growing cv. Nasi on heavy clay soil, found highly significant responses to N applied at 90 kg/ha, with yield increases of 18-36% over untreated plots over three seasons; significant response to P in 2 out of 3 seasons, and no yield response to K. N and P treatments tended to give increased numbers of doubled bulbs, but resulted in slightly lower bolting percentages, while the application of K tended to encourage bolting (7-23% increases). A high rate of 90 kg/ha of P_2O_5 gave no yield advantage compared with a lower rate of 45 kg/ha (confirming the comparatively low requirement for P in onions which was found by Zink, 1966). For N, a high rate of 180 kg/ha gave slightly lower mean yields than 90 kg/ha, suggesting that at this level, there might be some toxic effect on the onions, or possibly that P supply had become limiting. Later work in Sudan by Hassan (1984) which included irrigation timing and nitrogen as the factors studied, indicated that an irrigation interval of 10 days was the best for optimizing bulb yield, though rates of bulb doubling in both years of the trials were increased by both N fertilizer and frequent (7 or 10 day) watering. These trials confirmed that 90 kg/ha N gave higher bulb yields than 180 kg/ha; both bolting and doubling were increased at the higher N level (Hassan, 1984). The increase in bolting might have been a seasonal effect caused by an interaction between plant size and low night temperatures, that is, the plants were large enough in one season to be receptive to the cold stimulus. However, high bolting levels in plants raised from seed have also been reported by other workers to result from using low levels of N (for example, Brewster, 1983), so it is not easy to interpret results of this type, where a combination of plant age and nutrition factors are involved.

In Bangalore, southern India, Hegde (1986) included comparisons of N and irrigation requirements in field trials, but used soil-water potential measurements to decide on the intervals between irrigations. The optimum N level for bulb yield was 150 kg/ha, and irrigation at 0.45 bar or 0.65 bar soil-water potential was superior to using either lower (0.25 bar) or higher (0.85 bar) levels as a guide, on a well-drained sandy-clay loam using cv. Pusa Red. Adequate N supply resulted in increased water-use efficiency. The estimated yield for the calculated optimum N level was 44.5 t/ha, with N-use efficiency (kg bulb/kg N) of approximately 30 (Hegde, 1986). In Tamil Nadu, southern India, trials on the local Bellary onion on a red sandy-loam soil at several N and K rates allowed the optimum economic applications to be calculated, from the yield figures and the fertilizer prices, to be 51 kg N and 64 kg K/ha, used with a common application of 30 kg P/ha (Balasundaram *et al.*, 1983).

In areas of the tropics where soils are already of high fertility because of their previous cropping history, fertilizer use on onions may not be worthwhile. In Puerto Rico, for example, Alers-Alers, Orengo-Santiago and Cruz Perez (1979) did not obtain significant increases in yield when they grew cv. Texas Grano 502 on soil previously cropped with sugar-cane which had been well fertilized: yield of bulbs was 22 t/ha. The benefit of green manuring with *Styzolobium atterrimum* to onions in Brazil has already been mentioned (Araújo *et al.*, in preparation).

This selection of local trials from tropical regions shows the need for investigations which take into account the conditions of soil, water supply and fertilizer price which need defining for each onion-growing area. There may be a case also for trials to include variations in spacing; by increasing density slightly, for example, yields of moderate-sized bulbs might be increased under optimum irrigation and fertilizer treatments without also increasing the numbers of doubled or bolting onions. There may also be a need for further investigation into other yield-limiting factors such as trace-element deficiencies, as is suggested by the reports of increased garlic yields from Indonesia following the use of a trace-element dressing on garlic (Subijanto, 1988).

Chapter 5 Onion harvesting, drying and storage

INTRODUCTION

Several reviews of onion storage in the tropics have been written; the topic was discussed by Thompson *et al.* (1972), Thompson (1982), and more recently in a chapter of the TDRI publication *Pest Control in Tropical Onions* (1986). These articles necessarily used many research and development findings on onion storage in temperate regions, as until recently there have been comparatively few reports of tropical onion storage work on which to draw. The review by Thompson *et al.* (1972) in particular has been a source of valuable information for work on onion storage in the tropics in the last 17 years, when a number of onion handling and storage projects have been undertaken within tropical countries, notably Sudan, India, Brazil, Venezuela and Costa Rica. Many of these recent studies have helped to define the nature of onion storage problems in the tropics, and some have contributed to solving them by appropriate local means. While more has been found out about the problems of storage at ambient temperatures, with economic advance in many countries, the use of refrigerated storage in tropical climates is likely to increase; commercial units now exist in some countries, for example, Venezuela (Flores and Rivas, 1979).

Apart from the review articles specifically aimed at storage in the tropics, onion storage and post-harvest physiology in general have been well reviewed recently by Salunkhe and Desai (1984), Schouten (1987) and Komochi (1990), while in several countries advisory articles and publications have been written for growers (for example, Lutz and Hardenburg, 1968; MAFF, 1978; O'Connor, 1979; Werner and Seben, 1983; Ministerie van Landbouw en Visserij, 1986; *see* also Appendix 4).

Onions are stored where their production season is a limited one, because demand for the product varies little throughout the year. In some parts of the tropics, onions can be produced all year round. In these areas, long-term storage is not necessary, but is often found that the soft onions which are suited to this type of culture deteriorate quickly between the time of harvest and their arrival at the point of sale (for example, FUSAGRI, 1986). Onions of the Early Grano and Granex types are quickly attacked by storage pathogens, particularly if they are sold freshly harvested, without drying. Pre- and post-harvest techniques which can reduce these short-term losses are therefore also important. In regions where only a limited onion production season is possible during the year, onion storage under ambient conditions becomes a gamble for the producer, who has to balance the cost of storage, the loss in weight incurred during the drying process, and likely losses through deterioration in store, against the possible rise in price if marketing the crop is deferred for some weeks or months. Where onions are grown as an off-season crop, growers may be forced to sell rather than store their onions because they need cash immediately. In these cases, the farmers need a source of credit in order to keep their onions off the market until prices are more favourable.

In this chapter, the topics discussed include the pre-harvest and internal factors which influence storage ability in onions; the pathogens which attack stored onions, and the environmental conditions which influence the degree of damage which they can cause; and structures used for onion storage and the control of the storage environment. Examples of work in the tropics, or aimed at problems occurring in tropical conditions, are described to illustrate the difficulties of storing onions in hot climates, and proposed improvements in ambient storage techniques, based on a mathematical modelling approach to onion storage, are discussed. The topics of the cultivars grown in the tropics and their performance in storage, and the structures used to store onions in the tropics are also discussed towards the end of Part II, with reference to the ODNRI questionnaire results. Conclusions and recommendations are presented in Part III.

FACTORS WHICH INFLUENCE THE STORAGE ABILITY OF ONIONS

Onion cultivars vary considerably in their suitability for storage; genetically controlled factors which may influence storage performance include dry-matter content and pungency; skin colour, skin number and quality; and the length of natural dormancy of particular onion varieties. Pre-harvest cultural factors which contribute to storage quality include the fertilizer and water regime under which the bulbs were raised, and treatment with sprout suppressant (maleic hydrazide (MH)) before harvest. The degree of contamination of bulbs going into store by pathogenic organisms is an important factor which is difficult to assess at harvest, and which is likely to vary considerably from one season to another; some control by cultural means may be possible. Careful handling during harvesting, and drying of the outer skins, also referred to as curing, whether carried out in the store or in the field before the bulbs are put into store, are key steps in the success of onion storage. Within the store itself, the arrangement of the bulbs, in bulk, in boxes or sacks, on shelves, or in strings or bunches, and the provision for natural or forced ventilation and ideally, control of temperature, humidity and even storage atmosphere composition, all affect the success or otherwise of onion storage.

The inherited qualities which tend to occur in combination to give good storage ability in onions are high dry-matter content (Foskett and Peterson, 1950), high pungency (Thompson, 1949), and long dormancy. The genetic linkage between these qualities, particularly between long dormancy and high dry matter, is not absolute, however, and recently developed onion cultivars from Israel are claimed to have both long dormancy and low dry-matter content (7-9%: Rabinowitch, personal communication). Onion skins should be retained strongly during and after storage so that the bare scales are not exposed to damage, infection and rapid water loss. Varieties which have several layers of dry skins have a better chance of retaining some until they are sold or used than those which have only one or few skins when mature (*see* discussion on pp. 76-8).

STORAGE QUALITY OF ONION VARIETIES GROWN IN THE TROPICS

It is generally true to say that local onion varieties, which have been selected over many generations within the tropics, tend to have better storage qualities than imported short-day cultivars, most of which were not developed for storage use (*see* Chapter 2). This was also apparent from the questionnaire findings on the storage performance of varieties discussed in Part II, pp. 136-9. Trials in Niger (Nabos, 1976) demonstrated this particularly clearly; varieties from Niger could be stored at ambient temperatures with low rates of deterioration (<20%) for 6 months, whereas many imported cultivars, particularly those of the Early Grano and related types had deteriorated by 60-70% or more at 3 months. Some of the Creole and Australian cultivars gave intermediate results, but no other varieties stored as long as the West African ones (Nabos, 1976). In Brazil, Moreira Garcia *et al.* (1977) found that locally developed cv. Baia Periforme stored better than cvs. Granex 33 or Texas Grano 502; at 0°C, it could be kept for >6 months in good condition, and at ambient temperature it could be kept for up to 80 days compared with 60 days for the two US varieties. Storage qualities of the major groups of short-day onions grown in the tropics are discussed at greater length in Part II, based on the findings of the onion questionnaire.

PRE-HARVEST CULTURAL FACTORS AND STORAGE QUALITY

Vaughan (1960) in Oregon, USA, reported that excessive nitrogen (N) fertilizer and late irrigation resulted in higher levels of neck rot (*Botrytis allii*) in store in cv. Sweet Spanish. Vaughan *et al.* (1964) later found that neck rot levels in store could be kept down by careful handling of bulbs to avoid bruising, and by curing (that is, drying) in the field for at least 15 days before storage. The effects of N and late irrigation found earlier were attributed to increases in the succulence and diameter of the onion necks, which made them more difficult to dry. Other workers have noted that onions with well-closed necks are the most suitable for storage. Recommendations in extension literature are usually to stop irrigating 2 to 3 weeks before harvest, so that the bulbs and leaves can dry down well. Trials on artificial leaf desiccants have not shown any convincing advantages over natural drying, and have sometimes resulted in early sprouting of the bulbs (for example, Rickard and Wickens, 1977a).

In Egypt, Ali and El Yamani (1977) found that onion storage damage from disease, predominantly black mould and bacterial soft rots, was reduced when the number of irrigations was low (3 rather than 5 in the season) and that leaving the plants until 50% of them had fallen tops before lifting resulted in fewer storage losses than did lifting at 25% tops down. The bulbs, of cv. Giza 6, were stored in jute sacks at temperatures of 30-40°C and losses recorded over 4 months, from June to September.

The importance of adequate N nutrition in the early stages of growth was sufficiently emphasized in Chapter 3. Adequate N supply promotes rapid and complete bulb maturing, which is essential for good storage. Over-fertilization with N late in the growing season is to be avoided, since it tends to encourage thick-necking.

The influence of early N fertilization in discouraging bolting also indirectly affects storage quality, since bulbs which have bolted are of poorer quality and contain a remnant of dead flower stalk which can allow pathogens to enter the bulb. Sinnadurai and Abu (1977) described how farmers in northern Ghana remove onion flower stalks from the plants and sell them as a vegetable.

In Maharashtra, India, Wayse (1967) studied the N, P and K fertilizer effects on early (the first 15 days) storage of cv. N-207-1, a local red selection. The experiments were made during Rabi, the winter or cool season (sown late July, harvested late February), and the wetter Kharif (sown mid-February, harvested late December). For the Rabi crop, N fertilizer at 40 or 80 lb/acre (45 and 90 kg/ha) gave the lowest post-harvest weight loss of any treatment (9.5%), because of the increased numbers of completely matured bulbs which were produced. Even so, 14% sprouting occurred after 15 days with the high N treatment, and 22% with the no fertilizer treatment. For the Kharif crop, in which mean yields were only a quarter of those of the Rabi crop, all treatments showed mean weight losses of 20-22%, and the high N treatment resulted in 29% sprouting after 15 days, while the no fertilizer treatment gave 20%; 5-7% of the Kharif crop had rotted after 15 days in store. This experiment shows clearly some of the difficulties caused by seasonal factors in monsoonal climates; the Kharif crop, produced in the wet season, was judged completely unsuitable for storage. These onions would deteriorate considerably even if they took only two weeks to reach the market. Only the Rabi crop, which matures in the dry season, is usually stored in India.

A high N rate also had little effect on storage behaviour of some Indian onion varieties in trials by Bhalekar *et al.* (1987); losses were only 3% more in onions from plots given 150 kg/ha than from those given 75 kg/ha N. Storage differences between cultivars were much greater than the effects of N fertilizer. However, as was discussed in Chapter 3, the timing of N applications is crucial, as it must not be applied too late in the season, when it may encourage prolonged or renewed foliage growth. If onions with thick necks are topped and put into store, they are liable to continue leaf growth and the wounded necks are highly susceptible to invasion by pathogens such as soft rot bacteria.

TREATMENT WITH SPROUT SUPPRESSANT (MALEIC HYDRAZIDE)

The sprout suppressant chemical maleic hydrazide (MH) is applied as an aqueous solution to the leaves of an onion crop when they are senescent but still green. It is transported into the bulb along with the other assimilates and there acts to prevent cell division at the growing point (Isenberg *et al.*, 1974). Legal control over MH usage varies in different countries, and local regulations should always be consulted. Since the discovery by Wittwer *et al.* (1950) of its sprout suppressant properties, MH has been much investigated and is widely used on crops for storage in temperate regions (Isenberg and Ang, 1964) where onions are usually stored cold during the winter. The biological and economic aspects of allowing its continued use in the USA were discussed at length by Isenberg and Ferguson (1981). Timing of MH application is critical, as bulb texture is adversely affected if it is applied too early, and it fails to prevent sprouting if it is applied too late. This literature concerned with its use on onions has recently been reviewed by Komochi (1990). In the tropics, several workers have reported trials on MH, and some of these results have been encouraging, for example, Mathur *et al.* (1958) in India; Blanco and Leiderman, (1968); and Blanco and Oliveira, (1971), in Brazil. Other results have been less convincing, for example, Bhalekar *et al.* (1987) in India. Some of these experiments will be described.

EXPERIMENTS ON THE USE OF MALEIC HYDRAZIDE

Mathur *et al.* (1958) treated cv. Mysore Pink at 18 days before harvest with MH at 200, 400 and 600 ppm, before storing at cold (0° to 1.5°C, RH 80-90%) and warm ambient (15° to 30.5°C, RH 45-78%) temperatures at Mysore. Cumulative weight loss measured on healthy bulbs amounted to 32% for untreated and 17.7% for 600 ppm MH-treated healthy bulbs after 130 days in ambient storage, and losses declined with increasing MH dosage. Sprouting was completely prevented by the highest MH dosage, while 21% sprouting was recorded from the untreated bulbs. In cold storage, sprouting and rooting were reduced to very low levels by the two higher MH treatments, but reached 87% and 74% respectively for untreated bulbs, after 240 days in storage. The percentage of rotting, due mainly to *Aspergillus niger* and *Rhizopus nigricans*, was lower after the use of MH in both storage regimes.

Blanco and Leiderman (1968) at Campinas, SP, compared treatment of onions, cv. Pera Bojuda, at 18 to 10 days pre-harvest with doses of 100, 1500 or 3000 ppm of the MH 30 formulation, and found that treatment 10 days prior to harvest was the more effective. After 300 days in ambient storage, there was no sprouting and 40% of the bulbs were still saleable, whereas of the untreated bulbs 60% had sprouted and 40% rotted. In later experiments by Blanco and Oliveira (1971) in which a range of treatment dates were compared, the optimum theoretical date for treatment was calculated to be 19 days pre-harvest, and the most effective rates of application were 1000 or 1500 ppm a.i. MH. When applied at 3 weeks before harvest, these rates resulted in 67% and 65% respectively of the initial weight of bulbs surviving 150 days of ambient storage.

In Akola, India, Bhalekar, Kale and Kulwal (1987) compared doses of 0, 2000 and 4000 ppm MH, applied 3 weeks before harvest, and found little difference between mean treatment results in ambient storage, since differences in storage quality between the range of cultivars used were much greater than those shown by either N or MH treatments. MH-treated bulbs in fact sprouted more than untreated ones at 120 and 160 days in store. There appeared to be a slight decrease in rotting and loss of weight from desiccation after MH treatment. Possibly the timing of the MH treatment, at a period when mean maximum temperatures were in the high 30s°C, was too early or the leaves were drying too fast for effective translocation in this trial. In Bangalore, India, Narase Gowda *et al.* (1986) also found that MH used at 500 or 1000 ppm had little effect on the keeping quality of cvs. Bangalore Rose, Nasik Red and Bellary Red onions in a 5-month storage trial. Mean ambient temperatures were 25°-32°C and sprouting rates were comparatively low for the whole period for both treated and untreated bulbs, with cv. Nasik Red showing the best keeping quality and Bellary Red the worst. No observations were recorded on rotting in store.

The findings from India which found little benefit from using sprout suppressant on onions were confirmed by the high temperature storage experiments of Salama and Hicks (1987), on onions cv. Sentinel grown in New York State, USA. The bulbs were treated with MH at 2.24 kg a.i./ha at the 50% tops-down stage and stored at a range of three temperatures and at RHs of 40 and 60%. At the highest temperature, 30°C, respiration rates rose steeply with time in storage, and weight loss from the onions was related to greater bulb rotting at 60% RH than at 40% for both untreated and MH-treated bulbs. The 20-week experiment did not show any consistent advantage for MH treatment, and clearly, at 30°C storage, storage pathogens had such adverse effects on onion keeping quality that they overwhelmed any possible advantages from suppression of sprouts, at temperatures which in any case were high enough to prolong onion dormancy.

From the experiments discussed, it therefore seems likely that the value of MH will be greatest when it can be used in combination with cold storage with controlled humidity, and that its utility for ambient storage needs careful testing at local level. Its potential value for preventing sprouting may justify local trials in areas where the ambient storage temperature normally falls to levels which are likely to break high temperature dormancy.

TIMING OF HARVESTING

In general, the heaviest yields of bulb onions are obtained by leaving the bulbs in the field until the tops have dried down completely. This also gives the maximum opportunity for the inhibitors present in the leaves to enter the bulb. However, it has also been shown in some trials that an extended field drying period can result in more disease in store. This may be due to the multiplication of pathogens on the senescent leaves, so that spore inoculum can then spread onto bulb wounds during harvesting. Another factor is the increase in skin loss which occurs if bulbs continue to swell after the outer skins have started to dry (Rickard and Wickens, 1977b).

Harvesting systems commonly used with mechanized production systems in northern Europe deliberately sacrifice optimum bulb yield in favour of improved quality in terms of skin colour and retention. The onions are topped (that is, have their foliage cut off) and are lifted before the outer intact scales have started to dry, and are then dried artificially with rapidly circulating warm air in bulk stores to obtain a well-coloured, complete outer skin and dry neck. Some potential yield is lost by the early harvesting and topping, and some of the actual weight harvested disappears during bulb skin drying (amounting to perhaps 5% of the bulb weight lifted). Although in theory, therefore, bulbs may be left in the field until they are completely mature, that is, fully dormant, so as to obtain maximum recovery of assimilates from the leaves, in practice, bulbs are usually lifted or loosened from the soil when the leaves of 50–70% of the population have fallen over, which indicates that most of the crop is reaching bulb maturity. At this stage the outer skins are not yet fully dry nor the necks fully closed. Whether hand or mechanical lifting methods are used, the bulbs should be treated particularly carefully because the outer scales are easily damaged. Another reason for lifting the crop promptly is that re-rooting can take place if the bulbs are left too long in damp ground. If the ground is dry and the climate hot, bulbs can remain there without the danger of regrowth, as is the practice in parts of Sudan.

The decision when to harvest onions is usually partly economic. The grower may need to sell as soon as possible to obtain an immediate return; at certain seasons the prices for green, immature bulbing onions may be very high. Timing can also be influenced by other considerations, such as the risk of the crop being stolen if it is left in the field at a mature stage. Apart from these factors, the weather is probably next in importance to plant maturity stage in making the decision of when to harvest. If rain is likely, the crop risks being wetted and dried several times during field curing, resulting in skin staining by *Botrytis cinerea* (Sherf and MacNab, 1986), or the bulbs may have to be put into store while still damp, which favours disease development. Other factors influenced by rain falling on the drying bulbs are: the entry of bacteria through the neck, and the leaching of water-soluble anti-fungal compounds from the outer skins, where they are normally accumulated during drying. In many places in the tropics, bulbs are removed from the field only one or a few days after lifting from the soil, and the drying and curing is finished under cover (*see* Part II). When onions are left to dry in the field they should be covered by the foliage after lifting, when lying in the windrow, in order to prevent sun-scorching. Excessively high temperatures caused by direct heating can kill the surface tissue, spoil the appearance of the bulbs and allow pathogens to enter through the dead areas of the surface scales. In hot countries such as Sudan, heaps of bulbs may be left to cure in the fields under a covering of leaves before they are moved into store. A similar method is recommended in India for the development of good bulb colour (AADF, undated). The nature of the curing process is little understood, but the effect of high temperature on the development of onion skin colour has been documented. Onions cured by heat treatment at 27°C developed darker colours than those kept at 24° or 15°C after harvest (Bleasdale and Thompson, 1966). Biochemical changes in the phenolic compounds present in the skin may be involved in the development of dark skin colours.

Hoyle (1947) in the dry climate of Davis, California, USA, investigated the timing of harvest in relation to bulb maturity and its influence on duration of storage at ambient temperatures (21-29°C) of uncured onions in a naturally ventilated barn. Total losses in weight, including rots, during storage were always lowest from bulbs which were harvested with tops down and brown, and higher for those harvested with the tops green, whether down or up. The three varieties used showed very different susceptibility to loss in store: cv. Australian Brown (a thick-skinned cultivar with long dormancy) had no rotting; cv. Southport White Globe (grown for dehydration, with comparatively high dry matter) had a considerable amount, the worse the earlier it was harvested; and cv. San Joaquin (an early Californian variety), lost 40-50% of its initial weight through rotting after all treatments. These results therefore also demonstrate the importance of differences in genetic constitution on storage performance. Later experiments in which a sack grain dryer was used to dry the onions resulted in improved storage performance of cultivars suited to long-term storage (Hoyle, 1948). Trials on harvesting methods in Egypt showed that bulbs stored better after they had been dried for 9 days in the field without topping (leaf removal), compared to those topped or field-cured for shorter periods (Atwa *et al.*, 1974). In the dry climate of Egypt, natural drying outside at high temperatures was clearly beneficial for non-wounded bulbs. However, bulbs which had been harvested before they were mature could not be improved by field curing.

In Andhra Pradesh, India, pre-drying bulbs in the shade for 4 days rather than 7-10 days was found to reduce spoilage in store, (Rao *et al.*, 1967), a result which may reflect relative humidity in south India compared with Egypt.

In Hawaii, Kratky (1982) successfully used rain shelters over the onion beds to improve the storage quality of Maui (cv. Granex) onions which are grown all the year round in a wet climate.

DAMAGE DURING HARVESTING AND HANDLING

Isenberg (1955) tested onions for their ability to withstand falls onto a concrete floor or onto other onions from various heights, using cv. Yellow Globe Danvers, a cultivar which was described by Magruder *et al.* (1941b) as 'a very good storage variety' and 'firm or hard'. Severity of damage was related to the height dropped and to the size of the onions, a 6 ft (1.8 m) drop onto concrete giving an average of 50% of visibly damaged onions after 120 days in cold storage. Bruising changed the scale texture and made the outer fleshy scale soft, flattened and pithy in appearance when cut through; some scales were completely split, and sprouting sometimes followed wounding. Not only did decay start on the wounded areas themselves, but dropping the onions after harvest also caused sap to be exuded from the basal stem plate, resulting in infections of this area. Isenberg's conclusions were that onions should not be dropped more than 4 ft (1.2 m) onto a non-resilient surface. When they were dropped onto other onions, less damage resulted, but the first onions dropped into crates often showed the most damage. Softer, more easily damaged bulbs of varieties such as the Grano/Granex short-day types need to be treated with even greater care than the hard ones used in Isenberg's tests, and in the USA drops of more than a few inches are now avoided wherever possible during the handling of onions, and grading machinery is padded on the projecting corners.

The large-scale mechanical lifting and handling methods used for onion harvesting in Mediterranean and temperate climates are suitable only for hard onions; short-day varieties of the Grano/Granex type are usually pulled and bagged by hand in the USA. Texas Early Grano is susceptible to crushing when stacked in sacks (Eavis, personal communication), hence the recent US development of transporting and marketing early bulb onions in cartons (Pike *et al.*, 1989).

Physiological effects on the bulbs caused by wounding will be discussed in the sections concerned with dormancy and growth substances.

THE ONION BULB: A FOOD STORE FOR FLOWER AND SEED PRODUCTION

The dormant onion bulb is a storage organ produced during the plant's first season of growth. The bulb is a fleshy structure which contains simple and compound sugars, sulphur- and nitrogen-containing flavour precursors and a considerable volume of water in the swollen cells which make up the bulk of the bulb scales. This structure is protected against decay during the resting period by physical and chemical means. The physical protection is given by the dry outer papery scales, which form a closely fitting coat around the whole bulb except for the base plate and the neck. The base plate is protected by a corky outer layer, and the neck closes up tightly in properly matured bulbs so that the minimum area is available for water loss, (most of which occurs through the neck when the scales are intact (Apeland, 1971)), or for the entry of pathogens. Chemical protection is given by the accumulation, in the dry skins of coloured onions, of a group of water-soluble phenolic compounds which are active in preventing infection by certain fungi. These compounds include protocatechuic acid and catechol (Walker and Link, 1935; Owen *et* *al.*, 1950). Living onion scale tissue also has antibiotic properties, though many pathogens are capable of invading it, especially if it is wounded.

The onion bulb is a living organism, in which respiration continues to take place, albeit at a very low rate (Robinson *et al.*, 1975). If the onion is allowed to complete its life cycle, it forms flower initials in the interior of the bulb and later sprouts to produce leaves and eventually flowers and seeds. All onion varieties, whatever their storage qualities, will eventually attempt to follow this pathway. Some techniques of storage slow down the resumption of growth, for many months if they are successful, so that bulbs can be sold and consumed during an extended period. Certain treatments prevent regrowth completely, by stopping the cells at the growing point from dividing. MH-treated bulbs, for example, do not form yellow interior shoots late in the storage period, unlike untreated onions in which etiolated leaf blades are present. Gamma irradiation, which is also used to inhibit bulb growth in some countries, acts by disrupting the meristematic cells of the growing point, with similar results.

The normal dormant onion bulb is therefore a structure which if left to complete its life cycle, delivers its stored contents, including water, to the new shoots which emerge in the second season of growth, and the old bulb scales then senesce. The process of bulb senescence takes place in a regular way, with water and nutrients being drawn from the outer, older scales first and used by the new growth at the centre, (or centres, as the growing point is likely to divide during the storage period) of the bulb. The new shoots produced inside the bulb rapidly turn green once they emerge into the light. Once shoot growth is visible and the bulb scales have begun to shrink, the bulb is usually regarded as unsaleable. (The bulbs can be replanted when sprouting, and in some countries they are used to supply edible green shoots when other forms of onion are not available, for example, in Algeria: Benchaalal, personal communication).

Storage techniques, essentially, need to maintain conditions unfavourable for growth (by low- or high-temperature storage) or to prevent regrowth, for example, by MH or by gamma irradiation. Storage conditions should also be as unfavourable as possible for any organisms which attack and feed on the succulent bulb in the store (fungi, bacteria, mites, insects and rodents). The next parts of this chapter will examine internal bulb factors such as dormancy, pungency and dry-matter content and their effects on storage quality, before discussing storage pathogens and the factors which favour their invasion of the bulbs' food stocks.

DORMANCY IN ONIONS: TEMPERATURE EFFECTS

Dormancy in onions is extended by either low (0° to 5°C) or high temperature. High for this purpose is usually defined as being over 25°C, but probably varies considerably between and within populations (Miedema, in preparation). Karmarkar and Joshi (1941) in India studied the effect of a range of storage temperatures on red Bombay onions bought from local markets. Temperatures between 9°C and 15°C favoured rapid sprouting, while lower (0°C) and higher (24-29°C and 32-35°C) temperatures suppressed it. Rooting occurred at high relative humidity (RH) in both the low and intermediate temperature regimes. The onions stored at 24-29°C at ambient RH, which rose in the monsoon season, developed black mould over the skin; those kept at 32-35°C, at lower RH, remained sound for 8 months, though some shrinkage occurred. After removal of onions from 0°C and from 32-35°C to temperatures favourable to sprouting, those from the low temperature sprouted more rapidly than those from the high temperatures. Weight loss measurements showed that the two higher temperature regimes led to losses of > 20% of bulb weight after 6 months in storage. Most of the loss was due to complete drying of the outermost fleshy scale of the bulb; once the outermost scale was dry, the next fleshy scale began to lose water relatively fast. At 0°C the fresh weight losses were approximately half of those at the highest temperatures, and were partly due to the onset of sprouting at the seventh month of storage.

The results obtained by Karmarkar and Joshi (1941) are a classic illustration of how onions with good natural dormancy respond to a range of storage temperatures. An interesting comparison can be made with recent experiments in Georgia, USA, where Smittle (1988) experimented on storage methods aimed at extending the marketing season for cv. Granex, a short-day, low dry matter onion which is valued in the USA for its sweetness and low pungency. At room temperature (27±2°C, 70-85% RH), the quantity of marketable bulbs decreased by 12% to 25% per month. Only at 1°C could the storage period be effectively extended to 7 months, by use of controlled atmosphere (CA) storage with 5% CO_2+3% O_2. Onions stored under this regime remained 83% marketable 4 weeks after they had been taken out of storage and kept in ambient conditions. Storage in similar CA at 5°C was less successful, and CA with 10% CO_2+3% O_2 caused bulb damage which showed up as internal breakdown in bulbs during the first month out of store. While this project is a good example of what can be achieved with highly controlled storage conditions, Smittle (1988) demonstrates the difficulties of keeping onions which are not genetically adapted for long storage under warm, fairly humid ambient conditions (27±2°C with RH 70-85%); in 3 years of trials, fewer than 50% of the onions were marketable after 3-4 months of ambient storage. (Questionnaire informants gave an average storage time for Granex and related varieties of 1.7 months: *see* Part II). Most of the deterioration found by Smittle (1988) was due to decay, identified in one year specifically with *Aspergillus niger*, black mould, which became serious after 3 months of storage at room temperature. Both black mould and sprouting caused losses after 5 months of storage at 5°C in air. Weight loss from dehydration alone in storage was only 1-1.6% per month, and was not regarded as serious.

Abdalla and Mann (1963) in the USA took bulbs from a variety of storage temperature regimes and planted them at intervals onto damp peat. They distinguished between a period of rest, which is difficult to break, followed by a period of dormancy, during which growth may be resumed if the environment is favourable. Differences between cultivars in respect of length of overall dormancy were shown between the cvs. Excel, (derived from Yellow Bermuda), which had only a short rest period, and Australian Brown 5, a long-storing variety. Storage temperatures used ranged from 0°C up to 40°C. In bulbs of cv. Excel stored at 15°C, the inner leaves started to elongate after about two weeks, but they did not grow at either 0°C or 30°C during 10 weeks of storage. When cv. Excel bulbs were taken out of storage and planted, those stored at 5-15°C produced visible shoots most rapidly, and those stored at 0°C or 30°C took considerably longer to sprout. In cv. Australian Brown, however, storage at 20°C was as effective in depleting rest as the lower temperatures of 5-15°C. However, cv. Australian Brown was slower to sprout under all conditions than cv. Excel, though the same types of response were eventually shown. Unliked cv. Excel, Australian Brown showed no tendency to grow roots or sprouts in the store during the 16-week experiment.

The longer the bulbs had been in store, the quicker they sprouted visibly after planting. In cv. Excel, cell division took place at the growing point of the bulb, both in mature bulbs before storage and continuing during storage at 15°C, whereas in store at 0°C or 30°C the number of mitoses gradually declined.

The findings of Abdalla and Mann (1963) were confirmed by recent investigations in the Netherlands (Miedema, in preparation). Miedema studied the effects of temperatures, ranging from 5°C to 30°C, on rooting of dormant bulbs planted in moist vermiculite, and on sprouting in dry storage. Rooting occurred most rapidly at 10-15°C; it was strongly inhibited at 30°C. Sprouting in dry storage was also inhibited at 30°C, but the optimum temperature for sprouting varied from 10°C to 25°C, depending on the variety. Root and sprout extension of non-dormant onion bulbs, however, was not inhibited by high temperature; the optimum temperature was between 25°C and 30°C. Miedema also found that a high temperature treatment of 2-4 weeks at 35°C immediately after harvest considerably shortened the period of root and sprout dormancy when these were tested at 15°C.

Abdalla and Mann (1963) found that roots were always produced before shoots in the sprouting tests on damp peat. When the roots were removed, shoot growth was suppressed during the 6-week tests, while control bulbs with intact roots showed visible shoots after 4 weeks.

These findings were confirmed by Miedema (in preparation), who showed that sprout growth in de-rooted bulbs could be restored by supplying the cytokinin benzyladenine. This suggests that the promoting effect of the root system on sprout growth is mediated by cytokinins synthesized in the roots. Whether in dry storage, sprout growth depends on cytokinins from root primordia in the base plate, remains to be investigated.

GROWTH SUBSTANCES IN STORED ONIONS

Studies on the growth substances of stored onions and their changes throughout dormancy were reviewed recently by Isenberg *et al.* (1987). They explained the post-harvest events of rest, dormancy and regrowth in terms of the hormonal changes occurring in the bulbs. Their conclusions, for a variety of trials mostly on Japanese, North European and North American cultivars, can be summarized as follows. Auxins decline in foliage leaves and bulb apices during the final stages of green leaf decline and bulb expansion prior to harvest, and when the onion tops have fallen over, significant amounts of the growth inhibitor abscisic acid (ABA) are found in the leaves. This inhibitor appears to be transported to the bulb apex as the leaves dry out. Bioassays of European cultivars stored at 5-8°C during November showed low levels of auxins, cytokinins and gibberellins and a high level of inhibitor, at this time when no sprouting was visible. Further bioassays during the winter months showed a decline in inhibitor to a low level by February, while gibberellins increased to a maximum in December, followed by cytokinins, and then by auxins. In February – March a second gibberellin peak was found, accompanying sprout emergence. It was proposed that the first gibberellin peak took place at flower primordium induction after the first 3 months of cool storage; that the rise in cytokinins signalled the resumption of active cell division; and that the auxin peak was connected with shoot growth. Studies in the USA using two long-storing hybrids kept at 2°C confirmed that inhibitor levels were high relative to growth promoters during the first 3 months of storage, and that there was no sprout growth at this time (Isenberg *et al.*, 1974). This rest period was considered to last until January, when the dormant period started, during which cell division and the onset of sprouting took place.

Changes in plant growth substance levels during dormancy are among the aspects of onion behaviour in storage being studied currently in the Netherlands (Miedema, in preparation). Miedema has shown that bulbs in the early stage of rest can be induced to root again more readily by supplying the base-plate area with nutrient solution rather than water alone. In experiments on wounding dormant bulbs, Miedema has found that root dormancy can be broken by cutting off the outer parts of the basal plate, if the cut surface is then supplied with water. Bulbs which were cut across the top also sprouted more rapidly than dry intact bulbs, possibly because the physical barrier of the tight outer scales was removed, but also perhaps because of changes in the growth substance balance. Ethylene also promoted dormancy breaking, and this highly growth-active substance may be generated during wound healing. Miedema's findings tend to reinforce the need to avoid bulb wounding during and after harvest if dormancy is to be maintained.

Little attention has yet been given by plant physiologists to the qualitative differences between high temperature and low temperature inhibition of growth in stored onions. At temperatures of or about 0°C, growth almost stops, due to the extreme slowing down of all physiological processes. Even so, Karmarkar and Joshi (1941) found that onions began to sprout after 7 months at 0°C. Temperatures slightly below freezing can be used for onion storage, provided that the varieties used can withstand this treatment (usually applied to northern European or Russian cvs.; for example, Bruev and Rumyantsev, 1979). At temperatures slightly above freezing (2-5°C), dormancy is slowly depleted and flower initiation may take place in varieties which are adapted to cold climates. The temperatures most favourable for inducing flowering in long-day onions are usually stated to be about 5-12°C (for example, Meer and Bennekom, 1968), though in Nsukka, Nigeria, Uzo (1983) found a better flowering response from the Nigerian and Ghanaian cvs. Red Kano and Bawku after storage at 20°C than at 10°C (*see* Chapters 3 and 6). In experiments on shallot storage, Sinnadurai and Amuti (1971) reported that in Ghana, shallots usually remain dormant for 70 days after harvest when stored at ambient temperatures of 24-35°C, during which time up to 40% of the bulbs may be lost through disease or desiccation. When the shallots were stored at 15°C or below for periods of >50 days, percentages of flowering rose and reached a maximum of 78% for bulbs stored for 90 days at 10°C. Shoot regrowth after planting was enhanced by a period of as little as a month in cool storage, allowing farmers to produce more crops per year compared with ambient storage.

In high temperature storage, that is, at temperatures from about 22°C to 30°C or over, according to various studies, onion regrowth is suppressed, but the processes of respiration and transpiration continue more rapidly than in low-temperature storage, and result in greater weight loss from the onions (for example, Salama and Hicks, 1987). Studies on the storage of onion sets (small bulbs) have repeatedly shown that flower initiation is suppressed at high temperatures (for example, Heath and Holdsworth, 1948), but so far there have been no studies to show how this may be mediated through the presence, absence, or relative concentrations of particular growth substances at the apical region, compared with those present at low temperatures. Presumably, part of the genome which initiates or controls regrowth is prevented from functioning at the molecular level when unfavourably high temperatures are perceived by the plant. An understanding of how the plant detects this, and of the processes involved will require further study.

ONION DRY-MATTER CONTENT

Dry-matter content in bulb onions varies from low levels of 7-10% to high levels of 15-20%. The lower levels are usually found in rapidly-bulbing, soft-textured onions, generally with low keeping qualities, and the higher levels in onion cultivars selected or deliberately bred for dehydration. Normal storage varieties usually have dry matter contents of about 11-15%. Mann and Hoyle (1945) first suggested using refractometer readings of expressed onion juice as a guide to dry-matter content and defined the techniques needed to obtain consistent and comparable readings. Foskett and Peterson (1950) compared the storage ability, estimated as percentage sprouting on April 4th, (a date by which growth would normally have resumed in many onions stored at ambient temperatures), and the dry-matter content of a range of 60 US onion lines and varieties. Dry matter correlated well with the refractive index reading given by the onion juice, while regression of refractive index on percentage sprouting was highly significant. Since then the refractometer method has been widely used to select onions for high dry matter.

Onions with high dry matter are firmer and hence more resistant to damage during transport and storage; they tend to have thicker, better adhering skins and lose water less readily than onions which have higher water content and thinner skins. The latter are usually preferred for eating raw because of their milder flavour and more succulent texture. Onions with high dry-matter content tend to yield less than onions with low dry matter, and thus the high dry-matter cultivars may be less immediately attractive to growers, particularly if there is an economic need to sell the crop at the green bulb stage or as soon as it reaches its maximum size. The constituents of onion dry matter and their changes during storage have been extensively studied (reviews by Fenwick and Hanley, 1985; 1990).

ONION PUNGENCY

Pungency in onions is due to the presence in their juice of a number of sulphur-containing organic compounds which only release the volatile flavour components when the onion tissues are damaged. The enzyme alliinase which is present in the vacuole of the cells then hydrolyses the alkyl or alkenyl cysteine sulphoxides which are held in the cytoplasm (Lancaster and Collin, 1981) and various sulphides and higher sulphides are formed which constitute the typical onion flavours (Fenwick and Hanley, 1985). An additional compound known as the lachrymatory principle is thiopropanol-S-oxide, formed from a different precursor by another breakdown pathway. Secondary reaction products are also found which contribute to the total flavour (Whitaker, 1976). Pyruvic acid is released as part of the hydrolytic reaction, and this substance or pyruvate can be assayed as a crude guide to onion pungency, as it reflects total volatile production (Hanley and Fenwick, 1985). A more sophisticated procedure has been developed by Lancaster and Kelly (1983) for assessing the levels of the non-volatile flavour precursors in onion. Freeman and Whenham (1976) found that onion pungency increased for the first 190 days of onion storage then declined with the onset of sprouting. Smittle (1988) also noted that onion pungency increased during storage while total sugar content decreased. High pungency is usually found in onions with high dry-matter content, so although this is often associated with good storage quality, it has yet to be determined whether high pungency has a direct effect on storage performance, by, for example, inhibiting attack by micro-organisms. The flavour precursors probably act as a food reserve for the bulb, as suggested by their decline at the start of regrowth.

ONION SKIN QUALITY

Skin retention during storage depends not only on the physical state of the skins themselves, about which little has been published, but also on their number and on the treatment which the bulbs receive. Skin retention is strongly influenced by the RH of the storage environment; skin losses increased rapidly when RH was $<60\%$ (Bleasdale *et al.*, 1970). Apeland (1971) looked at the effects of onion scale quality on physiological processes in the onion and found marked differences in skin quality between cultivars; cultural factors had little influence on this, hence the differences must be genetic in origin. In experiments made on stored European onion varieties which had been cured at high temperatures (25-30°C) before storage, Apeland (1971) found that the presence of the outer scales slowed both respiration and loss of weight. Dry scales which were cracked led to greater weight loss from the onions than intact scales. Dry intact scales were thought to act as a gas barrier, affecting the internal atmosphere of the stored bulbs. Whether this has significance for storage duration is not yet clear. Ladeinde and Hicks (1988) have studied the internal atmosphere of onions and shown that the equilibrium level of internal oxygen in the bulb is lower, the higher the temperature. Possibly a lowered internal ratio of O_2/CO_2 (compare with the CA experiments of Smittle, (1988), discussed on p. 73) may contribute to the maintenance of high-temperature dormancy of onions.

In Poland, Doruchowski (1986a, b) studied the inheritance of skin quality of a series of onion F1 and F2 hybrids and their parents, in terms of skin thickness and adherence. Skin quality was highly variable, but had some potential for improvement by breeding. Dry skin thickness had a heritability coefficient of 30–60%, which was regarded as relatively low; that is, a large number of breeding lines would be needed in order to improve this trait. Skin adherence was partially dominant in the F1s. (Bulb firmness, an indicator of good resistance to transport and storage damage, was one of the least variable traits.) Dry skin colour in the straw yellow to brown range was correlated with strength and adherence; that is, the darker the skin, the stronger it was and the better it adhered to the bulb. The yellow/brown colours were attributed to two additive genes in the Polish varieties studied. No indication was given of skin number, a trait which is rarely mentioned in onion studies but which has a strong influence on bulb quality out of store (Hiron, personal communication).

Deterioration of onion skins during handling and storage was studied in Japan by Tanaka *et al.* (1985). Skin cracking, which led to sloughing of parts or entire skins, was caused by mechanical shocks to the bulbs during all the handling processes until marketing, while shape changes in the bulb associated with regrowth also led to skin cracking and loss. Onion varieties with long dormancy had less skin cracking from this cause than those which began root regrowth earlier in the storage period. Skin thickness itself was greatest in the area connecting the former leaf blade to the base plate, and least on the opposite side of the bulb, while vertically, it was greater at the neck than at the base of the bulb. Skin cracks started in the thinner areas of the skin. Because of the opposite arrangement of the leaves in the onion, it seems that a minimum of two entire skins should be preserved on a bulb, if it is to be reasonably resistant to skin loss. Tanaka *et al.* (1985) also tested skin tensile strength and thickness, and found that the two were correlated. Skins which were thicker than 0.04 mm and where tensile strength was >3 kg were highly resistant to skin cracking. Skin strength measurements might perhaps be used to select bulbs in a breeding programme.

STORAGE CONDITIONS AND SKIN RETENTION

The effect of humidity in store on skin retention has been noted in the course of studies to determine the best storage conditions to balance the opposing factors of dryness and high humidity. Dryness is desirable because it discourages rooting and mould pathogen development in store, and high humidity both helps to retain skins by reducing cracking and retards bulb weight loss. A three-stage drying process is recommended in the UK for onions which are undercut, topped at about 75 mm and brought into store on the same day. Firstly, the outside of the bulbs are dried with air at 30°C for a comparatively short time (2-3 days) in a rapid flow of air, of at least 425 m^3/h/t. Secondly, the drying is continued using intermittent ventilation with air at 65-75% RH, at a lower air flow rate of 170 m^3/h/t, and at a lower temperature of 27°C, until the necks of the onion are well closed and a good skin colour has developed. During the third stage, the temperature is allowed to fall very slowly, at a rate of 0.5°C per day or less, until the winter storage temperature of 3-5°C is reached, which can then be maintained by ventilation with outside air when necessary, to maintain a RH of $>60\%$ (MAFF, 1978; Shipway and Parkin, 1984; Lancaster, 1988). In practice, UK growers usually dry the onions to a 'rustling skin' stage as fast as possible and then try to maintain enough humidity in the store by adjusting the ventilation, to prevent further skin cracking. The recommendations on humidity levels with respect to skin retention are equally applicable to onion storage at ambient temperatures in the tropics. In regions where neck rot occurs, it is important that the onion necks be dried as rapidly as possible, so that the pathogen cannot travel down the damp neck tissue into the bulbs (Maude *et al.*, 1984).

Onion skin quality and the factors affecting skin retention after cold-temperature storage have been studied at Silsoe College in the UK (Murfitt, personal communication). The strength of onion skins in their wet and dry states, the influence of conditioning with air at different relative humidities on onions coming out of storage, and the effects of impact damage have been assessed. Onion skins are resistant to mechanical damage when they are relatively damp, and are at their most vulnerable when they are dry and inelastic, at moisture contents of 20% or less. It is desirable that the more unsightly outer skins be shed before the onions are marketed, particularly if intact, well-coloured skins have been formed underneath them. However, there is a danger that if the onions are handled or graded while the skins are very dry and brittle, too many layers will be lost, leaving skinned or bald onions. A conditioning process which warms up the onions with air containing sufficient moisture to allow the skins to remain flexible, while preventing condensation on the initially cold onions, is therefore recommended for onions being graded out of cool storage.

Murfitt (personal communication) found indications in one study that intact onion skins contribute substantially to bulb firmness. (This in turn may also affect resistance to deformation in transport and storage, and may be a partial explanation of difficulties experienced in the transportation of bulbs of the softer short-day varieties in the tropics, if they have not been dried sufficiently before packing into sacks to have at least one intact dry skin.) Another study showed that very rapid drying rates may result in greater skin brittleness. (Slow drying might allow the outer skin to maintain a more favourable moisture equilibrium with the lower layers and therefore to retain more flexibility.) Brazilian work (Müller, 1986) indicated that for onions harvested after top-fall, more skin loss after 2 months' storage took place after drying with air at 50°C for >3 h, compared with 2.5 h and 3 h drying at this temperature.

The general picture from the UK studies (Murfitt, personal communication) is that as onion skin dries out around a bulb, it both shrinks (to fit tightly) and becomes more brittle, so that impacts on the skin which is under tension may cause cracking. The skin is in equilibrium both with the internal scales and the exterior air, so that by manipulation of the relative humidity of the air, the skin can be kept at a moisture level which allows it to remain flexible and resistant to damage. No difference in onion skin strength was found in the equatorial as opposed to the polar direction, though skin thickness was shown to increase towards the neck, as in the work of Tanaka *et al.* (1985).

Soil texture was shown to affect skin quality and retention (Murfitt, personal communication), in that onions from sandy soil had better skin retention and showed less moisture loss in store than those grown on a peat soil. Mean skin number was also somewhat higher in onions from the sandy soil. (This might be attributed to a longer drying-out period for the onions at the approach of bulb maturity on the less water-retentive soil.) The start of regrowth at the end of storage, signalled by a bulging or expansion just above the base-plate region, was a major cause of skin splitting (Murfitt, personal communication). These studies are continuing.

ONION STORAGE PATHOGENS

Storage pathogens will only be noted briefly, as detailed accounts are available from Maude, 1983, 1990; Gupta and Pandey, 1986; TDRI, 1986; Sherf and MacNab, 1986; and Entwistle, 1990. The references listed are the sources of most of the information summarized below. Here, attention will be given particularly to the environmental conditions which favour the attacks of pathogens on stored onions and those at which they are killed or their growth slowed down, where these are known.

Fungal storage pathogens of onions vary in their methods of attack and in the conditions which favour their development in store. Most need high atmospheric humidity (80-100% RH) to develop, but their temperature requirements differ considerably. The paths of attack and environmental requirements for optimum development of the major fungal and bacterial storage pathogens are summarized below.

Fungal pathogens

Black mould (*Aspergillus niger*)

Black mould (*Aspergillus niger*) is a weak pathogen which can metabolize the catechol-related compounds in onions skins. It is sometimes reported to be less severe on white than on coloured onions, unlike neck-rot and smudge. The spores are produced on infected organic debris of many kinds, and the spread of infection in the field is favoured by hot, dry conditions. In inoculation tests, black mould development in onion tissue was favoured when the environmental RH was greater than 80% and temperatures were high (30°C). Fungal growth in culture was optimal at 32.5°C (Maude *et al.*, 1984; Maude and Burchill, 1988). Black mould can enter bulbs through wounds and attack the fleshy scales, but on otherwise sound bulbs the black sporulating areas may be limited to the outside skin, or be found between the dry skin layers in the neck area, presumably because humidity is higher there. Damage is limited at low temperatures. *A. niger* is often found with soft rot bacteria, when at high storage temperatures damage may be very severe (for example, Raju and Raj, 1980).

A. fumigatus and *A. alliaceus* have also been identified on onions and also develop under hot, damp conditions. Maude *et al.*, (1985) found that *A. fumigatus* occurred on stored onions at 35-40°C; 28-36°C was the reported range for activity of *A. alliaceus*, with growth inhibition at 16°C (Walker and Murphy, 1934).

Neck rot (*Botrytis allii*)

Neck rot (*Botrytis allii*) is seed-borne; it can spread in the growing crop from spores produced on the infected cotyledons, especially in wet seasons. Latent (non-visible) infections in the foliage move down into the neck during bulb drying, or spores produced by infected leaves under damp conditions infect bulbs through wounds, including those caused by cutting off the foliage before it is dry. Neck rot symptoms develop in bulbs during the first 2-3 months in store. At temperatures of 30°C and above, growth is inhibited and the fungus killed (Maude *et al.*, 1984), hence field drying in hot conditions can reduce its incidence (for example, Ali and El Yamani, 1977). Sporulation is favoured by temperatures of 15-20°C and high humidity, but bulb infection can develop at a wide range of temperatures from the low twenties °C to 0-2°C, so neck rot is particularly troublesome in low temperature storage. *B. byssoidea* can cause similar damage but is found less frequently. *B. squamosa* (*Sclerotinia squamosa*) attacks mainly white bulbs. Sclerotia formed on infected bulbs can carry over the disease from one year to another, so destruction or burial of infected bulbs is important. White and mild onion varieties are more susceptible to *Botrytis* spp. than coloured and pungent onions (Owen *et al.*, 1950).

Basal rot (*Fusarium oxysporum* f. sp. *cepae*)

Basal rot (*Fusarium oxysporum* f. sp. *cepae*) is a soil- and possibly seed-borne pathogen, which can kill seedlings. It enters the base plate region of growing plants via the roots and may not be noticeable at harvest, but can cause severe losses in storage. Temperatures of 28-32°C favour fungal development in the stored bulbs, but at lower storage temperatures (<15°C) it can cause premature sprouting (Walker and Tims, 1924). *F. solani* can also damage stored onions.

Smudge (*Colletotrichum circinans*)

Smudge (*Colletotrichum circinans*) is a soil-borne disease which attacks white onion varieties. Infection in the field is favoured by warm (optimum 24-29°C) wet conditions. Black sporulating lesions develop on the bulb surface in store from spores which infect bulbs in the field, especially if storage conditions are hot and humid. Rapid drying after harvest prevents the lesions from developing. Growth is inhibited at low temperatures (<10°C).

Purple blotch (*Alternaria porri*)

Purple blotch (*Alternaria porri*) is mainly a leaf disease, but it can cause surface damage on onion bulbs and allow secondary infection by storage rots, including bacteria. Purple blotch can also enter bulbs through wounds and lead to bulb rotting. It is carried over on field debris, and spreads in the field via spores formed on the leaf lesions after rain. Warm, humid conditions (optimum 22°C, 90% RH) favour its spread; approximately 10-12 hours of free water on the leaf surface are needed before sporulation takes place (Miller and Amador, 1981). In drier conditions, small white non-sporulating lesions are formed (Bock, 1964). Purple blotch can be associated with *Stemphylium* blight (*S. vesicarium*) of leaves and seed stalks, which may enter through the purple blight lesions.

Pink root rot (*Pyrenochaeta terrestris*)

Pink root rot (*Pyrenochaeta terrestris*) is a soil-borne disease of onion roots favoured by high soil temperatures (28-30°C). Though not itself a cause of major loss in stores, it is often associated with *Fusarium* basal rot, which may invade the base plate from pink root infected roots.

White rot (*Sclerotium cepivorum*)

White rot (*Sclerotium cepivorum*) is a long-lasting soil-borne disease which attacks the base of onion plants in the field and has an optimum temperature range of 10-20°C. Late field infections can continue to develop in storage, but the disease is inhibited by high temperatures. *Sclerotium rolfsii*, southern blight, is another soil-borne fungus which attacks a large number of different crops and has been identified as a cause of field and storage rots of onions and shallots (Aycock and Jenkins, 1960). The activity of this fungus is at a maximum at temperatures of 27-30°C and it needs wet conditions in order to spread in the field (reviewed by Entwistle, 1990).

Downy mildew (*Peronospora destructor*)

Downy mildew (*Peronospora destructor*) is a leaf and stalk infection which is favoured by humid conditions at temperatures from 4°C to 25°C. Spread by spores formed in wet conditions, it can infect bulbs systemically, leading to reduced quality and premature sprouting in store.

Twister or seven curls disease (*Glomerella cingulata*)

Twister or seven curls disease (*Glomerella cingulata, Colletotrichum gloeosporioides* in some publications) is a disease which is severe in some tropical countries. It damages leaves and bulbs in the field, and can lead to further rotting in store or to secondary infections through lesions on the scale surface. Leaf infection takes place when temperaures are 23-30°C and humidity is high. Conidia are dispersed by water splashing.

Blue and green moulds (*Penicillium* spp.)

Several species of blue and green moulds (*Penicillium* spp.) attack onions particularly in hot, damp storage conditions. They may also develop on cold stored onions under high RH. *Penicillium* spp. are often seen as colonies along the veins of outer scales of the bulb, but can also cause soft rots of the scales in hot conditions (optimum temperature for growth is about 25°C) especially after damage or primary infection by other pathogens.

A yeast, *Kluveromyces marxianus* var. *marxianus*, has recently been identified as a pathogen of stored onions in the USA (Johnson *et al.*, 1988). The symptoms developed more severely at 20°C and 27°C than at lower temperatures. The symptoms, a soft rot of the bulbs, were easily confused with those of bacterial soft rot (Johnson *et al.*, 1989).

Bacterial storage diseases

Almost all bacterial storage diseases are favoured by high storage temperatures of 30-35°C; only *Erwinia herbicola* caused damage when inoculated at <25°C (Taylor and Munasinghe, 1984). Onions normally carry a considerable population of bacteria, which spread from plant to plant in the field by contact (Tanaka and Saito, 1985), by irrigation, or by rain-splashing. Infection is aided by wounding and does not need high RH to develop once it is present in the soft tissue of the bulb, but bacteria do not spread easily from one scale to another, hence infected rings are often symptomatic in the bulbs. Bacteria may also develop as secondary infections on lesions caused by fungus, thrips, nematode or onion maggot attack.

Brown rot (*Pseudomonas aeruginosa*) is a dark brown rot reported from India, Papua New Guinea and Australia; it is not seen in stored onions until some weeks after harvest. It is caused by a bacterium which is common in the environment.

Soft rots (*Erwinia carotovora, E. aroidea, E. herbicola*, some *Pseudomonas* spp.) attack onions in store, generally developing more rapidly the higher the temperature. Entry is either through lesions or through the neck region under wet conditions.

Slippery skin (*Pseudomonas gladioli* pv. *alliicola*): typically, some complete scales may be affected with brown rot in store, while others are still sound; the second and third scale leaves from the outside are most commonly rotted. Slippery skin may be found to be severe after, for example, downy mildew attack. Pike *et al.*, (1989) found that slippery skin of cv. Texas Grand 1015Y was a transient symptom which disappeared when the outer scales of the bulb dried. Sour skin, (*Pseudomonas cepacia*): the outer scales only are affected and become yellow and slippery, with a smell like vinegar.

Other bacteria, such as *Lactobacillus* sp., may develop in stored onions at high temperatures, and it is likely that further bacteria capable of causing soft rots on onions remain to be identified.

In Australia, Cother and Dowling (1986) found seven genera of bacteria associated with onions, and suggested that when physiological changes take place in onion bulbs at high temperatures, some of the existing bacterial microflora usually present in bulbs can become pathogenic. Biochemical changes caused by fungal development may also allow such opportunistic bacteria to multiply. Internal bulb temperatures as high as 50°C were recorded in Australia, and internal breakdown of bulbs was observed to be more common after such very hot weather than after the cooler conditions of earlier harvests.

Other pathogens and pests which affect storage quality

Onions affected by the onion yellow dwarf virus deteriorate in store more quickly than sound bulbs.

Mites are sometimes suspected to transmit black mould between onions in stores; several species occur on onions and they may contribute to the spread of diseases which sporulate on the bulb surface. A *Rhizoglyphus* sp. mite in India attacks onions both in the field and in store, reportedly leading to sprouting (AADF, undated). Mites of this genus were also reported to be numerous on stored onions in Brazil (Campos *et al.*, 1986), where they were suspected to transmit fungal and bacterial diseases. Mites are mobile and feed on fungi and organic debris.

Some species of beetle attack onions in store in India (*Anthrenus ocenicus, A. jordanicus* and *Alphitobius laevigatus*: AADF, undated) where their attacks allow rot-causing pathogens to enter the bulbs.

ONION STORES AND MANAGEMENT STRATEGIES

From the notes on onion storage pathogens, and the previous information on onion dormancy under different temperature regimes, it is evident that at least two distinct approaches can be taken to onion storage. The two approaches are based on either low-temperature or high-temperature inhibition of growth of the onion bulb. In each case the relative humidity must be low enough to discourage the development of the major fungal pathogens, without being so low as to lead to excessive loss of skins and bulb desiccation. Two contrasting options are:

(i) to use high technology methods as developed in Europe and North America, involving controlled temperatures and humidities. Artificial drying is followed by storage at natural low temperatures or under refrigeration. These methods are suitable for large-scale farms or co-operatives in areas where the expected onion prices are high enough to justify the investment, and electricity supplies are reliable. Mechanical harvesting and bulk handling are usual, implying that the onion cultivars used must be firm and resistant to damage. For very extended storage, that is, of 8-10 months, sprout inhibitor treatment is essential. To consider using such methods in the tropics, high economic returns or import savings would be needed, as refrigeration would be necessary throughout the storage period. Good insulation of the stores would contribute to reducing their running costs. When unloading from refrigerated stores, problems of condensation on the bulbs, with free water promoting rapid root and shoot growth, would be likely. This might cause difficulties if transport to market was not tightly scheduled; controlled warming of the stored bulbs might be needed. Good control of high-temperature storage pathogens would be a major advantage of cool storage in the tropics; and

(ii) to use a cheaper system based on high-temperature storage and natural ventilation on a farm or local scale, where ambient temperatures are high enough to allow onions of good storage quality to remain dormant for at least some months. Traditional systems already in use in many parts of the tropics might be modified by adding forced ventilation capacity, so that the moisture generated by the drying and respiration of the stored onions could be blown out of the store. In very hot climates, cooler air could be drawn in at night with the aim of lowering the store temperature and raising the humidity to a level which would maintain skin quality, without being high enough to encourage mould growth, that is, the RH to be attained should be between 60% and 75%. Supplementary heating of the ventilating air may be required to reduce the RH. Within the stores, onions should not be massed together in bulk unless they are adequately ventilated, at least intermittently. It may be possible to reduce sprouting levels in this type of storage by treatment with MH sprout suppressant, but MH treatment does not confer immunity to storage pathogens. It is therefore essential that onions put into this type of storage should be well matured, undamaged, and sufficiently dried or cured such that disease development is not immediately encouraged by high humidity derived from the damp skins of the bulbs and from the higher respiration rates which follow recent wounding or bruising. In stores developed recently in Brazil, a combination of electric fans, under-floor ventilation and a wood-burning stove which can supply the ventilation system with heated air in conditions which require a lowering of humidity in the store, are the solution proposed to the problem of farm-scale onion storage in the southern state of Santa Catarina (Werner and Seben, 1983; Matos, 1987). The storage model will be described more fully below. In areas which are too remote, or where farms are too small to consider electric ventilation, improvements in store design to allow better natural air flow, for example, by storing onions in shallow layers on shelves of wire mesh, rather than in deep layers or on the ground, can offer some improvement in onion storage life by providing conditions unsuitable for fungal and bacterial attack and the associated root and sprout growth. Storage in strings, if labour is available, is also effective in promoting good ventilation around the bulbs.

BULK ONION STORES WITH TEMPERATURE AND HUMIDITY CONTROL

Thompson (1982) described such cool stores and their ventilation and control requirements, and more recently the factors needed for their efficient use in the UK have been discussed by Lancaster (1988), and in the Netherlands by Kristiaan and Hak (1989). The buildings used need load-bearing walls, since the onions may be stacked up to a height of 3 m inside the stores, and a system of ducts or under-floor ventilation with powerful fans. The three-stage drying and cooling procedure has already been described (*see* p. 77). If the air used for ventilation is very dry, partial recirculation of air within the store may be used to keep up the humidity and help to retain the skins. During the third stage of storage, temperatures in the onion stack are reduced by using cold ambient air, as long as its temperature is not less than −2°C, blown through at 170 m^3/h per tonne of onions. The aim at this stage is to keep the temperature of the onions at 3-5°C and the RH at 75-85%, so as to minimize weight loss without promoting regrowth or surface mould development. If refrigeration is used, the target temperatures are −1° to 0°C, at a similar RH of 75-85%. A number of sensing instruments and controls, preferably linked to a microcomputer with feedback, are required to monitor and control temperature, RH, and air flow rates. There is a danger of water condensing on the bulbs if warm outside air is allowed into the store, so normally only air which is cooler than the bulbs is used for ventilation. The storage details are given in the UK MAFF bulletin on *Dry Bulb Onions* (Fourth Edition, 1978), and store design and construction are described in UK MAFF *Short Term Leaflet* No. 136, Buildings for Onion Drying and Storage (*see* Appendix 4). Details of fans and other equipment needed, and charts for the calculation of dew-point at different temperatures are given in an extension bulletin from Oregon, USA, by Matson *et al.* (1985). Bulk onion stores management recommendations in other countries are described in the extension literature which is listed in Appendix 4.

COLD STORAGE EXPERIMENTS IN THE TROPICS

Some experiments have been reported from the tropics on the cold storage on onions. The work of Karmarkar and Joshi (1941), who used a temperature of 0°C successfully to prolong the storage of red Bombay onions has already been mentioned. Kapur, Mathur and Singh, (1953) stored white onions in Mysore, southern India at two low temperatures, but at high RH (85-90%), and found that the onions soon began to grow roots under these conditions. No rooting took place from bulbs stored at ambient temperature, which was therefore recommended. Mathur *et al.* (1958) studied the effects of MH treatment and low temperature storage at 80-90% RH, finding that at the low temperature, sprouting and rooting were delayed, though less than at the high ambient temperature.

Singh and Singh (1973) in Haryana, India, stored cvs. Punjab Selection and Nasik White at temperatures near 0°C for 150 days with no rotting or sprouting in store during this period; weight loss was 13%. Cold storage also gave better net economic returns than ambient storage. This result is one of the more encouraging reported from India.

In Brazil, Moreira Garcia *et al.* (1977) in a thorough study which included both cold and warm storage treatments, stored three popular onion varieties at 0°C and 81% RH in boxes at Campinas, São Paulo. The Brazilian cv. Baia Periforme kept well in the cool store for 6 months with only 5% weight loss, while storage of cvs. Granex 33 and Texas Grano 502 was less successful, as sprouting and rooting became severe after 120 days, and weight losses were > 10% by 6 months. When samples stored at 0°C for 100 days were removed to ambient temperature (mean 25°C) cv. Granex 33 sprouted the most rapidly (37% in 7 days) and cv. Baia Periforme the most slowly (10% in 30 days). Even after 190 days of storage at 0°C, the Baia variety only showed 14.5%

sprouting after 37 days at ambient temperature, an indication of its promising quality for refrigerated storage.

In Venezuela, Flores and Rivas (1979) compared the storage behaviour of 12 short-day cultivars which were kept at 2°C and 75% RH at Cagua, Aragua State. The growing season was dry (December to May) and the onions were grown under irrigation. All were grown from imported seed and were cured and selected for soundness before being stored. At the end of the 5-month trial, cvs. Blanco Amanecer, Hybrid Creoso and Madrugadora showed only 2% of sprouting in the 5 kg lots stored; these and cvs. Early Texas White Grano, Crystal White Wax [= White Bermuda] and White Creole were regarded as the most acceptable to consumers after storage. The cvs. Apacible, Dehydrator No. 6, Red Creole C-5, Early Texas Yellow Granex PRR and Yellow Granex PRR were more badly sprouted (12-30%). All the cvs. except for Blanco Amanecer showed some roots after the second month in store, but in most of them the roots only grew slowly at first; cv. Red Creole C-5 was the worst affected, reaching an unacceptable stage after 3 months in storage, and was also attacked by moulds (*Penicillium* sp.). These trials were regarded as encouraging, since in Venezuela the Grano/Granex types usually grown were well known to store for only a short time, as the Brazilian study (Moreira Garcia *et al.*, 1977) and also that of Smittle (1988) have confirmed.

Following the experiments of Flores and Rivas (1979), recommendations to farmers in Venezuela (FUSAGRI, 1986) now include advice on MH treatment (at 2.5 g/l, or 2.5 kg/ha, applied 2 weeks before harvest), to be used when it is intended to store onions under refrigeration for longer than 2 months. Sprout suppressant treatment is necessary since the principal varieties grown in Venezuela are of the Yellow Granex and Texas Grano types, which have relatively short periods of dormancy. Growers are also warned not to allow onions to be contaminated by earlier crop residues during the stringing process in barns or sheds. Flores, who contributed the chapter on harvesting and storage to the FUSAGRI (1986) bulletin on onion and garlic (*see* Appendix 4), wrote that onions could not be expected to keep longer than 3 weeks at ambient temperatures in Venezuela, and recommended MH treatment followed by storage at 1-2°C and 70-75% RH, when suitable varieties should last for 5 months.

STORAGE OF ONIONS AT HIGH AMBIENT TEMPERATURES

Since the pioneering work of Karmarkar and Joshi (1941) which contributed to defining the temperature responses of stored onions, most onion storage trials reported from the tropics have been comparisons of cultivar performance at ambient temperatures. There are also reports on different methods of storage, for example, comparisons of storage structures, containers or bulb arrangement in store. Recent work in Brazil on onion storage has contributed to a greater theoretical and practical understanding of the conditions needed for onion storage. A selection of work on high-temperature storage will be described here.

Sudan

Musa *et al.* (1973) found storage losses of about 50% after 6 months' storage of a local onion variety at ambient temperatures in Sudan. The onions, a red local variety Wad Ramli, were harvested at the end of June and hence had to be stored by farmers throughout the hottest part of the year. The traditional method is to pile the onions on wooden racks raised off the floor in straw storage houses built specially for the purpose. Only cured and selected sound bulbs were used in the experiments. Some bulbs were stored in bulk, according to local practice, and others in crates in the straw-built stores. The main causes of storage weight losses were shrinkage (30%) and pests and diseases (between 10% and 28% according to whether or not black mould damage was included).

There was very little sprouting until temperatures fell, towards the end of the storage period. Black mould (*Aspergillus niger*) was present on over 80% of the onions by the end of the storage period. It was noted that the presence of the pathogen on the bulbs is regarded as normal in local markets, perhaps an indication that it is usually confined to the outer skins. In one season when only soft rot disease was scored, it reached >9% at 18 weeks but did not then increase markedly in the next 6 weeks, which suggests that it did not spread much between bulbs, and was either somewhat controlled by the falling temperatures, or possibly only affecting the bulbs which originally carried the infection into store. In the bulk storage experiments, disturbing the stored bulbs to weigh them resulted in 5-7% more weight loss than from undisturbed bulbs weighed only at the end of the storage period. This result was probably due to increased skin cracking and shedding when the bulbs were moved. Removal of the diseased bulbs did not lead to better survival among the remainder, which again suggests that previous infection may be the chief factor involved. At the periods of most rapid disease development in the stores, mean monthly temperatures were >30°C, though ambient RH was only 53% or less. Six species of fungi, including *A. niger*, *A. nidulans* and *A. fumigatus* were isolated from diseased bulbs, and also six species of bacteria, of which only a species identified as *Erwinia carotovora* produced a soft rot when re-inoculated into onions. Small-scale tests on *A. niger* development at a range of temperatures indicated that at 5°C the disease was less damaging than at 20°C or over, and that the yellow cv. Dongla White was somewhat less affected than the red cv. Wad Ramli. Pests found in the stores included the moth *Ephestia cautella*, an unidentified beetle, and the mite *Acarus siro*.

The level of sprouting found in the Sudanese stored onion experiments was low until the 30th or 24th week in the two successive seasons of experiments, corresponding to final storage months with mean temperatures of 22.3°C and 20.9°C, and with mean minimum temperatures of 14.4°C and 7.0°C respectively. Sprouting levels rapidly rose to 40% in the cooler weather (Musa *et al.* 1973).

Physiological studies of Wad Ramli onions were made by Musa *et al.* (1974). These included resprouting tests like those of Abdalla and Mann (1963) and measurements of onion respiration. The planting studies showed that the onions had a rest period of 60 days following harvest, after which they could be induced to sprout increasingly rapidly with longer duration of storage. Their behaviour was therefore similar to that of the long-storing cv. Australian Brown, (Abdalla and Mann, 1963). Only bulbs infected by soft rots sprouted early in storage. Respiration rates declined after harvest to a more or less constant level for 20 weeks (rate approximately 20-25 mg CO_2/kg/h, cf. 3-8 mg CO_2/kg/h at 0°C to 20°C; Robinson *et al.*, 1975; 7.5 mg CO_2/kg/h rising over 7 months to 23.4 mg CO_2/kg/h in 25°C storage (Freeman and Whenham, 1976)). At 22 weeks the rate of respiration rose sharply, corresponding to the onset of active shoot regrowth when temperatures were falling. Levels of total soluble solids and of dry matter in the onions fell only slightly throughout the storage period (Musa *et al.*, 1974).

High temperature, controlled relative humidity trials in the United Kingdom

At the same time as the above studies in Sudan, trials were also made on high temperature storage with controlled humidity in the UK. Stow (1975a) stored UK-grown onions, cv. Wijbo (Rijnsburger type) at 30°C at RHs of 95%, 80% and 50%, and measured total weight loss and its components in an 8-month trial in 1971-72. From desiccation alone, bulbs lost about 2% fresh weight per month for the first two months, then the amount lost rose gradually each month, averaging about 5% at 5 months and 11% at 8 months. A high RH (95%) resulted in significantly more rotting in store from the third month onwards, and by the sixth month the cumulative rotted bulbs amounted to

22% at 95% RH, but only 8% at 50% RH. There was a consistently higher cumulative weight loss from all causes from the fifth to the eighth month at 95% RH than at lower RHs.

In the following season, Sudanese onions, cv. Wad Ramli, which had previously been in store for 2 months in Sudan, and UK-grown bulbs, cv. Rijnsburger, were stored at RHs varying from 35% to 70%. At this range, RH had no significant effect on total weight loss after 5 months of storage; the UK onions lost less than 1% fresh weight per month throughout, as did cv. Wad Ramli after the first month in store. Total weight loss was of the order of 2-4% per month during the second to fifth months. It was concluded that maintaining RH at 50-80% in stores at 30°C was likely to minimize losses from rotting and sprouting, which were of more importance (over 30% in 5 months) than those from desiccation (12%) (Stow, 1975a).

Stow (1975b) also compared 20 onion varieties in high-temperature storage for 6, 8 or 9 months at 30°C and 50% RH. The cultivars comprised a selection of intermediate and long-day varieties of varying storage quality, grown in the UK, and cv. Wad Ramli, grown in Sudan and stored there for 2 months at 25-40°C before being air-freighted to the UK. All the varieties showed high-temperature dormancy, and none had greater resistance to rotting, mostly caused by black mould, than the rest. Unlike the situation in low temperature storage, where neck rot appears relatively early in the storage period, at high temperature there was a gradual increase in the rate of rotting with time in storage. The New Zealand variety Pukekohe Longkeeper did not sprout at all in 8 months of storage (Stow, 1975b).

Brazil

Considerable work on onion storage at ambient temperatures has been done in Brazil. Storage onions there are mainly grown in the southern states of Rio Grande do Sul (RS), Santa Catarina (SC) and Parana (PR), which strictly speaking are outside the tropics, but experiments on storage methods and structures have also been reported from the states of Pernambuco (PE), Minas Gerais (MG) and São Paulo (SP) within the tropics. The studies of Campos *et al.* (1986) made in the 1960s at Campinas, SP, indicated that local varieties Monte Alegre, Baia Piriforme and Rio Grande withstood storage better than the imported short-day varieties Excel (Bermuda 896) and Texas Early Grano 502, and that storage quality was associated with higher soluble solids content of the bulbs (*see* p. 66). The presence of *Rhizoglyphus* mites and thrips on the bulbs was thought to contribute to the spread of the pathogens of the genera *Aspergillus*, *Fusarium*, *Penicillium* and of bacteria which were found on the stored onions. Also in south Brazil, the use of old shelving in onion stores resulted in higher onion storage losses from rotting, which became significant at the fourth month, compared with the use of new shelving (Müller, Miura and Frosi, 1988). This suggests that the fumigation of old stores to get rid of pests might be advantageous.

The trials at Campinas, SP by Moreira Garcia *et al*; (1977) which included both refrigerated and warm (mean 25°C, RH 84%) storage have already been mentioned. In warm conditions, cvs. Granex 33 and Texas Grano 502 did not store satisfactorily for longer than 60 days, or cv. Baia Periforme for over 90 days, when approximately 10% weight had been lost. Other studies in Brazil have been made on local storage methods, showing that storage in boxes was superior to bulk storage in Santa Catarina (Müller, Malburg and Frosi, 1985), and a similar study in north-east Brazil (São Francisco Valley, PE) showed that onions tied and hung in strings lasted better in store than those in bulk bins, or plastic or wooden boxes, at high ambient temperatures. This was attributed to the avoidance of wounding the neck at harvesting in the onions which were stored as strings (Calbo *et al.*, 1979).

More recently, studies were made in Brazil on the effect of bulb drying after harvest on storage (Müller, 1986), and on ventilation regimes in stores.

This work included the development of a mathematical model of onion store ventilation (Matos, 1986). The bulb drying study, which used comparatively short drying times at a rather high temperature, (55°C), did not show any significant differences between the drying treatments used as regards keeping quality, though bulbs harvested before the tops fell down gave significantly more sprouting in store than those harvested after top fall (23.6% and 11.1% respectively). Including multiple bulbs among stored onions had a bad effect on overall storage quality, as these bulbs had higher rates of rotting, sprouting and rooting in the store than single bulbs (possibly an effect of the wounding involved when multiple bulbs were split up). Over-drying at a high temperature evidently had a bad effect on later skin quality of bulbs harvested after top fall (Müller, 1986). Information from the ventilation study has now been incorporated into the recommended onion storage method for use in SC (Matos, 1987), to be discussed below. A considerable literature on onion storage now exists in Portuguese (*see* Appendix 4).

India

Storage trials in southern India at high ambient temperatures and humidities were described by Singh and Joshi (1975). The selected onions were stored in shallow crates in a ventilated room after curing. Monthly mean temperatures varied from 24.7°C in June to 20.35°C, (with a mean minimum of 14.2°C), in November. In a 40-variety trial, losses during storage varied from 43% to 100% for the different varieties compared over 5 months. The varieties which lost less than 50% during this period were Red Globe, Poona Red Globe, N-2-4-1, and EC 103485, (presumably a breeding line), which did not sprout at all. Sprouting was most severe in August, when RH was 92% during the rains. Total losses from rotting were 25%, and from sprouting, 52% by the end of the trial. Although the ambient conditions in this trial were some of the most extreme described in any storage experiments, the survival of a considerable number of bulbs without either sprouting or rotting suggests that a basis exists for further selection and breeding for storage quality. The aim of the experiments was to identify lines with good storage characteristics for such improvement work.

Studies of correlations of bulb traits with storage losses made on the same range of cultivars showed that disease losses were negatively correlated with total soluble solids (TSS) of the bulbs and positively with 'polar diameter', that is, bulb height. The latter finding suggests that it was the bulbs which had not reached complete physiological maturity before harvest, that is, those which had a tendency to be bottle-shaped or thick-necked, were most likely to rot early in store, probably because the necks could not readily be dried out. Onions which were flatter in shape, however, tended to sprout the most rapidly. Bulb weight was negatively correlated with TSS, that is, the larger the bulbs, the lower their solids content. TSS and 'polar diameter' were suggested as characters which could be used in selection for breeding (Singh and Joshi, 1978).

Pathak *et al.* (1974) in Punjab, India, compared a variety of traditional and modified storage arrangements using local onions, variety unspecified, at ambient temperature. The onions were stored either in heaps, crates, ventilated or non-ventilated cribs (with three different thicknesses of layers of onions), or in cold storage. The cribs were hexagonal structures with interior air ducts, and the ventilated treatments were given for 1 or 2 hours per day only. Losses of up to 60% of stored onions were said to occur locally when onions were stored in heaps on the floor. Cold storage with RH 80-85% at 1.5°C to 4.5°C encouraged sprouting, which occurred less quickly at ambient temperatures. After 14 weeks in cold storage, 38% of the bulbs had sprouted, consequently ambient long-term storage was preferred, even though all the ambient storage regimes gave total heavy losses in weight from desiccation, rotting or both. In the cribs, thicker (90 cm and 180 cm) layers of onions gave higher percentages of rotting than a thinner layer (45 cm), which was therefore recommended.

Some major drawbacks to interpreting this study were that the cultivars used were not identified and that the ambient temperature and humidity were not defined. As in many other onion storage experiments, the causes of rotting were also unidentified.

Bangladesh

In Bangladesh, another country where onions are particularly popular for cooking but where ambient storage leads to heavy losses, Husain (1985) tested several 'exotic' (that is, Indian) onion varieties against a local one and found that although yields were much higher in some of the imported varieties, keeping quality was significantly inferior to that of the Bangladesh selection, cv. Faridpur Bhati. After 150 days of ambient storage, the imported varieties Bombay Red, Nasik Red, R S 2603, Nasik Early Red and Pusa Red had hardly any surviving marketable bulbs, whereas cv. Faridpur Bhati had 30% in the Large and 66% in the Small class (size not defined) marketable. Failure of the bulbs to mature early enough in the field to avoid the rains expected in April was a factor in the poor performance of the imported cultivars, suggesting that a breeding programme for Bangladesh should aim particularly for earliness.

Costa Rica

A major study of storage losses was made in a high-altitude onion growing region of Costa Rica by Matheus and Valverde (1983). The study was made on 5 kg samples of cv. Yellow Bermuda onions which were stored in strings in farmers' barns in the Santa Ana area. Average weight loss after 10 weeks of storage was 12%, of which 10% was because of shrinkage and very little from disease or sprouting. After another month, disease loss, mostly from basal rot (*Fusarium oxysporum*) and from soft rot bacteria (*Pseudomonas* sp.) had increased to 5.7%. The onions were grown with irrigation in the dry season and the farmers did not attempt to store them for longer than 2-4 months. Temperatures in the storage period were 35.2°C to 16.2°C, RH 70-87%. This system, by which the tops are left on the onions and the base-plate exposed to the maximum ventilation on the outside of the strings, seems one of the more successful local systems reported from the tropics. However, it does not involve keeping onions for seed production, which would obviously present difficulties. Stringing the onions does require intensive hand labour.

STORAGE STRUCTURES IN THE TROPICS

A variety of storage structures has been developed in different parts of the tropics for onion storage. In general, the need to keep onions dry and well ventilated during storage is well understood, and on a small scale this is done by, for example, tying onions in bunches and hanging them up in the rafters of the house (India), laying them out on beds of coarse sand on floor of a barn or shed (Pakistan), or forming them into strings and storing them in ventilated sheds (Thailand, Costa Rica). Difficulties occur when methods are scaled up and the floor layers are piled up too high, large quantities of onions have to be brought inside in a hurry to avoid rain or theft, or tonnes of onions need sorting to remove rotted or sprouting bulbs. In West Africa, a model onion store was developed at Cambérène, Sénégal, with improved side ventilation and racks of wire-netting shelving on which onions could be stacked one or two layers thick, and which were narrow enough to allow deteriorated bulbs to be removed (Delvaque, 1979). In India, improved field stores based on traditional thatched 'chawls', but with more and thinner layers of onions, are also being investigated by the AADF. In Parana State, Brazil, experiments are being made in the construction of 10-tonne and 20-tonne rural onion stores suitable for small farms or co-operatives (Hamerschmidt and Sette, 1988), and in Santa Catarina, as has already been mentioned, more advanced model stores, based on studies by Matos (1986) of onion storage ventilation and heating requirements, are being promoted for use by growers. Onion stores are described by questionnaire informants in Part II.

A MATHEMATICAL MODELLING APPROACH TO ONION STORAGE

The mathematical model of the processes involved in onion store ventilation was developed by Matos (1986), based on ideas on onion storage from Israel (Felsenstein and Haas, 1980), where stores with ambient forced-air ventilation, and the addition of heat at times of high RH, are now used for storing onions rather than refrigerated stores. Some of the mathematical concepts on airflow through bulbs were developed in Israel. Matos (1986) took measurements in three onion silos 2 m tall and 0.56 m in diameter, which were intermittently ventilated at air flow rates of 0.5, 1.0 and 1.5 $m^3/min/m^3$ onions, at Viçosa, MG. The onions used were cv. Baia Periforme. Hourly measurements were made of bulb temperature, air humidity and dew-point, at several different layers in each silo over 3 months, and of the RH of the exhaust air at the top of each silo. Bulbs were examined at intervals and scored for sprouting, rooting and rots. The lowest rate of air flow was inadequate to keep the onions in good condition without sprouting, particularly in the top layers of the silo, where condensation took place on the bulbs, but the two higher ventilation rates, used during the driest periods of the day, allowed the storage period to be extended compared with that of unventilated bulbs. Air flow rates as low as 1 $m^3/min/m^3$ onions were only useful if continuously used, as when used intermittently this rate was insufficient to remove all the humidity generated by onion respiration in ambient temperature storage (Matos, 1986). Adjustment coefficients were added to the model to allow for the extra water vapour liberated by bulb deterioration during storage. It was also found that a term expressing the initial degree of curing of the bulbs should be used. The concept of heating the air used for ventilation so as to lower its RH and dry out the air in the stacks more efficiently was developed during this project, since at 75% RH or above that of the circulating air, it was thought that the onion skins themselves become more permeable to water vapour, hence encouraging water loss from the bulbs and pathogen development. Measurements made supported the apparently contradictory concept that increasing the difference in vapour pressure between the ventilating air and the stored onions resulted in lower, not higher rates of water loss from the onions. The reason was thought to be the decrease in permeability of onion skins to water as they dry out (Apeland, 1971). Hence the lower rates of weight loss by ventilating with air at 52.9% or 33.0% RH compared with air at 75% RH or above.

In the EMPASC (Empresa Catarinense de Pesquisa Agropecuaria SA) model onion store, the plans of which are published in Matos (1987), a bulk store with under-floor ventilation is provided with a wood-burning furnace capable of raising the temperature of the circulating air, and a system of fan-assisted air circulation with vents under the roof ridge, so that curing and storage can take place in the same building, and heated air can be circulated during the storage period if necessary. From observations and calculations made during development of the model store, air flow rates of 2.5 $m^3/min/m^3$ onions or above were suggested as being safe for onion curing and intermittent ventilation. For a 50-tonne store, for example, an air flow rate of 260 $m^3/min/m^3$ onions is needed, requiring a 4 h.p. axial fan, preferably with a motor external to the circulating blades, as the air temperature may be as high as 40 °C. Under the floor, a principal duct and a series of lateral ducts are arranged so that the laterals are 2 m long and 0.4 m apart. The ducts are covered by wooden grids which can be removed to allow cleaning. The walls are of reinforced masonry and capable of sustaining the weight of 2 m stacks of onions inside the structure. When loading the onion store, growers are advised to finish the drying of one layer of onions before loading any more on top. Ventilation is normally provided by using the ventilating fans to circulate dry outside air during the warmest part of the day. Additional heating is used during storage when the temperatures fall below 18°C, a temperature at which sprouting is promoted. The earlier work by Felsenstein and Haas (1980) suggested that where the RH of the air exceeds 75% for long periods, the air should be heated to lower its RH before it is circulated through the onion stores. This approach to a rational control of ambient storage condition needs practical testing in other tropical environments.

Further discussions of onion storage can be found in Parts II and III.

Part I A selective review of the literature

Chapter 6 Seed production in tropical onions

INTRODUCTION

A number of investigations of the agronomy of seed production in the tropics have been reported, particularly from India. The conditions which induce flowering in tropical varieties of onion are not yet well understood. In varieties which have been developed within the tropics there is often a strong tendency to bolt, that is, flower in the season of bulb production. This has been confirmed by the findings of the ODNRI questionnaire (Part II). The influence of temperature, plant size, and nutrition, particularly with nitrogen, on flower induction are still far from clear, and extrapolation from the results of trials on onions of temperate or Mediterranean origin can sometimes be misleading if applied to the tropical situation.

General information on onion seed production methods can be found in a number of publications on vegetable seed production (for example, Hawthorn and Pollard, 1954; George, 1985) and a most useful chapter on the topic appears in Jones and Mann (1963). A chapter on onion breeding, which includes much information on seed production techniques and discusses the influence of selection on quality in open-pollinated cultivars, was contributed by Pike (1986). Onion seed production literature was reviewed by Currah (1981a) and methods used have recently been described in practical terms by Peters (1990).

Much work on onion seed production in the USA has been directed at specific difficulties encountered in the production of hybrid onion seed, whereas in the tropics most onions grown are of the open-pollinated type. A notable exception is the popular Granex hybrid group, but this is grown from seed which is imported. Not only the varieties grown, but also the range of diseases which attack the seed crop, tend to differ within the tropics from those found in the higher latitudes, though thrips remains the major pest.

SEED PRODUCTION IN INDIA

Large quantities of onion seed are produced in India. A popular article by Singh *et al.* (1976) from Haryana, north India, summarized the methods used. Recommendations were to produce seed during the winter or cool season (Rabi). If the seed-to-seed (one season) method was to be used, sowing before November was advised in order to encourage flower stalk production. This method was earlier recommended for cv. Early Grano by Bhagchandani *et al.* (1970). The bulb-to-seed method, which usually involves growth in two seasons and allows bulbs to be selected for quality and storage ability, is the one more generally used in India. Bulbs are raised in the first season and the bulb field is rogued (that is, atypical plants are removed) during growth. The bulbs are lifted, cured and selected, stored during the hot weather, then planted again in the second season at a rate of about 4.5 t/ha (depending on size and growth habit) during early October. Attention is paid to removing thick-necked and doubled bulbs from the seed crop so as to maintain the quality of the variety. Recommended conditions for bulb storage are to use slatted crates or shallow trays under cover with plenty of ventilation. The field spacing suggested is 45 × 30 cm for bulbs weighing approximately 60 g. Fertilizer recommendations, derived from experimental work by Nandpuri *et al.* (1968) are to apply 62 kg/ha P, and 50 kg/ha K if it is needed, before planting, and 125 kg/ha N split into 2 doses, half to be given 2 weeks after planting the mother bulbs, when the shoots are appearing, and half 45-60 days later. Good weed control in the seed field, but avoiding deep cultivations; and irrigation every 15-20 days are suggested. The onion plants can be earthed up at 45 days, which will help to support the flower stalks and prevent lodging. Isolation distances of 1,000 m for foundation seed and 400 m for certified seed are recommended, following the advice of the Indian Government Central Seed Committee.* Further roguing should be done in the seed field to remove plants with leaf colour or habit which differ from those typical of the variety. Pollination is by honey bees and other insects, including wild bees and flies. Seed heads are harvested when they open to reveal the black seeds, and only the heads where seeds can be seen are picked on any one harvest date. The seed heads are cut or snapped off with a piece of the scape (main flower stalk) attached, dried and threshed when all the seed separates readily. Expected yields of seed are stated to be 0.8-1 t/ha (this is high by the standard of most reports from the tropics). Singh *et al.* (1976) also list plant protection measures for use in controlling seedling damping-off, basal rot, smut (*Urocystis cepulae*), purple blotch, black mould, thrips, onion maggot (*Hylemia* [*Delia*] *antiqua*), sunscald and potash deficiency.

The advisory publication produced by the AADF in India (undated) distinguishes two bulb-to-seed methods. The first, described as an annual method, takes less than a year and does not involve storing the bulbs. It is used for the varieties N-53, Agrifound Dark Red and Arka Kalyan, which are grown for cropping in the Kharif or monsoon season, that is, during the months of May to December. In the annual system, seed is sown in June-July, transplanting is in August-September and the bulbs are lifted and cured in October-November. After about 15 days they are replanted in the field in November-December, where they flower in February and produce seed by May.

The biennial method involves transplanting in December or early January, storing the bulbs from late May and replanting them in September or mid-October. This method is used to produce seed of the main Rabi or dry season varieties Pusa Red, Hissar-2, Nasik Red and others. Within India, the states of Maharashtra, Gujarat and Rajasthan are considered the best climatically for seed production. Heavy soils are recommended for their good anchorage and water retention and for the cooling effect which water evaporation from these heavier soils has on the plants producing the seed crop (AADF, undated).

AGRONOMY OF SEED PRODUCTION

The timing of transplanting and the effects of different storage locations and storage dates on onion seed production by the bulb to seed method at Chaubattia, Uttar Pradesh, India were investigated by Joshi *et al.* (1976). Using cv. Pusa Red, they found that in general, earliness both of transplanting the bulb crop (November 15) in the first year, and of planting the mother-bulbs (October 15) in the second year, significantly favoured good seed yield and quality. The early timings favoured firstly the production of large bulbs in the first season, and secondly, flower initiation in the next winter after the mother-bulbs had been planted. Bulbs intended for seed production were stored at three locations at differing altitudes, which gave a range of three different mean storage temperatures in these trials. Storage at the location with the highest mean temperatures (lower 30s °C) during the months of May to October also gave significant increases in seed production compared with storage at the two cooler sites, where many bulbs rotted and sprouted in store.

Authors' note: because onion is a cross-pollinated crop, isolation, particularly from crops of different bulb colour, is essential to maintain the purity of varieties. Additionally, contamination from pollen of flowering shallots or multiplier onions must be avoided if the level of splitting is to be kept down.

From these experiments, it is evident that flower initiation must occur in the field, after planting, rather than during the storage period itself, since seed production was most successful after storage of the bulbs at temperatures which would not have favoured flower induction (it would be too high, in the lower 30s °C). Clearly, during storage, it was advantageous to keep the bulbs at temperatures which were high enough to maintain dormancy, rather than at lower temperatures which might be expected to favour bulb vernalization, but which in practice were deleterious because they encouraged sprouting and rotting of the bulbs. Mean seed yield per plant was 12.70 g from early transplanting, the best storage environment, and October bulb planting; and 2.32 g from the worst combination of the three factors (Joshi *et al.*, 1976).

In Bangladesh, timing of mother-bulb planting was studied by Mondal and Husain (1980). Dates of planting ranged from the 13th October to the 13th November, and the 23rd October was found to give the highest seed yield of cv. Faridpur Bhati at Mymensingh in the one-season trial. It was suggested that at the earliest planting date, temperatures during shoot growth were too high for optimum production of umbels. The reason for this might be that the high temperatures encouraged early bulb formation, while preventing vernalization of the growing bulbs from taking place. This experiment, and those from India, show how critical is the timing of mother-bulb planting for seed production, and demonstrates how a difference of as little as two weeks can affect seed yield. Local trials of this kind are therefore recommended to determine the optimum planting dates in any area where onion seed production practices are not already well established.

Twelve years of research on onion seed production in Sudan were reviewed by Nourai (1984). The agronomic recommendations from this work were to plant the mother-bulbs in November to early December, to use 19 t/ha of manure with the addition of 86 kg N, or 43 kg N plus 43 kg P_2O_5, to plant medium-to-large size bulbs at high density (15 or 20 cm × 20 or 35 cm) in double rows on ridges, and to irrigate every 4-8 days. Seed production in the north of Sudan is easier than in sites farther to the south, because in the north the nights are cooler in winter, giving better bulb vernalization and therefore more flowering. More details of Sudanese work on onion seed production agronomy are given by Ahmed and George (1984) and Ahmed and Abdalla (1984).

Green (1972) and Bednarz and Kadams (1988) in Nigeria, and Nabos (1976) in Niger compared traditional West African bulb-cutting methods with the use of whole bulbs for seed production (described in Chapter 4) and concluded that the use of whole bulbs gave equally good or better seed yields. However, the practice of cutting across the top of the bulb, which is also used in Chile in the production of seed of the long-storage Valencia variety, may possibly have a function in stimulating sprout growth in very dormant bulbs, and it also enables selection against doubled centres in the bulbs to be carried out. Plant spacings varying from 20 × 20 cm to 30 × 30 cm, at a planting rate of 1 to 1.5 kg bulbs/m^2 were recommended by Bednarz and Kadams (1988). Peters (1990) in Israel recommends bulb planting rates of 10-20 t/ha in seed fields, depending on the cultivar used. Wider spacings lessen the risk of foliar disease building up and causing seed stalk damage, and also have advantages in allowing easier access for roguing the crop and for weed control.

In one of the few published reports of true seed production in tropical multiplier or shallot-like onions, Duqueza and Eugenio (1973) reported from the Philippines that the local cv. Batanes gave more seed from planting the bulbs without fertilizer than from plots on which N fertilizer was used; the best seed yield was 110.7 kg/ha in these experiments. This figure is low by world onion seed production standards, though not perhaps for seed crops in tropical regions. (Onion seed crops of 800-1000 kg/ha are normal in the USA). In Ethiopia, Jackson (personal communication) obtained seed of shallots in a highland area from a crop which was left in the ground rather than being lifted when its vegetative cycle was complete. Some races of shallots grown in the tropics apparently flower more readily than those grown in temperate climates, at least when grown at high altitudes. If reliable shallot multiplication from true seed could be achieved, it would have the advantage of producing a seedling crop which was free from any latent virus disease which might be present when shallots are multiplied vegetatively. It could also avoid the problem of the high cost of vegetative planting material, which in Ethiopia often has to be brought in from distant regions of the country (Jackson, personal communication). It may be possible to promote higher rates of flowering in shallots by cold treatment of stored bulbs, as discussed below. However, shallots are likely to produce very mixed progenies from a seeded crop unless considerable selection work is done; such a scheme is now in progress in Indonesia (Grubben, personal communication).

INDUCTION OF ONION FLOWERING BY COOL TEMPERATURES

In order to develop seed production of locally improved varieties of onion in the tropical north-east production region of Brazil, it was necessary to give mother-bulbs an artificial cold treatment to induce flowering. A few years ago, nearly all the seed of short-day varieties used in this region was imported. The new Brazilian varieties developed in the 1970s were created by mass selection from cv. Baia Periforme or other Brazilian lines normally grown in the cooler regions of the country (*see* Chapter 2), and when grown in the São Francisco Valley, PE, these lines did not experience sufficient cool weather to enable them to initiate flowers on a scale which would allow economic seed production. Aguiar *et al.* (1983) stored five onion lines, including Texas Grano 502, for varying lengths of time from 0 days to 75 days in cold storage at 7-8°C, then planted them out near Petrolina, PE to observe flowering and seed production. All the bulbs were planted in June, and completed their flowering and seed production at mean temperatures of 24.2°C to 29.5°C during June to October. The Brazilian varieties Pera IPA 1, Pera IPA 2, Baia Triunfo and Roxa do Barreiro performed comparatively well, while cv. Texas Grano 502 produced significantly less seed, and seed of poorer germination quality than the Brazilian varieties. After no, or only 15 days cold treatment, no onions flowered, and most cultivars responded to increases in cool storage duration from 30 days to 75 days with increases in seed yield.

Further experiments by Aguiar (1984), using three Brazilian IPA varieties, showed that the optimum length of cold treatment at 8-10°C to obtain >75% of bulbs flowering was 90 days, and that no significant increase in seed production resulted from lengthening the cold treatment to 120 days. Seed yields of over 1000 kg/ha from experimental plots were produced after the optimum cold storage treatment of the bulbs. The Brazilian varieties are apparently already somewhat adapted to seed production at warmer temperatures (Aguiar *et al.*, 1983), as shown by the fact that their inflorescences failed to abort at high temperatures after the bulbs were planted in the field, unlike those of cv. Texas Grano 502, the seed of which is usually produced at higher latitudes with naturally cool winters.

In Martinique, de Bon and Rhino (1988) reported using an artificial cold treatment lasting 45-60 days at 7-11°C to induce flowering in several varieties of onion, with results which varied according to the cultivars or breeding lines treated. The West African variety Violet de Galmi gave 86% flowering, cv. Parmel (from the Mediterranean area) 27%, Texstar and Spaniel 20% and the Russian cv. Strigunovski 8%. Hybrids between the European cultivars and cv. Violet de Galmi gave 67-87% flowering, suggesting that the easy bolting character of the Galmi onion was dominant in the crosses.

In the north of Côte d'Ivoire, a seed production scheme using the West African cv. Violet de Galmi was run in a collaboration between FAO and the local organization SODEFEL in the 1980s (Kuipers, personal communication). Timing of planting was critical in order to achieve a satisfactory seed yield, and only when bulbs were planted after 10th November were there sufficient cool nights during the winter, after the start of regrowth, to enable most of them to flower. Flowering percentage and seed yield increased with the number of hours of temperatures below 15°C during the first two months after planting, and it appeared from two seasons of observations that plants which received >300 hours below 15°C gave the highest percentages of flowering. Diurnal fluctuations of temperature of 10-33°C were common during the winter when the cool Harmattan wind was blowing from the Sahara. Seed yields in a large (10 ha) field were limited at first by lack of pollinators, and better yields obtained in subsequent seasons when honeybees were supplied while the onions were in flower (Kuipers, personal communication).

The induction of flowering in shallots in Ghana by cool storage treatment for 70-90 days at 5-15°C was already described in Chapter 5, in connection with dormancy shortening experiments (Sinnadurai and Amuti, 1971). In Indonesia, similar experiments at the Lembang Horticultural Research Institute (LEHRI) have shown that after only 4 weeks of cool treatment at 4-9°C, some shallots varieties responded by flowering, when grown at an elevation of approximately 1250 m (Prasodjo, personal communication).

ONION POLLINATION

Pollination of onion seed crops has been investigated in India by Singh and Dharamwal (1970) in Uttar Pradesh, by Rao and Lazar (1983) at Pune, Maharashtra, and by Kumar *et al.* (1985) in Himachal Pradesh. Singh and Dharamwal (1970) found that over 70% of pollinators on cv. Patna Red were honeybees (*Apis mellifera*) and established that pollinators were essential for a good onion seed crop. On cv. Nasik Red at Pune in March, *Trigona iridipennis*, a stingless bee, and *Apis cerana* (the eastern honeybee) and *A. florea* (the little honeybee), two tropical bees, were the principal onion pollinators, and mean seed yield was 3.6 g per umbel (Rao and Lazar, 1983). In Himachal Pradesh, the most effective pollinators found were *A. cerana indica*, *A. dorsata* and the drone fly, *Eristalis tenax*. The moth, *Helicoverpa armigera*, was also recorded in large numbers on the flowers of *Allium cepa*, *A. fistulosum* and a tetraploid interspecific hybrid onion (Kumar *et al.*, 1985). This moth may indeed have fed on and pollinated the onion flowers, but it was probably also laying eggs which would later result in larval attack on the pedicels and scapes of the seed crop, as it is the parent of the destructive head-borer or gram-borer caterpillar, a polyphagous pest reported from seed and bulb crops in India (Shinde and Sontakke, 1986).

Onion pollination biology has been reviewed by McGregor (1976), Waller (1983) and Currah (1990). In general, the larger the onion seed field, the greater is the need to provide pollinators, for example, by moving hives of honeybees into or near the field. Failure to provide adequate pollinators can result in poor seed crops. There is a particular danger of this occurring when seed production is increased in scale during an onion improvement programme. Even when bees are supplied, if crops or wild plants which are more attractive than onions to the bees flower simultaneously with the onion seed crop, the honeybees may avoid working of the onion flowers, and low seed yields can result.

High levels of potassium can be found in onion nectar in hot dry climates in the south-western USA, and these are thought to be discouraging to honeybees (Waller *et al.*, 1972). This problem does not appear to occur in European onion seed crops, where evaporation from the flowers is less intense and the nectar is normally more diluted. It is not known whether it occurs in other arid seed production regions. An alternative solution to the problem of providing pollinators may be to encourage blue-bottle or flesh flies to breed in the onion fields, by distributing carrion or dried fish among the flowering onions. Large flies are efficient pollinators of onion flowers, which provide them with readily accessible nectar.

SEED PRODUCTION PROBLEMS IN HOT, ARID ENVIRONMENTS

Problems occurring in the hotter onion-seed production regions of the USA have sometimes been attributable to excessively high temperatures causing overheating of the umbels, and research there has shown that very dense umbels are those most likely to give this problem (Tanner and Goltz, 1972). Chang and Struckmeyer, (1976) determined that of three temperatures tested for their effects on onion seed development, 35°C was more favourable than either 24°C or 43°C. At the higher temperature fewer seeds were set and seed abortion rates were higher than at 35°C. Although damage to seed crops at high temperatures is not reported from the tropics, it may possibly influence seed development adversely in years of unusual heat. Shortage of water at the critical 'milk' to 'dough' stages of seed development is known to have a deleterious effect on seed yields, and water shortage in the umbels can be caused by factors such as insufficient irrigation, pink root fungus attack on the roots, nematode attack, stem plate rots, seed stalk damage by pathogens or excessively drying winds (Harrington, 1974). In Niger, where small seed plots are grown by farmers, barriers woven from sticks are placed to shield the flowering onion plants from the drying Harmattan wind and the sand which it carries (Turner, personal communication).

PEST AND DISEASE CONTROL IN THE SEED CROP

If it is necessary to spray for thrips control during the onion flowering period, insecticides should be chosen which are relatively harmless to bees, and spraying should be done when the bees are not active on the flowers (that is, early in the morning or at dusk). Thrips can severely damage onion seed crops by feeding on the leaves, stalks and flowers themselves, where they eat the pollen and dry up the ovules. The lesions which they cause can allow pathogenic fungi to enter the plant. Recent trials in India have shown that *Stemphylium* blight, which is difficult to control on seed crops, may be associated with high thrips numbers on the plants (AADF, 1989).

Better coverage of onion seed stalks when spraying against *Stemphylium* sp. on flower stalks in Israel was reported by Grinstein *et al.* (1988) when a two-directional air-assisted placement spraying technique with chlorothalonil was used, in comparison with normal cloud spraying with the same chemical, which did not achieve good coverage. The dangers of protective sprays affecting pollen quality were pointed out by Mann (1977) in the case of Dithane fungicide use.

Other fungal pathogens which cause serious losses to seed crops are downy mildew and purple blotch (often found with *Stemphylium* blight). The *Botrytis* diseases which attack seed stalks and heads under damp conditions form lesions on, and may girdle the seed stalk, and can kill the seeds or infect them, so that neck rot can be transmitted to the seedlings (Maude and Presly, 1977a and b). Purple blotch disease can kill the seed heads completely or lead to flower stalk breakage at the weakened points on the stem (Munõz de Con *et al.*, 1985). *Fusarium* has been shown to infect onion seeds (Katan *et al.*, 1975). The temperatures at which most of these pathogens are particularly active were defined in Chapter 5.

USE OF PLANT GROWTH REGULATORS IN SEED CROPS

Gibberellins in particular have been used to try to increase the number of seed stalks produced by onions. Corgan and Montano (1975) used gibberellic acid (GA_3) treatment in New Mexico on a seed-to-seed crop of cv. Yellow Grano sown in September. Flowering percentage increased from 42% with no treatment, to 60% after GA_3 was sprayed onto the plants in late winter at 1000 ppm, and seed yields were highest after the hormone was applied on

February 21st. Timing of the sprays was critical, as earlier treatments sometimes adversely affected seed yield. In Israel, Naamni *et al.* (1980) applied GA_3 to emerged onion flower stalks and reported 30% seed yield increases in cv. Grano, apparently due to the larger umbels produced after treatment. Loper and Waller (1982) at Yuma, Arizona, on a seed-to-seed crop of cv. White Creole sown in mid-October, found that spraying gibberellic acid at 50 ppm or 500 ppm on March 7th gave 80% of bulbs flowering compared with 65% from untreated plants, and that 40% more seed per m^2 was produced after the GA_3 spray.

The mechanism of action of the GA sprays on the seed crop has not been investigated. It seems reasonable to suggest that when the flower stalks are growing out from the bulbs, GA treatment may allow a higher proportion of the flowering shoots, induced by the cool winter temperatures, to continue to develop and produce umbels, including some which might otherwise abort under the influence of increasing light intensity and longer days during the spring. It would be interesting to try GA treatments on onion seed crops within the tropics, where bud abortion may also reduce seed yields to an extent which has not yet been determined.

Another type of growth substance which has been used on seed crops with the aim of reducing seed stalk height and preventing the seed stalks from lodging (falling down) is ethephon ((2-chloroethyl)phosphonic acid). This substance is metabolized by the plant to release ethylene. Levy *et al.* (1972) and Corgan (1975) showed that spraying ethephon on plants which were coming into flower reduced overall seed stalk height and decreased the amount of lodging. Corgan (1975) found that after sprays of 2500 ppm and 5000 ppm, lodging in cv. Excel was reduced from 53% to 10%, though a higher dose of ethephon resulted in diminished seed yield. Ethephon treatment might be beneficial to onion seed producers in areas subject to strong winds at seed harvest time, but experiments over several seasons would be needed to determine the best timings and rates of application, as ethephon can cause reductions in the numbers of flower stalks (Levy *et al.*, 1972).

SEED HARVESTING EXPERIMENTS

Globerson *et al.* (1981) in Israel studied the timing of onion seed harvesting and determined that seeds with 50-60% dry matter, 45-50 days after flower opening, were able to germinate; and that the best time to harvest mechanically was when the seeds were at 60-70% dry matter, or to use another criterion, when 1-3% of the umbels were showing black seeds. This was said to be 10-12 days before the traditional time for hand harvesting. With this early seed harvest date, leaving a long stalk attached to the umbels while they dried was important in order to maintain seed quality.

In experiments on cv. Sweet Spanish in California, it was found that seeds could be harvested at moisture contents from 66% down to 52% before shattering of the umbels led to serious seed wastage (Steiner and Akintobi, 1986). Delaying harvesting after 20-30% of umbels showed some black seed was found to result in seed losses by Neal and Ellerbrock (1986) in the USA.

SEED DRYING, CLEANING AND STORAGE

Because onion seed is short-lived under poor storage conditions, it should be cleaned and dried down to a low moisture content as rapidly as possible, without overheating, and preferably packed in air-tight containers at approximately 6% moisture, when it should keep well even at relatively high ambient temperatures. Seed can be cleaned quite effectively by simple hand methods of rubbing, sieving and winnowing. It may also be washed rapidly, which allows low quality seed and corky debris to be separated quickly from the high quality seed which sinks in water. This method should only be used when the seed can be dried again quickly to $<12\%$ moisture, in order to preserve its viability (Peters, 1990).

The danger to seed viability from high humidity was shown in work by Rocha (1959) in Brazil. Onion seed samples conditioned to different moisture levels were kept at temperatures from 30°C up to 60°C for times of up to 2 hours only, and those with moisture contents of 11% to 15% showed falls in germination after being so heated. In longer-term tests, seeds with 13% or 15% moisture were useless after 104 days in sealed containers at 25°C.

A system used in Sri Lanka avoids the need for extended seed storage by timing of the seed production season so that the fresh seed can be used almost straight away by the local farmers (Kuruppuruachchi, personal communication). Under this regime, seed is sown in March, the seedlings are transplanted two months later, and the bulbs harvested by early August. They are replanted in mid-November, flower in December and the seed is ready to harvest in March, when it is needed by the farmers. Selections have been made locally for low levels of bolting in the bulb crop (15-20%), but this material flowers well after replanting at low altitudes without any need for artificial vernalization, at a rate of approximately 70%, in mean temperatures of 23-24°C (Kuruppuruachchi, personal communication). The selected material has been found unsuitable for growing at high altitudes in Sri Lanka because in the cooler locations, rates of bolting in the bulb crop are too high (ca. 60%). This method may suggest an alternative production system for other remote areas where there are no facilities for control of seed drying or possibilities for sophisticated seed packaging.

Chemical treatment of seed against fungal diseases was mentioned briefly in Chapter 4. As onion seeds can carry several diseases, including neck rot and other *Botrytis* species, *Fusarium, Rhizopus,* and also bacteria, it would seem worth investigating in the tropics the suggestion by Rudolph (1986) that onion seed could safely be treated with fungicidal and insecticidal dressings for up to 3 years prior to sowing, with no reduction in the germination rate (though presumably the seed was stored under controlled low-temperature conditions in these tests). It would be interesting to find out how much of the rapid deterioration reported in onion seed in hot climates is due to pathogens as opposed to high temperature and humidity alone. In India, Gupta *et al.* (1984) found 11 species of fungi on onion seeds from production fields; *Aspergillus niger, A. flavus* and *Drechslera* [*Cochliobolus*] *australiensis* were the most pathogenic. Of six seed dressings tested, benomyl was found the most effective. In the UK, seed dressings of 1 g a.i benomyl per kg of seed, often with the addition of thiram, are routinely used on onion seed to control neck rot and damping-off diseases (Maude and Presly, 1977b). Research on the possible effect of fungicidal seed treatments on the incidence of black mould on stored onions is currently in progress in Sudan in association with NRI and IHR, Wellesbourne, UK (Hayden and Maude, in preparation).

Breeding and selection for the improvement of onions in the tropics, and the role of the seed production manager in this process, are discussed further in Part III.

Part II

The onion questionnaire findings

INTRODUCTION

The questionnaire compiled at ODNRI in 1986 was circulated to research and extension workers in tropical and subtropical countries in order to find out from the people directly concerned, the current practices and the problems perceived to be connected with onion storage. The questionnaire began by asking in general terms, the status of the onion in the country or region, and then enquired in more detail into the actual varieties grown and their characteristics, the methods of harvesting and drying used, and the causes of loss during storage. The questionnaire itself is included as Appendix 1 in this bulletin (*see* pp. 183-9).

RESPONSE TO THE QUESTIONNAIRE AND ANALYSIS OF THE RESULTS

The questionnaire was circulated in two batches, one in 1986 and another, which included versions in French and Spanish, in 1988. Over 200 questionnaires were sent out, and 72 replies were received by April 30th, 1989, the cut-off date for inclusion of the results in the bulletin. The rate of response, at over one-third of the questionnaires distributed, was satisfactory for a survey of this kind.

Some questions were not answered by all the respondents, and for some questions, multiple answers were permitted, and are included in the totals presented. The number of informants who answered each question is therefore stated. Sometimes separate informants from the same country gave different answers. There may be several possible reasons for this: that conditions differ between regions of a country; that people's areas of specialized knowledge vary; or that perceptions of a given situation lead to differing subjective judgements. Rather than attempting to make any further judgements on the validity of these differing answers, they have been allowed to stand and included in the total results. In the tables in which individual informants are identified by means of code numbers, results include all the answers given. In other tables, answers within countries have been amalgamated or the actual numbers of responses are shown (in Table 3 for example). For Question 21, which asked about other types of *Allium* grown, only the positive answers are included.

Total results are necessarily weighted in favour of the countries with larger numbers of respondents. For detailed results, reference should therefore be made to the tables. In a very few cases where answers were obviously omitted inadvertently, or where a misunderstanding was shown by a later answer or comment, answers were inserted in the appropriate sense before the analysis of the results.

THE RESULTS OF THE SURVEY

Replies were received from 46 countries by the end of April 1989, and the names and addresses of the informants are listed alphabetically in Appendix 2. Each questionnaire returned was given a code number, which is used in some of the tables of results to identify the source of information. For convenience of reference, these code numbers are shown in numerical order, together with the names, countries and territories of the informants, in Appendix 3. Several replies were received from some countries: India (8), Brazil and Sudan (4), Indonesia and Pakistan (3), and Egypt, Ghana, Kenya, Nigeria, Zambia, Sri Lanka, Barbados, Venezuela, and Australia (2 each). The other countries and territories from which one reply was received were Côte d'Ivoire, Ethiopia, Israel, Malawi, Mauritania, Niger, Senegal, Sierra Leone, Swaziland, Tanzania, Togo, Tunisia, Turkey, Zimbabwe, Bangladesh, Malaysia, Mauritius, Thailand, Yemen (North), Yemen (South), Belize, Costa Rica, Jamaica, Martinique, Panama, Argentina, Chile, Ecuador, Fiji, Hawaii, Papua New Guinea and the Philippines.

Some major onion producing countries in the tropics are not included in this list: Mexico and Colombia, for example. However, the forty-six countries represented give a reasonably good coverage of the tropics and subtropics, as well as including some non-tropical regions (for example, Turkey and central Chile) where onion production is important but from which information is not easily obtainable: all of the replies received have therefore been included in the tables and analysis of the results.

The main body of detailed results is presented in Tables 3 to 11, where an alphabetical arrangement of countries within major regions is adopted. In the text, the total responses to individual questions are discussed and amplified where necessary. Some of the questions where considerable amounts of factual information were supplied (for example, on cultivars and on storage structures) are also discussed at length later in the chapter. Many of the comments from informants are quoted directly.

The first four questions asked for information on the importance of the onion crop nationally, about the frequency of onion imports and the extent to which onions are stored. The answers given are shown in Table 3, where countries and territories are listed under the five regional groups: Africa and Mediterranean; Asia; Caribbean and Central America; South America; and Oceania (which includes Australia).

Table 3

Summary of replies to questions 1-4

Country/territory	Number of replies	Question 1. Importance of onion as a crop			Question 2. Storage of onions			Question 3. Are onions imported?			Question 4. Are imported onions stored?			
		major	minor	not grown	always	sometimes	no	every year	some years	no	always	sometimes	no	N/A
Côte d'Ivoire	1		1					1				1		
Egypt	2	2			2	1				2				2
Ethiopia	1	1				1				1				1
Ghana	2	1	1		1	1		2				2		
Israel	1	1								1				1
Kenya	2	2				1	1			2				2
Malawi	1		1			1				1				1
Mauritania	1	1				1		1				1		
Niger	1	1			1					1				1
Nigeria	2	2				1				2				1
Senegal	1	1				1		1			1			
Sierra Leone	1	1			1			1				1		
Sudan	4	4			4					4				3
Swaziland	1	1				1		1				1		
Tanzania	1	1			1					1				1
Togo	1		1				1	1					1	
Tunisia	1	1				1		1				1		
Turkey	1	1			1					1			1	
Zambia	2	1	1		1	1			1	1			1	1
Zimbabwe	1		1		1					1				1
Bangladesh	1	1			1				1				1	
India	8	8			8					8				8
Indonesia	3	2	1		1	1	1	1	1	1			2	1
Malaysia	1		1	1				1				1		
Mauritius	1	1			1			1					1	
Pakistan	3	2	1		2	1			3			2	1	
Sri Lanka	2	2				1	1	2			1		1	
Thailand	1	1			1				1			1		
Yemen (North)	1	1			1					1				1
Yemen (South)	1	1			1			1			1			

Country/territory	Number of replies	Question 1. Importance of onion as a crop			Question 2. Storage of onions			Question 3. Are onions imported?			Question 4. Are imported onions stored?			
		major	minor	not grown	always	sometimes	no	every year	some years	no	always	sometimes	no	N/A
Barbados	2	2			1		1	2			2			
Belize	1		1			1		1				1		
Costa Rica	1		1		1				1				1	
Jamaica	1	1				1			1				1	
Martinique	1		1				1	1			1			
Panama	1	1				1		1				1		
Argentina	1	1			1					1				1
Brazil	4	4			1	2				4				3
Chile	1	1			1					1				1
Ecuador	1	1				1				1				1
Venezuela	2	2				2			1	1		1		1
Australia	2	1	1		1	1		1	1	1			1	1
Fiji	1		1			1		1			1			
Hawaii	1		1			1		1				1		
Papua New Guinea	1		1		1			1			1			
Philippines	1		1		1					1				1
Total	72	55	17	1	37	25	6	24	11	38	8	16	11	34

Table 4

Replies to Questions 5 and 6. In how many seasons are onions grown, and in which months?

Country/territory	Code number of informant	Number of seasons in which onions are grown	First season	Second season	Third season
Côte d'Ivoire	59	1	Sep/Nov – Feb/Apr		
Egypt	11	2	Aug/Sep – Mar/May	Oct/Nov – Mar/Jun	
	12	2	Aug/Sep – Mar/May	Nov/Dec – May/Jun	
Ethiopia	8	C	October – March	June – October	
Ghana	7	C	May – August	Sep – December	
	52	C	Mar/Apr – Aug/Sep	Aug/Sep –Dec/Jan	
Israel	31	3	Late Aug – Dec/Jan	Oct/Nov – Mar/May	Feb – July
Kenya	21	C			
	23	2	March – Jul/Aug	October – Feb/Mar	
Malawi	58	1	Feb – October	June – September	
Mauritania	44	1, 2	November – Apr/May		
Niger	54	2	Sep/Nov – Nov/Feb	November – Jan/Feb	
Nigeria	5	2	Nov/Apr – Jan/May	Jun/Oct – Sep/Nov	
	6	2	October – Mar/Apr	Apr/Mar – Aug/Sep	
Senegal	68	2			
Sierra Leone	53	1			
Sudan	13	2	Sep/Nov – Jan/May	Jan/Mar – May/July	
	14	1	November – June		
	15	2	Dec/Jan – May/Jun	Sep/Oct – Jan/Mar	
	16	2	Oct/Nov – Apr/May	August – Dec/Jan	
Swaziland	41	1	March – November		
Tanzania	17	C	April – Jul/Aug	November – March	
Togo	66	1, C	April – July	October – December	
Tunisia	47	1	December – May/June		
Turkey	26	1	April – August	Jan/Feb – Jun/July	
Zambia	19	2	April – Aug/Sep	Dec/Feb – Apr/June	
	22	1, 2	Apr/May – August	August – November	
Zimbabwe	20	1, 2	Feb/Mar – Aug/Sep		
Bangladesh	43	1	Nov/Dec – April		
India	9	2, C	July/Aug – Nov/Dec	Oct/Nov – Mar/Apr	Jan/Feb – Apr/May
	27	2			
	40	2	Jan/Feb – Apr/May		

Country/territory	Code number of informant	Number of seasons in which onions are grown	First season	Second season	Third season
India—*continued*	42	C	Oct/Nov – Apr/May	May/June – Nov/Dec	
	45	2	January – May	Mid Aug – December	
	48	2	May/July – Aug/Sep	Oct/Nov – Jan/Feb	
	51	2	November – March		
	55	2	November – April	June – October	
Indonesia	65	C	March – May	December – March	
	69	1	March – July		
	70	1, 2, C	May – August	February – May	
Mauritius	37	2	March – July/Aug	July – Nov/Dec	
Pakistan	1	2	October – February	January – March	
	46	1	Oct/Nov – May/June		
	61	2	September – Jan/Feb	Dec/Jan – Apr/May	
Sri Lanka	56	1	Mar/Apr – July/Aug		
	57	1, C	February – Apr/May	Apr/June – August	
Thailand	18	1	Nov/Dec – Mar/Apr		
Yemen (North)	49	2	October – March	February – July	
Yemen (South)	25	2	Sep/Oct – Mar/Apr	July/Nov – Jan/Apr	
Barbados	3	2	Sep/Dec – Jan/May	June/July – Nov/Dec	
	4	C	June – January		
Belize	36	1	October – March		
Costa Rica	28	2	September – February	April – July	
Jamaica	10	2	Sep/Oct – Dec/Jan	Mar/Apr – Aug/Sep	
Martinique	2	1	Nov/Jan – Mar/May		
Panama	72	1	Sep/Oct – Jan/Apr	July/Aug – Nov/Dec	
Argentina	29	1	Mar/Apr – Oct/Dec	June/Aug – Jan/Mar	Mar/Oct – Oct/Nov
Brazil	24	2			
	33	2, C	February – May	April – October	
	35	C	Jan/Mar – May/July	Apr/June – Sep/Dec	
	50	2, C	Apr/June – Nov/Jan	February – June/July	
Chile	30	2	June – February	January – Sep	April – Dec
Ecuador	39	2	May/June – Nov/Dec	Dec/Jan – June/July	
Venezuela	34	1, C	All year round	Oct/Nov – Dec/Jan	
	62	1, C	October – February	November – January	
Australia, NSW	63	1	May/June – Nov/Dec	Mar/May – Sep/Oct	
QD	38	1	Mar/July – Aug/Nov		
Fiji	60	1	May – October		
Hawaii	71	C	Continuous		
Papua New Guinea	67		Non-seasonal		
Philippines	64	1	Oct/Dec – Feb/Apr		

Notes: Column 3: 1 = 1 season; 2 = 2 seasons; C = continuous.

Table 5

Informants, onion cultivars grown in their countries and estimates of the percentage of local production from the cultivars, grouped by major regions

Code number	Correspondent, country and names of cultivars grown	Estimated percentage of national or regional production
Regions: Africa and Mediterranean		
59	Kuipers, Côte d'Ivoire	
	Violet de Galmi	95
	Texas Yellow Grano	5
11	Mansour, Egypt	
	Giza 6	40
	Beheri	60
	Giza 20	5
12	El-Shafie, Egypt	
	Giza 6 Mohassan	35
	Local Beheri	65
	Giza 20	5
8	Mirkensa/Jackson, Ethiopia	
	Adama Red	20
	Ethiopian Shallot	70
	Red Creole	2
	Mermiru Brown	8
7	Doku, Ghana (Legon)	
	Bawku	75
	Texas Grano	10
	Red Creole	10
52	Johnson, Ghana (Accra)	
	Bawku	*
	Texas White Grano	*
	Texas Yellow Grano	*
	Legon Red	**
	Legon White	**
31	Rabinowitch, Israel	
	Beit Alpha	*
	Ori	*
	Grano	*
	Ben-Shemen	*
	Moab	*
21	Waithaka, Kenya (Nairobi)	
	Red Creole	50
	Tropicana F1	20
	Bombay Red	*
	Yellow Granex	*
	Texas Grano	*
23	Ndungu, Kenya (Thika)	
	Red Creole	50
	Bombay Red	20
	Tropicana F1	10
	Texas Grano	10
	White Creole	<5
58	Kumwenda, Malawi	
	Texas Grano	30
	Pyramid	15
	De Wildt	*
	Shallots	25
	Australian Brown	10
	Bon Accord	10
	Hojem	10
44	Ba, Mauritania	
	Violet de Galmi	50
	Early Texas Grano	30

Code number	Correspondent, country and names of cultivars grown	Estimated percentage of national or regional production
54	Naino, Niger	
	Violet de Galmi	80
	Blanc de Galmi	10
	Blanc de Soumarana	10
5	Denton, Nigeria (Ibadan)	
	Kano Red	90
	White	10
6	Erinle, Nigeria (Zaria)	
	Gindin Tasa	*
	Wuyan Bijimi	*
	Wuyan Makorowa	*
68	Samb/Cissokho, Senegal	
	Jaune hatif [Early yellow]	40
	Violet de Galmi	20
	Texas Grano	10
	Yaakar	10
	Red Creole	10
	Jaune [Yellow]	10
53	George, Sierra Leone	
	Texas Grano	90
	Red Creole	10
13	Mohamed, Sudan (New Halfa)	
	Nasi	*
	Sagi Red	*
	Dongola Yellow	*
14	Musa, Sudan (Khartoum)	
	Wad Ramli and other local red cvs.	80-90
	Dongola Yellow	*
	Nassi	*
15	Ahmed/Faragalla, Sudan (Khartoum)	
	Saggai	55
	Shundi Yellow	30
	Dungula White	10
	Nasi	5
16	Mohamedali, Sudan (Ed-Damer)	
	Red (various local names)	98
	Dongola Yellow	1
	Nasi	1
41	Gama, Swaziland	
	Texas Grano	80
	De Wildt	3
	Pyramid	15
	Granex 33	2
17	Marandu/Swai, Tanzania (Arusha)	
	Red Creole	60
	Red Bombay	30
	Texas Grano	5
	Shallots	5
66	Avochinou, Togo	
	Local yellow	*
	Red Creole	*
	Texas Grano	*
47	Ben Abderrazak, Tunisia	
	Early White	35
	Ultra Red	13
	Aarbi	25

Code number	Correspondent, country and names of cultivars grown	Estimated percentage of national or regional production
26	Kaynas, Turkey (Istanbul)	
	Yalova-12	25
	Kantartopu	20
	Imrali Kirmasi	20
	Valencia	15
	Yalova-15	10
	Yalova-3	3
	Corum	5
	Mor Sogan	2
19	Wright, Zambia (Chisamba)	
	Henry's Special	10
	Extra Early Premium	80
	Granex	10
22	Msikita, Zambia (Mazabuka)	
	Texas Early Grano	80-90
	Yellow Granex	5-10
	Other	1-5
20	Cole, Zimbabwe (Harare)	
	Dessex, Early Premium	15-20
	Pyramid	50
	Texas Grano	5
	Gold Rush	10-15
	Hojem	10

Region: Asia

43	Mondal, Bangladesh (Mymensingh)	
	Faridpur Vati	80-90
	Taherpuri	10-20
9	Kale/Bhat, India (Maharashtra)	
	N-53 (rainy season)	60
	N-780 (Baswant) (rainy season)	5
	N-2-4-1 (winter season)	25
	Nasik Red (winter and summer crops)	60
	N-257-9-1 and other white cvs. (winter and summer crops)	15
	Other local red cvs.	30-35
27	Kaul, India (New Delhi)	
	Pusa Red	30
	N-53	30
	N-2-4-1	25-30
	Bellery Red	*
	Punjab Selection	*
	Nasik Red	60
	Rose onion	*
	N-257-9-1	15
40	Shukla/Gupta, India (Bhopal)	
	Pusa Red	*
	Pusa Ratnar	*
	N-53	*
	Patna Red	*
	Nasik Red	*
	White Patna	*
	Red Globe	*
	Large Red	*
42	Pandey/Gupta, India (New Delhi and elsewhere)	
	Agrifound Light Red	20
	Pusa Red	20
	N-2-4-1	10
	Agrifound Dark Red	40
	N-53	10
45	Maurya/Singh/Singh, India (Varanasi)	
	Pusa Red	30
	Nasik Red	30
	N-53	40

Code number	Correspondent, country and names of cultivars grown	Estimated percentage of national or regional production
48	Irulappan, India (Tamil Nadu)	
	Bellary	*
	Shallots, Co.1, Co.2, Co.3, Co.4, Mov.1 and Agrifound Dark Red	*
51	Datar, India (Maharashtra)	
	Red	*
	White	*
55	Sen/Bose, India (Calcutta)	
	Early Grano	*
	Pusa Red	*
	Pusa Ratnar	*
	Nasik Red	*
	Patna Red	*
	N 404	*
	N 53	*
	N 207-1	*
65	Van der Meer/Hadi, Indonesia	
	Shallots	90-95
69	Beets, Indonesia	
	Shallots	*
70	Turral, Udin, Jaya and Hamzah, Indonesia	
	Shallot varieties:	
	Ampenan	50
	Cloja	15
	Bima	10
	Bima Kuning	10
	Bauji	10
	Balijo	5
	Suminep	*
	Bawang Lampung	*
	Betawi Cipanas	*
	Maja Kuning	*
32	Leong, Malaysia	
	Shallots (experimental)	**
37	Gayan, Mauritius	
	Rouge local (Potiah)	7
	Gatchi	10
	Rodrigues	8
	Red Creole	15
	Yellow Texas and others	10
1	Baloch, Pakistan (Islamabad)	
	Red Tunic (local)	60
	White Tunic (Texas Early Grano)	30
	Others	10
46	Tahir Chaudhry, Pakistan (Azad, Jammu and Kashmir)	
	Texas Early Grano	25
	Local White	75
61	M H A Chaudhry, Pakistan (Faisalabad)	
	Phulkara	45
	Faisalabad Early	31
	Desi Early Red	20
56	Kuruppuruachchi, Sri Lanka	
	Poona Red	90
57	Wirasinghe, Sri Lanka	
	Poona Red	5
	Common local red [shallot]	90
	Vedala Vengayam [multiplier onion]	5
18	Tonguthaisri, Thailand (Chiang Mai)	
	Yellow Granex	90

Code number	Correspondent, country and names of cultivars grown	Estimated percentage of national or regional production
49	Abdulla, Yemen (North)	
	Texas Early Yellow Grano	*
	Pusa Red	*
	Red Creole	*
25	Salaam/Hambari/Barker, Yemen (South)	
	Bombay Red	>98
	Red Creole and Golden Creole (eaten green)	*
	Baftaim	<1
Region: Caribbean		
3	Chandler, Barbados	
	Golden F1	2
	Texas Early Grano 502	35
	Robust White F1	5
	Granex F1	39
4	Brereton, Barbados	
	Golden F1	75
	Texas Yellow Grano	10
	Granex F1	3
	Texas Grano 502	10
	Robust White F1	2
36	Magloire, Belize	
	Yellow Granex	90
	Red Creole	10
28	Valverde, Costa Rica	
	Yellow Bermuda	25
	Granex	50
	Dessex	10
10	Lawrence, Jamaica	
	Texas Early Grano	70
	Red Creole	6
	Granex F1	1
	New Mexico Yellow Grano	20
	New Mexico White Grano	2
	White Mexican/El Toro	1
2	Daly/de Bon, Martinique	
	Yellow Granex	*
72	Sanchez/Urriola/Serrano/Panama	
	Granex 33	60
	Granex 429	21
	Granex Yellow	14
	Dessex	3
	Texas Grano 502	1
	Red Granex	0.5
Region: South America		
29	Marti, Argentina (Formosa)	
	Morada INTA	3
24	Costa, Brazil (São Paulo)	
	Baia Periforme Precoce	60
	Granex	20
	Pira Ouro	5
	Texas Grano	15
33	Costa, Brazil (whole)	
	Granex F1	10
	Baia Periforme	50
	Pera Norte	10
	Criola	10
	IPA-5	5
	Texas Grano	10
	Pira Ouro	5

Code number	Correspondent, country and names of cultivars grown	Estimated percentage of national or regional production
35	Araujo, Brazil (Pernambuco)	
	Texas Grano 502	40
	Pera Norte	10
	Baia Periforme	35
	Others	15
50	Kimura, Brazil (whole country)	
	Granex 33 and Texas Grano 502	35
	Baia Periforme and derivatives	45
	Norte 14, Jubileu and Crioula	20
30	Escaff, Chile (Santiago)	
	Calderana or Copiapina	10
	Texas Grano 502	5
	Torontina or Pascuina	15
	Valenciana	70
39	Paredes, Ecuador (Ambato)	
	Blanca [white]	35
	Paiteña or Colorada [red]	65
34	Añez, Venezuela (Merida)	
	Texas Early Grano 502	40
	Yellow Granex F1	30
	Excel 986 (Bermuda 986)	10
	New Mexico Yellow Grano	10
	Islena Amarilla	2
	Islena Roja	3
	Red Burgundy	2
	'Criolla'	3
62	Avila/Flores, Venezuela (Cagua)	
	Texas Early Grano 502	90
	Granex 33	5
	Granex 429	5
Region: Oceania		
38	Schrodter, Australia (Gatton, Queensland)	
	Early Lockyer White (local seed)	10
	Early Lockyer Brown (local seed)	1
	Early Lockyer White (commercial seed)	30
	Early Lockyer Brown (commercial seed)	4
	Golden Brown (local seed)	5
	Gladalan White (commercial seed)	30
	Gladalan Brown (commercial seed)	20
63	Shann, Australia (Narromine, NSW)	
	Early Lockyer White	2
	Gladalan Brown	10
	Early Creamgold and Creamgold	50
	White Spanish	5
	Golden Brown	2
	Gladalan White	5-10
	Torrens White	2
60	Datt, Fiji	
	Superex	50
	Tropi Red	10
71	Kratky, Hawaii	
	Granex	*
	Texas Yellow Grano	*
67	Gorogo/Pitt, Papua New Guinea	
	Gladalan Brown	50
	Awahia	25
	Superex	25
64	Villamayor, Philippines	
	Red Globe	25
	Red Creole	20
	Yellow Granex	15
	Shallot	40

Notes: * no estimate given
** grown only experimentally

Table 6

List of major varieties of onions and their characteristics as recorded by questionnaire respondents

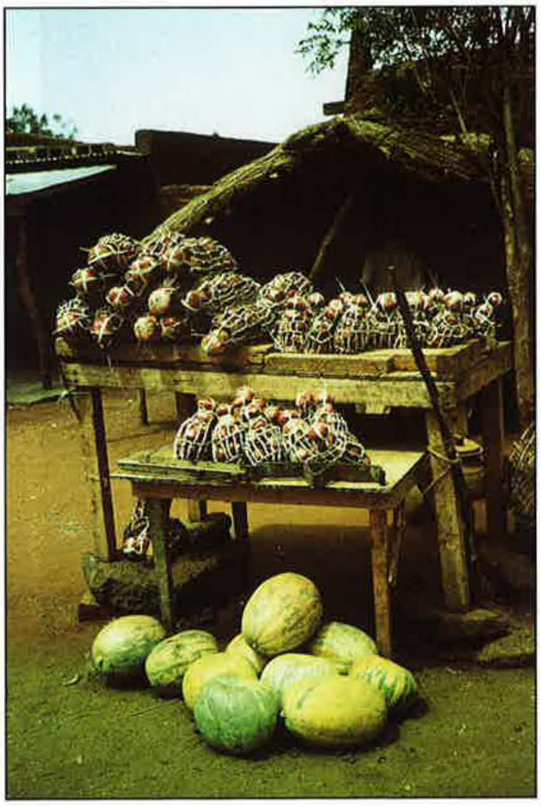
Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Region – Africa and Mediterranean										
Côte d'Ivoire	5-10°N	59	Violet de Galmi	Red/brown	Pink/white	1, (2, 3)	40-80	15-20	1-2	NC
			Texas Yellow Grano	Yellow	White	V	40->80	20-25	N/A	NC
Egypt	25-30°N	11	Giza 6	Yellow	White	1	40-80	25	8	NC
			Beheri	Yellow	White	5	40-80	50	10	DB, TN
			Giza 20	Yellow	White	3	40-80	50	10	NC
		12	Giza 6 Mohassan	Yellow	White	1	40-80	25	8	NC
			Beheri	Yellow, red	White/red	V	40-80	37.5-50	10	DB, TN
			Giza 20	Yellow	White	3	40-80	37.5-50	10	NC
Ethiopia	8-10°N	8	Adama Red	Red	Red/white	3	40-80	20	2	DB, TN, B
			Mermiru Brown	Brown	White	3	40-80	20	2	DB
			Shallot	Red	Red/white	V	<40	15	4	NC
			Red Creole	Red	Red/white	3	40-80	20	2	–
Ghana	5-10°N	7	Bawku	Red, pink, white	Pink/white	5, 6	<40	–	Long	DB
			Texas Grano	Brown	White	3	<40	–	–	NC
			Red Creole	Reddish pink	Pink	5	<40	–	–	NC
		52	Bawku	Red	Red/white	2	40-80	6	12	NC
			Texas White Grano	White	Green/white	6	40-80	4	.5	N/A
			Texas Yellow Grano	Yellow	–	–	<40	–	.5	N/A
			Legon Red	Red	–	–	–	–	–	–
			Legon White	White	–	–	–	–	–	–
Israel	31-33°N	31	Beit Alpha	Light brown	Cream/white	8	40-80	40-50	None	DB
			Ori	Light brown	Cream/white	9	40-80	40-50	None	NC
			Grano	Light brown	Cream/white	8	40-80	50	None	NC
			Ben-Shemen	Light brown	Cream/white	2	40-80	50	5-6	NC
			Moab	Light brown	Cream/white	3	40-80	80-100	5-6	NC

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Kenya	4°S-4°N	21	Red Creole	Red	Red/white	3	40-80	10-17	3-6	NC
			Tropicana F1	Red	Red/white	4	40-80	10-17	<6	NC
			Bombay Red	–	–	–	–	–	–	–
			Yellow Granex	–	–	–	–	–	–	–
			Texas Grano	–	–	–	–	–	–	–
		23	Red Creole	Red	Red/white	2	40-80	17	4-5	DB, TN
			Bombay Red	Purple/red	Red/white	4	40-80	17	3-4	TN
			Tropicana F1	Red	Red/white	2	40-80	17	4-5	DB, TN
			Texas Grano	Yellow	White	9	40-80	15-17	1.5-2	TN
			White Creole	Green/white	White	2	40-80	17	3-4	DB, TN
Malawi	10-17°S	58	Texas Grano	Yellow	White	5	40-80	20-25	3	NC
			Pyramid	Yellow	White	1	>80	30	3	NC
			De Wildt	–	–	–	–	–	–	–
			Shallots	Red	Red/white	2	<40	–	4	DB†
			Australian Brown	Brown	White	3	40-80	–	3	NC
			Bon Accord	Brown	White	4	40-80	–	3	NC
			Hojem	Brown	White	4	40-80	–	3	NC
Mauritania	14–27°N	44	Violet de Galmi	Purple	Purple, mixed	V	40-80	20-40	3-6	NC
			Early Texas Grano	Yellow	Yellow	3, 4	<40-80	20-30	1-2	NC
Niger	11-23°N	54	Violet de Galmi	Purple		3	>80	55	7	NC
			Blanc de Galmi	White	White	4	>80	45	6	NC
			Blanc de Soumarana	White	White	6	>80	40	6	TN
Nigeria	4-14°N	5	Kano Red	Brown	Red/white	V	40-80	20-30	.75-1	TN
			White	White	White	V	40-80	15-25	3-4	TN
		6	Gindin Tasa	Red	White/pink	1	>80	20	6	TN
			Wuyan Bijimi	Red	White/pink	3	>80	20	6	–
			Wuyan Makorowa	Red	White/pink	2	>80	20	6	TN
Senegal	13-17°N	68	Jaune hatif	Yellow	Yellow	1	<40	30	1	NC
			Violet de Galmi	Red	Red	4	40-80	45	2	NC
			Texas Grano	Red	Red	3	40-80	35	2	NC
			Yaakar	Red/purple	Red	4	40-80	30	2	NC
			Red Creole	Red	Red	2	<40	35	2	NC
			Jaune	Yellow	Yellow	1	<40	30	1	DB
		73‡	Violet de Galmi	Red	White	1	–	35-65	3-4	B
			Yaakar	Light yellow	White	2	–	25-35	Good	Late
			Jaune hative de Valence	Light yellow	White	5	–	40-70	Bad	Not pungent
			Jaune de l'Espagne	Light yellow	White	4	–	40-70	Bad	Not pungent
			Texas Early Grano 502 PRR	Light yellow	White	4	–	40-80	Bad	Not pungent

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Sierra Leone	7-10°N	53	Texas Grano	Yellow	White	4	40-80	–	1.5-2	TN
			Red Creole	Red	Red/white	3	<40	–	<1.5	
Sudan	12-17°N	13	Nasi	White	White	2	40->80	12.5-25	DB, TN	
			Sagi Red	Red	Red	2	40-80	12.5-25	DB, TN	
			Dongola Yellow	Yellow	White	2	40->80	12.5-25	DB, TN	
		14	Wad Ramli and other local red cvs.	Red/brown	Red or brown	V	40-80	20	5	NC
			Dongola Yellow	Brown	White		–	–	–	–
			Nassi	White	White		–	–	–	–
		15	Saggai	Red	White	4	40-80	20	4-5	DB
			Shundi Yellow	Yellow	White	2	40-80	20-25	5-6	DB
			Dungula White	Yellow	White	5	>80	25	5-6	DB
			Nasi	White	White	3	>80	22.5-30	2	NC
		16	Red types (including Wad Ramli, Saggai, Shendi, Hilalia, Kunnur)	Red	Red/white	2, 3	40->80	20-50	3-6	DB, TN, B
			Dongola Yellow	Yellow	White	2, 3	40->80	20-50	3-6	DB, TN, B
			Nasi	White	White	2	40->80	20-50	3-6	DB, TN, B
Swaziland	25-27°S	41	Texas Grano	Straw/light brown	Light cream/white	9	40-80	30	1	TN
			De Wildt	Straw/light brown	Light cream/white	1	40-80	25-30	3	NC
			Pyramid	Straw/light brown	Light cream/white	1	40-80	25-30	>3	NC
			Granex 33	Straw/light brown	Light cream/white	4	40->80	25-47	1	TN
Tanzania	3-12°S	17	Red Creole	Red	White	3	40-80	10-12.5	3-6	TN
			Red Bombay	Red	Red/white	2	40-80	10-12.5	3	DB, TN
			Texas Grano	Yellow	White	5	40-80	15-20	1-2	NC
			Shallots	Varied	Varied	V	<40	2.5-5	2-3	NC
Togo	6-11°N	66	Local variety	Light yellow	White	5	<40	–	–	DB
			Red Creole	Red	Red/white	4	40-80	–	–	NC
			Texas Grano	Yellow	White	5	40-80	–	–	NC
Tunisia	31-37°N	47	Early White	White	White	6	<40	8	5	NC
			Ultra Red	Dark red	Red/yellowish	4	40-80	10-15	4	TN
			Aarbi	White	White	1	40-80	8-15	5-6	DB, TN

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Turkey	35-42°N	26	Yalova-12	Yellow	Yellow/white	4	40-80	35	6	NC
			Kantartopu	Brown/yellow	White/purple	2	40-80	30	6	TN
			Imrali Kirmasi	Brown/yellow	White/purple	6	40-80	30	6	DB
			Valencia	Yellow	White	4	40->80	40	3-4	NC
			Yalova-15	Yellow	Yellow/white	6	40-80	30	6	DB
			Yalova-3	Yellow	Yellow/white	5	40-80	35	3-4	NC
			Corum	Brown/yellow	White/purple	8	40-80	25	4	TN
			Mor Sogan	Dark red/purple	Purple	2	40-80	20	2-3	NC
Zambia	12-18°S	19	Henry's Special	Yellow	White	5	40-80	25	.5	NC
			Extra Early Premium	Brown	White	3	40-80	45	5	NC
			Granex	Brown	White	4	40-80	30	.5	NC
		22	Texas Early Grano	Yellow	White	9	>80	40	2-3	TN
			Yellow Granex	Yellow	White	5	40-80	30	2-3	NC
Zimbabwe	16-22°S	20	Dessex	Yellow	White	3	40-80	25	2-6	NC
			Early Premium	Yellow	White	3	40-80	20-25	6	NC
			Pyramid	Yellow	White	1	40-80	15	N/A	NC
			Texas Grano	Yellow	White	3	40-80	15-20	N/A	NC
			Gold Rush	Yellow	White	3	40-80	20	6	NC
			Hojem	Yellow	White	6	40-80	15	N/A	NC
Region—Asia										
Bangladesh	19-27°N	43	Faridpur Vati	Brown	White	V	<40	10	7-8	DB
			Taherpuri	Brown	White	2	40-80	12	8-9	NC
		74‡	Taherpuri (Rajashahi)	Brown	White	1-2	<40	4-5	5-6	DB
			Faridpur Vati	Brown	White	V	<40	3-4	4-5	DB
			Kailas nagar (Marikgonj)	Red/brown	White	V	<40	3-4	3-4	DB
			Local	Brown and red	White	V	<40	3-4	3-4	DB
			Imported	Red	White	3-4	40-80	10-12	.5-1	NC
India	19°N	9	N-53 (rainy season)	Red/purplish	Red	2	40-80	20	.5-1	DB, TN
			N-780 (Baswant)	Pink/red	Red/pink	3, 4	40-80	25	1-2	NC
			N-2-4-1	Light black/red	Cream/white	4	40-80	30-35	2-4	NC
			Nasik Red	Red	Red	2	40-80	20	1.5-2.5	DB, TN
			N-257-9-1 and other white vars	White	White	2	40-80	25-30	2-3	DB
			Local red cvs.	Red	Deep red	3	40-80	N/A	1	DB, TN

Plate 1



(M. R. TURNER)

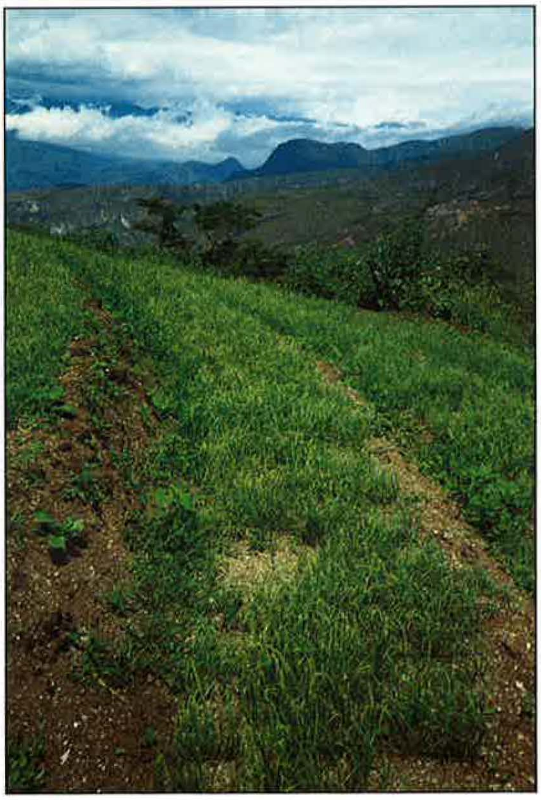
Onions packed for sale at roadside, Niger

Plate 2

(M. E. MONTERO MORA)

Onion strings in store in Costa Rica

Plate 3



(F. J. PROCTOR)

Onion seedlings in nursery beds, Ecuador

Plate 4

(F. J. PROCTOR)

Sorting multiplier onions at the market, Ecuador

Plate 5

(T. J. KUIPERS)

Mature onion crop, Côte d'Ivoire

Plate 6

(M. R. TURNER)

Protected plot for seed production, Niger

Plate 7

(T. J. KUIPERS)

Seed production field, Côte d'Ivoire

Plate 8

(M. R. TURNER)

Onion harvesting in Niger, cut leaves in heaps

Plate 9

(N. J. HAYDEN)

Drying onions in the field under leaves, Sudan

Plate 10

(N. J. HAYDEN)

Sudanese onion store or rukuba

Plate 11

(F. J. PROCTOR)

Onion store with low and high ventilators, Costa Rica

Plate 12

(J. K. BISBROWN)

Experimental bulk onion storage bins, Yemen (South)

Plate 13

Shallot beds, Indonesia

(R. PRASODJO SOEDOMO)

Plate 14

Shallots stored in rafters, Indonesia

(R. PRASODJO SOEDOMO)

Plate 15

Black mould

(F. J. PROCTOR)

Plate 16

Double bulb

(F. J. PROCTOR)

Plate 17

Double and thick-necked onions, Ethiopia

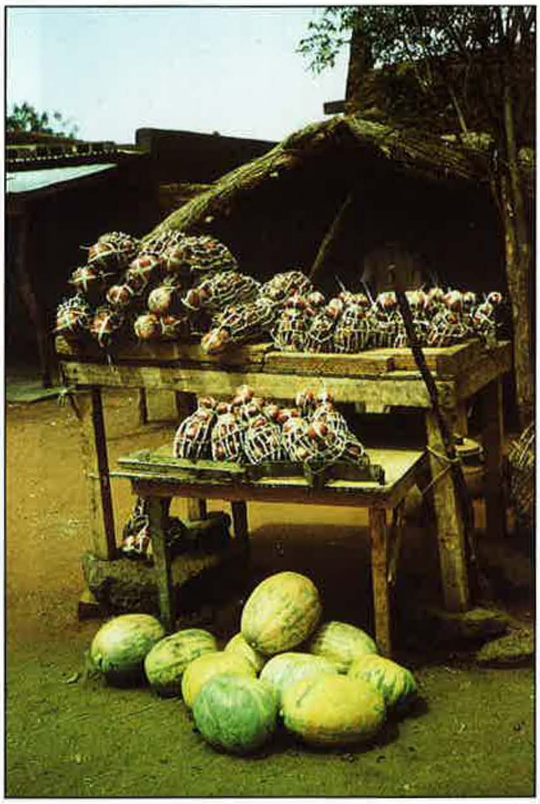
(F. J. PROCTOR)

Plate 18

Onions cut across the neck, Niger

(M. R. TURNER)

Plate 1



(M. R. TURNER)

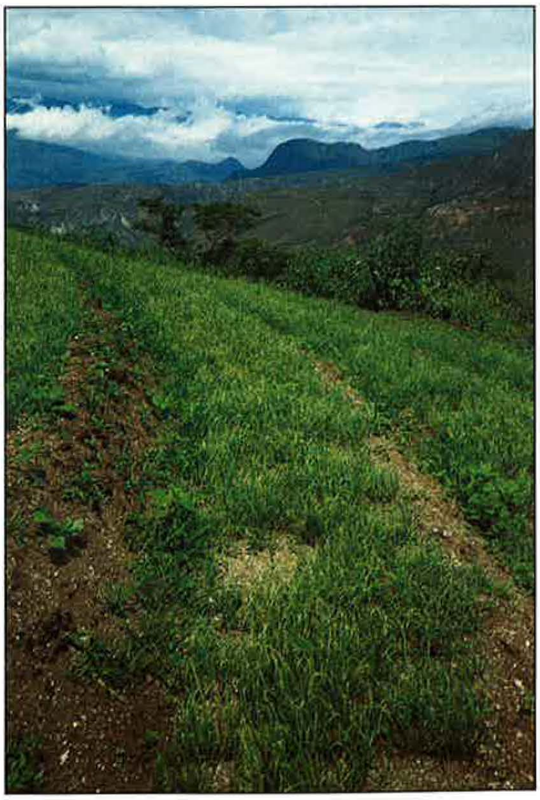
Onions packed for sale at roadside, Niger

Plate 2

(M. E. MONTERO MORA)

Onion strings in store in Costa Rica

Plate 3



(F. J. PROCTOR)

Onion seedlings in nursery beds, Ecuador

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Sorting multiplier onions at the market, Ecuador

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Mature onion crop, Côte d'Ivoire

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Protected plot for seed production, Niger

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(F. J. PROCTOR)

Black mould

Plate 16

(F. J. PROCTOR)

Double bulb

Plate 17

(F. J. PROCTOR)

Double and thick-necked onions, Ethiopia

Plate 18

(M. R. TURNER)

Onions cut across the neck, Niger

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
India–*continued*	28°N	27	Pusa Red	Red	Red/white	3	40-80	20-25	4-5	NC
			N-53	Red	Light red	3	40-80	15-20	1-2	DB
			N-2-4-1	Light red	Cream/white	2, 4	40-80	25-30	4	NC
			Bellery Red	Red	Light red	3	40-80	20	3	DB
			Punjab Selection	Red	White/red	4	40-80	20	1.5	NC
			Nasik Red	Red	Red	2	40-80	20	1.5-2.5	DB, TN
			Rose onion	Dark red	Red	3	<40	15	3-4	NC
			N-257-9-1	White	White	2	40-80	25-30	2-3	DB
	23°N	40	Pusa Red	Brown	–	1, 2, 3	40-80	25-30	3-6	DB
			Pusa Ratnar	Brown	–	1, 2, 3	40-80	25-30	3-6	DB
			N-53	Brown	–	1, 2, 3	40-80	25-30	3-6	DB
			Patna Red	Red	–	1, 2, 3	40-80	25-30	3-6	DB
			Nasik Red	Red	–	1, 2, 3	40-80	25-30	3-6	DB
			White Patna	White	–	1, 2, 3	40-80	25-30	3-6	DB
			Red Globe	Brown	–	1, 2, 3	40-80	25-30	3-6	DB
			Large Red	Brown	–	1, 2, 3	40-80	25-30	3-6	DB
	28°N	42	Agrifound Light Red	Light red	Red/white	2	40-80	25-30	4-5	NC
			Pusa Red	Light red	Red/white	2	40-80	20-25	4-5	NC
			N-2-4-1	Light red	Red/white	2	40-80	20-25	4-5	NC
			Agrifound Dark Red	Dark red	Red/white	2	40-80	20-25	2-3	NC
			N-53	Red	White/red	2	40-80	10-20	2-3	NC
	25°N	45	Pusa Red	Bronze	White	4	40-80	25-30	4	NC
			Nasik Red	Dark red	White	4	40-80	25-30	4	NC
			N-53	Dark red	White	4	40-80	20-25	4§	NC
	10°N	48	Bellary	Light red	Light pink	3	40-80	15-18	4	TN
			Shallot, Co. 1, Co. 2, Co. 3, Co. 4, Mov. 1 & Agrifound Red	Pink to brown	Light pink/white	V	<40	15-30	2-2.5	multiple† bulblets
	19°N	51	Red	Red	Red/white	1, 2, 3, 4	40-80	10	10	DB
			White	White	White	1, 2, 3, 4	40-80	10	10	DB
	23°N	55	Early Grano	Yellow	Yellow	4	>80	47.5	–	–
			Pusa Red	Red	Red	3	40-80	30	–	–
			Pusa Ratnar	Red	Red	5	>80	50	–	–
			Nasik Red	Red	Red	3	>80	30	–	–
			Patna Red	Red	Red	3	40-80	25	–	–
			N-404	Dark red	Red	2	40-80	20	–	–
			N-53	Scarlet	Red	–	–	19.7	–	–
			N-207-1	Red	Red	2	40-80	36	–	–

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Indonesia	8°S	65	Shallots (many)	Brown/purple	Light purple	5	<40	8-10	5	DB†
	8°S	70	Ampenan	Red	Red/white	5	<40	13-14	9	DB†
			Cloja	Red	Red/white	5	<40	10-15	9	DB
			Bima	Red	Red/white	5	<40	10-15	9	DB
			Bima Kuning	Red	Red/white	6	<40	10-15	9	DB
			Bauji	Red	Red/white	6	40-80	9-12	9	DB
			Balijo	Red	Red/white	4	>80	max 20	9	DB
			Suminep	Red/violet	White	7	<40	8-10	9	NC
			Bawang Lampung	–	–	–	–	–	–	–
			Betawi Cipanas	–	–	–	–	–	–	–
			Maja Kuning	–	–	–	–	–	–	–
Mauritius	20°S	37	Rouge local (Potiah)	Red/white	White	4	<40	5-10	2	NC
			Gatchi	Red	White	4, 5	<40	15-20	3	NC
			Rodrigues onions	Red	White	4, 5	<40	10-15	3	NC
			Red Creole	Red	Red/white	3	40-80	30-37.5	2	TN
			Yellow Texas and others	Yellow	White	1, 2	40-80	30-37.5	3	TN
Pakistan	33°N	1	Red Tunic	Red	Red	2, 9	40-80	20-25	3-4	NC
			Texas Early Grano	White	White	2, 9	40-80	20-22.5	3-4	NC
	34°N	46	Texas Early Grano	Red, yellow	Yellow	4	<40-80	4-5	–	TN
			Local White	White/brown	Red/white	2-5	<40	3-4	–	TN
	31°N	61	Phulkara	Red	White/red	4	40-80	25	2-3	NC
			Faisalabad Early	Red	White/red	4	40-80	30	3-4	NC
			Desi Early Red	Red	Red/white	4	40-80	25	2-3	–
Sri Lanka	6-10°N	56	Poona Red	Red	Red/white	3	40-80	15	1-2	NC
		57	Poona Red	Brown/red	White	3	40-80	10	1-3	NC
			Local Red (shallot)	Brown/red	White	6	<40	15	6-8	NC
			Vedala Vengayam	Brown/red	White	6	<40	15	6-8	NC
Thailand	18°N	18	Yellow Granex	Yellow/brown	White	3	40-80	–	4-5	–
Yemen (North)	12-17°N	49	Texas Early Yellow Grano	White/yellow	White	2	>80	54.3	1	NC
			Pusa Red	Brown	White	2	40-80	38.8	6	DB
			Red Creole	Red	White	2	40-80	–	6	NC
Yemen (South)	12-18°N	25	Bombay Red	Brown/red	White	3	40->80	19-28	3	DB, TN
			Red Creole (used green)	–	–	–	–	–	–	–
			Golden Creole (used green)	–	–	–	–	–	–	–
			Baftaim	Brown	White	4, 5	40->80	19-28	>6	NC

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Region—Caribbean										
Barbados	13°N	3	Golden F1	Yellow/brown	Yellow	3	40-80	17.5	N/A	TN
			Texas Early Grano 502	Yellow/brown	Yellow	5	40-80	17.5	N/A	TN
			Texas Yellow Grano	Yellow/brown	Yellow	5	40-80	17.5	N/A	TN
			Robust White F1	White	White	4	40-80	17.5	N/A	TN
			Granex F1	Yellow/brown	Yellow	2	40-80	25	N/A	TN
		4	Golden F1	Golden brown	White	1	40-80	17.5-25	1.5	NC
			Texas Yellow Grano	Yellow/brown	White	6	40-80	20-25	1.5	NC
			Granex F1	Brown	White	2	40-80	17.5-20	1	NC
			Texas Grano 502	Brown	White	5	40-80	20-25	1.5	NC
			Robust White F1	White	White	3	40-80	17.5-20	1.5	NC
Belize	16-18°N	36	Yellow Granex	Brown	Yellow	3	40-80	6.7	<1	NC
			Red Creole	Red	Red	2	40-80	7.8	2-3	DB, TN
Costa Rica	8-11°N	28	Yellow Bermuda	Yellow	Yellow/white	1	40-80	20	3	NC
			Granex	Yellow	Yellow/white	2, 3	40-80	30	1	TN
			Dessex	Yellow	White/yellow	3, 4	40-80	35	2	DB
Jamaica	18-19°N	10	Texas Early Grano	Yellow	White	5	40-80	12.5	2	DB, TN
			Red Creole	Red/purple	Purple	1	<40	10	3-6	DB, TN
			Granex F1	Yellow	White	4	<40	15	2	NC
			New Mexico Yellow Grano	Yellow	White	4	<40	10	2	NC
			New Mexico White Grano	White	White	2	<40	9	1	NC
			White Mexican/E1 Toro	White	White	1	<40	9	1	NC
Martinique	15°N	2	Yellow Granex	Yellow	White	1, 2	40-80	10-20	1	NC
Panama	7-9°N	72	Granex 33	Yellow	White	5	40-80	–	–	NC
			Granex 429	Yellow	White	5	40-80	–	–	NC
			Granex Yellow	Yellow	White	3	40-80	–	–	TN
			Dessex	Yellow	White	1	40-80	–	–	NC
			Texas Grano 502	Yellow	White	6	40-80	30	–	NC
			Red Granex	Red	Pink	5	40-80	28	–	TN
Region—South America										
Argentina (N)	25°S	29	Morada INTA	Red	Red/white	4, 5	40-80	20	4-5	DB
Brazil	23°S	24	Baia Periforme Precoce	Yellow	White	Pear	>80	10-20	4-5	NC
			Granex	Yellow	White	1	>80	>20	1	NC
			Pira Ouro	Yellow	White	4	>80	20	2	NC
			Texas Grano	Yellow	White	8, 9	>80	20	1	NC

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Brazil–*continued*	(whole country)	33	Granex F1	Yellow	White	1	>80	30	1	NC
			Baia Periforme	Yellow	White	6	40-80	20	4	NC
			Pera Norte	Brown	Reddish	1	40-80	10	6	NC
			Criola	Brown	Reddish	3	40-80	15	6	NC
			IPA-5	Yellow	White	5	40-80	15	2	NC
			Texas Grano	Yellow	White	9	>80	20	1	–
			Pira Ouro	Yellow	White	6	40-80	20	2	–
	9°S	35	Texas Grano 502	Yellow	White	9	>80	20	1	TN
			Pera Norte	Red	White	2	40-80	15	3	TN
			Baia Periforme	Orange	White	5	40-80	15-20	2	TN
	(whole country)	50	Granex 33	Yellow	White	2	>80	11-12	3	TN
			Texas Grano 502	Yellow	White	4	40-80	11	2	NC
			Baia Periforme and derivatives	Orange/greenish yellow	White	Pear	40-80	10	4-5	NC
			Norte-14	Orange/dark yellow	White	4	40-80	10-12	6	NC
			Jubileu	Orange/dark yellow	White	5, Pear	>80	15	5	NC
			Crioula	Orange/dark yellow	White	4, Pear	40->80	15	6	NC
Chile	33°S	30	Calderana or Copiapina	Light yellow	White	1, V	>80	40	N/A	NC
			Texas Grano 502	Yellow	White	8, 9	40-80	25	N/A	NC
			Torontina or Pascuina	Yellow	White	3, 4	>80	25	2	NC
			Valenciana	Yellow/brown	White	3, 4	40->80	30	5	–
Ecuador	1°S	39	Blanca	White	White	7	large	–	–	–
			Paiteña or Colorada	Red	Red/purple	2, 3	large	8.8	–	–
Venezuela	8°N	34	Texas Early Grano 502	Yellow	White	5	40-80	20	1	–
			Yellow Granex F1	Light yellow	White	2	40-80	25	1	–
			Excel 986 (Bermuda 986)	Cream/yellow	White	1	40-80	18	1	–
			New Mexico Yellow Grano	Yellow	White	2	40-80	25	1	DB, TN
			Islena Amarilla	Yellow	White	2	40-80	20	1	–
			Islena Roja	Red/pink	Red	2	40-80	20	1	DB, TN
			Red Burgundy	Red	Purple	4	40-80	18	2	–
			'Criolla'	Yellow, pink	White, red	7	40-80	8	2	–
	9°N	62	Texas Early Grano 502	Yellow	White	9	40-80	25-30	1.5	DB, TN
			Granex 33	Yellow	White	9	40-80	30	1.5	NC
			Granex 429	Yellow	White	9	40-80	30	1.5	NC

Country/territory	Latitude (approx)	Code	Variety	Skin colour	Flesh colour	Shape*	Size (mm)	Average yield (t/ha)	Expected storage (months)	Defects**
Region—Oceania										
Australia (NSW)	32°S	63	Early Lockyer White	White	White	3	40-80	25	1-2	NC
			Gladalan Brown	Brown	White	4	40-80	35-40	2-3	NC
			Early Creamgold	Yellow/brown	White	4	40-80	30	6-8	NC
			Creamgold	Yellow/brown	White	4	40-80	35	6-8	NC
			White Spanish	White	White	4	40-80	35	6-8	NC
			Golden Brown	Brown	White	4	40-80	25-30	2-3	NC
			Gladalan White	White	White	4	40-80	35	2-3	NC
			Torrens White	White	White	4	40-80	35	6	–
(QD)	27°S	38	Early Lockyer White	White	White	3, 4	40-80	25-30	1	NC
			Early Lockyer Brown	Brown	White	3, 4	40-80	25-30	1-2	NC
			Golden Brown	Golden brown	White	4	40-80	30	2	NC
			Gladalan White	White	White	3, 4	40-80	30	1	NC
			Gladalan Brown	Brown	White	3, 4	40-80	30	1	NC
Fiji	16-19°S	60	Superex	Brown	White	3	40-80	15	3	NC
			Tropi Red	Red	Red/white	6	40-80	15	4.5	NC
Hawaii	19-22°N	71	Texas Yellow Grano	Yellow	White	6	40->80	–	–	DB, TN
			Granex	Yellow	White	3, 4	40->80	–	–	DB, TN
Papua New Guinea	2-10°S	67	Gladalan Brown	Brown	Light yellow	4	40-80	15	0-2	TN
			Awahia	Purple	Purple/white	2	40-80	20	0-2	NC
			Superex	Brown	Light yellow	2	40-80	15	0-2	NC
Philippines	5-18°N	64	Red Globe	Red	Red	1, 2, 3	40-80	37	5	NC
			Red Creole	Red	Red	1, 2, 3	40-80	18	5	NC
			Yellow Granex	Yellow	White	4, 5	40-80	23	1	NC
			Shallot (local)	Red	Red	6	<40	15	8	DB†

Notes:

* Key to shapes: see NRI onion questionnaire, Appendix 1, p. 189

** Defects: DB = double bulbs
TN = thick-necked bulbs
B = bolting
NC = defects not common

§ Normally grown in Kharif season, expected storage time then – 7-10 days only

† Doubling is normal in shallots

‡ Entries coded 73 (Senegal) and 74 (Bangladesh) were received too late for inclusion in the analysis and are shown here for information only

Table 7

Summary of replies to questions 8 and 9 on sources of planting material and degree of bolting in the bulb crop

Country/ territory	Number of replies	Question 8. Source of planting material		Question 9. Does bolting occur in the bulb crop?
		Seed	Sets	
Côte d'Ivoire	1	L, I		S, N
Egypt	2	S, L	L	N
Ethiopia	1	S, L, I	S	S
Ghana	2	S, L, I		A, S
Israel	1	L	L	S
Kenya	2	I		S
Malawi	1	I	L	N
Mauritania	1	L, I		S
Niger	1	S, L	S	S
Nigeria	2	S, L	S, L	S
Senegal	1	S, L, I	S, L	S
Sierra Leone	1	I		N
Sudan	4	S, L	S	A, S, N
Swaziland	1	S I		N
Tanzania	1	S, L, I	S, L	A
Togo	1	I	L	N
Tunisia	1	S, L, I	S, L	A
Turkey	1	S, L, I	S	S
Zambia	2	L, I		S
Zimbabwe	1	I	S	S
Bangladesh	1	L		N
India	8	S, L	S, L	A, S, N
Indonesia	3	I	S, L, I	S
Mauritius	1	S I	S	A N
Pakistan	3	S, L, I	S, L	S
Sri Lanka	2	S I	L	S, N
Thailand	1	I		N
Yemen (North)	1	L, I		N
Yemen (South)	1	S I		A N
Barbados	2	I		N
Belize	1	I		N
Costa Rica	1	I	L	N
Jamaica	1	I		N
Martinique	1	I		N
Panama	1	I	S	N
Argentina	1	L		A
Brazil	4	S, L, I	S, L	A, S, N
Chile	1	S, L, I		S
Ecuador	1	S, L		N
Venezuela	2	I	S, L	S, N
Australia	2	S, L, I	L	S
Fiji	1	I		N
Hawaii	1	I		N
Papua New Guinea	1	L, I		N
Philippines	1	I	L	N

Key: For Question 8, S = Save their own, L = Locally produced, and I = Imported.
For Question 9, A = Always, S = Sometimes and N = Never/rarely.

Table 8

Replies to questions 10–12 on onion harvesting

Country/territory	Code number of informant	Question 10. At what stage are onions harvested?	Question 11. How are the onions dried?	Question 12. How long are the onions left to dry?
Côte d'Ivoire	59	F	a d	B C D
Egypt	11	H	a c e	D
	12	H	a e	D
Ethiopia	8	S H F	a b c e	A B C D
Ghana	7	F	e	D
	52	S	a	D
Israel	31	H	a c	B C
Kenya	21	F	e	D
	23	H	c	C
Malawi	58	H	g	D
Mauritania	44	H F	b c	A B
Niger	54	H	a c	D
Nigeria	5	F	b	D
	6	H	e	C
Senegal	68	H	a c	C D
Sierra Leone	53	H	g	C
Sudan	13	H F	c	B
	14	F	e	D
	15	F	a e	A
	16	S H	b	C
Swaziland	41	F	e	D
Tanzania	17	H	e g	B D
Togo	66	S F	c	D
Tunisia	47	F	a b g*	B
Turkey	26	S H	a	D
Zambia	19	S H	a d	D
	22	H	a d	C
Zimbabwe	20	H	a c f	D
Bangladesh	43	F	e g	B
India	9	S H	a	B
	27	F	a b c	D
	40	F	a	D
	42	F	a	C
	45	H	e	C
	48	H	e g	B D
	51	F	c	C
	55	H	c	C
Indonesia	65	H	a	D
	70	H	a f	D
Mauritius	37	H	b c	C
Pakistan	1	F	b c	B
	46	F	a g	C
	61	H	e	C
Sri Lanka	56	H	c e	B
	57	F	a c e	B
Thailand	18	S H	e	A C
Yemen (North)	49	F	a	D
Yemen (South)	25	F	a	B C D
Barbados	3	H	a	C D
	4	F	a	D
Belize	36	H	e	D
Costa Rica	28	S H	a c	C
Jamaica	10	H	e	D
Martinique	2	S H	e	A B
Panama	72	F	a	A
Argentina	29	H	e	C
Brazil	24	F	a b	D
	33	H	a b e	D
	35	H	a	D
	50	H	a c f g**	B
Chile	30	H	a	C
Ecuador	39	H	c d	B
Venezuela	34	H	a c	B
	62	F	a	A B
Australia	63	S F	c e f	B D
	38	H	e f	B
Fiji	60	H	e	D

Country/territory	Code number of informant	Question 10. At what stage are onions harvested?	Question 11. How are the onions dried?	Question 12. How long are the onions left to dry?
Hawaii	71	H	e	B C
Papua New Guinea	67	H F	e	A B C
Philippines	64	H	e	B

Notes: * Under covered shelters, sometimes with straw.
** (a) In the north-east (Pernambuco and Bahia); (c) In the south (Rio Grande do Sul and Santa Catarina); (f) Recently introduced in south Brazil.

Key: Question 10: S = with tops still standing; H = with tops half fallen; F = with tops completely fallen.
Question 11: a = in the field in rows; b = in the field but in piles, bags or boxes; c = in the field as in (a) or (b) and subsequently held in a ventilated covered place; d = in the field as in (a) or (b) and subsequently held in forced-air store; e = removed from the field immediately after harvest and held in ventilated covered place; f = removed from the field immediately after harvest and dried with forced air; g = other.
Question 12: A = <one day; B = 2–4 days; C = 5–6 days; D = longer than 8 days.

Table 9

Replies to questions 13–14 on onion storage

Country/territory	Code number of informant	Question 13. Who stores the onions (>2 weeks)?	Question 14. How are onions stored?
Côte d'Ivoire	59	F G	L B O(7)
Egypt	11	F G	L B T
	12	F R G	L B T
Ethiopia	8	F M R G O	L B O(8)
Ghana	7	F M R	B T
	52	R	T O
Israel	31	F M O(1)	L B O(9)
Kenya	23	F G	B
Malawi	58	F R	B
Mauritania	44	F M G	L B
Niger	54	F	L
Nigeria	5	F R	T O(10)
	6	F R	L
Senegal	68	F M	L B
Sierra Leone	53	F R	B T
Sudan	13	F M R O(2)	L B
	14	F	L
	15	F M R G	L B
	16	F	B
Swaziland	41	R O(3)	T
Tanzania	17	F M	L B
Togo	66	F	B
Tunisia	47	F G	L O(11)
Turkey	26	F	B T
Zambia	19	F	L
	22	F	L
Zimbabwe	20	F R	L
Bangladesh	43	F M R	L
India	9	F M G	L
	27	F M R G	L
	40	M	L
	42	F M	L B
	45	F M	L
	48	F M O(4)	L T O(12)
	51	F R G O(5)	B
	55	F M O(6)	L B
Indonesia	65	F M	B T
	70	F M R	T
Mauritius	37	F M G	L O(13)
Pakistan	1	F M R G	L B
	46	M	B
Sri Lanka	57	F M G	L B T O(14)

Country/territory	Code number of informant	Question 13. Who stores the onions (>2 weeks)?	Question 14. How are onions stored?
Thailand	18	F M	T
Yemen (North)	49	F M R G	B
Yemen (South)	25	F M G	B
Barbados	3	F M R	B
	4	M R	B
Belize	36	F	L T
Costa Rica	28	F	T
Jamaica	10	F R	L B
Martinique	2	R	
Panama	72	F	
Argentina	29	F	T
Brazil	24	F M R	B
	33	F M R	T O[15]
	35	F M	T
	50	F M	L B O[16]
Chile	30	F M	L
Ecuador	39	M	L
Venezuela	34	F M R	L B T
	62	M G	B
Australia	63	F M	O[17]
	38	F	O
Fiji	60	F M G	B
Hawaii	71	F	B
Papua New Guinea	67	–	L B
Philippines	64	F M R	B

Notes: Question 13. (1) Regional Council: Farmers' organisation. (2) Some consumers. (3) National Agricultural Marketing Board may store onions depending on rate of sales. (4) Government funded agencies. (5) Consumer. (6) Co-operative societies.
Question 14. (7) On ventilated shelves at the seed production station. (8) Bunches. (9) In bins. (10) Spreading of bulbs with alternative layers of dry straw or sand. (11) Or in layers with straw. (12) L: limited; T: for seed purposes; O: bulbs are stored in long ventilated thatched sheds of various dimensions depending on the quantity. (13) Long-term storage at Agricultural Marketing Board in crates. (14) On stakes (Bombay onion). (15) And on racks [used for bunches]. (16) Bunches (in farmers' stores). (17) Bulk crates (half tonne).

Key: Question 13: F=farmer; M=middleman; R=retailer; G=government; O=other.
Question 14: L=loose; B=in bags or sacks; T=tied in strings; O=other.

The national situation

Question 1. 'Does your country grow onions (*Allium cepa var. cepa*)?'

All 72 respondents answered: 55, that onions were of major importance; 17, of minor importance, and one (Malaysia), that onions are not grown. Onions were perceived as a minor crop in 16 countries: Ghana (1 of the 2 informants), Côte d'Ivoire, Malawi, Togo, Zambia, Zimbabwe, Indonesia (where shallots are of greater importance), Pakistan (1 of 3 informants, from Kashmir), Belize, Costa Rica ('of normal importance'), Martinique, Australia (Queensland), Fiji, Hawaii, Papua New Guinea and the Philippines. All the answers are given in column 3 of Table 3 (*see* pp. 101-2).

Question 2. 'Does your country store (i.e. hold between harvest and consumption) home-grown onions at any stage in the post-harvest chain? (*see* also question 13)'

A total of 67 respondents answered this question.

'Yes – always' – 37 respondents;

'yes – under certain circumstances' – 25 respondents, and

'no' – 6 respondents.

In 26 countries onions are always stored. Six countries from which came answers that home-grown onions were never stored were Kenya (1 out of 2 replies, i.e. ½), Togo, Indonesia (⅓), Sri Lanka (½), Barbados (½) and Martinique. Details are shown in Table 3, column 4 (*see* pp. 101-2).

Question 3. 'Does your country import from other countries?'

Twenty-four (24) respondents answered 'yes – every year', 11 'yes – in certain years' and 38, 'no'. All 72 respondents answered the question. The answers given are in Table 3, column 5 (*see* pp. 101-2).

Countries and territories which import onions every year were 21 in number: Ghana, Côte d'Ivoire, Mauritania, Senegal, Sierra Leone, Swaziland, Togo, Tunisia, Indonesia (⅓), Malaysia, Mauritius, Sri Lanka, Yemen (South), Barbados, Belize, Martinique, Panama, Australia (QD), Fiji, Hawaii and Papua New Guinea. This list may be compared with the FAO trade figures in Table 2 (*see* p. 21), which show that many other tropical countries also imported onions in 1987.

The 20 countries/territories which answered that onions are never imported were: Egypt, Ethiopia, Israel, Kenya, Malawi, Niger, Nigeria, Sudan, Tanzania, Turkey, Zambia (½), Zimbabwe, India, Indonesia (⅓), Yemen (North), Venezuela (½), Argentina, Brazil, Australia (New South Wales) and the Philippines. Some of these countries are in fact major exporters of onions (e.g. India, Egypt, Turkey): *see* Table 2 (FAO trade figures) (p. 21).

The 10 countries from which came replies that onions are imported in certain years were Zambia (½), Bangladesh, Indonesia (⅓), Pakistan, Thailand, Costa Rica, Jamaica, Venezuela (½) and Australia (QD). (It should be noted that some countries and territories function as trading centres for onions: for example, Singapore (*see* Table 2); while others have a seasonal export trade and may also import onions when there is a deficiency in the national supply: e.g. Pakistan).

The differing answers from Indonesia to Question 3 were due to the fact that one correspondent was referring to bulb onions only, which are imported every year, and two to shallots (imported to a limited extent, or not imported, according to the view taken).

Question 4. 'Are your imported onions stored between arrival in your country and consumption?'

Of 69 respondents, 38 answered 'not applicable', and of the remainder, 8 answered 'yes – always', 16 'yes – in certain circumstances', and 11 'no'.

The 7 countries and territories replying that imported onions were always stored after arrival were Senegal, Sri Lanka (½), Yemen (South), Barbados, Martinique, Fiji and Papua New Guinea.

Fourteen countries answered that imported onions are sometimes stored, and 9 that they are not stored after importation. The information is shown in column 6 of Table 3, pp. 101-2.

Seasons when onions are grown

Question 5. 'How many onion crops are grown per year in your country?'

The complete range of answers received to Questions 5 and 6 is given in Table 4 (*see* pp. 103-4). In this and other tables, the answers from individual informants are indicated by a code number which is shown beside the name and country of the person concerned in Appendix 2, and also together with the address of the informant in Appendix 3.

Sixty-nine (69) answers were received to this question; 'one crop': 27 answers; 'two crops': 36 answers; 'continuous': 18 answers. More than one answer was given by several respondents, in cases where the situation varies in different production areas of the same country. In Mauritania, for example, two crops per year are grown near the coast, and one in inland areas.

Twenty-three (23) countries reported that one crop per year is grown. These countries were varied; in some, onions are grown as a rain-fed crop in winter (e.g. Tunisia, Turkey) while in others, the cool season is dry and onions are grown then under irrigation (e.g. Niger).

The 22 countries where two crops are grown, at least in some regions, are Egypt, Kenya (½), Mauritania (coastal belt), Niger, Nigeria, Senegal, Sudan (¾), Zambia, Zimbabwe, India (⅞), Indonesia (⅓), Mauritius, Pakistan (⅔), Yemen (North), Yemen (South), Barbados (½), Costa Rica, Jamaica, Panama, Brazil (¾), Chile and Ecuador. Many of these countries grow one winter season crop for storage and another rain-fed crop which is consumed straight away (Rabi and Kharif crops respectively in India). In several cases, the answer 'one season' was given to Question 5 but two seasons of production were noted in answer to Question 6. In these cases, different production regions may have been referred to.

In 13 countries, at least some regions exist with continuous onion production: Ethiopia, Ghana, Israel (3 separate seasons noted), Kenya (½), Tanzania, Togo, India (⅜), Indonesia (⅔, referring to shallots), Sri Lanka (½), Barbados (½), Venezuela (at low altitudes), Brazil (NE) and Hawaii. Many of these countries are quite close to the equator. Israel is exceptional in that a range of onions of different day-length responses can be grown there at the appropriate seasons.

Question 6. 'In the production region(s) what is the approximate crop season? (Write in name of month(s))'

Planting dates and harvest dates were requested, under 'Major crop or area 1' and 'Minor crop or area 2'. Sixty-seven (67) replies were received to this question, showing in general that the drier part of the year is used for growing the major onion crop in most countries of the tropics, with the minor crop being grown in the warmer, wetter season, though this pattern was not invariably followed. In some cases, the areas were defined, in others it was not obvious whether different areas or different seasons were referred to. The seasons given are shown in Table 4, columns 4-6, pp. 103-4.

The cultivars grown and their characteristics

Question 7 was headed **'Local onion production'** and was presented as the framework of a table, with additional notes which defined the type of data needed in the different columns (see questionnaire, Appendix 1, p. 185). Information was requested on the cultivars of onion grown, the approximate percentage of the national crop which each named cultivar represented, the skin and flesh colours of the bulbs, the shape (making use of the key in the questionnaire, *see* Appendix 1, p. 189), the size, using three diameter classes, the approximate average yield when grown under typical conditions of the informant's country, and the usual storage life of the variety (in months) when stored under ambient conditions. Correspondents were asked to note whether the defects doubled bulbs (DB) or thick necks (TN), or both, were common in the varieties. Where bolting was noted as a defect, this is shown in Table 6 (*see* pp. 111-19).

The names of the cultivars and the percentage of national production which they were estimated to represent are shown in Table 5 (*see* pp. 105-10), together with the code number and name or names of the informants. No attempt was made to produce country lists by amalgamating replies from different correspondents here. Considerable differences within some countries will be noted, which may reflect regional differences in the range of cultivars grown, while in others the different answers expressed may simply show how judgements of the same situation can vary between individuals with different viewpoints. The details of the characteristics of the cultivars are given in Table 6, where they are listed alphabetically by country under regional groups (*see* pp. 111-19).

The geographical distribution of different types of onion cultivars grown in the tropics will be discussed later in this section, with particular reference to their storage behaviour as shown in Table 6.

The responses to Questions 8 and 9 on sources of seed and planting material, and frequency of bolting in the bulb crop, are given in Table 7, where the replies are amalgamated under country headings (*see* p. 120).

Sources of seed and planting material, and degrees of bolting

Question 8. 'Where do farmers obtain their planting material?'

This information was requested under the headings 'Onion seed' and 'Onion set' (sets are small dry bulbs specially produced for growing on into saleable bulbs at later seasons, but were sometimes also used to refer to shallot propagating material). The options offered for the replies were: 'save their own', 'locally produced', 'imported' and 'other'. Seventy-one (71) respondents answered the question. Many indicated that planting material is obtained from several different sources. In some cases, the geographical source of the varieties used can be guessed through the names of the cultivars listed previously in Tables 5 and 6. The replies given are shown in columns 3 and 4 of Table 7, (*see* p. 120).

For onion seed, the total numbers of answers were: 'save their own', 27; 'locally produced', 42; 'imported', 46; 'other', nil.

For onion sets, the total replies were: 'save their own', 22; 'locally produced', 22; 'imported', 2 (referring to shallots in Indonesia only); 'other', 1 (referring to the production of sets in Australia in other states and supplied to Queensland).

Some interesting regional differences appeared in the replies to this question. All the countries of the Caribbean region (including Venezuela), for example, used imported seed exclusively, though sets were grown locally in some. All of the South American countries from which replies were received (with the exception of Venezuela) obtained some onion seed locally and also reported the importation of seed. (Later information received from Ecuador confirmed that seed of the Texas Early Grano type is now being used there: Yepez, personal communication). Onion seed is not usually imported by the large Asian countries, India and Bangladesh, though the islands of Mauritius and Sri Lanka, and the continental countries of Pakistan, Thailand, Yemen (North) and Yemen (South), all use imported onion seed, and so does Indonesia (⅓). (Further information from Indonesia is that in the highland regions, onion seed from Israel and the USA is now being grown on an increasing scale (Hadi, personal communication)). In the Africa/Mediterranean group, the countries of Egypt, Israel, Niger, Nigeria and Sudan reported no importation of seed, but Kenya, Sierra Leone, Togo, Zambia (½) and Zimbabwe did not mention local onion seed production. (Onion seed, cvs. Texas Grano and Pusa Red, is, however, produced in Zambia (Mathai, personal communication)).

Farmers were reported to save their own onion seed in 21 countries, and to raise their own sets in 17. Sets were raised locally in 15 countries.

Question 9. 'Is it common for the bulb crop to produce flowers and seeds?'

The total answers to this were: 'always', 10; 'sometimes', 36; and 'never/ rarely', 29. Seventy (70) respondents replied to the question, some distinguishing between imported varieties which did not bolt, and local ones which did (e.g. Mauritius). All the replies have been amalgamated into column 5, Table 7 (*see* p. 120).

The 10 countries where flowering in the bulb crop was always reported to occur were Ghana (½), Sudan (¼), Tanzania, Tunisia, Bangladesh, India (⅛), Mauritius (local cvs.), Yemen (South), Argentina and north-eastern Brazil.

The 26 countries or areas where bolting was reported never or rarely to be a problem were: Côte d'Ivoire (certain onion crops), Egypt, Malawi, Sierra Leone, Sudan (¼), Swaziland, Togo, India (2/8), Indonesia (⅓), Mauritius (imported cvs.), Sri Lanka (½), Thailand, Yemen (North), Yemen (South) (some crops), Barbados, Belize, Costa Rica, Jamaica, Martinique, Venezuela (½), Brazil (some areas and crops), Ecuador, Fiji, Hawaii, Papua New Guinea and Philippines. The striking lack of bolting in onions grown in the Caribbean area is probably associated with the extensive use there of the imported yellow Grano and Granex varieties (see Tables 5 and 6). The areas which reported bolting 'always' or 'sometimes' include most of the African and Asian onion-producing countries where locally developed cultivars are grown (excluding Egypt). The islands of Oceania also returned answers which indicated that bolting rarely or never occurred. Another possible explanation of these and the Caribbean results may therefore be that island climates do not have sufficient seasonal temperature variation to permit onion bulb vernalization, whereas continental climates may have sufficient cool nights to allow bolting in tropically adapted onions (*see* Chapter 6).

Methods of harvesting, drying and storing onions

The next three questions refer to methods of harvesting and drying onions, and individual answers are in Table 8 (*see* pp. 121-2).

Question 10. 'At what stage are the onions harvested?'

Total answers were: 'with tops still standing': 11

'with tops half fallen': 44

'with tops completely fallen': 29.

There were 70 replies, some of which gave more than one answer, for example, that some early crops were harvested while the tops were still upright, and others with the tops wholly or partially fallen, particularly if the onions were intended for storage. Countries reporting harvest of at least some crops while the tops are still upright were Ethiopia, Ghana (½), Sudan (¼), Togo, Turkey, Zambia (½), India (⅛), Thailand, Costa Rica, Martinique, and Australia (NSW): some of these informants explained that the early crop is harvested before maturity because of high demand at that time. In some countries, such as Togo, half of the onion crop is reportedly consumed as green onions. The other countries reported harvesting when the onion leaves are somewhat, or completely, fallen. Each informant's answer is shown in column 3 of Table 8 (*see* pp. 121-2).

Question 11. 'How are the onions dried?'

Seven options are given here. Many informants replied that more than one drying method was used in their country, or that the early crop was not dried for long, but that the crop for storage was dried for several days. Total replies were as follows: thirty-four (34), dried in the field in rows (i.e. windrowing); 11, in the field but in piles, bags or boxes; 22, in the field followed by holding in a ventilated covered place; 4, in the field followed by holding in a store with forced air; 28, removed the onions from the field immediately after harvest and held them in a ventilated covered place; 5, removed them from the field immediately after harvest and dried them with forced air; and 8, described other methods of drying, some of which involved drying in the sun by day and removing the onions to a protected place at night (e.g. Malawi); and others, drying under the shade of trees (e.g. Bangladesh).

The four countries reporting some forced-air drying with temperature control were Zimbabwe, Indonesia (⅓), Brazil (¼) and Australia (NSW and QD). The individual replies are shown in column 4 of Table 8, with notes where further information was supplied (*see* pp. 121-2).

Question 12. 'For what period of time are the onions left to dry before storage or marketing?'

The options provided here ranged from less than 1 day to more than 8 days. The answers received from 70 respondents were as follows:

'less than one day', 8;

'2-4 days', 24;

'5-6 days', 24; and

'longer than 8 days', 34.

The countries reporting a very short drying time usually also showed another option, suggesting that only when market demand justified haste, were the onions dried so little before sale. Individual answers are given in column 5 of Table 8 (*see* pp. 121-2).

The next two questions dealt with who stores onions and the methods used for storage, in terms of the physical arrangement of the bulbs. The results are given in Table 9 and the notes to the table (*see* pp. 122-3).

Question 13. 'Who stores the onions? If more than one type of person, please indicate. By storage we mean more than a time of 2 weeks.'

This question was answered by 67 respondents. The regional replies are shown in Table 10 below.

Table 10

Participants in the onion storage and marketing system, classified by region

	Africa	Asia	Caribbean, S. America and Oceania
Farmer	25	16	17
Middleman	8	18	13
Retailer	12	6	8
Government	8	8	0
Other	4	3	1

The agents mentioned in the 'other' category were principally marketing boards (Mauritius, Swaziland, Venezuela) and co-operatives (*see* notes to Table 9, p. 123). There was comparatively more storage by farmers and less by middlemen in Africa compared with Asia, and in Central and South America several informants mentioned that supermarket chains store onions, and in some cases (e.g. Panama) that substantial storage losses can occur there. The complete replies are shown in Table 9, column 3 (*see* pp. 122-3).

Question 14. 'Are onions usually stored?'

This question was intended to be, 'How are onions usually stored?', and went on to give several possible storage options. The total responses from the 66 informants who replied were:

loose: 35;

in bags or sacks: 38;

tied in strings: 19; and

other: 13.

Many informants indicated that more than one type of onion storage method is used in their country (see column 4, Table 9). The methods noted under the heading 'Other' are given in the notes to Table 9, (*see* p. 123).

Onion stores and the need for improvements

Questions 15-17 asked about onion stores, their construction, capacity and degree of environmental control. The term 'purpose-made stores' in question 15 was taken by some respondents to refer to technically advanced stores, while by others it was taken to refer to any kind of store used particularly to house onions. The options presented for the answers in this question were also somewhat ambiguous. Some of the interesting structures described in answer to this set of questions will therefore be quoted directly later under the heading 'Onion storage structures in tropical countries', (*see* p. 140) while the total numbers of responses only are given here.

Question 15. 'Are there purpose-made stores for the storage of onion in your country?'

To this, 68 informants replied. Twenty-two (22) answered 'yes'; 32, 'no'; and 18, 'some'. Some informants entered more than one answer, mainly from countries where a few controlled temperature stores exist but where most farmers still use the local traditional storage methods.

Question 16. 'If *No* to question *14*' (i.e. *15*, and so altered in the 1988 questionnaires), **'describe how the onions are stored'.**

Thirty-three (33) replies were given here; some respondents also supplied further information in answer to question 17.

Question 17. 'If *Yes* to question *14*' (i.e. *15*), **'describe the store'.**

Thirty-three (33) replies were given here, and up to 41 answers were supplied to the questions on store capacity, building materials and ventilation. Question 17 concluded by asking whether the onion stores were temperature and humidity controlled, to which the overwhelming answer was 'no' in both cases. The figures were: temperature controlled, 7; not controlled, 45; (don't know, 2); relative humidity controlled, 3; not controlled, 46; (don't know, 4). Temperature controlled stores were reported from Zambia (½), Zimbabwe, Mauritius, Panama, Venezuela (½), Brazil (¼) and Hawaii, with humidity control in some stores in Mauritius, Panama and Venezuela only.

Questions 18 to 20 asked for information and judgements about the perceived need for improvements in 'seed quality', 'storage of onion', and on the amounts and causes of onion loss in store.

Question 18. 'Do you consider that there is a need in your country to:

improve the quality of seed' (Answers: yes, 56; no, 11)

'improve the storage of onion' (Answers: yes, 63; no, 5)

In each case, those giving the answer 'Yes' were asked why there was such a need. Fifty (50) responded to the 'seed' question, and 60 to the 'storage' question with comments.

The reasons given for needing seed improvements were chiefly technical, having to do with the quality of the seed itself (low purity, poor germination) rather than qualitative, though many respondents mentioned the need for varieties with better yield, and in some cases the need for varieties with improved storage ability was emphasized. Other respondents who answered were satisfied with seed quality, even though most of the varieties grown in their country might be those with naturally low storage qualities; there were therefore differences in the interpretation of the meaning and scope of this question. Broken down into greater detail, needs for improved quality characters (including higher yield, longer storage and disease resistance or tolerance) were mentioned by 28 informants; for greater seed purity and uniformity of cultivars by 12 informants; better germination of the seed by 9; freedom from bolting in the cultivars grown by 4; better seed availability or seed industry organization by 4; and improved packaging by one respondent. A requirement for better handling of imported seed within the country was mentioned from Costa Rica, and for better maintenance of seed viability of imported seed within the country, from Thailand. A correspondent from Venezuela commented on the need to break dependency on imported onion seed. Correspondents from Turkey, Egypt and India mentioned the need for improvements in the quality of onion varieties for export.

The reasons given for needing improved storage were overwhelmingly concerned with the reduction of storage losses (40), which were often stated to be heavy. Fifteen respondents also mentioned that better storage technology is needed to extend the marketing period for onions in order to improve the returns from the crop. The need for greater self-sufficiency in onion supply was noted by 9 informants, and the desirability of reducing onion price fluctuations by 6. Two correspondents mentioned the need to improve onion storage to help seed production, in answering this question.

The next two questions, 19 and 20, dealt with the amount and causes of storage loss in onions. Individual informants' replies to both questions are given in Table 11 (*see* pp. 131-2).

Levels and causes of onion storage losses

Question 19. 'Do you consider that you have high levels of post-harvest loss of locally produced onion?'

Overall total answers were: 'yes', 44; 'no', 10; 'sometimes', 18.

The 8 countries giving 'no' answers were Ghana, Malawi, Togo, Zambia, Indonesia (⅓), Ecuador, Fiji and Papua New Guinea. (Some of these correspondents had already stated that little storage takes place in their countries: see Table 3). Most of the Asian respondents (19 out of 21) stated that onion storage losses were high, while answers from the African/Mediterranean group were more mixed (14 high; 6 not high; 9 sometimes high), with a greater proportion of answers in the 'sometimes' group. Details can be found in column 3 of Table 11 (*see* pp. 131-2).

Question 20. 'What are the main technical factors which limit storage?'

This question was answered by 69 respondents.

The 'other' category included economic reasons, for example the expense of buying disease and pest control chemicals. Full details are shown in Table 11, columns 4 to 7, with additional notes where the 'Other' category was used (*see* pp. 131-2).

Table 11

Replies to questions 19 and 20. Storage losses and their principle causes

Country/territory	Code number of informant	Question 19. Are there high levels of loss in locally produced onions?	Question 20. What are the chief technical factors which limit storage? Disease	Sprouting	Rooting	Shrivelling	Other
Côte d'Ivoire	59	Y					(10)
Egypt	11	Y	S	S			(11)
	12	Y	A	R	N	R	
Ethiopia	8	Y (1)	A	A		A	
Ghana	7	N					
	52	N	S	A	A		(12)
Israel	31	S (2)	S	S	R	S	
Kenya	21	N	S	S	R	S	
	23	S	A	S	R	S	
Malawi	58	N (3)	A	S	S	R	
Mauritania	44	S	S	R	R	R	
Niger	54	Y	A	S		A	
Nigeria	5	Y	A	A	R	S	
	6	S	A	S	R	S	
Senegal	68	Y	A	A	R	A	
Sierra Leone	53	Y	A	S		S	
Sudan	13	Y	A	S	S	A	
	14	Y	S	S	N	A	
	15	S	S	R	R	S	
	16	Y	A	S	N	A	
Swaziland	41	Y	A	S	N	S	
Tanzania	17	S	S	S	S	A	
Togo	66	N	S				
Tunisia	47	S	A	S	S	R	
Turkey	26	Y	S	A	S	R	
Zambia	19	N (4)	S	R	R	A	(13)
	22	Y, N (5)	A	S	S	A	
Zimbabwe	20	S	A	A			(14)
Bangladesh	43	Y	A	A	S	A	
India	9	Y	A	A	A	A	(15)
	27	Y	S	S	A	A	
	40	Y	R	A	R	R	
	42	Y	S	S	R	A	
	45	Y	S	A	N	A	
	48	Y	A	A	S	A	
	51	Y	A	S	N	S	
	55	Y	A	A	R	A	
Indonesia	65	N	S	A	A	S	
	69	Y	S	S		R	
	70	S	S	A	S	A	
Mauritius	37	Y	A	A	A	S	(16)
Pakistan	1	Y	A	A	R	R	
	46	Y	S	A	S	R	
	61	Y	S	A		A	
Sri Lanka	56	Y	A	R	N	S	
	57	Y	A	R	R	A	
Thailand	18	Y	A	A			(17)
Yemen (North)	49	Y	A	A			
Yemen (South)	25	Y	A	A	R	A	
Barbados	3	S (6)	A	A		A	(18)
	4	Y	S	S			
Belize	36	Y	A	A	N	S	
Costa Rica	28	S	S	A	R	A	
Jamaica	10	S	A	S	R	R	
Martinique	2	Y	A				(19)
Panama	72	Y	A	A	A		(20)
Argentina	29	Y	A	A	A	R	(21)
Brazil	24	S	S	S	S	R	(22)
	33	S (7)	A	R	R	N	(23)
	35	Y	A	R	R	N	
	50	Y	A	R	R	S	(24)
Chile	30	Y	S	A	S		
Ecuador	39	N		S			

Country/territory	Code number of informant	Question 19. Are there high levels of loss in locally produced onions?	Question 20. What are the chief technical factors which limit storage? Disease	Sprouting	Rooting	Shrivelling	Other
Venezuela	34	Y	S	A	S		
	62	S (8)	R	A	A		(25)
Australia (NSW	63	S	S	S	R	S	
QD)	38	S (9)	A	S			
Fiji	60	N	A	S	N	R	
Hawaii	71	Y	A				
Papua New Guinea	67	N		S			(26)
Philippines	64	Y	R	A	N	R	

Key: Question 19: Y = yes; N = no; S = sometimes.
Question 20. A = always; S = sometimes;
R = rarely; N = never.

Notes: Reply No. 65, from Indonesia, refers to shallots only.

(1) Depends on type of storage, harvest maturity and storage duration. Shallots store better under some circumstances than onion.
(2) 'Sometimes': depends on cultivar and on handling. When cv Ben Shemen or any of the F1 hybrids are stored in well ventilated shade, losses are minimal.
(3) 'No': because most of the crop is sold or consumed without much storage.
(4) 'No': we are subject to many power failures which does have an effect, also rain or hail damage in October.
(5) 'Yes': when you consider it from the point of view of small producers. 'No': when from point of view of large-scale producers who can afford to build modern storage facilities.
(6) 'Sometimes': this occurs when acreages exceed that required to supply the demand.
(7) 'Sometimes': losses may be due to continuous rain during harvest.
(8) Approximately 20% losses in storage.
(9) If stored, white onions can suffer from high losses.
(10) For the first 4 months, cv Violet de Galmi can be stored without trouble. After that, the bulbs sprout, the roots develop, and the bulb then becomes very susceptible to disease.
(11) The handling is bad.
(12) Chemicals like Roxion, Cymbush etc. are quite costly for the onion farmers. Thus, they are not able to effectively control the spread of diseases which occasionally affect their produce.
(13) Dehydration under hot store conditions.
(14) Growing practices affect onions at lifting and subsequently quality during storage.
(15) Non-availability of onion variety suitable for long storage of 5-6 months.
(16) 1. Lack of know-how in storage. 2. High rainfall, therefore humidity during storage period and no means of keeping stores dry especially when stored at ambient temperature, 70° F [21° C].
(17) Hot and humid conditions during the rainy season cause storage problems in onion. Generally the stored onions rot or sprout.
(18) Variety, lack of controlled storage conditions.
(19) Climate during the growing season very rainy.
(20) Dealing with crop disease and post-harvest management, including training (see Part II, p. 143).
(21) Insects (flies).
(22) There is a Brazilian onion disease named 'mal-das-sete-voltas' – onion anthracnose – which may cause post-harvest losses in stored bulb onions.
(23) Answers to Q 20 refer to cvs Criola and Pera Norte, the best Brazilian cvs for storage.
(24) High levels of inflation, decapitalization of the producer, organization of the system of production/commercialization.
(25) The use of varieties with short storage life.
(26) Sprouting of imported onions (sometimes).

Table 12

Overall totals in different classes, Question 20

	Always	Sometimes	Rarely	Never
Disease	37	26	3	0
Sprouting	29	28	9	0
Rooting	8	13	21	10
Shrivelling	22	14	15	2
Other 12				

Table 13

Overall totals in different classes, Question 21

	Yes	No	Don't know
Shallots (*Allium cepa* L. var *aggregatum*)	29	22	5
Bunching onion (*A. fistulosum*)	18	7	5
Garlic (*A. sativum*)	53	11	3
Leek (*A. ampeloprasum*)	25	24	6
Chive (*A. schoenoprasum*)	8	27	13

Table 14

Replies to question 21. Allium crops other than bulb onions grown on a commercial scale

Country/territory	Shallots	Bunching onion	Garlic	Leek	Chives
Côte d'Ivoire	*			*	
Egypt			*	*	
Ethiopia	*		*	*	
Ghana	*	*			
Israel			*		
Kenya	*		*	*	*
Malawi	*				
Mauritania				*	
Niger			*		
Nigeria			*		
Senegal	*		*	*	
Sierra Leone	*	*			
Sudan		*	*		
Tanzania			*		
Tunisia		*	*		
Turkey		*	*		
Zambia		*	*		
Zimbabwe		*	*	*	
Bangladesh			*		
India	*	*	*	*	
Indonesia	*	*	*	*	*(1)
Mauritius	*		*	*	
Pakistan	*	*	*		
Sri Lanka	*		*	*	
Thailand	*	*	*		
Yemen (North)			*	*	
Yemen (South)			*	*	
Barbados	*				
Belize	*				
Costa Rica			*		
Jamaica					*
Martinique					*
Argentina		*	*		
Brazil	*	*	*	*	*
Chile			*		
Venezuela	*	*	*	*	*
Australia	*	*	*		
Fiji			*		
Papua New Guinea		*	*	*	
Philippines	*		*		

Notes: Countries from which no answers were returned are omitted. Positive answers only are included.

(1) In Indonesia, chinese chives (*A. tuberosum*) and rakkyo (*A. chinense*) are also grown.

Other *Allium* crops grown commercially

The last question on cropping concerned other *Allium* crops that were grown commercially. Total answers in each category are shown in Table 13 and the amalgamated positive answers are given in Table 14.

In Indonesia, Chinese chives (*A. tuberosum*) and rakkyo (*A. chinense*) are also grown. It is possible that the 'bunching onion' category caused some confusion, as it is not always recognized that *A. fistulosum*, the Japanese bunching onion, is a different species from *A. cepa*, the bulb onion, which can also be grown for bunching or salad onions. A large number of replies mentioned garlic. Shallots and leeks were each mentioned a similar number of times, but their regional distribution was different. Chives are not often grown as a commercial crop even in temperate countries, though herb production was mentioned in Australia.

Information on current onion research

The final four questions were requests for information on onion research, for copies of reports of onion work and for any further comments.

Question 22. 'Do you know of any onion variety trials, selection or breeding programmes, currently in progress in your country? If so please give details of objectives and/or contact addresses.'

66 responses were received from 42 countries.

Question 23. 'Do you know of any research and development work in progress on post-harvest handling and storage of bulb onions in your country? Please give details and/or contact addresses.'

50 responses were received from 31 countries.

Question 24. 'TDRI [now NRI] would appreciate receiving copies of reports/papers/information on onion production, storage and marketing relevant to your country. If you can supply us with such copies thank you. If you cannot provide papers please write the reference details below.'

46 responses were received on the questionnaires from 29 countries, as well as many copies of extension literature, research reports and theses dealing with onion storage. Some of the extension publications are listed in Appendix 4.

Comments from informants

Question 25. 'Please make any further comments you consider important below.'

41 responses were received in questionnaires from 29 countries, as well as several in letters accompanying them. The comments were interesting and varied, and some of them will now be quoted, as they provide direct insight into the problems of onion production and storage in tropical countries, and indicate where those working there feel that research and development are needed.

'The main problem with storage is that in our country, yellow varieties of onion are preferred (Granex type) which have little storage ability (short-day type), and there is no good selection in the field to eliminate damaged bulbs' (Venezuela)

'Better keepability and better storage facilities would be much in favour of the farmer . . . A severe problem however is want of money and (frequently) debts so that farmers have to sell directly after harvest' (Indonesia)

'In Kenya, onions are not really held at any point after harvest, before consumption, for more than 2 weeks. The farmers almost always sell their crop immediately after curing, at the local market, or to the Horticultural Crops Development Authority (HCDA), a governmental parastatal organization which has the mandate to market onions in the country. The HCDA hold the onions briefly (usually less than 2 weeks) in a warehouse stacked on pallets in plastic netbags' (Kenya)

'We have a breeding project [on] tropical onion. To produce onion at lower latitude, the cultivar has to be of short dormancy bulb, to respond [to] nitrogen dressing to overcome high temperature, but steady 12-hour [day-length] all year round. In tropical region[s], it is possible to grow onion all year round, with appropriate short-day variet[ies]. So storage problem[s] can be minimized, if you compare with one harvest per year, with the long-day onion in temperate zone[s]' (Brazil)

'Thrips and purple blotch (*Alternaria* sp.) are the major problems in the field. On the other hand, rotting (caused by *Penicillium* and *Aspergillus*) and sprouting account for substantial deterioration in the bulbs in storage, rendering them unsuitable for consumption. In addition, black moulds and greening are also noticed in white onions' (Maharashtra, India)

'The future is for production of onion for export, especially for Gulf. There is a need for the improvement of storage qualities of onion. Research on storage and post-harvest handling need some support and technical assistance and training' (Sudan)

'All our seed is imported from [the Republic of] South Africa or [the] USA. Cultivars grown [are] well tested for agronomic characteristics, yield, quality and storage life in Zimbabwe. Mostly hybrids, but open-pollinated Texas Grano and Hojem grown by peasant farmers' (Zimbabwe)

'Onion is a major vegetable crop in Zambia. The country requires short-day, heat tolerant cultivars. Such cultivars are nearly impossible to find' (Zambia)

'Onion production is extremely limited in Belize at the moment. No more than 10 acres per year. Major constraints to increased production are control of purple blotch disease (*Alternaria porri*) and storage. Seed quality is good but there is a need to identify suitable varieties for our conditions. Only low technology storage is considered relevant. No fungicides or sprout inhibitors are used at present. Information on the former would be appreciated' (Belize)

'(a) Genetic material of better storing short-day onion should be exchanged between leading institutes carrying out research on onion in tropical and subtropical/temperate regions.

(b) There is a need to give greater emphasis on improvement of the local onion storage structures by reducing the loading height or provision of forced ventilation as also some ways to be devised to reduce losses.

(c) Farmers and others involved in the post-harvest handling of onions, need to be educated with the latest technology available on post-harvest management of onion.' (AADF, India)

'Bangladesh experiences huge loss[es] of onion consignments during storage every year and for that matter has to import onions in some years. Programmes may be initiated to reduce this loss of onions in storage' (and training is requested: Bangladesh)

'Problems of flowering during the first year of growth; quality of seed (seed produced is not really clean, lack of machinery); high demand for seed; white varieties are preferred by our society' (Tunisia)

'The losses due to onion storage ranged up to 60% in the month of September 1988, when humidity was more than 90%. Soaking of onion bulbs in 1-2% carbendazim improved storage life. . . . there is a correlation between the size of bulb, the closed apex and disease incidence' (Maharashtra, India)

'The post-harvest sector of the onion industry in Ghana has not been well developed. This can be attributed to the fact that the scale of local production is very low. Moreover, whatever is produced locally is readily marketed. The food habits of some Ghanaians are such that they even use the leaves of the bulbs as vegetables. The bulk of the onion consumed locally is imported' (Ghana)

'Several other [onion] types are found scattered in other regions where onions are grown in small quantities. These races or varieties have not been studied in detail' (Niger)

'The information on this questionnaire is confined to [the] big onion (*Allium cepa*); when the national production is less than 10% of the country's demand and the extent of cultivation is approximately 400 ha, and a single crop is done per year. However, the onions that are cultivated commercially in the country are of the *aggregatum* group, which produce a cluster of bulbs from a single planter bulb. This type of onions are known as red onions and are more pungent. These type of onions are grown in wider climatic areas in the country throughout the year. There are two main local varieties; one produces viable seeds. Planting is normally by bulbs (sets); and seed onions are normally stored for 2-3 months in the form of bundles in well-ventilated sheds' (Sri Lanka)

'Onions in Malawi are more available during [the] dry season and very scarce in the warm rainy season. [Could NRI] . . . send us day-neutral cultivars for evaluation and any instructions on storage of onions' (Malawi)

THE STORAGE ABILITY OF THE ONION CULTIVARS GROWN IN THE TROPICS

In Chapter 2 of this bulletin, the principal classes of onions grown in the tropics, and their geographical origins, where known, were described briefly. It is now possible to fill out the picture in greater detail from the questionnaire replies, which refer to the experience of the informants working in commerce or extension in a variety of tropical and subtropical environments. In Table 5 (*see* pp. 105-10) lists of cultivars, with their estimated contributions to national production are shown, and in Table 6 (*see* pp. 111-9) the details of onion colour, shape, yield, storage times and defects of named cultivars are given.

In attempting to draw any conclusions from the questionnaire answers, it must be borne in mind that the information provided has certain limitations, that is, it is not verifiable, unlike experimental data. The environments in which the crops are stored vary considerably and market pressures may also contribute to the results reported.

Early Grano and Granex group

With the above reservations being noted, some general conclusions are still immediately obvious. The low storage qualities of the onion cultivars classed are US-type short-day Grano and Granex varieties under tropical ambient storage conditions are confirmed.

The mean storage life, calculated on the basis of 25 individual estimates, for cvs. Texas Grano, Texas Early Grano, Texas Grano 502, New Mexico Yellow Grano and other cultivars with similar names combined together, was 1.6 months. (Where a range of storage times was quoted, the mid-point of the range was taken in order to calculate the overall mean. Answers where the informant stated that the variety is not stored at all were therefore excluded).

For cvs. Granex, Granex 33 and 429, Yellow Granex, Henry's Special, Dessex, and other US short-day hybrids, as a group, the average from 20 individual storage estimates was 1.7 months, practically the same as for the Grano group.

Red Creole

The other widely grown onion variety, cv. Red Creole, and a few other cultivars with related names, for which 11 correspondents gave estimates, had a calculated mean storage time of 3.5 months. However, six of the informants who mentioned cv. Red Creole gave estimates or maximum range figures of over 5 months in storage, the wide ranges (for example, 2-6 months) presumably being due to seasonal, regional or storage facility variation within their countries. Interestingly, information from Hawaii on the cultivar Awahia, which is grown in Fiji and Papua New Guinea, is that it was derived from cv. Red Creole in 1956-60 by selection against splitting bulbs, and it is stated to store in Hawaii for 6 months without refrigeration (Sakuoka, personal communication). Other more recent Red Creole selections are now being marketed by some of the seed firms listed in Appendix 5.

'Hard brown' cultivars

Another major, though very diverse, class of onion cultivars with distinctly superior storage qualities is the 'hard brown' group, which usually requires a longer day-length for maturity than the first two groups mentioned above, and hence is more often found outside, or on the margins of, the true tropics. This class might also be taken to include the long-storing Spanish ('Valenciana tardia' type) onions of commerce, from which some of the named varieties below are probably derived (*see* Chapter 2). The broad group includes Egyptian and Turkish brown onions; the Australian cvs. Creamgold and Early Creamgold; Israeli cvs. Ben Shemen and Moab; Australian Brown, Bon Accord and Hojem from Malawi (South African seed); Dungula Yellow from Sudan; de Wildt and Pyramid from Swaziland; Extra Early Premium from Zambia; Early Premium and Gold Rush from Zimbabwe; Baftaim from Yemen (South); Baia Periforme and its derivatives from Brazil; Valenciana from Chile; and Superex from Fiji. Calculating on the basis of 25 individual references to cultivars, the mean storage time for this miscellaneous group was 6.5 months. If, however, the two Egyptian informants' answers (giving 3 varieties with very long storage periods) are omitted, the average result, based on 19 individual references to varieties, is still 5.7 months. This suggests that where such varieties can be grown, storage problems should not be so serious as in the more humid tropics nearer to the equator, where there is a physiological requirement to grow onions which are more day-length indifferent than the 'hard brown' group of cultivars.

Shallots and multiplier onions

A further distinctive group is the shallot/multiplier onion complex, about which much still remains to be discovered (see Chapter 2). Twelve correspondents quoted storage periods for this group, and the mean was calculated at 4.7 months, on the basis of figures which ranged from 2 months to 9 months from different correspondents in Ethiopia, Malawi, Tanzania, India, Indonesia, Mauritius, Sri Lanka and the Philippines. Clearly, within this group there is promising genetic material for further improvement by breeding. Progress is already being made in shallot breeding and selection in Indonesia (Grubben, personal communication).

West African cultivars

Red onions from West and Central (Sudan) Africa form a distinct class which is known well within the region of origin for its good storage potential, but is little grown outside the area and does not appear to have entered the commercial seed trade internationally. Based on 11 individual reports, 5.4 months' storage period was the overall mean for this group (four reports were of cv. Violet de Galmi, the others for local red onions from Ghana, Nigeria and Sudan; *see* Table 6 pp. 111-4).

Onions from India, Pakistan and Bangladesh

The red-brown onions from the Indian sub-continent are rather more widely known outside their own areas than the African varieties, since they are grown in East Africa, Yemen (North) and Yemen (South) under the common name 'Bombay Red' and in Sri Lanka as 'Poona Red'. Seed of cv. Pusa Red is also produced in Zambia (Mathai, personal communication). The storage time estimates given for this group as a whole numbered 35, but it should be noted that individual informants tended to quote the same storage period length for all or most or the cultivars which they listed (possibly reflecting the suitability of the local climate for storage, or their own experience from experiments; *see* Table 6, pp. 114-5). The cv. N-53 has been omitted from the calculation of the mean storage figure, as this cultivar is grown in India in the Kharif or wet season and is usually sold immediately. For the remainder of the red or red-brown cultivars, including those grown outside India, Pakistan and Bangladesh, (but not from Mauritius), the average storage life was calculated to be 4.0 months. This figure is however heavily weighted in favour of the correspondents who named the most varieties (see Table 6, pp. 114-5). The reportedly good storage performance of cv. Pusa Red in Yemen (North) (6 months) and the exceptionally long storage potential of the two Bangladesh varieties, (in spite of the heavy storage losses noted elsewhere in the questionnaire) demonstrate some of the interesting potential for improvement among this group, and also the pressing need to preserve the existing genetic diversity among onions now grown in the Indian region.

White onions

White onions have often been stated to have shorter storage life than coloured ones, for reasons which are largely connected with the chemical protectant content of the bulb skins, mentioned in Chapter 5, p. 71. However, the questionnaire returns show the dangers of attempting to generalize on the basis of bulb skin colour alone. Among the white onion varieties mentioned, many partake of the long storage character of the local populations from which they are derived; for example, Blanc de Soumarana and Blanc de Galmi in Niger are stated to store for 6 months and Violet de Galmi for 7 months. The White variety from northern Nigeria stores for 3-4 months and the local Kano Red for less than this. Storage estimates for cv. Nasi in Sudan are variable (2 or 3-6 months).

From Tunisia, white varieties which store for 5-6 months are recorded. Few white varieties were recorded from the Americas, though they are popular in Mexico. The Australian cv. Torreus White can be stored for up to 6 months.

Reports in the literature also suggest that cv. White Creole has exceptionally good storage properties compared with many coloured varieties (for example, Saxena *et al.*, 1974, in Guyana). This variety was used in breeding many of the existing dehydrator onions available commercially (Call, personal communication). Presumably high dry-matter content is one of the characteristics tending to improve storage quality which the cultivar shares with its colour variant, Red Creole. Following selection work in Niger to stabilize the white skin character in local varieties by Nabos (1976), attempts were made in France to cross cv. White Creole with the West African white cultivars Blanc de Galmi and Blanc de Soumarana in the 1970s to try to improve their dry-matter content, even though the yield of cv. White Creole in Niger was only 40% of that of the local Galmi onion used for comparison. In the questionnaire returns, cv. White Creole was mentioned only in Kenya, with a storage period of 3-4 months. Cv. White Creole is still available commercially from a limited number of firms (*see* Appendix 5), and there may be some danger of its disappearance from commerce if in future the more profitable hybrid cultivars are developed for sale in the tropics.

In India, cv. White Patna stored for 3-6 months in one report, and an unnamed white variety for 10 months in another. These and the West African results suggest that there is scope for selecting white onions with good storage qualities for the tropics, particularly if they can be grown in a dry season when leaf diseases are less serious. Though they lack resistance to smudge and neck rot compared with coloured onions, white varieties have been found less susceptible to black mould than red or brown onions by some researchers (Hatfield, Walker and Owen, 1948; Jones and Mann, 1963).

Other cultivars grown in the tropics

There are some situations where the onions grown cannot easily be fitted into any overall group. In Ethiopia, for example, the varieties Adama Red and Mermiru Brown are recent selections from Sudanese stocks, which, in the cooler highlands of Ethiopia, have proved to be susceptible to leaf disease. Comparatively short storage times of 2 months were quoted for these varieties from Ethiopia, probably because at high altitudes the temperatures and relative humidity are such as to encourage early sprouting. A long period of intensive selection may therefore be needed, when onion introductions are made from one climatic zone to a different one at a similar latitude, to modify their characteristics for the new environment.

The onions grown in Ecuador were stated by the informant there to be local varieties, but international seed firms are also known to sell in Ecuador, and the variety Texas Grano is among those grown from imported seed. As approximately half of the onion crop is used green, the question of storage does not arise with much of the crop. The local red cultivar (Colorada or Paiteña) is in fact a multiplier or shallot type of onion (Yepez, personal communication) which is propagated vegetatively.

Onions in Brazil

Within Brazil, our correspondents again made the point that there is no need for storage for onions grown in the tropical region of the country, where cv. Texas Grano is popular. However, the local Baia Periforme types are now being actively developed by both local extension and university breeders and by seed companies because of their valuable properties for seed production in a tropical area, for production from sets, and for their comparative resistance to leaf diseases. In the south of Brazil, the varieties Crioula, Norte-14 and Jubileu are stated to store for 5-6 months, and these are also selections from Baia Periforme (see Chapter 2).

JUDGING STORAGE DISORDERS: A QUESTION OF EXPECTATIONS

It is a complicated matter to relate the storage disorders, mentioned by informants as being serious causes of loss, to the cultivars grown. Needs and expectations of onion storage life themselves vary greatly between geographical regions; for example, in the Caribbean, long storage is rarely attempted. In some cases no direct connection is possible because several different types of onion from distinct groups may be grown within the same country, and in question 20 no information was requested on cultivars. However, from Table 5 (*see* pp. 105-10) it can be seen that in the Caribbean region the varieties grown are predominantly of the US short-day Grano/Granex types, while the group of eight Indian respondents mainly describe local red and white varieties. In both areas, disease and sprouting are noted as a major cause of loss in storage, but from Table 6 it is evident that these problems occur over a much shorter time-scale in the Caribbean region than they do in India, where storage times of up to 5 or 6 months are common. One notable difference between these areas is that in the Caribbean, all onion seed is imported, while in India many farmers produce their own onion seed (*see* Table 7, column 3, p. 120), and hence it is vital for Indian farmers to be able to store the mother bulbs from one dry season to the next. In all countries where the seed trade is not extensively organized by commercial firms, this consideration is an important one, and lengthens the perspective with which growers regard onion storage, in addition to any requirement for extending the period of bulb marketing. The difference in expected onion storage life is also shown by the different importance given to shrivelling as a cause of loss in the two regions; though it was not usually rated a serious problem in the Caribbean, it was noted as always causing loss by 6 out of 8 correspondents from India.

ONION STORAGE STRUCTURES IN TROPICAL COUNTRIES

Methods of storing onions in the home, on the farm, and in specialized or common warehouses were described by informants in answer to questions 15 to 17. Here, some examples of each will be quoted from the questionnaires.

Onion storage in the home

Ghana: [in strings] 'in ordinary village kitchen, hung from ceiling, or multipurpose barn, also hanging from ceiling.'

Egypt: 'loose bulbs and covered with rice straw, with or without shading. Sometimes bulbs are stored in bags or sacks. [Capacity:] tens of tons. [Construction:] – on the floor or on the top floor of farmer's house. – many bulbs are stored under raised cover. [Ventilation:] – by putting bulbs in thin layers. – or by special arrangement of sacks.'

Sudan: '. . . or in houses, huts and under trees in bags.'

Tanzania: 'after they are dried in the sun, they are put in bags or sacks, and then piled inside a house or a shaded place. Occasionally the bags are checked for sprouted bulbs, and if some are noted, the bags are emptied and the bulbs are redried again in the sun. The sprouted ones or rotted ones are taken out.'

Belize: 'The onions are tied into bunches and hung over fireplace, or stored piled in wire mesh boxes'.

Sierra Leone: 'Onions are stored in old barns or in houses or kitchens in either bags or by spreading the bulbs on the floor'.

Indonesia (referring to shallots): 'Planting material is predominantly kept in bunches in the kitchen'. 'Normal farmer storage practice is to hang the bulbs from the rafters in the kitchen'.

Informants mentioned storage in the kitchen several times, which suggests that the need to keep onions and shallots dry and warm (to discourage sprouting) during storage is well understood. In Ghana the drying itself was evidently done there. It is also possible that some constituents of woodsmoke may have an inhibiting effect on onion sprouting, as a technique for smoking onion bulbs prior to storage has been reported from China.

Storage in specialized farm structures

Twenty-four correspondents described locally constructed traditional-style onion stores, made with porous walls of straw, corn stalks, bamboo poles or woven bamboo, which allow natural ventilation, and sometimes incorporating platforms or shelves on which the bulbs are placed in bulk or in layers. Roofs are usually thatched but may be reinforced with plastic.

Ten informants mentioned the use of farm stores of more modern construction, with brick or cement walls, and corrugated iron or asbestos roofs.

However, most of these did not have forced ventilation (with the exception of some of the newer stores in southern Brazil, and some in Zambia, *see* Question 17, p. 129).

A selection of the answers given will be quoted.

Traditional onion stores

India (Maharashtra): 'Farmers store the bulbs in temporary structures made of tomato poles ('chawls'). [Construction:] bamboo, sorghum or maize stalks. [Ventilation:] through the openings between the bamboo poles'.

India (New Delhi): 'Crib type storage, structure made of bamboo strips and *Saccharum spontaneum*, under natural ventilation' [Capacity:] 10-45 quintals [1-4.5 tonnes].

India (Varanasi): 'Multi-storied store house are made with bamboo sticks. Tops of the store houses are covered with thatch. During heavy rains, store houses are covered with polythene sheets. A thick (6-8 inch, [=15-20 cm]) layer is placed on each floor. Sometimes bulbs are also stored on kachha floor in well-ventilated rooms.'

India (Tamil Nadu): 'Onions are stored in the field itself in long and narrow thatched structures. Dimensions: length – 8 ft [ca. 2.5 m], breadth – 4 ft [ca. 1.25 m], height – 4 ft. Made of bamboo – roof with thatching, plaited coconut leaves or dried grasses. Bottom 6-9 inches [15-22.5 cm] above ground for bottom air circulation. [Capacity:] 2,000 kg. [Ventilation:] Enough space is provided between the bamboo [uprights] for natural ventilation on all sides.'

Nigeria: '(a) A mud house is built with two or three large windows. Onions are spread on the floor covered with grass.

(b) In some areas special shelves, made of grass mats, and raised about 1-1.5 m above the ground are used for onion storage. The shelves are either placed inside buildings or constructed outside and provided with grass roofs to protect the bulbs against sun and rain. In both structures bulbs are stored loose and the amount may vary between 200 kg (for the shelves) to a few tonnes (for the mud houses). [Construction:] Mud, wooden sticks, grass, corn or sorghum stalks. Natural ventilation.'

Nigeria: 'Storage is in barns with the bulbs arranged either on elevated racks or on the floor. Dry grasses are used in alternate layers with the bulbs, starting with dry grass. Bulbs are also sometimes tied with the leaves on poles.' [The use of sand is also mentioned].

Sudan: 'In cottages made of straw (3-4 m in diameter). Generally loose. Generally raised from the ground. [Construction:] Wood and straw, sometimes mud huts.'

Sudan: 'Huts are constructed from wood and straw, and shelves are also made from wood and straw. Onions are stored on shelves and on floor . . . Natural ventilation (windows).' [or by circulation of air through the straw walls].

Indonesia (shallots): 'Wooden or bamboo racks are used as a frame on which to hang bunches of shallots. Some commercial producers use racks in lean-to stores which have porous woven bamboo walls. Normal seed storage [that is, propagating material] for an individual farmer is up to 100 kg (for 0.1 ha). [Ventilation:] normally by natural ventilation through porous walls.'

Mauritania: 'In ventilated shelters, either on shelves or on mats, boxes or other things, so as to avoid contact with the ground. [Capacity:] very variable. [Construction:] Wood, straw, etc.'

Senegal: 'Sheds made of local materials: thatch, wood, shelves, open at the sides, size 5 m×2 m. [Capacity:] 30 tonnes. [Construction:] Wood, thatch (straw), close-meshed wire netting.'

Costa Rica: 'Shelter, wood frame and roof covered with zinc sheets, transverse pieces of wood [beams] and the bulbs tied in strings are hung up from these pieces of wood. [Capacity:] Variable: 5-75 tonnes.' [Ventilation holes are left in the side walls and between the walls and the roof].

Thailand: '[Onions] are tied up in bundles and hung up on bamboo rods placed horizontally in the well-ventilated covered storage house. Hardwood is normally used for the construction of onion and garlic storage in Chiang Mai area. Naturally ventilated. The storage has an enclosing wall, it [that is, the individual store] is open on all sides.'

Small-scale ventilated farm storage structures were also described from Fiji, Papua New Guinea and Niger.

Non-traditional farm stores

Israel: 'Shaded: loose, in sacks or in bins in a well-aerated shed. [Capacity:] several to tens of tonnes. [Construction:] Asbestos roof, netting or wooden walls with sizeable openings for ventilation. Natural aeration.'

Brazil: 'Only in south of Brazil, farmers store onion bulbs from January up to June in warehouse [barn]. There is a wide array of storage. Some of the most recent has hot dry air forced through the store. [Capacity:] Variable – from 10 to 100 tonnes. Usually storage capacity ranges from 10 to 30 tonnes. [Construction:] Bricks and wood. [Ventilation:] There is lateral opening. The most recent storage has hot dry forced air.'

Zambia: 'Store is 145 ft$\times$27 ft$\times$18 ft. A side air duct with laterals every 5 ft to force air through onions. [Capacity:] 40,000$\times$10 kg pockets. [Construction:] cement blocks, steel trusses, asbestos roof. [Ventilation:] open at both ends.' [Temperature but not RH controlled].

Zimbabwe: 'Brick and mortar building with ventilated floor through which heated air is blown. >90%. [Capacity:] Depends on store: but up to 2,500 tonnes.'

Ethiopia: 'Wooden structure with raised floor made with spaced poles. Sides open. Often thatched huts are used for storage. [Capacity:] 50 tonnes. [Construction:] Round timber with corrugated iron roof. [Ventilation:] Open sides and ventilated floor.'

Yemen (South): 'Open-sided sheds with galvanized roofs, gravel or concrete floors. 20$\times$10$\times$3-5 m or 60$\times$20$\times$3-5 m. [Capacity:] total (several sheds) 6000 tonnes. [Construction:] wood, zinc sheet roof.'

Other countries where huts, barns and sheds on the farm are used include Turkey, Pakistan, Jamaica, Argentina, Mauritius, Australia, Ecuador, parts of India, Swaziland, Yemen (North), Brazil, Venezuela, Chile, Malawi and Togo.

Merchants' stores and others

Venezuela: 'Wholesalers: do not store adequately. Keep onions a short time before sending them on to retailers. Retailers: large supermarkets have good storage conditions. Small shops keep them under ambient conditions.'

Mauritius: 'Co-operatives have sheds that can hold up to 200 tonnes. Agricultural Marketing Board has a capacity of 1200 tonnes at ambient, 2000 tonnes cold – 0°C. [Construction:] mostly concrete (because of cyclones). [Ventilation:] windows, narrow space between roof and walls. Temperature and RH controlled in the AMB stores.'

Venezuela: 'Most storage is at ambient temperature. The firm VECOFRAINCA in Carabobo state has commercial stores with temperature and RH control. [Capacity:] 600-800 tonnes. [Construction:] Aluminium. [Ventilation:] Forced air.'

Hawaii: 'With other commodities in wholesalers' warehouses.'

Indonesia: 'Some planting material is kept by traders in well-ventilated stores.' 'Buyers use big purpose-made racks in purpose-built galvanized/brick/bamboo-walled stores.'

Sudan (describing government stores): 'Sheds: rectangular. Floor made of concrete. Sides open.'

The very small number of stores within the tropics with any temperature and humidity control was striking. Some informants mentioned that stores with such controls exist within their countries (frequently as a result of the activities of aid agencies) but are not being used for onion storage, for example, in Barbados (a 27-tonne store) and Panama. The reasons why these stores are not being used are not clear.

CAUSES OF LOSS IN STORAGE

Table 11 and its notes (*see* pp. 131-2) provide a certain amount of information on the causes of loss of onions during storage. No details were requested on the NRI questionnaire of the actual diseases, for example, which cause loss, or of the response to storage of different cultivars, though a certain amount can be inferred by comparing Table 6 (cultivars and their characteristics) (*see* pp. 111-9) and Tables 11 and 12 (*see* pp. 131-2). As has already been noted, disease is the most obvious cause of serious loss in storage.

A particularly pertinent note was added from Panama (summarized as Note 20, Table 11 (*see* pp. 132)) which will be quoted in full here:

'1. Management of crop disease.

2. Post-harvest management of the bulbs
    a. Damaged bulbs
    b. Rotting bulbs
    c. Bulbs with very thick necks which do not fall down
    d. Dirty bulbs
    e. Lack of facilities for artificial drying

3. Our programme of investigations gives priority to the development of techniques for the post-harvest management of onions.

4. Training of the researchers who are currently working on onion production.'

Literature sent from Panama contains results from the onion drying experiments using simple solar heaters constructed from wood and polythene sheet. These experiments show that even with cultivars which are not well adapted to long storage (Grano and Granex types), improvements can be achieved by efficient bulb drying before storage. The bulb defects listed in 2a-c above are those which should rule out onions from storage: the problem of dirty bulbs should be overcome by efficient drying, which allows the dirty outer skin to be removed before the bulbs are loaded into the store.

Further information is clearly needed on the diseases which attack stored onions in particular countries. These and other research and development topics will be discussed in the next part.

Part III

Conclusions and recommendations

INTRODUCTION: THE MAIN THEMES

The purpose of this bulletin, and of the questionnaire circulated to onion workers, is to define the problems faced by farmers growing and storing onions in the tropics, and to suggest research and extension approaches to solving these problems. In the course of collecting information and analysing the responses to the questionnaire, five main themes emerged. They are:

(i) the need for cultivar improvement for the tropics, including seed quality improvement;

(ii) the need for better understanding of the reaction of onion cultivars grown in the tropics to the varied environments found under short day-lengths;

(iii) the need for information on agronomic advances in onion growing to be applied more widely within the tropics;

(iv) the need for more specific information on the events of onion drying and the curing process, and on the influence of these post-harvest events on the storage performance of onions in the tropics; and

(v) the need to obtain and apply measurements of the environment within onion stores so that rational and economic improvements in storage technique can be made, suited to the economic resources available to the different participants in the post-harvest chain.

A corollary of the last point is that causes of post-harvest loss in onions should be identified, and if these causes are pathological, then appropriate environmental and, if necessary, chemical means of control should be developed.

The review, the questionnaire findings, and discussions with workers from a variety of countries, have been used to reach the conclusions and recommendations presented here. They will be discussed under the topic headings used in Part I: genetic resources and cultivars; environmental responses; agronomy; storage; seed production; and, in addition, information. The conclusions and recommendations listed are not intended to be definitive, but to focus on key issues where progress towards better onion yields and improved storage performance may be possible, and to indicate some approaches which could be used to achieve these ends.

1 GENETIC RESOURCES, EXISTING CULTIVARS, EXOTIC INTRODUCTIONS, AND THE POSSIBILITIES FOR GENETIC ADVANCE

1.1 Genetic resources

All areas in which farmers still produce their own onion seed can be regarded as potential sources of useful onion genetic variability, and the collection and conservation of onion genetic material from such areas should be undertaken with urgency. This is particularly important in isolated regions where local selection has taken place over many generations. The efforts of the National Bureau for Plant Genetic Resources in India to collect and characterize onion germplasm exemplify what can be done (Thomas and Dabas, 1986). Interviews with local people at the time of collection of seed or planting material should be used to find out what properties of the varieties are particularly valued. Areas such as Pakistan, Iran, Afghanistan and the Central Asian Republics of the Soviet Union are of particular interest as collecting sites, as they are geographically nearest to the onion's presumed centre of origin. Collecting work on garlic illustrates the possibilities of finding interesting material in this region. The garlic clones usually cultivated are infertile (that is, they do not produce viable seeds), but in Soviet Central Asia several fertile garlic samples were obtained from local markets (Etoh, 1986).

The question of *in situ* preservation (Altieri and Merrick, 1987), if necessary by offering financial incentives to farmers, should also be examined with urgency on an international basis, as it appears likely that there will be a rapid expansion by multi-national seed companies into cultivar development in short-day onions. The existing locally developed genetic resources of onion and shallot in the tropics are likely to be depleted very fast, once sufficient quantities of seed become available of tropically adapted improved and particularly of hybrid cultivars. Hybrid onion seed is now being sold, for example, in Indonesia (Hadi, personal communication). Currently there are still opportunities to collect onion, shallot and multiplier onion germplasm with local adaptation in parts of the tropics, notably in India, Pakistan and Bangladesh, West and Central Africa, and the highlands of Central and South America. The material should be collected and evaluated in gene banks and also maintained if possible in its traditional sites. Collections of shallots are already being made in Indonesia, and there are areas of Africa which could also yield interesting vegetative material. It may be necessary to submit shallot accessions to heat treatment and tissue culture in order to free them from latent viruses and multiply them for distribution.

Part of the work of gene banks, particularly those attached to research institutes or colleges where breeding is done, is to define the characteristics of the accessions so that useful heritable characters can be located. Much work of this kind is needed in alliums (Astley *et al.*, 1982; Astley, 1988). In practice, such characterization work is very expensive to run and hence is usually associated with a particular breeding objective. Screening for disease resistance, for example, usually requires the collaboration of pathologists capable of developing specialized tests and maintaining stocks of the pathogen, possibly as several distinct isolates of known geographical origin. The results of screening work are then listed in the data files held by gene banks; the lines which carry resistance or other useful genes can then be multiplied and distributed to interested breeders. Screening for resistance is urgently needed for several diseases of onions prevalent in the tropics, for example purple blotch, *Stemphylium vesicarium*, 'mal-das-sete-voltas' (*Glomerella cingulata*), *Fusarium oxysporum* f.sp. *cepae* and the storage disease *Aspergillus niger*. Later it can be expected that studies on the molecular mechanisms of infection and resistance will contribute to the development of resistant cultivars.

The existing network of gene banks holding *Allium* accessions under conditions suitable for long-term storage was listed by Toll and van Sloten (1982), in an International Board for Plant Genetic Resources (IBPGR) publication. At that date, twelve gene banks held *Allium* seed collections at temperatures of $-10°C$ to $-20°C$, and since then a number of others have been added to the network. Gene banks with special responsibility for *Allium* material internationally, as distinct from national collections, are located in: the United Kingdom at the Institute of Horticultural Research, Wellesbourne; the Centre for Genetic Resources in the Netherlands; the Research Centre for Agrobotany, Tapiozsele, Hungary; the National Plant Germplasm System, USA, and the National Institute of Agricultural Research, Japan. For vegetatively propagated material, the Israeli Gene Bank for Agricultural Crops, Bet-Dagan, Israel, holds the 'field gene bank for short-day material', and the Plant Breeding Institute for Vegetables, Olomouc, Czechoslovakia, has similar responsibility for long-day material, i.e. the shallot and other vegetative material is maintained there after going through quarantine. Within Europe, including Turkey, Israel and the Soviet Union, a total of 23 organizations are now holding *Allium* accessions in the European Co-operative Programme for the Conservation and Exchange of Crop Genetic Resources, and at many of these sites, characterization and evaluation of *Allium* collections is taking place. The IBPGR Directory of Germplasm Collections, Vegetables, is currently being updated.

1.2 Existing cultivars grown in the tropics

1.2.1 The range of development

The onion cultivars which are currently grown in the tropics differ to an extraordinary extent, showing a spectrum of development which extends from the local land-races of Sudan and Niger, named only for their localities of origin, to the US-bred hybrids of the Granex type which are widely grown in the Caribbean, South America and Southern Africa (*see* Tables 5 and 6, pp. 105-19). The questionnaire survey was evidently made at a time of extreme contrasts, and these contrasts probably also signify that it is a time of rapid change. It is noticeable that the most highly bred varieties available by no means fulfil all the requirements of those who grow them, as shown by some of the judgements and comments of correspondents (*see* Part II). At the same time, the tropically adapted onion races of the Old World are appreciated for their valuable qualities of heat resistance, ease of flowering and long dormancy at high temperatures, even though they often have defects such as splitting and doubling, thick necks and bolting. Many of these defects are susceptible to reduction through efficient selection. There are encouraging possibilities for the improvement of traditional types of onion by well-organized seed multiplication and relatively simple breeding methods within tropical countries (Currah, 1985).

1.2.2 Yield versus keeping quality

The range of cultivars grown in the tropics can be appreciated from the lists in Tables 5 and 6 (*see* pp. 105-19): their characteristics are discussed in Chapter 2 and in Part II. A point which is worth emphasizing here is that cultivars which have rapid bulbing and heavy yields do not usually have good storage properties, and are generally susceptible to early sprouting and to storage pathogens. (The newer Israeli short-day cultivars which are now on trial at tropical sites may show improvements in these respects, once results are available (for example, Peters *et al.*, 1989)). The cultivars or races which have long dormancy at high temperatures have traditionally tended to give lower yields and to be higher in dry-matter (DM) content and pungency compared with the low dry-matter types. Indeed, it is tempting to suggest that the onion has a ceiling dry-matter yield per unit area under any given agronomic system, and that this can be distributed either in heavy crops of low dry-matter onions or in lighter crops of higher dry-matter onions, but not as yet in both. Some evidence on this point was noted by Grubben (1977) from the work in Green (1973) in northern Nigeria; the conclusions from a comparison of DM and yields in the contrasting cultivars Texas Grano and Bombay Red were that the former, with a yield of 50 t/ha at 6% DM gave 3 t DM/ha, while Bombay Red, which gave 30 t/ha at 15% DM, was producing 4.5 t DM/ha. The development of hybrid cultivars adapted for the tropics may eventually allow yields of better storing onions to be improved, but possibly at the expense of the growers' or even the nation's loss of self-sufficiency for seed supplies.

1.2.3 Creole varieties

Some of the short-day onion cultivars commercially available are listed in Appendix 5. Some seed firms recommend cultivars described as being especially suitable for growing in the tropics (implying perhaps that they were bred or selected there), and some are claimed to be 'improved' varieties based, for example, on Red Creole and on Indian red onions. The cv. Red Creole was maintained in the USA for many years without a high level of selection, hence doubling became a widespread defect (S. de Groot, personal communication), but recently the commercial possibilities of this old onion race are being increasingly recognized and more attention is being given to its quality characters and potential for adaptation to different tropical regions. The related White and Yellow Creole cultivars are likely to contribute germplasm to the development of new varieties of onions for the tropics which will have better dry-matter content and increased storage ability compared with the US short-day varieties now widely grown. Creole cultivars may also be used increasingly as sources of inbred parents for onion hybrids intended for the tropics.

1.2.4 Cultivar availability

The difficulties of obtaining seed of certain improved Indian cultivars have already been noted, though the Associated Agricultural Development Foundation in India is now offering four selections including the recently developed Agrifound Light Red and Agrifound Dark Red. In Brazil, the other major tropical country where considerable breeding from local onions has taken place, some recently developed tropically adapted varieties are sold commercially (*see* Appendix 5), and these might be put into trials in other locations in the tropics, particularly where improved brown-skinned onions are required. The longest lists of short-day onions are from the US seed firms which are rapidly expanding their tropical markets, particularly in South America. Breeders in Israel are aiming specifically to improve storage quality in short-day onions, and trial reports are awaited with interest.

European seed firms do not yet offer a wide range of short-day onions, but some are starting to develop onions and shallots suitable for the tropics, and true or botanical seed of shallots may eventually become available (G. C. Beemsterboer, H. de Groot, personal communication). Trials on onions and shallots are currently taking place in Indonesia and Thailand (A. Hadi, W. C. Beets, personal communication). There is a pressing need for more published information on the appearance, physiological response to environment, agronomy, and chemical content of the whole range of tropical shallots and multiplier onions. The possibility that shallots contribute to the keeping qualities of cooked food also needs investigation; shallots may contain high levels of antibiotic factors, related to their high dry matter and pungency. Early attempts at true seed production usually show a high level of heterozygosity among shallot populations, but are allowing the selection of clones with desirable characters (Hadi, personal communication). From the work of Messiaen in the West Indies, lines with greater homozygosity have reportedly been produced (Grubben, personal communication).

1.3 Exotic introductions

1.3.1 Crossing between temperate and tropical onions

The introduction of desirable characters from onions which are not adapted to the tropics into those which are grown there has not yet taken place on a large scale, though crosses have been made between European and Egyptian onions (Meer, personal communication) and French and West African varieties in recent years (Anaïs and Schweisguth, 1978). There is little evidence of rapid genetic improvement in tropical onions following crosses made between such onions and onions from higher latitudes with desirable characters such as higher dry-matter content. Problems arise with this type of cross as the day-length adaptation of the two parents differs (thus flowering is difficult to sychronize) and the offspring, at least in the F1, may be less well adapted to the short-day environment than the tropical parent (Anaïs and Schweisguth, 1978). The hybrids may also have a greater cold requirement for flower induction than the tropically adapted parent (de Bon and Rhino, 1988). These characteristics in the progeny of exotic crosses can probably be improved by repeated back-crossing to the tropical parent, followed by selection for the desired characters in the selfed back-cross generations. The characters selected should include easy flower induction in the mature bulb, though without easy bolting in the first season of growth; this implies that the capacity to produce flower stalks should be highly bulb size-dependent. The successful manipulation of this character by selection can be demonstrated by the bolting-resistant Japanese autumn-sown onion varieties which are grown in Western Europe. The Japanese onions resist flower induction when they are a larger size in comparison to the Rijnsburger type of onion which is normally sown in spring in Europe (Shishido and Saito, 1977; Brewster, 1985).

Onion crosses which are difficult because of lack of synchronization of flowering can be made using pollen which has been dried and stored for months under liquid nitrogen (Ganeshan 1986).

1.3.2 Alternative *Allium* crops for the tropics

From the answers to the onion questionnaire, it seems that there are many parts of the tropics where the whole available range of edible allium crops is not grown. In some areas, for example, *Allium fistulosum* was not grown commercially, and in others, leeks were not used. There may be opportunities here for the introduction of a greater range of alliums than are now grown, to fill some of the supply gaps with palatable alternative onion substitutes, and also to contribute to a more varied diet. Most of these crops are easily grown from seed; only in the case of shallots and garlic is it necessary to introduce vegetative planting material. Kurrat (*A. ampeloprasum*) is a near relative of the leek, widely grown from seed in Egypt for its green tops, which can be cut repeatedly; it might be introduced to the South American tropics and to some island environments. Chinese chives and rakkyo are perennials which are rarely grown outside East and South-East Asia, but which could probably be grown equally well around the Caribbean and in parts of Africa, in a way similar to chives in Europe. Seeds of these crops are available from East Asian seed companies. The dangers of introducing perennial carriers of disease, particularly viruses, should however be investigated before these suggestions are taken up.

1.4 Possibilities of genetic advance in onions for the tropics

1.4.1 The characters amenable to improvement by breeding and selection

Many examples of genetic improvement in onions have been mentioned in this bulletin. Three onion improvement schemes in the tropics, based on mass selection in Ethiopia (Jackson, personal communication), stratified mass selection in Brazil (Melo *et al.*, 1978), and recurrent selection aimed at the production of improved synthetic varieties in Niger (Nabos, 1976) were reviewed by Currah (1985). The three schemes each produced improvements in yield and uniformity of onion populations after comparatively few seasons of work, though significantly, the advances obtained were not always easy to maintain (Turner and Jackson, personal communication). Although the onion responds well to simple selection methods applied consistently over a number of seasons, the dangers of relaxing this selection pressure during subsequent seed production cycles, and the defects which are liable to appear as a result, are well known to experienced breeders; they were listed by Pike (1986). He noted genetic drift towards flat rather than round shape; multiple centres; easy bolting; poor storage quality; and low soluble solids, as characters against which selection pressure must be maintained even after the 'finished' variety is released.

Conversely, some of onion characters which respond to selection are:

storage quality (Pike, 1986);
skin quality (Doruchowski, 1986b);
single centres (Ahmed and Ahmed, 1976);
bulb shape (McCollum, 1971);
resistance to *Colletotrichum gloeosporioides* (=*Glomerella cingulata*) (Costa and Melo, 1984);
resistance to downy mildew (Angelov *et al.*, 1977);
resistance to neck rot (Miyaura *et al.*, 1985); and
resistance to premature bulbing (Melo *et al.*, 1978).

Desirable characters which already reportedly exist in some tropically adapted onions include the following:

pink root rot resistance or tolerance (cvs. Excel, Cojumatlan, 'PRR' lines of cv. Texas Early Grano and other cultivars);
purple blotch resistance (cv. Red Creole, red shallot from Ethiopia);
smudge and neck rot resistance (red and brown varieties, particularly those with deep skin colour);
thrips resistance (cv. Texas Early Grano);
high dry-matter content (Creole varieties);
long dormancy (cvs. Violet de Galmi, Blanc de Soumarana, Faridhpur Bhati, Creole varieties); and
good skin characters for growing under sprinkler irrigation or rainy conditions (Baia Periforme and derivatives, Costa, personal communication).

1.4.2 Development and maintenance of improved onion cultivars

The above lists show that in theory there are many possibilities for genetic improvement of onions in the tropics. For practical, lasting improvements to be achieved, however, sufficient resources must be available for many successive seasons of breeding work and progeny testing, and for the continued maintenance of the foundation stock. Preferably, selection of bulbs within the production area, and storage under the normal conditions of the area should be the methods of maintenance used. Breeding which involves crossing together of onions from different geographic sources within the tropics might bring the additional benefit of increased heterozygosity within onions populations, which is usually accompanied by increased vigour and hence also higher yields, whether in hybrid or open-pollinated populations (Dowker and Gordon, 1983). Onion breeding methods were described by Jones and Mann (1963), Pike (1986) and Dowker (1990). However, lasting results from breeding programmes are only achieved when full local adaptation in a population is attained, and this entails selecting under the full range of environmental conditions experienced over a number of years. The possible pitfalls, particularly in seed production and quality maintenance (discussed in Chapter 6) should be borne in mind when embarking on an onion improvement scheme. Even within a comparatively small country, differences in altitude, for example, can give very large differences in percentages of bolting between sites only a few miles apart, because of differences of temperature between sites (Kuruppuruachchi, personal communication; *see* also Chapter 6, p. 98).

2 ONION PHYSIOLOGY AND THE TROPICAL ENVIRONMENT

Two main groups of problems, the control of bulbing, and the control of flowering, (including the associated topic of prevention of bolting in the bulb crop) are covered in this section on onion physiology and the tropical environment. Dormancy will be discussed later with storage topics.

2.1 Control of bulbing in tropical onions

The control of bulbing in tropical onions was examined in some detail in Chapter 3. More information is rapidly becoming available on the responses of the US short-day types of onion to day-length and temperature, but the responses of other cultivars (including the important Creole group) or land-races from the tropics have not yet been examined systematically under controlled conditions.

2.1.1 Field experimentation

The most useful information so far available on the majority of tropical onions has been obtained from trials using successive sowing and transplanting dates, with careful observation on the timing of the onset of bulbing and the incidence of defects, and accompanied by the collection of temperature and day-length data, as exemplified in the work of Robinson (1971, 1973) in Zimbabwe, and Ramtohul and Owadally (1979) in Mauritius.

A problem likely to be encountered in physiological studies is that when cultivars are still genetically highly mixed, variance of response is likely to be great; hence large populations are needed to obtain statistically convincing results. The advantage of the situation is that variable populations present opportunities for selection for early or late maturity, if sufficient resources can be found for such work. Though field studies of the type described above require considerable effort, more evidence of this kind is needed to define the optimum environmental conditions for particular onion varieties. Where new varieties are introduced into a country or potential production region, replicated successional trials can determine the best times for planting to obtain crops of good quality while avoiding problems of splitting, premature bulbing and bolting. Such trials might also lead to the development of alternative onion growing systems for the less favourable times of year, such as using sets produced in the hot weather to obtain early bulbs at the end of the rainy season, or the production of green or semi-bulbed onions to supply local markets at seasons when fully matured bulbs cannot be produced. An example from Pakistan is the use of bulb onion sets planted early in the autumn, which split into 2–6 small bulbs for use in November – December, considerably earlier than conventional bulb onions produced from seed (M. A. Nazir Chaudhry, personal communication).

2.1.2 Defining what controls onion bulbing

Mathematical modelling of the bulbing responses of onion varieties is an approach now being investigated in the United Kingdom to determine the photo-thermal requirements for bulbing in certain onion cultivars. This method has already been used successfully on flowering in leguminous crops to separate those which are day-length sensitive from those which are insensitive, by using the concept of rate of progress to flowering (that is, the reciprocal of time to flower) graphed against photoperiod and temperature (summarized by Roberts *et al.*, 1988). When applied to onion bulbing, this method should allow the circumstances which lead to bulbing induction to be defined more clearly. Such information is particularly needed in the so-called 'day-neutral' or less day-length-sensitive varities of onion which are the most useful for all-year-round production in tropical environments (*see* Chapter 3). However, it seems likely that other factors such as plant age, and perhaps also spacing and N supply, will need to be brought into the equations describing onion growth and bulbing response before the relative importance of each can be described in an integrated model. Although such work may not yet be possible in most tropical countries, the results being obtained from controlled environment studies on onions in temperate regions should be followed and used to advance the understanding of the reaction of onions to environmental factors.

2.1.3 Light intensity effects on onion bulbing

Light intensity is another factor which in controlled environment studies has been shown to influence onion bulbing, but which has not been studied systematically in tropical regions of production. The low productivity of onions in the equatorial tropics has sometimes been attributed to the heavy cloud cover common in these areas, while the generally good bulbing of onions in highland zones of high light intensity which are not too cold for vegetative growth has also been noted. Countries which combine several contrasting climatic zones and altitudes, such as Ethiopia, Mexico, Ecuador, Colombia and Venezuela, would be suitable sites for such investigations.

2.2 Control of flowering, including bolting, in tropical onions

2.2.1. Field studies on bolting

Bolting in onions is another problem where a physiological approach is needed, and again it is a topic where the variable nature of many locally raised tropical onion populations means that large numbers of plants must be observed, in well-defined environmental conditions, before the causes of the high bolting rates which are often reported (*see* Part II) can be determined. As well as environmental records during cool season growth of the crop, the interaction of N nutrition and plant size or age on bolting also needs further local study. If, as seems likely, readiness to bolt is often dependent on the size of the plant, the effect of early dressings of N on dry season crops, grown under conditions when nights are becoming cooler, may be to allow the plants to reach a 'bolting inducible' stage early in the growing season, and thus to become vernalized during subsequent periods of cool nights. The work of Kuipers (personal communication, *see* Chapter 6, p. 94) on timing of plantings to induce flowering in mother-bulbs in Côte d'Ivoire, where a cold requirement was defined in terms of hours below a threshold of 15 °C, may suggest possible lines of approach for work on the prevention of bolting induction in young onion plants. Such work would require successional sowings and the careful recording of leaf number and the onset of bolting throughout the growing season, together with weather records sufficiently detailed to allow the calculation of a critical threshold temperature and the accumulated degrees of the critical cool temperature over time throughout the growing period. Because evidence also exists which points to N starvation during the early stages of growth as a factor which encourages bolting in the first growing season, factorial experiments combining different N levels, sowing and planting dates and temperature recording are needed to solve this complicated problem.

Simple anatomical observations of the growing points of the plants, made at intervals, would also help to define exactly when the critical stage for flower induction occurs (for example, Kampen, 1970; Brewster, 1983). Once the mean values are established for a variable population, a new population with relatively higher bolting resistance than the parental one might be created by the application of a more severe artificial cold treatment, and the selection of plants which fail to bolt.

2.3 Controlled environment studies on tropical onions

Many of the investigations suggested above are really agronomic trials in which the environment is monitored and related to plant response, rather than conventional physiological studies in which the environment is controlled; the latter require expensive equipment which is generally in limited supply to physiologists even in developed countries. However, studies such as those of

Steer (1980 a, b), Mondal *et al.* (1986 a, b, c) and the recent work of Wiles (1989) in the United Kingdom show the valuable information that can be obtained using equipment in which light quantities and spectra, temperature and day-length are controlled. In future, perhaps more research workers from tropical countries, during study abroad, will be able to make use of such controlled environments to investigate the onions which are grown in their own countries. It is hoped that increasingly, facilities for such work will become available within tropical countries in the future.

3 AGRONOMY: OVERCOMING THE FACTORS WHICH CONTRIBUTE TO LOW ONION YIELDS IN THE TROPICS

3.1 For agronomy to be up-graded, economic inputs are needed

The low onion yields recorded from many tropical countries are apparently as much due to economic factors, such as shortage of money to invest in good quality seed, spray equipment and pesticides, as to failure to grow the crop well. The comments from informants in Part II, quoted at length in the answers to question 25 in particular, often made this point. From the extension literature sent to ODNRI from many tropical countries it was evident that efficient methods of growing onions are known. If the available advice is followed, good onion crops can be produced, at least in the most suitable seasons for onion growth, in many countries of the tropics (*see* Appendix 4, list of extension literature). However, where farmers cannot invest in such items as knapsack sprayers, fertilizers, and supplies of pesticides to control thrips and the common diseases, it is difficult to see how onion yields can be improved, though even here weed control and the optimum timing of operations can contribute to improved crops. Provision of agricultural credit at reasonable rates and improvements in the infrastructure of transport and marketing seem more pressing needs than agronomic studies in many places. An example from Indonesia has already been quoted, of the rise in garlic production in recent years resulting from an integrated effort to improve technical inputs, planting material, credit arrangements and marketing (Subijanto, 1988).

Apart from these structural aspects, agronomic techniques exist which can increase onion productivity, provided modest economic inputs are possible.

3.2 Conventional agronomic improvements

No specific recommendations have been made here for seed rates or the spacing of transplants. It is felt that local practice, modified if necessary through local trials to take account of changes such as improvements in seedling survival with the use of improved cultivars, should be taken as a guide. The very great differences in recommendations on these matters from tropical countries are based on local experience (for example, of predicted seed viability for sowing rates) and will evolve with the growing systems in use over the course of time. The recommendations for further work made here largely refer to the introduction of agronomic techniques which may well entail trials on seed rates and spacing to obtain the fullest possible benefit in terms of yield.

3.2.1 Herbicides

The use of herbicides, in particular, although it has not been discussed at length in this bulletin, should be of particular benefit to small farmers, particularly where hand labour is scarce and expensive, as timely weed control is essential for onions to reach their full potential yield. Local sources should be consulted to find out which herbicides are approved for use on onions, and extension workers should run trials with newer materials especially against pernicious weeds such as nutgrass (*Cyperus* spp.). The TDRI (1986) manual lists herbicides which are currently used on onions and advises on the tropical weeds which they control.

3.2.2 Fertilizers: requirements, monitoring and placement

The fertilizer requirements of the onion crop are becoming better understood. The French CTIFL (1983) bulletin, for example, estimates that an onion crop of 40 t/ha of bulbs will contain approximately 120 units (kg/ha) N, 50-80 units P_2O_5, 150 units K_2O, and 20 units MgO. Onions also use considerable Ca, estimated as 131 kg/ha CaO for a crop of 31.8 t/ha (Prats, 1970). Which of these elements will need supplementing, and to what extent, in a particular situation, is best determined by local trials. Where possible, preliminary soil analysis should be used to decide on a realistic range of concentrations of fertilizer to apply. The inclusion of economic data in trials of this kind (for example, Madan and Sandhu, 1983; Balasundaram *et al.*, 1983) in published results is particularly useful.

The fate of fertilizer in the soil is a topic of intense current interest in temperate countries. Modelling approaches to fertilizer requirements are being applied to vegetable production to determine when the various nutrient elements are needed by crops of different types, and how best to apply them, with the aim of reducing unnecessary fertilizer use (for example, Scaife 1988). Studies of this kind will contribute to the understanding of vegetable nutrition in all regions of production. However, the comparatively rapid disappearance of N from soil in the tropics will probably require local studies to elucidate its movement in relation to crop needs in different environments. Direct sampling of the sap of growing crops with indicator strips can be used to monitor and adjust their nutritional status (Scaife and Turner, 1984; BDH, 1984). In onion, this technique may be useful to check that the N content of young plants is maintained at a sufficient level to promote vegetative growth until the onset of bulbing. For maincrop onions in the United Kingdom, levels of 2000 ppm NO_3 at a plant fresh weight of up to 1 g, and of 60 ppm at a plant weight of 1-20 g are recommended (BDH, 1984). Trials at extension level in the tropics might test the potential benefits of early N monitoring for onion growers.

Fertilizer placement in the soil can reduce the total quantities needed. Phosphorus should be most effective when placed accurately below the site of transplanting in ridges or beds; trials are needed on techniques for application and to test the results. The use of fertilizers incorporating sulphur (for example, ammonium sulphate) to enhance the pungency of onion flavour is apparently already appreciated by farmers in the tropics (Kuruppuruachchi, personal communication), but the use of slow-release N fertilizers such as sulphur-coated urea on onions might avoid the need for later top dressings. The need for adequate quantities of K and of Ca for onions has already been discussed in Chapter 4.

3.2.3 Irrigation

Local trials on the timing and cost/benefits of water use can also be valuable to onion growers. The work in Sudan of Hassan (1984) and in southern India of Hegde (1986), discussed in Chapter 4, could be used as examples for work of this type, which is especially needed in areas where onions are not a traditional crop.

Salinity and high soda content in irrigation water are difficult problems for growers. Eventually, it may be possible to increase the tolerance of onions to higher salt concentrations by breeding, based on the response of plants at the vegetative stage (Wannamaker and Pike, 1987). At present, progress is being made in Israel using fresh water to establish the crop and brackish irrigation water later in the growth cycle (Pasternak *et al.*, 1984). This may suggest a research approach to the problem elsewhere.

3.3 Recent agronomic improvements

3.3.1 Soil solarization and other soil amendment techniques

Soil solarization promises to be a relatively cheap method of sterilizing onion nursery plots and should be studied and applied in the tropics. It might be particularly useful in traditional onion-growing areas where soil-borne pathogens such as pink root rot, basal rot and nematodes cause losses, particularly if long rotations cannot be used. Many weed seeds are also killed by soil solarization, an additional potential benefit for the onion grower. Other more speculative topics for future investigation should include the deliberate introduction of vesicular-arbuscular mycorrhizae in onion crops (*see* Chapter 4).

3.3.2 Direct sowing, and mechanization of onion harvesting

Cheaper methods of onion growing, including direct seeding with complete weed control using herbicides, should be investigated in areas where onions can be grown on an extensive scale. Mechanization of harvesting is possible using topping, undercutting and lifting machinery if large areas have to be brought into storage rapidly; efficient drying is necessary in storage if no field drying is practised. In areas where onions are grown in heavy soil and left to dry out after the last irrigation, it may be difficult even to hand lift without damage. If this is the case, loosening the bulbs from the soil before it becomes completely dry may be helpful, and suitable tools such as forks should be used for this purpose. The practice of giving a late irrigation to soften the soil before lifting seems likely to encourage the spread of soft rot bacteria. Studies may be necessary to see whether this is the case.

3.3.3 Seed treatment with pesticides

Pest control in tropical onions was recently reviewed in a publication of the same name (TDRI, 1986), and the detailed recommendations made there will not be repeated here. However, seed treatment with fungicide, and, if necessary, insecticide, is a relatively simple technique which could benefit onion growers in the tropics if its benefits were demonstrated there. Local trials on rates of application using permitted pesticides are recommended, and such trials need following through to the storage period to show the value of the technique. New techniques of seed coating which are being developed in Europe give a safer and more resistant coating than the older dusts, with better adhesion and economy of chemical.

The possibility of using fungicides to extend seed viability in tropical climates merits study. Recently, it has been suggested that onion seed might be treated with pesticides well before the time of sowing with no ill effects (Rudolph, 1986). Trials with a range of potentially useful fungicides under hot climatic conditions are needed to test this idea. Fungal metabolites have been shown to have serious effects on onion viability and seedling vigour in India (Gupta and Mehra, 1984). Currently, seed dressings aimed at reducing the infection of bulbs by black mould are being investigated in Sudan (Hayden and Maude, unpublished work), and the efficacy of thiram and benomyl seed treatment against neck rot in the stored onion crop was shown over 10 years ago in the United Kingdom (Maude and Presly, 1977b). This is an area where collaborative work between pathologists, agronomists and seed producers is urgently needed.

3.3.4 Pest and disease monitoring, prediction and control

Since 1970, strategies for pest and disease control which rely less than formerly on the heavy use of chemical pesticides and more on an understanding of the population cycles and epidemiology of the pests or pathogens have been developed. The aim of such strategies is to use chemicals only when necessary, in order to avoid economic levels of damage. In the case of fungal infections, protectant sprays can be applied to crops only when weather conditions favour infection. The use of pesticides based on *Bacillus thuringiensis* for the control of caterpillars is another comparatively recent development which is now being recommended, for example, in Venezuela (FUSAGRI, 1986) for caterpillar control. These newer strategies have become necessary because of the rapid development of resistance to over-used chemical pesticides. The first step towards the development of the newer control systems however remains the accurate identification of the pest or disease organism or complex which is causing the damage.

Some recent US developments in the prediction of disease epidemics are noteworthy for possible future application in intensive onion-growing areas of the tropics. In New York, a weather-based system named BLIGHT-ALERT has been developed for predicting the timing of fungicidal spraying against leaf blight caused by *Sclerotinia (Botrytis) squamosa* (Vincelli and Lorbeer, 1989). In south Texas, the conditions which allow purple blotch to invade onions have been defined, and growers are warned when spraying is necessary by radio on the local farming programme, thus saving unnecessary spray applications (Miller and Amador, 1981; O'Higgins, 1988b). These and similar techniques rely on a detailed knowledge of the environmental requirements for the fungi to invade the onion leaves. As automatic electronic apparatus for weather recording becomes relatively cheaper, extension workers in the tropics may find that such warning systems become economically viable within their onion growing areas. This approach may be possible in areas where regular outbreaks occur of diseases which are sufficiently well understood. Diseases of which the biology and epidemiology are not well known need detailed study to determine the climatic factors which lead to attack, before monitoring techniques can be applied. Identification of parasites and predators of pests, and of possible biological control agents of fungi, is another aspect which can contribute to the development of integrated control methods.

Monitoring the build-up of thrips populations on onion to predict spraying regimes, and spraying to control thrips at various population intensities has been studied in the USA. The economic benefits of controlling the pest were clear (Edelson *et al.*, 1989). Thrips control reduces the number of wounded sites on onion leaves through which leaf and later storage pathogens can enter, while if unchecked the insects may not only reduce yields, but can also lead to leaf regrowth rather than the attainment of dormancy late in the bulbs' vegetative cycle. Simple counts of insects per plant can be used as a measure, once they have been correlated with levels of damage to the crop. Pest monitoring studies such as this could be used in tropical areas to increase the efficiency of pesticide use. Training in the use of insect trapping and environmental monitoring techniques may be necessary.

Insect and mite pests of onions and their control by chemical, biological and integrated programmes have been reviewed comprehensively by Soni and Ellis (1990). Nematodes or eelworms of onions were listed in the TDRI (1986) publication, and were also reviewed by Green more recently (1990). Where nematodes are carried by seeds, fumigation is the required treatment to prevent further spread.

4 ONION PRE-HARVEST TREATMENT, HARVESTING, CURING AND STORAGE

4.1 Onion pre-harvest treatment

4.1.1 The need for a multi-disciplinary approach

The influence of fertilizer and irrigation timing on the keeping quality of onion is a research topic which needs a collaborative approach, as it involves lengthy field, environmental and storage studies. The participation of a plant pathologist to identify the organisms which cause storage loss is of particular help. The onion variety or varieties grown for such studies should be chosen carefully, as trying to store cultivars which are genetically unsuited for it has been one of the factors leading to confusion on this topic (*see* Hoyle, 1948, for example).

4.1.2 Timing of fertilizers and irrigation during bulb formation

It seems evident from the published literature (*see* Chapter 3) that late applications of nitrogenous fertilizer delay the maturation of onion bulbs and may also encourage late regrowth of the foliage leaves, resulting in thick-necked bulbs. Irrigation towards the end of bulb development should be avoided, so that re-rooting and bulb swelling after the thin outer skin has 'set' (that is, has stopped expanding around the growing bulb) do not take place. Whether irrigation should be stopped relatively early or late should be decided with reference to plant development and the texture of the soil; irrigation should be stopped earlier on a heavy soil than on a light one. Trials on these aspects of harvesting may be justified in areas where onions have not traditionally been grown.

4.1.3 Pre-harvest fungicide treatment to reduce storage losses

An interesting recent development in the prevention of storage diseases is the use of fungicides on plants in the field late in the vegetative cycle to reduce storage losses. Work aimed at defining effective treatments to achieve this is in progress in India (AADF Annual Reports 1985-86, 1986-87) and in Australia (Morris; and Letham and Salvestrin, unpublished work). Treatments with sodium 2,4,5-trichlorophenoxide and with dichloran prior to harvest have shown promise in trials of this type (Aycock and Jenkins, 1960; Hughes, 1970), but testing over a number of seasons is necessary to show whether the benefits are economic, and also to study the effect of reducing attack by certain fungal pathogens on the development of others, such as bacteria. The simple treatment of bulbs with calcium carbonate, which reportedly reduced levels of black mould on bulbs in Japan (Tanaka and Nonaka, 1981), warrants further investigation in tropical environments.

4.2 Timing of harvesting, and methods of handling for initial drying

4.2.1 When should onions be harvested and how should they be dried?

The timing of harvesting should be decided with reference to the local climate and conditions. Where rain is likely to fall during the period when bulbs are drying, it is probably better to remove them to a dry, sheltered but well-ventilated place after lifting than to leave them in the field. This will avoid staining, minimize the spread of diseases which sporulate on the dying foliage or spread by rain splashing under damp or wet conditions, and allow bulb drying to proceed without interruption. However, if the expected weather is dry, the bulbs can be windrowed in the field, with suitable protection from sun-scald, or be brought into a ventilated place. The most effective bulb management involves immediate removal from the field into a drier or store with forced air ventilation. Ideally, onions should be topped to 2-4 cm after most of the leaf has dried, and then cured or dried with heated air at a low humidity (60-70% RH) until the necks are fully closed before being stored. In areas where neck rot is a problem, drying at 30°C or above should kill the neck rot fungus before it can enter the bulb (*see* Chapter 5).

If controlled heating is not possible, it is better to dry the onions thoroughly in the field in the sun than to top them and put them into storage straight away, provided that field temperatures are not so high as to cause sun-scald of the bulb surface. Practices such as piling the bulbs under leafy covers to dry and cure have probably been developed in traditional systems to avoid sun damage. Because such systems risk allowing humidity to rise to high levels inside the heaps, consequently allowing fungi to become established on wounds, the bulb drying should preferably be done in an environment with better air circulation around the bulbs. Such an environment can be provided by placing the bulbs in thin layers on permeable shelves, or laying them out thinly spread on the floor or on a bed of gritty sand. Stringing or bunching is done only after the bulb skins and leaves have dried somewhat.

4.2.2 Handling during harvesting and store loading

The training of growers and field labourers in the careful handling of bulbs during the harvesting and drying operations is an important step in improving the quality of the onion crop, and this point should be emphasized by extension personnel. It is most important to avoid mechanical damage to the bulbs throughout lifting, collecting up and drying. Cuts across the fleshy parts of the bulbs below neck level when removing the leaves are particularly dangerous, as the wounded area is liable to rapid infection if the bulbs remain at warm or high temperatures. Soft rot bacteria can develop rapidly at temperatures above 25°C (Taylor and Maude, unpublished data) and once bacteria have entered the fleshy parts of the bulb, through wounds or other lesions, they are not dependent on high relative humidity to continue their growth. It does not appear that bacteria move easily between bulbs within stores, so most of the infection which develops must enter during growth or harvest (Taylor, personal communication). The major pathogen of stored onions at high temperatures, black mould, is present on the leaves in the field (Hayden and Maude, in preparation) and can rapidly enter the bulbs through wounds. When it is present in combination with soft rot organisms, deterioration can be very rapid (Raju and Raj, 1980). Complete surface drying and neck closure without bulb damage is therefore essential for storage of onions to avoid rapid and heavy losses from pathogen attack.

4.3 Curing of onions: is it just drying or something more?

The processes which occur during onion skin drying need further study, as was noted in Chapter 5. Skin characters such as thickness, colour and the influence on the skin's development of temperature and humidity, have been described and in the case of colour, may even be manipulated in current European practice, but what actually happens as the skin dries is not yet fully understood. In particular, the accumulation in the drying onion skin of the anti-fungal phenolics described by Walker and Link (1935) deserves closer study from biochemists. The use of the term curing itself suggests that a process which is rather more complex than mere drying is involved; possibly some polymerization of substances present in the drying skin may take place. The biochemical processes of onion skin colour development, and the relation of these processes to the antibiotic content of the skin, have not advanced greatly since they were reviewed by Jones and Mann in 1963 (Fenwick and Hanley, 1990). Herrmann, in 1958, suggested that during onion curing a process analogous to tanning takes place, by which oxidation products from protocatechuic acid form the darker colours of onion skins. This idea has not apparently been pursued. Another interesting aspect which needs investigation is the leaching of the anti-fungal compounds from the onion skin by rain during field drying, and its effect on the susceptibility of the bulbs to disease.

4.4 Developing new bulb drying techniques

Solar drying is a technique which may prove valuable for the post-harvest treatment of onions in tropical regions. It should be possible to increase the marketability of onions, even of comparatively low dormancy, by drying the skins and necks fully before they are sold, provided that they are not already heavily infected with soft rot bacteria. Solar panels are also a possible source of heated air for blowing through onion stores to remove the moisture generated by the bulbs. Another recent suggestion is to use wood-burning stoves for this purpose, as in the south Brazilian model store described in Chapter 5. These possibilities need further practical trials before they can be widely recommended.

4.5 Defining storage problems

The problems which occur during the storage of onions are of three main kinds: genetic, environmental and pathological. Genetic differences in the length of dormancy between onion varieties are the chief determinants of the suitability of onion varieties for storage; they were discussed earlier. Environmental problems include how to achieve either the low temperatures or the warm temperatures which enable onion dormancy to be maintained, while keeping the relative humidity in the store low (<80%). Pathological problems are related to several factors: the degree of damage sustained by the onions during harvest; the amount and nature of the inoculum load which the bulbs carry, and the related aspect of hygiene in the field and the store; and ventilation, humidity and temperature conditions in the store itself.

4.5.1 Cold storage of onions in the tropics

Conditions for the cold storage of onions are now well known, but this method is expensive and requires constant supplies of power, so its economic use in many parts of the tropics cannot yet be justified. Flores and Rivas (1979) in Venezuela showed that the life of onions can be extended by cold storage, and trials of the kind described in Chapter 5 should be run to compare the storage performance of available varieties if cold storage is considered likely to be economically viable. Many high temperature pathogens, including the soft rot bacteria, can be controlled by low temperature storage, as can basal rot and black mould (*see* Chapter 5). Losses from disease during cold storage can be expected to be considerably lower than those in the cheaper ambient or heated air storage, provided that humidity can be maintained below 80% RH. Neck rot, however, should be carefully controlled by seed treatment and hot air drying of the bulbs, as this disease is likely to develop from latent infections at cool storage temperatures.

Additional equipment for rapid warming and drying the bulbs as they come out of cold storage may be needed to prevent condensation on the bulb surfaces and rapid rooting and sprouting: these points are now being investigated in the United Kingdom (Murfitt, personal communication). Cold storage in which the humidity cannot be reduced to a suitable level for disease control is also likely to encourage rooting and sprouting in store, possibly leading to heavy losses, and is not advisable.

Guidance to the design and operation of cold stores in developing countries, including information on alternative energy sources, is available from an FAO publication (FAO 1984).

4.5.2 High-temperature storage

The use of high-temperature storage (in practice, above about 22°C) needs further research and development work in the tropics. The lowest practical temperature at which sprouting is suppressed varies between onion cultivars (Miedema, personal communication) and needs defining more closely for the onions grown and stored in the tropics. Stores in some tropical and subtropical areas may need heating at night to raise the temperature above the danger level for the promotion of sprouting, in order to maintain bulb dormancy. Air heating may also be justified if humidity in the onion store needs to be reduced during wet or cool weather.

In some areas of the tropics, such as the desert regions, or central India before the monsoon season, problems of storage may be associated with excessively high temperatures inside stores. Temperatures above 35°C lead to increased respiration rates, causing excessive water loss, shedding of skins and encouraging the development of soft rots in the heat stressed bulbs. Onion stores in these dry climates may need to draw in cooler, damper air at night to lower the temperature of the bulbs and so raise the RH to prevent the skins from cracking excessively.

4.5.3 Experiments on onion storage and storage pathogens

Some storage investigations are currently being done in Yemen (South) and in Sudan as part of the current ODNRI programme on the improvement of storage of onions in the tropics. These studies involve measuring environmental variables inside the stores and the level of storage losses under different regimes and after seed and field treatment of the crop with fungicides (Hayden and Maude, in preparation). It is hoped that studies of this kind can be used to define the optimal conditions and store management strategy for warm ambient storage of onions.

4.5.4 Economic aspects of onion storage: when is it worthwhile to store onions?

Whenever warm storage is used for onions, it is likely that weight losses will be greater than those from cold storage, since onion respiration is higher at high temperatures and more water is lost through the skins and necks of the bulbs. Consequently, the economics of storage and the point at which growers should decide to sell rather than continue to store onions can be influenced by a country's approach to the regulation of supply, including onion imports and their selling prices. Import restrictions need to be in line with the national production estimates, quality for storage of the local crop and consumer price preferences. Uncertainty about government policy on this matter is likely to have a destabilizing effect on the area of onions planted.

4.5.5 Modelling the storage environment

Development of mathematical modelling of the environmental changes in onion stores during drying and storage has been suggested by the work of Müller (1986) and Matos (1986) in Brazil. Work of this kind does not necessarily need to be done in a tropical environment, and may have useful applications outside the tropics and even for other crops. The translation of the two Brazilian theses from Portuguese into a more easily accessible language would help to make the methods developed more widely available.

4.6 Bulb treatments to prevent sprouting

4.6.1 Maleic hydrazide

The use of maleic hydrazide (MH) on onions to prevent sprouting was discussed in Chapter 5. Effective treatment with this chemical has been more difficult to achieve on a repeatable basis in the tropics than in temperate climates, perhaps because of timing difficulties with the application of the spray; some successful results have been reported. The use of the chemical itself may not be permitted in certain countries, or for particular export markets, so the local regulations governing its use should always be checked before undertaking any trials with MH. Recent recommendations from Venezuela suggest that MH can be of value when combined with cold storage, to extend the marketing season for short-day onions (FUSAGRI, 1986). For use with ambient storage, MH treatment has the disadvantage that it does not kill the pathogens present on the bulbs, so that varieties which are susceptible to storage rots can still suffer heavy losses even though sprouting in store may be reduced. The effect of MH in reducing storage losses, which is sometimes found, is probably connected with the lack of sprouting and the consequent delay in senescence of the outer bulb scales. MH and the following topic, irradiation, have been well reviewed by Komochi (1990).

4.6.2 Irradiation

The controversial method of preventing onion sprouting, by irradiation with gamma rays, has not been described at length here. However, recent information from Indonesia suggests that the technique is being considered there for prolonging the storage life of shallots (Hadi, personal communication), and experiments have also been reported from other tropical countries, for example Mauritius (Goburdhun, 1978) which showed promising results. Irradiation does reduce the activity of pathogens and hence may be more useful than MH for improving the ambient storage life of onions. Reports of experiments in which benefits were obtained by irradiation are available (for example, Silva *et al.*, 1975; Thomas *et al.*, 1986).

5 SEED PRODUCTION

5.1 Storage of bulbs

5.1.1 Preservation of bulbs

Neither irradiation nor MH treatment should be applied to bulbs which are needed for seed production, as both methods prevent the production of flower shoots. Dressings of fungicide may be applied to help to preserve the mother-bulbs during storage. Small-scale trials on fungicides for this application would be useful.

5.1.2 Vernalization (cool treatment) of bulbs during storage

The storage temperature treatments needed to induce flowering in bulbs intended for seed production were investigated in a series of experiments in north-east Brazil by Aguiar (1984), described in Chapter 6. More work of this type is needed in other areas of the tropics, particularly where seed of the Grano/Granex type is required.

Cold treatment of shallots might induce higher percentages of flowering and improve seed yields; this method also requires experimental work, as the idea of producing true seed of this crop is only now receiving attention commercially. Experiments by Sinnadurai and Amuti (1971) in Ghana suggested that dormancy in West African shallots could be broken by a comparatively brief cold treatment of a month at 10°C, and that better vegetative growth and higher bulb yields were obtained; longer cool storage (a minimum of 50 days) promoted flowering. Experiments of this kind are needed on shallots from different geographical regions.

5.1.3 Timing of planting out for seed production

For tropically adapted cultivars, planting out the bulbs at the right time, also discussed in Chapter 6, appears to be the most important factor in obtaining good flowering, and can be investigated by trials with successional planting dates at 2- or 3-week intervals. Problems of within-plant competition between bulbing and flowering are likely to be especially severe if mother-bulbs are planted while temperatures are still high.

5.2 Plant health problems in seed production

In any parts of the world where the climate is humid at the time of flowering and seed ripening, production of healthy onion seed presents difficulties. Spraying regimes severe enough to keep diseases such as purple blotch, downy mildew and *Stemphylium vesicarium* under control may have an adverse effect on pollen germination, or discourage pollinating insects from visiting the flowers, as may measures taken to control thrips. Improvements in spraying technique to achieve better fungicide cover on the waxy flower stalks of onion for the control of *Stemphylium* are reported from Israel (Grinstein *et al.*, 1988). Similar methods should be tried elsewhere.

5.3 Quality maintenance

Recommendations for the improvement of seed production at the most basic level are to make sure that seed is only saved from bulbs which matured in the first season without bolting. The practice of saving seed from bolting plants in the bulb crop is very understandable, in circumstances when the farmer may doubt if sufficient bulbs can be stored in good condition until the next growing season to make production from bulbs possible, but if the genetic quality of the seed is to be improved, this practice must be avoided. Not only the seed crop itself, but adjacent and nearby bulb crops, must have their flower stalks removed if cross-pollination from undesirable stocks is to be prevented. This is essentially a seed production management problem, and in countries where horiticultural seed production is not yet well-organized, it is likely to prove very intractable. In onion-growing areas where a co-operative approach to the onion crop is possible, with encouragement from extension workers, credit availability and a seed storage and distribution system with at least some control over drying, cleaning, storing and packaging the seed, cash incentives allied to an inspection system might offer a solution. However, farmers are rightly hesitant about schemes which do not leave them in control of their own seed supply, and it is likely that not all individuals will be willing to co-operate. If simple variety maintenance on a local basis fails, this leaves the market open to international firms using technically advanced methods of seed production and packaging, to introduce well-presented improved varieties produced under controlled conditions, as has already happened in many of the South American tropics. It will be a significant loss if this occurs in Asia and Africa before genetic improvement leading to the development of modern commercial varieties can be carried out within the local onion stocks.

6 INFORMATION

6.1 Sources

Large quantities of information on the growing and storage of onions in the tropics are already available in published form. Publication however is not the same as accessibility, and whereas most workers in developed countries now have good access to abstract journals and computerized data-bases, it is difficult for many workers in developing countries, particularly on the non-staple crops, to obtain up-to-date information. Where onions and shallots are concerned, there may also be language barriers, as reports on these crops appear in a variety of languages, reflecting the world-wide interest in the alliums.

Abstracting journals are a major source of information for scientists who can consult them. The Commonwealth Agricultural Bureaux International journals *Horticultural Abstracts, Plant Breeding Abstracts, Weed Abstracts, Review of Applied Mycology* and *Review of Applied Entomology* provide a way into the onion literature, while *Abstracts on Tropical Agriculture*, published by the Royal Tropical Institute, Amsterdam, covers vegetable work in the tropics and probably gives South-East Asia rather more attention. Valuable reviews on onions have appeared in the abstracting journals in the past (Baradi, 1971; Brewster, 1977). Many national Societies for Horticultural Science take articles on onions in their journals, and popular farming magazines are a good source of local information on new developments. The USA has a magazine, *Onion World*, which is entirely devoted to the crop; it contains popular articles summarizing research findings, which can give a lead on where interesting developments are taking place.

There is still no genuinely international journal for horticultural science in the tropics. While this deficiency exists, horticultural scientists in the tropics can help their colleagues in other countries by submitting reports of their work for publication in journals such as *Scientia Horticulturae, Tropical Science, Tropical Agriculture (Trinidad), Experimental Agriculture* and the *Journal of Horticultural Science*, United Kingdom, which welcomes review articles. The ISHS meeting proceedings, published in the Acta Horticulturae series, are also valuable sources of published information on horticulture in the tropics. The *Proceedings of the Inter-American Society for Tropical Horticulture* are less readily accessible in Europe, but should be available through abstracting journals; many articles are in Spanish, with summaries in English. For the francophone areas, *L'Agronomie Tropicale*, the journal of IRAT, offers an opportunity to publish work on onions. Several Indian national and regional horticultural journals regularly contain accounts of onion research and development work, and the AADF publishes a substantial annual report which would be of value to many onion workers elsewhere in the tropics.

In the United Kingdom the predecessors of NRI, the Overseas Development Natural Resources Institute (ODNRI), the Tropical Development and Research Institute (TDRI) and the Tropical Products Institute (TPI), produced several publications on onion storage, and more recently a manual on pest control in tropical onions, which is still available from NRI. Following the interest aroused by the onion questionnaire, the *Onion Newsletter for the Tropics* has been initiated by NRI, and the first number appeared in December 1989.

6.2 How articles on onions can be written more clearly: a note for writers and editors

Perhaps in conclusion, a few suggestions can be made to those who write about onions, so that the information contained in articles reporting experimental onion work will be more useful internationally and avoid ambiguity. If these suggestions are used as guide-lines, it should be easier to understand and make use of the onion literature for comparisons of cultivars and their behaviour between countries of the tropics.

1. Localities of trials should be identified not only by the name of the site (for example, farm, research station or university department) but also by the latitude and longitude. The altitude in metres should also be stated.

2. Dates of field operations and of the visible onset of bulbing (if this is not being measured by bulbing ration or cessation of leaf appearance, *see* Chapter 3) should be recorded. The date and month should be clearly distinguishable (that is, define whether the month or the date comes first if using numbers for both, as normal practice differs between countries.)

3. The day-length fluctuations during the period of field experimentation should be stated: for example, when the onions were sown, DL was . . .; when they were transplanted, it was . . .; bulbing was initiated/visible when DL was . . .. If this is not possible, the extremes of DL during the growing season should be noted.

4. Climatic data for field trials should be presented as the monthly maxima, minima and means for the duration of field experiments. If experiments are concerned with the incidence of bolting, hours of night temperatures below a critical level may be important, and these additional data should be recorded and presented. For storage experiments, at least the mean monthly relative humidity figures should be presented. Graphs can be used to show more detailed records.

5. Where irrigation is used, the frequency and if possible the amount of water applied at each irrigation should be stated. Any rain falling during such experiments should be recorded. Salinity of the irrigation water should be recorded if it is likely to have an effect on the growth of the onions (*see* Chapter 4).

6. Where climatic data are available, a comparison of experimental conditions with the local 25-year average may be informative, particularly if the season leads to any unexpected results (if, for example, rain causes higher disease incidence than usual).

7. Pest and disease control measures used, including herbicides, should be listed and dated, not referred to as 'according to local recommendations' or similar phrases.

8. The terms used in describing fertilizer use should be clearly defined and should refer to metric weight applied per hectare rather than to any other measure of area. Similarly, weight of crop produced should be reported in metric tonnes or kg per ha, with an indication of the size of plots on which the estimate is based.

9. Onion cultivars used in experiments should be defined more closely than is usual at present, giving the cultivar name, its source (for example, seed company, local market, locally saved seed) and country of immediate origin, if this is known. These details will help in comparisons of cultivars which are now being grown in a large number of countries from seed which may be either imported, produced locally by a seed firm or saved by farmers, all under the same name. Particular care should be taken with accounts of storage trials, where in the past the cultivar of onion in question has not always been defined.

10. The word 'seed' should be reserved for true or botanical seed, that is, the small propagules produced by the flower. The use of 'seed' to describe any other kinds of planting material, such as the propagating material of shallots, is potentially ambiguous and should be avoided. (This is more difficult in languages other than English, so an equivalent to the term 'vegetative propagating material' may be needed). The term 'sowing' should be used for the action of placing botanical seed in the ground. The term 'planting' is ambiguous, and if it is used, the propagule in question should be defined, for example 'sets were planted . . .' , 'split bulbs were planted . . .'. The term 'transplanting' is clearer and is normally used for the moving of a green-leaved seedling to the site where it will form a bulb; its use should be confined to describing this operation. 'Transplants' are the seedlings, usually of about pencil thickness, which are so moved. 'Sets' are usually small dry bulbs, and if they are not, (for example in Nigeria where 'sets' are split and sprouted bulbs which produce flower stalks), an exact description should be given of the propagule in question.

Conclusion

The information contained in this bulletin is based on published literature, the analysis of the world-wide questionnaire, and national and regional bulletins, as well as direct sources, including correspondence and personal contacts. There remain, however, significant gaps in the knowledge base; these have been highlighted in the relevant sections of the bulletin.

The authors hope that this publication will stimulate an increased interest in onions in tropical regions and would welcome comments and supplementary information for inclusion in any later revision of this work.

An urgent need exists to create a sustainable international network and resource which can assist the long-term expansion and maintenance of onion as a crop in tropical regions. It is hoped that this document will provide a basis for consideration of the technical aspects of this issue to be addressed at both international and regional levels.

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Appendices

APPENDIX 1 THE NRI ONION QUESTIONNAIRE

ONION STORAGE IN TROPICAL REGIONS – QUESTIONNAIRE

Please answer the questions based on your knowledge of the normal situation, or the generally accepted practice for your country. If you wish to add further information or comments please continue on the reverse of the sheets indicating clearly which question you are referring to.

Full Name(s) of person(s) completing questionnaire: ....

Organization: ....

Contact Address: ....

....

....

....

Thank you in anticipation of your help with this project.

Do you wish to receive a copy of our report on completion? Yes ☐ No ☐

Please reply to: Ms F. J. Proctor for Dr Leslie Currah
Natural Resources Institute*
56-62 Gray's Inn Road
London WC1X 8LU
United Kingdom

*Previously known as the Tropical Development and Research Institute.

Please tick the appropriate box in answer to questions below:

1. Does your country grow onions (*Allium cepa* var. *cepa*)?

   Yes – of major importance ☐
   Yes – of minor importance ☐
   No ☐

2. Does your country store (i.e. hold between harvest and consumption) home grown onions at any stage in the post-harvest chain? (see also question 13)

   Yes – always ☐
   Yes – under certain circumstances ☐
   No ☐

3. Does your country import from other countries?

   Yes – every year ☐
   Yes – in certain years ☐
   No ☐

4. Are your imported onions stored between arrival in your country and consumption?

   Yes – always ☐
   Yes – in certain circumstances ☐
   No ☐
   Not applicable ☐

5. How many onion crops are grown per year in your country?

   One crop per year ☐
   Two crops per year ☐
   Continuous production ☐

6. In the production region(s) what is the approximate crop season? (Write in name of month(s))

	Planting date	Harvest date
Major crop or area 1		
Minor crop or area 2		

7. Complete this table. See notes below for guidance.

LOCAL ONION PRODUCTION

Name of variety	Percentage of production	Bulb characteristic				Yield	Storage	Defect
		Colour skin	Colour flesh	Shape	Size			
See note (a) below	See note (b) below	See note (c) below		See note (d) below	See note (e) below	See note (f) below	See note (g) below	See note (h) below

Notes for guidance to question 7

(a) Use local name and import seed name if available.

(b) Give an approximate indication of the percentage of the national crop which the variety represents.

(c) What are the skin and flesh colours, e.g. white, yellow, brown, red, red/white, green/white, variable (mixed).

(d) What is the shape of the bulbs of each listed variety? See Figure 1 attached. Write into the box the number which corresponds to bulb shape. If the bulb shape is highly variable, write V.

(e) What is the typical size of the bulbs of each variety grown under your conditions?

Write A if less than 40 mm maximum diameter
B if 40-80 mm maximum diameter range
C if more than 80 mm maximum diameter

(f) Referring to the key below indicate approximate average yield for each variety when grown under the typical conditions of your country.

Record in either tonnes/hectare or tons/acre

(g) Indicate the usual storage life of each variety when stored under ambient conditions. Write down storage life in months.

(h) are the following defects seen:

Many double bulbs	write A
Many bulbs with thick necks	write B
Many double bulbs and thick necks	write C
Defects are not common	write D

8. Where do farmers obtain their planting material?

	Onion seed	Onion set
Save their own	☐	☐
Locally produced	☐	☐
Imported	☐	☐
Other	☐	☐

9. Is it common for the bulb crop to produce flowers and seeds?

Always ☐
Sometimes ☐
Never/rarely ☐

10. At what stage are the onions harvested?

With tops still standing ☐
With tops half fallen ☐
With tops completely fallen ☐

11. How are the onions dried?

(a) In the field in rows ☐
(b) In the field but in piles, bags or boxes ☐
(c) *a* or *b* and subsequently held in ventilated covered place ☐
(d) *a* or *b* and subsequently held in forced-air store ☐
(e) Removed from the field immediately after harvest and held in ventilated covered place ☐
(f) Removed from the field immediately after harvest and dried with forced air ☐
(g) Other: please specify ☐

12. For what period of time are the onions left to dry before storage or marketing?

less than 1 day ☐
2-4 days ☐
5-6 days ☐
longer than 8 days ☐

13. Who stores the onions (if more than one type of person please indicate)? By storage we mean more than a time of 2 weeks.

Farmer ☐
Middleman ☐
Retailer ☐
Government ☐
Other: please specify ☐

14. How are onions usually stored?

Loose ☐
In bags or sacks ☐
Tied in strings ☐
Other: please specify ☐

15. Are there purpose-made stores for the storage of onion in your country?

Yes	☐
No	☐
Some	☐

16. If *No* to question *15*, describe how the onions are stored.

17. If *Yes* to question *15*, describe the store.

How many kilograms can it hold?

What building material is it constructed of?

How is the store ventilated?

Is temperature controlled? Yes ☐ No ☐ Don't know ☐
Is relative humidity controlled? Yes ☐ No ☐ Don't know ☐

18. Do you consider that there is a need in your country to:

improve the quality of seed of onion available? Yes ☐ No ☐
If Yes, why

improve the storage of onion? Yes ☐ No ☐
if Yes, why

19. Do you consider that you have high levels of post-harvest loss of locally produced onion?

Yes	☐
No	☐
Sometimes	☐

20. What are the main technical factors which limit storage?

	Always	Sometimes	Rarely	Never
Disease	☐	☐	☐	☐
Sprouting	☐	☐	☐	☐
Rooting	☐	☐	☐	☐
Shrivelling	☐	☐	☐	☐

Other please specify ☐

21. Which of the following crops are grown on a commercial scale in your country?

	Yes	No	Don't know
Shallots (*Allium cepa* L. var. *aggregatum*)	☐	☐	☐
Bunching onion (*Allium fistulosum*)	☐	☐	☐
Garlic (*Allium sativum*)	☐	☐	☐
Leek (*Allium ampeloprasum*)	☐	☐	☐
Chive (*Allium schoenoprasum*)	☐	☐	☐

22. Do you know of any onion variety trials, selection or breeding programmes, currently in progress in your country? If so please give details of objectives and/or contact addresses.

23. Do you know of any research and development work in progress on post-harvest handling and storage of bulb onions in your country? Please give details and/or contact addresses.

24. TDRI would appreciate receiving copies of reports/papers/information on onion production, storage and marketing relevant to your country. If you can supply us with such copies thank you. If you cannot provide papers please write the reference details below.

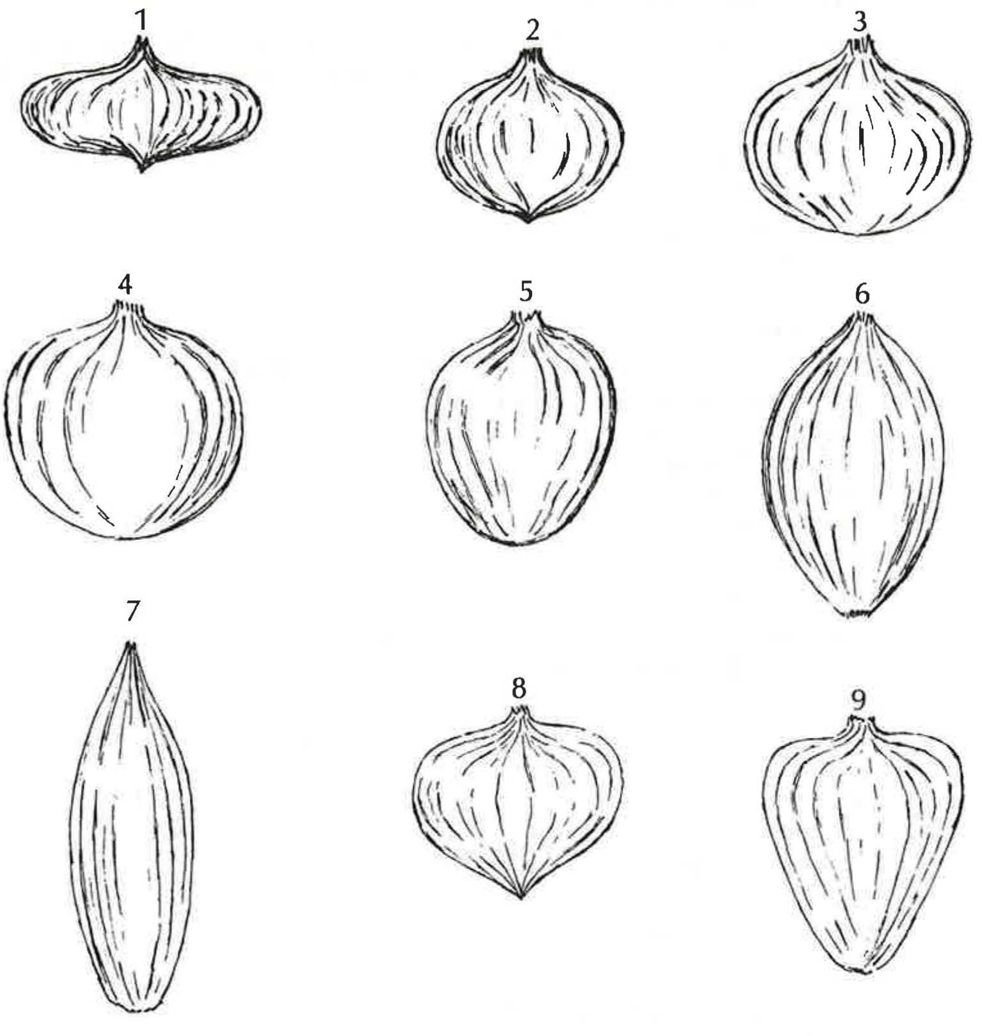
25. Please make any further comments you consider important below.

Thank you for your co-operation in completing this questionnaire.

F. J. Proctor

Figure 1

Shapes of onion bulbs



1 Flat	5 High globe
2 Thick flat	6 Spindle
3 Flattened globe	7 Cylinder
4 Globe	8 Flat top

9 High top

APPENDIX 2 NAMES AND ADDRESSES OF QUESTIONNAIRE INFORMANTS, ARRANGED ALPHABETICALLY

Informants are listed alphabetically under the surnames of the first person named on the questionnaire. The numbers are identity codes which are listed numerically in Appendix 3.

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Turkey

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Malaysia

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Bangladesh

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National Irrigation Research Station
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Mazabuka
Zambia

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Food Research Centre
PO Box 213
Khartoum North
Sudan

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INRAN
BP 429
Niamey
Niger

23 Julia N. Ndungu
Vegetable Section
National Horticultural Research Station
PO Box 220
Thika
Kenya

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Facultad de Ciencia y Tecnologia de Alimentos
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Ministry of Agriculture and Agrarian Reform
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FAO, PO Box 6265
Khormakser
Aden
Yemen (South)

68 A. Samb and Cheikh A. K. Cissokho
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BP 486
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Sénégal

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Instituto de Investigación Agropecuaria de Panamá
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Chiriquí
Panamá

38 G. N. Schrodter
Dept of Primary Industries, Queensland
Research Station
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Queensland 4343
Australia

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Sénégal

55 Dr. Sumitra Sen and Dr. T. K. Bose
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Dept of Botany
University of Calcutta
Calcutta – 700019
India

63 D. A. Shann
Arthur Yates & Co. Pty Ltd.
Research and Development Division
PO Box 124
Narromine
N. S. W. 2821
Australia

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Central Institute of Agricultural Engineering (ICAR)
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Berasia Road
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18 Dr. T. Tonguthaisri
Mae Jo Institute of Agricultural Technology
Chiang Mai 50290
Thailand

70 H. Turral, A. Udin, B. Jaya and H. Hamzah
Madura Groundwater Groundwater Irrigation Project
c/o P2AT Madura
PO Box 34
Pamekasan 69301
Madura
Indonesia

and LEHRI, Indonesia (*see* under Meer)

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57 S. Wirasinghe
Dept of Agriculture
Peradeniye
Sri Lanka

19 P. Wright
Lonrho Farms
Kalangwa Estates Ltd
PO Box 820009
Chisamba
Zambia

APPENDIX 3 CODE NUMBERS, NAMES AND COUNTRIES OF QUESTIONNAIRE INFORMANTS, ARRANGED NUMERICALLY

The code numbers are those used in the tables of Part II to identify the informants. They are arranged numerically.

1	Baloch	Pakistan
2	Daly/de Bon	Martinique
3	Chandler	Barbados
4	Brereton	Barbados
5	Denton	Nigeria
6	Erinle	Nigeria
7	Doku	Ghana
8	Mirkensa/Jackson	Ethiopia
9	Kale/Bhat	India
10	Lawrence	Jamaica
11	Mansour	Egypt
12	El-Shafie	Egypt
13	Mohamed	Sudan
14	Musa	Sudan
15	Ahmed/Faragalla	Sudan
16	Mohamedali	Sudan
17	Marandu/Swai	Tanzania
18	Tonguthaisri	Thailand
19	Wright	Zambia
20	Cole	Zimbabwe
21	Waithaka	Kenya
22	Msikita	Zambia
23	Ndungu	Kenya
24	Costa	Brazil
25	Salaam/Hambari/Barker	Yemen (South)
26	Kaynas	Turkey
27	Kaul	India
28	Valverde	Costa Rica
29	Marti	Argentina
30	Escaff	Chile
31	Rabinowitch	Israel
32	Leong	Malaysia
33	Costa	Brazil
34	Añez	Venezuela
35	Araújo	Brazil
36	Magloire	Belize
37	Gayan	Mauritius
38	Schrodter	Australia (QD)
39	Paredes	Ecuador
40	Shukla/Gupta	India
41	Gama/Nkwanyana	Swaziland
42	Pandey/Gupta	India
43	Mondal	Bangladesh
44	Ba	Mauritania
45	Maurya/Singh/Singh	India
46	Tahir Chaudhry	Pakistan
47	Ben Abderrazak	Tunisia
48	Irulappan	India
49	Abdulla	Yemen (North)
50	Kimura	Brazil
51	Datar	India
52	Johnson	Ghana
53	George	Sierra Leone
54	Naino	Niger

55	Sen/Bose	India
56	Kuruppuruachchi	Sri Lanka
57	Wirasinghe	Sri Lanka
58	Kumwenda	Malawi
59	Kuipers	Côte d'Ivoire
60	Datt	Fiji
61	Chaudhry	Pakistan
62	Avila/Flores	Venezuela
63	Shann	Australia (NSW)
64	Villamayor	Philippines
65	Meer/Hadi	Indonesia
66	Avochinou	Togo
67	Gorogo/Pitt	Papua New Guinea
68	Samb/Cissokho	Senegal
69	Beets	Indonesia
70	Turral/Udin/Jaya/Hamzah	Indonesia
71	Kratky	Hawaii
72	Sanchez	Panama
73	Seck	Senegal
74	Hossain/Ahmed	Bangladesh

APPENDIX 4 EXTENSION PUBLICATIONS ON ONION GROWING AND STORAGE, LISTED UNDER COUNTRIES AND TITLES; BOOKLIST

This list is not intended to be exhaustive. It includes publications which have been received from correspondents while preparing the bulletin or which were used to obtain information on onion growing and storage in tropical countries for inclusion in the bulletin.

BRAZIL

Cebola: Resumos Informativos. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Departamento de Informação e Documentação, Brasília, 1980, pp. 313.

Cura e Armazenamento de Cebola com Utilização de Ventilação Forçada – Armazem Modelo EMPASC. Comunicado Tecnico No. 113, Secretaria da Agricultura e do Abastecimento, Empresa Catarinense de Pesquisa Agropecuária S. A. (EMPASC). 1987, pp. 12. By A. T. de Matos.

Instruções Técnicas para o Cultivo Comercial de Cebola em Rondônia. Circular Tecnica No. 12, Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA)/ Unidade de Execução de Pesquisa de Âmbito Estadual (UEPAE), Porto Velho, Rondônia, 1987, pp. 21. By M. da Penha Angeletti and A. F. Almeida da Fonseca.

Recomendações Técnicas para o Cultivo da Cebola (Allium cepa *L.*) *no Estado do Acre.* Circular Técnica No. 8, EMBRAPA/UEPAE, Rio Branco, Acre, 1983, pp. 20. By M. U. Corrêa Nunes.

Sistema de Produção para Cebola, Santa Catarina. Empresa Catarinense de Pesquisa Agropecuária S. A. (EMPASC) and EMATER/ACARESC – Serviço Extensão Rural, 1983, pp. 45.

CHILE

El Cultivo de la Cebolla. Boletin Divulgativo No. 24, Instituto de Investigaciones Agropecuarias, Estación Experimental La Platina, Santiago, 1979, pp. 51. By M. Escaff G., A. Aljaro U., H. Sanz B–M., and C. Quiroz E.

El Cultivo de la Cebolla. Corporación de Fomento de la Producción, published in El Campesino, May 1987, pp. 25-48. By A. Bravo Martinez and P. Aldunate.

COLUMBIA

El Cultivo de la Cebolla de Bulbo. Federacion Nacional de Cafeteros, 1985, pp. 20.

FRANCE

L'Oignon. Institut National de Vulgarisation pour les Fruits, Légumes et Champignons (INVUFLEC), 1976.

L'Oignon de Jours Courts en Région Méridionale. Centre Technique Interprofessionel des Fruits et Légumes (CTIFL), 1983, pp. 79.

Oignons – Onions. International Standardisation of Fruit and Vegetables. [in French and English] Organisation for Economic Co-operation and Development (OECD), 1984, pp. 49.

INDIA

Onion Production in India. Associated Agricultural Development Foundation (AADF), (undated), pp. 71.

INDONESIA

Budidaya Bawang Merah. Sinar Baru, Bandung, pp. 1-15, 1983. By Hendro Sunarjono.

Membudidayakan 5 Jenis Bawang Merah. Sinar Baru, Bandung, pp. 64-69, 1986. By Rismunandar.

NETHERLANDS

Het Drogen en Bewaren van Zaai-uien. Ministerie van Landbouw en Visserij, Vlugschrift voor de Landbouw Nr 86-02, 1986, pp. 12.

OMAN

Al-Bassal wa Al-Thun. Ministry of Agriculture and Fisheries, Sultanate of Oman, 1986, pp. 40.

PANAMA

Guia para el Productor de Cebolla. Instituto de Investigación Agropecuaria de Panama (IDIAP), 1984, reprinted 1986, pp. 27. By G. de Leon, E. de Leon and A. Velasquez.

THAILAND

Introduction, Selection, and Production of Onions as a Replacement Crop for Opium Poppy in Thailand. Semi-Annual Report No. 5, Division of Horticulture, Dept. of Agriculture, Bangkok, 1979, pp. 19. By T. Tonguthaisri, K. Choompirom, S. Khamiam and N. Poolperm.

TURKEY

Bazi Soğan Çeşitlerinin Hasat Sonrasi Fizyolojileri Üzerinde Çalişmalar II. Ataturk Horticultural Research Institute, Yalova, 1987, pp. 38. By K. Kaynas, F. G. Çelikel, Ü. Ertan, T. Türkeş and M. Altin.

UNITED KINGDOM

Buildings for Onion Drying and Storage. Short-Term Leaflet 136, Ministry of Agriculture, Fisheries and Food (MAFF), 1973, pp. 16.

Dry Bulb Onions. Booklet 1, (4th edn) Horticultural Enterprises. Agricultural Development and Advisory Service (ADAS), Ministry of Agriculture, Fisheries and Food (MAFF), 1978, pp. 77. By P. Tatham.

EEC Standards for Onions. Ministry of Agriculture, Fisheries and Food (MAFF), 1975, pp. 10.

Pest Control in Tropical Onions. Tropical Development and Research Institute (TDRI, now NRI), 1986, pp. 109.

The Storage and Handling of Onions. Tropical Products Institute (TPI, now NRI), G 160, 1982, pp. 14. By A. K. Thompson.

UNITED STATES OF AMERICA

Colorado Onion Integrated Pest Management. Colorado State University Co-operative Extension Bulletin 547A, 1990, pp. 22. By H. F. Schwartz, P. Westra and W. Cranshaw.

Harvesting, Handling, and Storing Yellow Sweet Spanish Onions. Idaho Agricultural Experiment Station Bulletin 526, 1971, pp. 31. By L. G. Williams and D. F. Franklin.

*Onion Storage – Guidelines for Commercial Growers.*Pacific Northwest Extension Publication PNW 277, 1985, pp. 15. By W. E. Matson, N. S. Mansour and D. G. Richardson.

Using Temperature and Humidity as guides to Curing and Storing Onions. Michigan State University Cooperative Extension Service, Extension Bulletin E-1409, 1980, pp. 4. By D. H. Dewey.

VENEZUELA

Cebolla y Ajo. Fundación Servicio para el Agricultor (FUSAGRI), Serie Petroleo y Agricultura No. 9, 1986, pp. 90. By A. Flores G., H. Ayala C., P. J. Rodríguez G., M. Albarracín C., R. Mendt P., M. Cermeli L. and V. Grana S.

ZIMBABWE

Onion Production. Department of Conservation and Extension, 1980. pp. 12. By P. D. Wells.

Onions. ZFC Advisory Service, 1987, pp. 12.

Onion (*Allium cepa*). In: *Agricultural Technical and Extensions Services Horticultural Handbook*, 1983, pp. 218-243. Edited by F. Wood.

INTERNATIONAL

Onions – Guide to Storage. International Standard ISO 1673-1978 (E). pp. 3.

Design and Operation of Cold Stores in Developing Countries. FAO Agricultural Service Bulletin No. 19 (2), 1984. Food and Agriculture Organization of the United Nations.

BOOK LIST

AGRIOS, G. N. (1969) *Plant Pathology.* New York: Academic Press. pp. 629.

BOSE, T. K. and SOM, M. G., (eds.) (1986) *Vegetable Crops in India.* Calcutta: Naya Prokash. pp. 755+xxiii.

DENNIS, C., (ed.) (1983) *Post-Harvest Pathology of Fruits and Vegetables.* London: Academic Press. pp. 264.

HERKLOTS, G. A. C. (1972) *Vegetables in South-East Asia.* London: George Allen and Unwin. pp. 525.

JONES, H. A. and Mann, L. K. (1963) *Onions and their Allies*. London: Leonard Hill. pp. 286.

PURSEGLOVE, J. W. (Revised 1985) *Tropical Crops*. Monocotyledons. New York: Longman. pp. 607.

RABINOWITCH, H. D. and BREWSTER, J. L., (eds.) (1990) *Onions and Allied Crops. Volume I, Botany, Physiology and Genetics*, pp. 273. *Volume II, Agronomy, Biotic Interactions, Pathology and Crop Protection*, pp. 320. *Volume III, Bichemistry, Food Science, and Minor Crops*, pp. 265. Boca Raton, Florida: CRC Press.

SALUNKHE, D. K. and DESAI, B. B. (1984) *Postharvest Biotechnology of Vegetables, Volume II*. Boca Raton, Florida: CRC Press, pp. 208.

SGARAVATTI, E., (ed.) (1986) *World List of Seed Sources*. AGP: SIDP/86/2. Rome: FAO. pp. 425.

SHERF, A. F. and MACNAB, A. A. (1986) (2nd edn) *Vegetable Diseases and their Control*. New York: John Wiley and Sons. pp. 728.

TINDALL, H. D. (1993) *Vegetables in the Tropics*. London: MacMillian. pp. 533.

YAMAGUCHI, M. (1983) *World Vegetables. Principles, Production and Nutritive Values*. Westport, CT: AVI Publishing Co. pp. 415.

APPENDIX 5 SHORT-DAY ONIONS: SEED SUPPLIERS AND CULTIVARS

Cultivar lists are those supplied by the seed firms or taken from the 1989 catalogues under the heading 'short-day onions' and no endorsement of the performance in the tropics of the varieties listed is intended by their publication here. Local trials are recommended.

Hybrid cultivars are denoted by the addition of [H]. Hybrids will not breed true if seed is saved from the bulbs grown.

Agroceres S/A CP 30723 01210 São Paulo SP Brazil	Baia Periforme Jubileu Pera IPA 1 Pira-Ouro Baiaouro AG-59 Baiadura AG-732
Agroflora S/A Rua Teodoro Sampaio, 2550 4o andar CEP 05406 São Paulo SP Brazil	Baia Periforme Baia Precoz Piracicaba Baia Super Precoz IPA 6 Pira Oro Sel. Pirana Sel. Texas Grano 502
Asgrow Seed Co. International Kalamazoo Michigan 49001 USA	Granex 33 [H] Granex 429 [H] Texas Grano 502 Texas Grano 502 PRR Texas Grano 1015Y Texas Grano 438 Contessa Dorada Perla

Associated Agricultural Development Foundation Kanda Batata Bhavan 2954-E, New Bombay Agra Rd Nasik 422 001 India	Agrifound Light Red Agrifound Dark Red Pusa Red Agrifound Rose
Bejo Zaden B.V. PO Box 50 1749 ZH Warmenhuizen The Netherlands	Patriot [H]
L Daehnfeldt Faborgwej 248 Postbox 185 DK 5100 Odense C Denmark	Texas Early Grano 502 PRR New Creole Dana Snowy
East-West Seed Co., Inc. PO Box 1187 Makati 1299 Metro Manila Philippines	Red Pinoy
Ferry-Morse Seed Co. Box 4938 Modesto California 95352-4938 USA	Sweetex [H] Granex Yellow PRR [H] Texas Early Grano 502 Texas Early Grano 502 PRR Red Creole Oro Grande [H] Ultra [H]
Gro-Trade (Pty Ltd) PO Box 508 Greytown 3500 Republic of South Africa	Texas Grano 502 PRR Red Creole Pyramid
Harris Moran Seed Co. 26239 Executive Place Hayward California 94545 USA	Hybrid 1036 [H] King Creole Red Creole C XII
Hazera Seed Co. PO Box 1565 Haifa 31015 Israel	Nissan [H] Barak [H] Galil (also called Grandstand) [H] Marathon [H] Moab [H] Anak [H] Granex 2000 [H] Yellow Granex Hazera [H] Arad [H] Atlas [H] Sivan [H] Granada [H] Ori Yodalef Niv Texas Grano 502 Texas Grano 502 PRR Haemek Granada Beth Alpha Autumn

Early Red
Red Synthetic
Dehydrator 86

Hygrotech Seed (Pty) Ltd
422 Skilder St
Silvertondale 1084
Republic of South Africa

Dessex [H]
Early Yellow Premium [H]
Gold Rush [H]
Gran Prix [H]
Henry's Special [H]
Special 38 [H]
Equanex [H]
Yellow Granex [H]
Pyramid
Hojem
Texas Grano 502

National Seeds Corp. Ltd
Beej Bhavan
Pusa Complex
New Delhi 110012
India

N-53
Pusa Red

Neuman Seed Co.
PO Box 1530
El Centro
California 92244
USA

Reina Blanca Z506 PRR [H]
White Granex PRR [H]
Z508 PRR [H]
Z513 PRR [H]
Nova PRR [H]
Yellow Granex 99 PRR [H]
Z218 PRR [H]
Z235 PRR [H]
Z238 PRR [H]
Z209 [H]
Z222 [H]
Z222 PRR [H]
Red Comet PRR [H]
Burgundy PRR [H]
Premium Yellow Grano PRR [H]
Crystal Wax/Bermuda White
El Toro PRR
L303 – Early White Eclipse
New Mexico White Grano
White Creole
White Grano PRR
White Pearl Barletta
New Mexico Yellow Grano PRR
Texas Grano 502
Texas Early Grano 502 PRR
Yellow Bermuda/986 Excel
Yellow Creole
Red Burgundy Improved
Red Creole C-5
Red Creole Select
Red Grano PRR

Nickerson-Zwaan B.V.
PO Box 19
2990 AA Barendrecht
The Netherlands

Granny X
NIZ 23-1001 [H]
NIZ 01-11 [H]
Everest

Nirdosh Seeds Co.
Miralam Mandi
Hyderabad 500 022
India

Nasik Dark Red
Pusa Red
Bunch variety

J. E. Ohlsens Enke A/S Roskildevej 325 A DK-2630 Taastrup Denmark	Yellow Granex [H] Trigon [H] Aristo Red Creole Rubina Excell Texas Early Grano 502 Texsano
Petoseed Co., Inc. PO Box 4206 Saticoy CA 93004-0206 USA	Equanex [H] Granex Yellow PRR [H] Creole Red Texas Yellow Grano 502 Select Granoble
Pocha Seeds Pvt Ltd Post Box No. 55 Near Sholapur Bazaar Poona 411 040 India	Bombay White Poona Red N-Early Red Nasik Red
Rio Colorado Seeds Ltd 4701 Gila Ridge Rd Yuma AZ 85365 USA	Rio Bravo [H] Rio Hondo [H] Sweet Georgia [H] Rio Enrique [H] Rio Ringo [H] Rio Estrella [H] Rio Grande [H] Yellow Granex [H] Texas Early Grano 502 PRR Ringer Grano Improved NuMex BR-1 NuMex Sunlite Rio Plata [H] Rio Jefe [H] Diaga [H] Rio Redondo [H] Rio Unico [H] Silver Spring Rio Blanco Grande Rio Raji Red [H] RCS 7524 [H] Burgundy Red Creole
Rotian Seed Co. PO Box 350 Arusha Tanzania	Ringo (ex Bombay Red) Credo (ex Red Creole) White Granex [H]
Royal Sluis Postbox 22 1600 AA Enkhuizen The Netherlands	Yellow Granex PRR [H] White Granex [H] Tropicana Red [H] Texas Early Yellow Grano 502 Texas Early Yellow Grano 502 PRR Red Creole (C5) White Creole PRR Yellow Bermuda Red Bombay
Seed Centre 4 Court Compound Market Ranchi 834001 India	NU-53

Simlaw Seeds Simpson & Whitelaw Ltd, PO Box 40042 Kijabe St Nairobi Kenya	Bombay Red Red Creole Texas Grano Tropicana [H]
Sluis en Groot B. V. PO Box 13 1600 AA Enkhuizen Netherlands	Texas Early Grano (and other standard varieties on demand)
Sunseeds Genetics, Inc. PO Box 1438 Hollister CA 95024-1438 USA	Dessex [H] Early Yellow Premium [H] Gold Rush [H] Gran Prix [H] Henry's Special [H] Special 38 [H] Yellow Granex [H] Yellow Granex Improved [H] Golden [H] Red Commander [H] Red Delight [H] Red Granex [H] Rojo [H] Tropicana [H] Brilliant [H] Early Supreme [H] Robust [H] White Granex [H] White Tampico [H] Dehydrator No. 3 [H] Dehydrator No. 5 [H] Primero White Creole PRR Burgundy California Early Red Red Creole C-5 Red Creole PRR PVP Red Grano Regal Crystal White Wax Early White Grano PRR Eclipse L303 El Toro Colossal Excel 986 Nu-Mex BR-1 Ringer Grano Texas Early Grano 502 Texas Early Grano 502 PRR Yellow Creole
Sutton & Sons (India) Pvt Ltd PO Box 9207 13D, Russell St Calcutta 700 071 India	Red Globe Nasik Red White Globe

Takii & Co., Ltd PO Box 7 Kyoto Central Kyoto, 600-91 Japan	Superex [H] Tropic Ace [H] Granex Yellow [H]
Arthur Yates & Co. Pty Ltd PO Box 72 Revesby Sydney NSW 2212 Australia	Early Lockyer Brown Gladalan Brown Supply Early Golden Globe Endeavour [H] Early Creamgold Early Lockyer White Lockrose White Savages Flat White Gladalan White Torrens White
Yates New Zealand Ltd PO Box 1109 Auckland 1 New Zealand	Yellow Granex PRR [H] Texas Early Grano 502 PRR Prelude Tropic Brown Red Creole C-5 Tropi Red
Samuel Yates Ltd Withyfold Drive Macclesfield Cheshire SK10 2BE UK	Discovery [H]
Zaadunie B. V. Westeinde 62 PO Box 26 1600 AA Enkhuizen Netherlands	Aldobo Cadix Alix Marix

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