Guidelines for pest management research to reduce stored food losses caused by insects and mites (ODNRI Bulletin No. 22)

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GUIDELINES FOR PEST MANAGEMENT RESEARCH TO REDUCE STORED FOOD LOSSES CAUSED BY INSECTS AND MITES

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Preface

This bulletin provides information and guidelines for research aimed to reduce food losses caused by insects and mites. It is based upon the experience of grain storage scientists at ODNRI but includes many references to other workers.

The guidelines should be of particular use to scientists in developing countries who undertake research on storage pest management. The short overview, which follows this preface, should assist agricultural development planners who may have opportunities to promote and support such research as a component of projects intended to increase food availability.

The bulletin deals specifically with insects and mites because, in many developing countries, these pests are clearly responsible for substantial losses which could be reduced. It relates mainly to stored food grains but also to other crop and livestock products which may be dried sufficiently for long-term storage: that is, all those which are susceptible to damage by storage insects and mites.

ODNRI Storage Department (Slough)
September 1988

Overview

OVERVIEW

The management of insects and mites on stored products: research guidelines

Losses in stored food crops due to infestation by insects and mites are substantial and sometimes susceptible to reduction; but cost-effective and sustainable loss reduction requires that pest management should be more completely integrated with storage management.

This bulletin outlines and discusses:

- some traditional concepts of pest management;
- the various factors which affect the status of insects and mites as pests of stored products;
- the currently available techniques for storage and for the control of insects and mites;
- the various factors and issues which determine the practical acceptabiliy and feasibilty of technological improvements in storage systems.

The relevant terminology, currently used to describe integrated pest management concepts, is defined and explained.

Appropriate general objectives for research on storage pest management are stated and suitable planning steps for research programmes are outlined.

The guidelines are intended:

(i) to outline the scope for integrated pest management (IPM) in the control of stored products insects and mites;

(ii) to indicate IPM objectives;

(iii) to guide storage scientists towards attainable research objectives;

(iv) to assist agricultural development specialists in their policy planning for stored products.

The importance of stored products

Durable agricultural products ('stored products') are basic materials with a traditional value that is greatly due to their suitability for storage. Cereal grains, especially, are critically important as human food. In developing countries much of the cereals production is by subsistence farmers for whom storage characteristics are particularly important.

The storage of durables is an essential and sometimes costly operation. Research is needed to optimize commodity management practices which, in most cases, must include insect pest management. There is considerable scope for the better use of conventional pesticides and their integration with other control measures. Thereby, the availability and acceptability of essential foodstuffs can be increased and the problem of insect resistance to pesticides, insofar as it stems from inefficient pesticide use, can be reduced.

Objectives for storage pest management

The pragmatic objective is to reduce losses of quality and quantity in stored commodities, especially foodstuffs; thereby increasing their availability and acceptability.

Technical objectives are:

(i) to reduce the status of a pest or pest complex, in a particular storage management system, to an economically acceptable level by compatible control measures;

(ii) to ensure that the control measures, including any pest monitoring procedures, are cost-effective in the particular system;

(iii) to ensure that negative environmental effects are minimized.

To achieve pest management objectives, the introduction of improved pest control procedures may be insufficient. Modification of the scale and location of storage facilities and, in some cases, of the intended storage period, may also be needed. Pest management methodology may need, therefore, to influence storage management decisions.

Losses in existing systems and possible loss reductions

Variations in storage losses are more closely related to climate and to the presence or absence of incentives for loss reduction than to the particular form or technique of storage.

Further work should be directed to situations in which losses are clearly susceptible to reduction and can be assessed in relation to the total costs of the modifications needed. Improvements must be both technically possible and clearly beneficial if they are to succeed.

Existing pest management systems

The control of insects and mites on stored products currently depends heavily upon the use of fumigants and residual pesticides. Such treatments are not always used compatibly and cost-effectively.

Prospective systems

Long-term possibilities depend heavily upon socio-economic development, especially in agriculture, marketing and agro-industry. These in turn are dependent upon sound and progressive development policies.

The development and implementation of improvements

To develop and implement pest management improvements, all relevant factors, in every particular situation, must be identified and their effects analysed. Factors of change, especially marketing incentives, are generally of crucial importance.

Agricultural marketing organizations have a key role in the development of incentives. National governments can influence such developments and international organizations and bilateral aid agencies can assist. Agricultural programmes with economically feasible, long-term development objectives are essential.

Extension services are also important and should give more attention to locally identifiable problems and to the costs and benefits of technically feasible improvements.

The investment of resources

The refinement of stored products pest management requires further applied research under practical storage management conditions. The investment of resources in pest management improvements should include substantial research inputs, but these must be judiciously applied, carefully directed and cost-effectively productive.

Research framework: the starting point

On socio-economic grounds pest management improvements are needed wherever a pest, or pest complex, is significantly reducing the quality or quantity of stored food products. However, pest management strategies must take account of planning and management objectives. Development plans and marketing operations, at the same time, should give more attention to pest management opportunities. A joint appraisal of the fundamental issues is generally needed.

Step 1 – identification of primary objective

This may be to increase the availability of a particular commodity but the underlying purpose must also be identified.

It may be: to achieve rural self-sufficiency;

or: to achieve national self-sufficiency, with opportunities for stock-piling and the export of possible surpluses;

or: to create an exportable surplus in response to a world market demand.

Step 2 – determination of storage management policy and commodity management requirements including pest management

For example:

- how, where and by whom is the commodity to be procured, stored, processed (if necessary) and transported (where necessary)?
- what are the targets for quantity and quality?
- will infestation be a constraint? – in particular, will insects and mites cause or contribute to direct or indirect losses of quantity and/or quality?
- what are the commodity management requirements in terms of staffing and equipment?
- should pest control operations be conducted by existing staff, extra staff or a specialist agency?

Probable targets for research can be identified. Possible situations include:

- staple food production, on smallholder farms, for on-farm storage and domestic or local consumption;
- cash-crop production (including food crops) on smallholder farms;
- cash-crop production on large farms;
- commercial importation of foodstuffs.

Each situation needs to be approached with the same research objectives but the eventual IPM solutions may be very different.

Research objectives should be:

(i) to reduce losses, of quantity and/or quality, and any other development constraints due to infestation by storage insects and mites;

(ii) to ensure that recommended procedures for pest control are mutually compatible, can be cost-effectively integrated with the production/marketing system and do not favour the development of resistance to pesticides;

(iii) to provide means whereby the procedures can be monitored, evaluated and modified when necessary so as to maintain their cost-effectiveness.

Research programmes should include the following steps:

(i) analysis of commercial objectives and constraints;

(ii) identification of any underlying socio-economic development objectives and any possible developments that might provide relevant incentives or reduce existing constraints;

(iii) investigation of the perceived pest problem in actual or realistically simulated situations;

(iv) assessment and evaluation of actual losses;

(v) adaptive research to test the efficacy, cost-efficiency and compatibility of available pest control techniques;

(vi) analysis of benefit/cost ratios and practical constraints for the various IPM options;

(vii) innovative applied research to develop alternative pest-control techniques if the available options are insufficient or if potentially feasible and preferable possibilities are identified.

Allocation of research responsibilities

The various organizations able to collaborate may include:

- in-country agricultural research stations;
- in-country development planning institutes;
- universities, in-country or overseas;
- in-country agricultural training colleges;
- in-country storage and marketing organizations;
- international agricultural research institutes
- natural resources development institutes, in-country or overseas.

In some cases it may be advisable to distribute the research responsibilities. University postgraduate departments or leading natural resources development institutes might best undertake innovative research whereas a local storage organization, if it has or can acquire sufficient expertise, might best undertake the loss assessment work. However, experienced technical direction of the work, including all in-country adaptive research and extension, will be needed.

VUE D'ENSEMBLE

Les grandes lignes de la recherche sur la gestion pour reduire les pertes de produits alimentaires stockées causées par les insects et les acariens

Les pertes sur les denrées stockées dues à une infestation par insectes et acariens sont importantes et peuvent parfois être réduites. Toutefois, une réduction efficace et soutenue de ces pertes exige d'intégrer davantage la lutte contre les nuisibles à l'exploitation du stockage.

Le présent bulletin présente et examine:

- certains concepts traditionnels de la lutte conre les nuisibles;
- les divers facteurs qui touchent à la situation des insectes et acariens en tant que nuisibles des denrées stockées;
- les techniques actuellement disponibles pour le stockage, ainsi que pour le contrôle des insectes et acariens;
- les divers facteurs et questions qui déterminent l'acceptabilité et la faisabilité pratiques d'améliorations technologiques dans les systèmes de stockage.

La terminologie pertinente actuellement employée pour décrire les concepts d'une lutte intégrée contre les organismes nuisibles est définie et expliquée.

Les objectifs généraux d'une recherche sur les nuisibles des denrées stockées sont énoncés et les diverses opérations ayant trait aux programmes de recherche sont exposées dans leurs grandes lignes.

Ces directives se proposent:

(i) de mettre sommairement en évidence la possibilité d'une lutte intégrée contre les nuisibles pour le contrôle des insectes et acariens des denrées stockées;

(ii) d'indiquer les objectifs d'une lutte intégrée contre les nuisibles;

(iii) de guider les chercheurs spécialisés dans le stockage vers des objectifs de recherche accessibles;

(iv) d'aider les spécialistes en développement agricole dans l'élaboration de leur planning pour les denrées stockées.

L'importance des denrées stockées

Les produits agricoles durables ('denrées stockées') sont des matériaux de base dont la valeur traditionnelle tient pour beaucoup à leur aptitude à se conserver. Les grains céréaliers, en particulier, revêtent une importance critique en tant que produit alimentaire destiné à l'homme. Dans les pays en voie de développement, une grande parte de la production céréalière provient de fermes autoconsommantes pour lesquelles les caractéristiques de stockage sont particulièrement importantes.

Le stockage de produits durables est une opération essentielle qui peut s'avérer coûteuse. Il faut entreprendre des travaux de recherche en vue d'optimiser les pratiques de gestion des marchandises, lesquelles doivent, dans la plupart des cas, comporter une lutte contre les insectes nuisibles. Le champ d'action pour une meilleure utilisation des pesticides conventionnels et leur intégration dans d'autres mesures de contrôle est considérable. Une telle démarche permettrait d'accroître la disponibilité et l'acceptabilité de denrées alimentaires essentielles et de réduire le problème de la résistance des insectes aux pesticides, pour autant que celui-ci découle d'une mauvaise utilisation des pesticides.

Ojectifs d'une lutte contre les nuisibles des produits stockées

L'objectif pragmatique est de réduire les pertes en qualité et en quantité des produits stockés, et plus particulièrement des denrées alimentaires, accroissant de ce fait leur disponibilité et leur acceptabilité.

Les objectifs techniques sont:

(i) de ramener la situation d'un nuisible ou d'un ensemble de nuisibles, dans un système particulier de gestion de stockage, à un niveau économiquement acceptable au moyen de mesures de contrôle compatibles;

(ii) de s'assurer que ces mesures de contrôle, y compris toute procédure éventuelle de surveillance des nuisibles, présentent un rapport coût-efficacité en relation avec le système en question;

(iii) de s'assurer que les effets négatifs sur l'environnement sont minimisés.

L'introduction de procédures de contrôle améliorées peut s'avérer insuffisante pour qu'une lutte contre les nuisibles atteigne ses objectifs. Il peut s'avérer également nécessaire de modifier l'envergure et l'emplacement des installations de stockage, ainsi que, dans certains cas, les durées de stockage prévues. C'est ainsi que les méthodes lutte contre les nuisibles peuvent parfois influencer les décisions relatives à la gestion de stockage.

Pertes dans les systèmes existants et réductions possibles des pertes

Les variations dans les pertes de stockage sont plus étroitement liées au climat et à la présence ou à l'absence d'encouragements visant à réduire les pertes, qu'à une quelconque forme ou technique particulière de stockage.

De plus amples travaux devraient s'orienter vers des situations où les pertes sont manifestement susceptibles d'être réduites et où elles peuvent être évaluées en fonction du coût total des modifications requises. Pour se voir couronnée de succès, toute amélioration doit être techniquement réalisable et présenter de nets avantages.

Systèmes existants de lutte contre les nuisibles

La lutte contre les insectes et acariens des produits stockés est actuellement largement tributaire de l'utilisation de fumigateurs et de pesticides à effet rémanent. De tels traitements ne sont pas toujours utilisés de manière compatible et rentable.

Systèmes éventuels

Les possibilités à long terme dépendent grandement des développements socio-économiques – notamment en agriculture, commercialisation et agro-industrie – lesquels sont à leur tour tributaires de politiques de développements sensées et progressistes.

Mise au point et introduction des améliorations

Pour mettre au point et introduire des améliorations dans une lutte contre les nuisibles, il convient d'identifier tous les facteurs s'y rattachant dans chacune des situations particulières et d'en analyser les effets. Les facteurs de changement, spécialement les encouragements à la commercialisation, sont généralement d'une importance cruciale.

Les organisations responsables de la commercialisation agricole ont un rôle-clé dans le développement de ces encouragements. Les gouvernements nationaux sont en mesure d'influencer de tels développements que les organisations internationales et les bureaux d'aide bilatérale peuvent ensuite appuyer. Il est essentiel d'avoir des programmes agricoles présentant des objectifs de développement à long terme qui soient économiquement réalisables.

Les services de vulgarisation sont également importants et devraient accorder davantage d'attention aux problèmes localement identifiables, ainsi qu'aux coûts et bénéfices des améliorations techniquement réalisables.

Investissement des ressources

Le perfectionnement d'une lutte contre les nuisibles des produits stockés exige un surcroît de recherche dans des conditions pratiques de gestion de stockage. L'investissement de ressources visant à améliorer une telle lutte devrait donc inclure des apports importants pour la recherche, mais il convient toute fois que ceux-ci soient appliqués avec discernation, dirigés avec attention et aussi qu'ils soient productifs en termes de coût et d'efficacité.

Cadre de la recherche: le point de départ

En termes socio-économiques, il convient d'apporter des améliorations à une telle lutte lorsqu'un nuisible, ou ensemble de nuisibles, réduit de manière significative la qualité ou la quantité de denrées stockées. Il faut, toutefois, que les stratégies d'une lutte contre les nuisibles prennent en considération les objectifs de planning et de gestion. Les plans de développement et les opérations de commercialisation doivent en même temps accorder davantage d'attention aux occasions propices à une telle lutte. Une appréciation mutuelle des questions fondamentales est généralement requise.

Opération 1 – identification de l'objectif premier

Il peut s'agir d'accroître la disponibilité d'une denrée particulière, ce que n'empêche que le but sous-jacent doit être lui aussi identifié.

Celui-ci peut être: la réalisation d'une autarcie rurale;

ou: la réalisation d'une autarcie nationale, avec possibilités de stockage et exportation des excédents éventuels;

ou: la création d'un excédent exportable en résponse à une demande du marché mondial.

Opération 2 – définition d'une politique d'exploitation de stockage et des besoins – lutte contre les nuisibles incluse – en matière de gestion des marchandises

Par example:

- comment, où et par qui la marchandise sera obtenue, stockée, transformée (si nécessaire) et transportée (où il le faut)?
- quels sont les objectifs en termes de quantité et de qualité?
- l'infestation sera-t-elle une contrainte? En particulier, les insectes et les acariens causeront-il ou contribueront-ils à des pertes directes ou indirectes en quantité et/ou en qualité?
- quels sont les besoins en matière de gestion des marchandises pour ce qui concerne le personnel et l'équipement?
- les opérations de contrôle des nuisibles devraient-elles être conduites par le personnel en place, du personnel supplémentaire ou une agence spécialisée?

Les objectifs probables de la recherche peuvent être identifiés. Les situations éventuelles comprennent:

- production alimentaire de base, sur de petites exploitations, pour un stockage sur place aux fins de consommation domestique ou locale;
- production de cultures de rapport (y compris cultures vivrières) sur de petites exploitations;
- production de cultures de rapport sur de grandes exploitations;
- importation commerciale de denrées alimentaires.

Chaque situation exige d'être abordée avec les même objectifs de recherche mais il se peut que les solutions de lutte intégrée contre les nuisibles soient chaque fois très différentes.

Les objectifs de recherche doivent être:

(i) de réduire les pertes en quantité, ainsi que toute autre entrave au développement résultant d'une infestation par insectes et acariens des denrées stockées;

(ii) de s'assurer que les procédures préconisées pour une lutte contre les nuisibles sont mutuellement compatibles, peuvent être rentablement intégrées au système de production/ commercialisation et ne favorisent pas le développement d'une résistance aux pesticides;

(iii) de fournir les moyens par lesquels ces procédures peuvent être contrôlées, évaluées au besoin en vue de rester rentables.

Les programmes de recherche doivent inclure les opérations suivantes:

(i) analyse des contraintes et objectifs commerciaux;

(ii) identification de tout objectif socio-économique sous-jacent et de tout développement éventuel susceptible de fournir des encouragements appropriés ou de réduire les contraintes existantes;

(iii) examen du problème du nuisible remarqué, la rentabilité et la compatibilité des techniques disponibles pour le contrôle des nuisibles;

(v) évaluation et estimation des pertes réelles;

(vi) analyse des rapports bénéfice/coût et des contraintes pratiques pour chacune des diverses options de lutte intégrée.

(vii) recherche appliquée innovatrice pour mettre au point des techniques de contrôle de remplacement si les options disponibles ne suffisent pas ou si d'autres possibilités potentiellement réalisables et préférables sont identifiées.

Attributions des responsabilités de la recherche

Parmi les diverses organisations en mesure de collaborer peuvent figurer:

- les stations de recherche agricole du pays;
- les instituts de planification du développement du pays en question;
- les universités, du pays en question ou étrangères;
- les collèges de formation agricole du pays;
- les organisations de commercialisation et de stockage du pays;
- les instituts internationaux de recherche agricole;
- les instituts pour le développement des ressources naturelles, du pays en question ou étrangers;

Il peut s'avérer souhaitable, dans certains cas, de répartir les responsabilités de la recherche. Les divisions universitaires du troisième cycle ou les principaux instituts pour le développement des ressources naturelles sont parfois mieux placés pour entreprendre des travaux de recherche innovateurs alors qu'une organisation locale de stockage, ayant ou pouvant acquérir les compétences requises, peut souvent mieux s'acquitter des travaux d'évaluation des pertes. Il est toutefois exigé que l'opération d'ensemble, travaux de recherche adaptative et de vulgarisation compris, s'effectuent sous une direction technique expérimentée.

RESUMEN

Gestion de insectos y acaros en productos almacenados: directrices de investigation

Aunque las pérdidas en cultivos alimenticios almacenados, como resultado de haber sido infectados por insectos y ácaros, son considerables, en algunos casos, su impacto puede reducirse. Sin embargo, toda reducción en las pérdidas que quiera poseer un carácter rentable y sostenible requerirá que la gestión de plagas quede más completamente integrada con la gestión de almacenamiento.

En este boletín, se presentan y examinan los puntos siguientes:

- algunos conceptos tradicionales de gestión de plagas;
- los distintos factores que afectan la condición de los insectos y ácaros como plagas de los productos almacenados:
- técnicas de almacenamiento y control de insectos y ácaros hoy día disponibles;
- diversos factores y problemas, que determinan la aceptabilidad y viabilidad prácticas de mejoras tecnológicas en los sistemas de almacenamiento.

Definición y explicación de la terminología apropiada hoy día en uso para describir conceptos integrados de gestión de plagas.

Se presentan asimismo los objetivos generales apropiados de investigación sobre gestión de plagas en productos almacenados, junto con las líneas generales de los pasos de preparación apropiados para programas de investigación.

Estas directrices tienen por objeto:

(i) delinear el alcance de una gestión integrada de plagas (GIP) en el control de insectos y ácaros encontrados en productos almacenados;

(ii) indicar los objetivos de la GIP;

(iii) orientar a los científicos del sector havia objetivos de investigación alcanzables;

(iv) prestar asistencia a los especialistas en desarrollo agrícola en la planificación de la política a seguir con los productos almacenados.

Importancia de los productos almacenados

Los productos agrícolas no perecederos ("productos almacenados") son materials básicos con un valor tradicional, debido en gran parte a su adecuabilidad para almacenamiento. En particular, los granos cerealeros poseen una importancia crucial como alimento humano. En los países en desarrollo, gran parte de la producción cerealera se encuentra en manos de agricultores de subsistencia, para quienes las características de almacenamiento poseen una importancia particular.

El almacenamiento de productos no perecederos es una operación esencial y, a veces, costosa, necesitándose la realización de trabajos de investigación, que tengan como objetivo la mejora de las prácticas de gestión de productos que, en muchos casos, deberán extenderse a la gestión de plagas, existiendo amplias posibilidades para un mejor aprovechamiento de los pesticidas tradicionales y su integración con otras medidas de control. Como resultado de ello, podrá conseguirse un incremento de la disponibilidad y aceptabilidad de productos alimenticios esenciales, a la vez que se reduce el problema de la resistencia de los insectos a los pesticidas, en tanto en cuanto es un resultado de un empleo ineficiente de dichos productos.

Objetivos para una gestión de las plagas que afectan a los productos almacenados

Desde un punto de vista pragmático, el objetivo deberá ser la reducción de pérdidas en la calidad y cantidad de los productos almacenados, especialmente de los productos alimenticios, con lo que se conseguirá incrementar su disponibilidad y aceptabilidad.

Objetivos técnicos:

(i) reducir la condición de una plaga o complejo de plagas, dentro de un sistema específico de gestión de almacenamiento, a un nivel económicamente aceptable mediante, medidas de control compatibles;

(ii) conseguir que las medidas de control – incluyendo cualquier procedimiento de supervisión de plagas – sea rentable, dentro de un sistema particular;

(iii) conseguir reducir al mínimo los efectos ambientales negativos.

Es posible que, para lograr los objetivos de la gestión de plagas, la introducción de procedimientos más adecuados de control no sea suficiente, pudiendo ser que se requiera también una modificación de la escala y ubicación de las instalaciones de almacenamiento y, en algunos casos, del período de almacenamiento proyectado. En consecuencia, puede que la metodología de la gestión de plagas tenga que influenciar las decisiones sobre gestión de almacenamiento.

Pérdidas en sistemas operativos y su posible reducción

Las variaciones en las pérdidas de almacenamiento se hallan más estrechamente relacionadas con el clima y con la presencia o ausencia de incentivos para reducción de pérdidas que con el método o técnica particular de almacenamiento.

Deberían realizarse nuevos trabajos dirigidos a situaciones en las que pueden claramente reducirse las pérdidas, realizando su evaluación en relación con los costes totales de las modificaciones requeridas. Para que tenga éxito, cualquier mejora deberá ser técnicamente posible y claramente beneficiosa.

Sistemas actuales de gestión de plagas

En la actualidad, el control de insectos y ácaros en los productos almacenados depende, en gran manera, del empleo de fumigantes y de pesticidas residuales, tratamientos que no siempre se utiliza de manera compatible y rentable.

Sistemas futuros

Las posibilidades a largo plazo dependen, en gran parte, de avances socioeconómicos, particularmente en agricultura, marketing y agrotécnica. Dichos avances dependen, a su vez, de la aplicación de políticas de desarrollo progresivas y bien fundadas.

Desarrollo y aplicación de las mejoras

Con objecto de desarrollar y llevar a la práctica mejoras de gestión de plagas, se hace necesario identificar todos los factores pertinentes, analizando sus efectos. Por regla general, los factores de cambio – particularmente, los incentivos de marketing – poseen una importancia crucial.

Las organizaciones agrícolas de marketing poseen un papel clave en el desarrollo de incentivos. Los gobiernos nacionales pueden ejercer su influencia sobre dicho desarrollo, al que también pueden prestar su asistencia las organizaciones internacionales y agencias de ayuda bilateral. Resulta esencial contar con programas agrícolas con objetivos económicamente viables de desarrollo a largo plazo.

Contando con una importancia similar, los servicos de extensión agraria deberían prestar mayor atención a problemas localmente identificables y a los costos y beneficios de la aplicación de mejoras técnicamente viables.

Inversión de recursos

El perfeccionamiento de la gestión de plagas en productos almacenados exige nuevos trabajos de investigación aplicada, bajo condiciones prácticas de gestión de almacenamiento. Si bien la inversión de recursos en mejoras de la gestión de plagas debería incluir una asignación importante al sector de la investigación, dicha asignación deberá ser juiciosamente aplicada, cuidadosamente dirigida y productivamente rentable.

Punto de partida: marco investigativo

Por razones de carácter socioeconómico, se hace necesaria la introducción de mejoras en la gestión de plagas siempre que une plaga o complejo de plagas lleve a una reducción significativa de la calidad o cantidad de los productos alimenticios almacenados. Valga apuntar, sin embargo, que toda estrategia de gestión de plagas deberá tomar en consideración objetivos de planificación y gestión. Al mismo tiempo, los planes de desarrollo y operaciones de marketing deberían prestar mayor atención a las oportunidades de gestión de plagas. En general, se necesita una evaluación conjunta de los problemas fundamentales.

Paso 1 – Identificación del objetivo primario

Ello podría ser el incremento de la disponibilidad de un producto particular, si bien se hace necesario identificar tambien el objetivo subyacente.

Ello podrá ser: la consecución de una autosuficiencia rural;

o: obtener una autosuficiencia nacional, con oportunidades de almacenamiento y exportación de posibles excedentes;

o: la creación de un excedente exportable, como respuesta a las demandas del mercado mundial.

Paso 2 – Determinación de la política de gestión de almacenamiento y requisitos de gestión de productos, incluyendo la gesión de plagas

Por ejemplo:

- modo, lugar y organización que deberá adquirir, almacenar, elaborar (si fuere necesario) y transportar (donde sea necesario) el producto;
- ¿Cuáles son los objetivos de cantidad y calidad a lograr?
- ¿Constituirá la infestación un obstáculo? En particular, los insectos y ácaros ¿causarán o contribuirán a que se produzcan pérdidas directas o indirectas de cantidad y/o calidad?
- ¿Cuáles son los requisitos de gestión de productos, en términos de personal y equipo?
- las operaciones de control de plagas ¿deberían correr a cargo del personal existente, personal adicional o de una agencia especializada?

Podrán identificarse objetivos probables de investigación, incluyéndose entre las situaciones posibles:

- producción de alimentos básicos en minifundios, para almacenamiento en explotación y consumo doméstico o local;
- producción de cultivos para la venta (incluyendo cultivos alimenticios) en minifundios;
- producción de cultivos para la venta, en explotaciones agrícolas de envergadura;
- importación comercial de productos alimenticios.

Si bien cada situación requiere los mismos objetivos de investigación, es posible que las soluciones GIP encontradas sean muy distintas.

Los objetivos de toda investigación deberían ser:

(i) la reducción de pérdidas cuantitativas y/o cualitativas, así como de cualquier otro obstáculo al desarrollo, resultante de la infestación con insectos y ácaros;

(ii) asegurar que los procedimientos recomendados para el control de plagas son compatibles, que pueden ser integrados rentablemente con el sistema de producción/marketing y que no favorecen el desarrollo de resistencia a los pesticidas;

(iii) proporcionar medios que permitan la supervisión, evaluación y modificación de los procedimientos cuando sea necesario, para mantener su rentabilidad.

Todo programa de investigación debería incluir los pasos siguientes:

(i) análisis de objetivos y restricciones comerciales;

(ii) identificación de todo objetivo de desarrollo socioeconómico subyacente y de cualquier posible desarrollo, que pudiera proporcionar incentivos adecuados o reducir obstáculos ya en existencia;

(iv) investigación del problema percibido en situaciones reales o simuladas de manera realista;

(v) evaluación de pérdidas reales;

(vi) investigación adaptiva para probar la eficacia, rentabilidad y compatibilidad de las técnicas disponibles para el control de plagas;

(vii) análisis de la relación coste/beneficio y de las restricciones prácticas para las distintas opciones de GIP;

(viii) investigación innovativa aplicada para el desarollo de técnicas alternativas de control de plagas, cuando las opciones disponibles sean insuficientes o cuando se identifiquen posibilidades potencialmente viables y preferibles.

Asignación de responsabilidades de investigación

Entre las organizaciones que podrían colaborar se cuentan:

- las granjas experimentales agrícolas del país;
- los institutos nacionales de planificación del desarrollo;
- universidades, nacionales o extranjeras;
- colegios nacionales de capacitación agrícola;
- organizaciones nacionales de almacenamiento y marketing;
- institutos internacionales e investigación agrícola;
- institutos para el desarrollo de recursos naturales, tanto nacionales como extranjeros.

En algunos casos, puede que resulte aconsejable la distribución de las responsabilidades de investigación. Los departamentos universitarios de postgraduados o institutos importantes para el desarrollo de recursos naturales podrían encargarse particularmente de trabajos innovativos de investigación, mientras que una organización local de almacenamiento – caso que cuente o pueda adquirir con suficientes conocimientos técnicos – podría dedicarse de manera más eficaz de la labor de evaluación de pérdidas. Esto no obstante, se necesitará también una experta dirección técnica de los trabajos, incluyendo toda labor nacional de extensión agraria e investigación adaptiva.

Chapter 1

Introduction

STORED GRAIN LOSSES

Insect pests of stored grain cause considerable, variable losses in many developing countries (*see* Tables 1-3). Experience has shown that such losses are not easily reduced in the absence of well-integrated policies and plans to develop the total system of production, marketing, storage and distribution (Tyler and Boxall, 1984). Ill-conceived plans for increased production can, on the contrary, result in greater storage losses.

The storage of food grains and other durable agricultural commodities, for human and animal consumption, is one element in a management system intended to supply, cost-effectively, acceptable food when and where it is needed. Acceptability standards may vary according to the circumstances but satisfactory quality and a sufficient quantity are essential. The control of storage pests is one activity contributing to the maintenance of both quality and quantity but the procedures used, in each case, must suit the particular purpose and show a clear benefit.

Table 1

Examples of comprehensive studies to measure storage losses at the farm level

Country	Crop	Period of storage (months)	Cause of loss	Estimated percentage loss of weight and range	Reference
Zambia	Maize	7	Insects	1.7 to 5.6	Adams & Harman, 1977
India	Paddy	7	Insects, rodents, mould	4.26 ± 1.33	Boxall *et al.*, 1978
Kenya	Maize	up to 9	Insects, rodents	3.53 ± 0.25	de Lima, 1979
Malawi (2 districts)	Maize	up to 9	Insects	3.2 ± 3.4 1.8 ± 3.5	Golob, 1981
	Sorghum	up to 9	Insects	1.7 ± 0.5	
Nepal	Maize	6	Insects, rodents	5.7 ± 3.2	Boxall and Gillett, 1982
	Wheat	3	Mould	2.4 ± 1.9	
	Paddy	8	Insects	3.4 ± 2.2	
Turkey	Wheat	8	Insects, mould	3.7 ± 1.9	Boxall (pers. comm.)
Tanzania	Maize	3–6.5	Insects	8.7	Hodges *et al.*, 1983
Swaziland	Maize	unspecified	Insects Moulds Rodents	3.66 0.53 0.16	de Lima, 1982
Bangladesh	Raw and parboiled paddy	3–4	Insects, rodents	2.4 (rice equivalent) (average for 3 crop seasons)	Huq, 1980
Honduras	Maize	7	Insects	5.5	de Breve *et al.*, 1982

Source: (Tables 1–3): Tyler & Boxall (1984)

Note: The relatively high % loss shown here for Tanzania represents the situation in Tabora region following the outbreak of infestation by the new pest *Prostephanus truncatus* and before the initiation of the current control campaign.

Table 2

Examples of comprehensive studies to measure various post-harvest losses at the farm and village level

Country	Crop	Stage	Cause of loss*	Estimated percentage loss of weight and range	Reference
Dominican Republic	Paddy/rice	Harvesting/ threshing	Incomplete threshing Scattering	18.1 ± 13.0	la Gra *et al.*, 1982
Malaysia	Paddy/rice	Harvesting	Shedding	1.5	Calverley *et al.*, 1977
		Threshing	Unthreshed grain on straw	9.2	
Philippines	Paddy/rice	Harvesting		1-3	de Padua, 1974
		Handling		2-7	
		Threshing		2-6	
		Drying		1-5	
		Storage		2-6	
		Milling		2-10	
Bangladesh	Rice	Harvesting		1.5	Greeley, 1982
		Field stooking		0.5	
		Transportation		0.5	
		Threshing		1.8	
		Storage		2.6	

Source: (Tables 1–3): Tyler & Boxall, 1984

Note: *Cause undefined except where stated otherwise.

Table 3

Examples of comprehensive studies to measure various post-harvest losses at the commercial level

Country	Commodity	Stage	Cause of loss	Estimated percentage loss	Reference
Cuba	Various processed foodstuffs	Storage (3 months)	Rodents	1.0	Hernandez & Drummond, 1984
Cyprus	Barley and wheat	Storage (3.5 months)	Insects	3.54	Tyler, 1981
Mali	Millet	Storage (8 months)	Insects	1.0	Rowley, 1984
Dominican Republic	Paddy/rice	Drying (rice mill)	Breakage	8.1% reduction in whole grain	la Gra *et al.*, 1982
		Milling	Breakage	2.3% reduction in whole grain	
		Public sector storage	Spillage	0.35	
Pakistan	Paddy	Market storage	Various	1.8	Chaudhry, 1980
		Wholesale storage	Various	3.2	
		Public sector storage	Various	3.0–5.0	
		Processing (milling)	Various	4.0–6.0	
	Wheat	Processing	Various	2.06	
	Maize	Processing	Various	2.5	

Source: (Tables 1–3): Tyler & Boxall (1984)

SCOPE AND PURPOSE

Storage pest management, as an aspect of commodity management (Evans and Graver, 1987), should be an integral part of the total production-distribution system. Pest management research, in this area, needs to take account of the objectives of the system and its constraints. Likewise, production plans and marketing operations should give more attention to the opportunities for cost-effective pest management.

The following material is intended:

(i) to outline the scope for integrated pest management (IPM) in the control of stored products insects and mites;

(ii) to indicate IPM objectives;

(iii) to guide storage scientists towards attainable research objectives;

(iv) to assist agricultural development specialists in their policy planning for stored products.

THE IMPORTANCE OF STORED PRODUCTS AND THE NEED FOR RESEARCH

Durable agricultural products (stored products) are commodities of plant or animal origin that can be dried, naturally or artificially, to a moisture content at which they can be stored safely so long as they are sufficiently protected. They are basic commodities, in domestic use and in commerce, and their traditional value is greatly due to their suitability for storage.

Cereal grains, especially, are critically important as human food. In developing countries they comprise more than 75% of the basic staples, by weight, and provide more than 60% of the per caput energy intake. Much of the production is by subsistence farmers for whom the storage characteristics of the grain are particularly important.

Other important stored products include pulses, dried cassava, oilseeds and dried fish.

The storage of durables is an essential and sometimes costly operation. Research is needed to optimize commodity management practices which, in most cases, must include pest management. Losses due to pests can only be contained at an economically acceptable level by control measures based upon knowledge of the biology and ecology of the pests and a better understanding of their responses to control measures. The increasing resistance of insect pests to contact insecticides and fumigants is a major problem. There is, however, considerable scope for the better use of conventional pesticides and their integration with other control measures. The integration of various control techniques, which has come to be known as integrated pest management, has become a focus for research in stored products work (Evans, 1987a), as in other areas.

INTEGRATED PEST MANAGEMENT (IPM)

The term integrated pest management has been variously defined, and one aspect is sometimes overlooked. For pest management to be completely integrated it is essential that the programme of control measures, whether it be simple or complex, should be fully integrated into the operational management system which it is intended to serve. Research that does no more than demonstrate how various control techniques can be integrated with each other is unlikely to be put to practical use. Research must also show how the proposed package of control measures can be made to fit the operational system and, most important, must be able to meet the functional objectives of that system which will include cost-effectiveness.

INSECTS AS PESTS OF STORED PRODUCTS

Insects are commonly the most significant pests of stored products. Unlike rodents and birds they are not easily excluded from stores by physical barriers and they are well adapted to life in the characteristically dry storage environment. Durable commodities, when fit for storage, form a micro-environment in which the relative humidity is below 70%. So long as this can be maintained, they are relatively safe from bacteria and moulds but not from storage insects. Moreover, in the course of their development, these latter pests produce heat and moisture which may lead to the re-establishment of moulds and other micro-organisms.

Climatic conditions in the tropics favour a considerable range of important insect pests (*see* Table 4). Insect development generally proceeds fastest in the range 25-30°C. Developmental periods, from egg to adult, are then about 4-5 weeks. Multiplication rates are likely to be at least tenfold per generation and are potentially much higher. Humidity also affects the development of insect infestation. High humidity favours most insects and also permits mould growth which attracts a wider spectrum of insect pests (*see* Table 5). Conversely, crops harvested and stored at very low moisture content, as in regions where the climate is exceptionally dry, will be less rapidly damaged by most storage insects. However, dry conditions will tend to favour a few species, such as *Rhyzopertha dominica* and, especially, *Trogoderma granarium*, which are particularly well adapted to dryness.

In extremely adverse conditions of low humidity, low temperature or food scarcity, some storage insects are able to survive for long periods in a relatively inactive state. The classic example is *T. granarium* which, in the larval stage, can survive without food for many months.

In the absence of effective control measures, the only factors that will limit insect multiplication are temperatures above or below the optimum range, overcrowding on a restricted food supply and competition from other organisms. Predators, parasites or pathogens may sometimes dramatically suppress insect population growth. This commonly occurs, in practical storage situations, only where pest populations have reached such high levels that the damage to the commodity may be unacceptably high. Nevertheless, some of these agents of biological control do have potential relevance in pest management

Table 4

Important insect pests of tropical stored products

COLEOPTERA:	ANOBIIDAE	*Lasioderma serricorne* (F.)
	BOSTRICHIDAE	*Rhyzopertha dominica* (F.) *Prostephanus truncatus* (Horn)*
	BRUCHIDAE	*Acanthoscelides obtectus* (Say) *Callosobruchus* spp. *Zabrotes subfasciatus* Boheman
	CUCUJIDAE	*Cryptolestes* spp.
	CURCULIONIDAE	*Sitophilus oryzae* (L.) *S.zeamais* Motschulsky
	DERMESTIDAE	*Trogoderma granarium* Everts** *Dermestes* spp.
	SILVANIDAE	*Oryzaephilus surinamensis* (L.)
	TENEBRIONIDAE	*Tribolium casteneum* (Herbst)
LEPIDOPTERA:	GELECHIIDAE	*Sitotroga cerealella* (Olivier)
	PYRALIDAE	*Ephestia cautella* (Walker) *Plodia interpunctella* (Hubner)

Notes: * Now established in Africa as well as in the Americas.
** Common only on very dry grain; especially in Sahelian North Africa.

Table 5

Insect species (additional to those in Table 4) found on underdried stored products or their residues

COLEOPTERA:	ANTHRIBIDAE	*Araecerus fasciculatus* Degeer
	BOSTRICHIDAE	*Dinoderus* spp.
	BRUCHIDAE	*Bruchidius* spp. *Specularius* spp.
	CLERIDAE	*Necrobia rufipes* Degeer *Thaneroclerus buqueti* Lefevre
	CRYPTOPHAGIDAE	*Henoticus californicus* (Mann.) *Cryptophagus* spp.
	DERMESTIDAE	*Attagenus* spp. *Dermestes* spp.
	LATHRIDIIDAE	*Corticaria* spp. *Lathridius* spp.
	MYCETOPHAGIDAE	*Typhaea stercorea* (L.)
	NITIDULIDAE	*Carpophilus* spp.
	OSTOMIDAE	*Tenebroides mauritanicus* (L.)
	PTINIDAE	*Ptinus* spp.* *Trigonogenius* spp.* *Gibbium* spp.
	SILVANIDAE	*Cathartus quadricollis* (Guerin)
	TENEBRIONIDAE	*Alphitobius* spp. *Gnatocerus* spp. *Palorus* spp.
LEPIDOPTERA:	OECOPHORIDAE	*Endrosis sarcitrella* (L.)*
PSOCOPTERA:		*Liposcelis* spp.

Note: * Common only in cool upland tropics.

and their possible uses, together with the uses of other biological methods, should not be overlooked.

Storage insects are generally quite small. Most are about 2-3 mm long and the largest, such as warehouse moths and the 'cadelle' beetle (*Tenebroides mauritanicus*), have a body length not more than about 1 cm. The damage done by a single insect, in terms of actual food consumption, is generally quite little. In the grain weevils, for example, it amounts only to some 10-20 mg, per insect, during the larval feeding stage. It is the capacity for very rapid population growth that makes insect infestation a major cause of food loss in storage.

Smallness of size also makes most storage insects relatively inconspicuous except when very numerous. Reports of sudden insect infestation in stored commodities are commonly due to a failure to observe the insects until the numbers present are already dangerously large. Detection of storage insects at low population densities is made more difficult by their non-random distribution in the infested commodity.

In order to deal effectively with insect infestation and prevent the problems and losses that it causes, there is need for considerable refinement of existing control methods and for the development of more fully-integrated pest management programmes.

MITES (ACARINA) AS PESTS OF STORED PRODUCTS

The mites associated with tropical stored products (*see* Table 6) are less well known than storage insects but the need for more attention to be paid to mites in pest management programmes is becoming more widely recognized. Predatory mites, as factors in the control of insect populations, may be of particular interest.

Table 6

Important mites (Acarina) associated with tropical stored products

SARCOPTIFORMES:	*Acarus* spp. *Glycyphagus* spp. *Suidasia* spp. *Tyrophagus* spp.
TROMBIDIFORMES	*Acarophenax* spp.* *Acaropsis* spp.* *Cheyletus* spp.*
PARASITIFORMES	*Blattisocius* spp.*

Note: * Predators on other mites or insects.

Losses caused by mites in storage have been little studied, but it has been found that the nutritive value of pig feed heavily infested by *Acarus siro* is seriously reduced. Mites may also cause allergic responses in animals eating infested feedstuffs and in workers handling them. Pest management strategies for stored products must certainly take account of mites as well as insects.

INTERACTIONS WITH OTHER PESTS

The main thrust of this bulletin is towards the development of storage management programmes which incorporate improved strategies for the prevention or reduction of losses caused by insects and mites. However, the interactions between these arthropod pests and moulds, which are also a major problem in many areas, must not be forgotten. It is essential that management strategies for the control of insects and mites should take full account of associated infestation problems; including not only moulds and mycotoxins but also rodents and birds.

INTERACTIONS WITH COMMODITY MANAGEMENT AND STORAGE MANAGEMENT

The following treatment of storage pest management is commodity-related because, in most situations, the nature of the pest complex is largely determined by the nature and condition of the stored commodity. This, in turn, is largely determined by the form and effectiveness of storage management. In this context, storage management means management of the production, procurement and eventual distribution of the stored product. Ideally, it includes commodity management, to optimize the storage characteristics of the commodities to be stored, and it should avoid unnecessarily protracted storage as well as the use of unsuitable storage locations.

PATTERNS AND PERIODS OF STORAGE

The spatial distribution of stored commodities (i.e., the location and scale of storage sites) and the periods for which they are stored are largely determined by the needs of the supply system, which generally relate to commercial objectives. Storage patterns and periods will clearly have a significant effect upon the nature and extent of storage pest control problems.

For non-staple cash crops, such as groundnuts, other oilseeds, and coffee and cocoa, storage is a largely commercial undertaking. Patterns and periods of storage are generally related closely to marketing opportunities.

For cereal grains, in developing countries, the common pattern of storage leaves 70% or more of the grain in storage at the farm level, the remainder being stored regionally in supply depots operated by grain marketing authorities, private traders and grain processors. There are some exceptions. In Africa, for example, the proportion of the maize crop procured by the marketing authority in Zimbabwe is greater; in Sudan, a large part of the sorghum crop is procured, mainly for export, by private traders; in Kenya, the wheat crop is almost entirely procured by the marketing authority and, after a period of on-farm storage, is held in buffer depots or at wheat mills. Comparable exceptions occur elsewhere.

Storage periods, in developing countries, are generally in the range 6-12 months, except in areas climatically suited to the production of a second crop, where the period may be 4-6 months. In Ethiopia and Sudan, considerable quantities of sorghum may be stored for 1-2 years or longer by trader-farmers, commonly in large underground pits. Long-term storage is generally a speculative investment with eventual profit, in times of grain shortage, as the objective. In such circumstances quality conservation, including pest control, is not usually a major concern and losses may be considerable. The same is true of the storage of feed grain. In Sudan, considerable stocks of sorghum, held in traders' stores for eventual export, suffer very heavy damage by the Khapra beetle (*Trogoderma granarium*). In several parts of South-East Asia, cassava stocks, for use in animal feeds, also suffer heavy insect infestation.

Extended storage, as a long-term safeguard against the risk of periodic grain shortages ('strategic storage'), is a matter of concern to national governments as well as a means of profit to speculative traders. Many countries have undertaken, or are planning, programmes to this end. Kenya, for example, began to maintain a considerable maize grain reserve (initially about 100,000 tonnes) in the early 1970s. Indonesia has recently increased its minimum rice stock reserve considerably. Storage periods, in these instances, may be of 2-3 years' duration and, technically, might be even longer.

THE INFLUENCE OF CLIMATE ON STORAGE

Storage periods are affected by climate primarily through climatic influences on crop frequency, but the interaction of climate and period also affects storage technique. In very dry climates, storage structures may be considered superfluous. For example, very large stocks of grain are held relatively safely in open-air stacks in Sudan. Alternatively, the dryness of the grain may facilitate hermetic storage (*see* p. 19). In humid climates, or during a rainy season, some form of protective cover or enclosure is essential. Where the storage period spans a wet season and a dry season, storage structures may need seasonal modification (Golob, 1984).

The relationship between climate and storage pattern is of particular interest for centralized storage. Within an administrative region there may be considerable climatic variation which affords some opportunity to choose locations for storage with regard to climate as well as to logistics. In general, the latter consideration tends to override others. This may be sensible so long as the storage organization can provide the necessary equipment and management experience to cope with pest control at locations where the climate is conducive to infestation. However, agricultural development plans that require increased storage capacity should give attention to the influence of climate when considering the location of storage sites. There are many medium-to-high altitude locations in the tropics where the ambient temperature at night is much lower than it is during most of the day. Where the temperature fluctuations give early morning air temperatures below 20°C there are useful possibilities for grain cooling by selective aeration (Gough and McFarlane, 1984). This technique is most applicable in centralized storage where the use of mechanically aerated storage bins should be feasible. In arid regions there are also opportunities for cost-effective climatic control (Calderon *et al.*, 1989).

TRADITIONAL CONCEPTS OF STORAGE PEST MANAGEMENT

Several elementary concepts of pest management are commonly applied, to a greater or lesser extent, in all storage systems including those used by smallholder farmers and rural traders. They represent elements of pest management which exist in most traditional storage systems. It is essential that these traditional elements should be taken into account and, where possible, built upon in the development of improved strategies.

1 The concept that material should be selected for storage on the basis of fitness with regard to the storage period

The material to be stored is commonly selected for soundness (i.e., freedom from mechanical damage, weather damage and previous pest damage) and dryness. If it is not sufficiently dry it is further dried before storage or by aeration in store. Greater 'fitness' is required where the intended storage period is relatively long.

2 The concept that storage periods should be limited to the shortest possible time

Smallholder farmers, storing food grains for their own use, commonly find that the storage period is predetermined by the cropping season. Where possible, they may take advantage of bi-modal rainfall patterns to plant a second foodgrain crop each year. A reduction of the storage period from 10-12 months to 4-6 months, especially in tropical climates, greatly reduces the significance of storage insect pests.

Traders, including farmers who market their own products, commonly dispose of their goods, if they can, before infestation becomes evident. However traders and larger commercial storage organizations may sometimes take the risk of protracted storage if they are reasonably sure of an eventual profit. Long-term storage is most commonly practised where the level of quality acceptable to the eventual user is relatively low.

3 The concept that cooling will reduce infestation

In most situations, any reduction of temperature in the stored product will retard intrinsic deterioration. Reduction to below 20°C will also reduce insect multiplication rates. Regular cooling, either by forced aeration with naturally or artificially cooled air, or by exposure to low overnight temperatures in ventilated storage structures such as traditional 'crib' stores, is necessary to maintain the effect because insect activity will not be entirely prevented at temperatures near 20°C. The limited insect activity will still produce heat which will accumulate unless removed. Grain temperatures need to be reduced below 17°C if insect activity is to be more completely prevented. Even this target may be attainable, by aeration or outdoor storage, in those tropical regions where the altitude exceeds 1500-2000 m. Unfortunately, the common risk of theft, in many parts of the world, discourages outdoor storage.

The concept of grain cooling must be applied with caution in situations where store temperatures are so high (>40°C) that most insect pests are unable to survive, but where the stored grain, unless intended for use as seed, will not suffer severe damage. In such circumstances, limited cooling may serve only to lower the temperature to a range more optimal for insect infestation (Prevett, 1961a). Intrinsic spoilage will be retarded but efficient insect control will become more necessary.

4 The concept that heating, to a sufficiently high temperature, can disinfest grain without spoiling it

Farmers in many parts of the tropics use 'sunning' as a means of driving out insects from infested grain and, perhaps, in an attempt to kill any larvae which may be inside the grains. In practice, the technique may or may not be effective, depending upon whether or not the grain is spread sufficiently thinly and exposed to the sun for a long enough period. Enhanced effects can be achieved by the use of simple solar dryers and, in more sophisticated systems, by the use of mechanical hot-air dryers. Other methods of heating may also be used; small quantities of grain can, for example, be heated over a fire.

In large-scale storage, tightly built bagstacks of infested grain may, eventually, be largely disinfested by the rise in temperature caused by the infestation. Insect infestation, in the low-altitude tropics, quite soon generates temperatures approaching 40°C. As a means of control this may be somewhat questionable, but it has been advocated in the past as an emergency measure (T.A.Oxley, private communication) and has been seen to be effective in some instances.

5 The concept of store hygiene and site sanitation as a means of reducing infestation

Store hygiene is commonly advocated as an essential prerequisite for the control of storage insects. However, high levels of store hygiene may be difficult to achieve and may have insufficient impact on insect infestation in crops harvested in tropical regions. A good standard of orderliness and cleanliness is generally desirable for many reasons, but intensive store hygiene may not always be economically justifiable. In tropical climates, practical store cleaning measures are unlikely to solve the infestation problem completely. Improved hygiene in farm stores, where it can be maintained cost-effectively over a considerable area, can be expected to reduce pre-harvest infestation by storage insects, but the possible benefits have yet to be demonstrated in practice. This and other unproven benefits of intensified store hygiene warrant more research in the IPM context.

DEFINITIONS

The following terms have been widely used in relation to the management of pre-harvest crop pests. The definitions given here accord, as far as possible, with those given elsewhere, but are modified where necessary to make them more precisely relevant to storage pest management.

Pest status This describes the importance of a pest in a particular set of circumstances.

The status of any pest may vary, according to the circumstances. The general objective of pest management is to reduce the status of a specific pest, together with any associated pest complex, by altering the circumstances.

Economic damage This means any damage that results in an economically significant loss of quality or quantity.

In pre-harvest pest management it is sometimes possible to distinguish low levels of pest damage, for which the growing plant is able to compensate, from those levels of damage which cause a yield reduction. A threshold for economic damage in the development of infestation, sometimes referred to as the economic injury level, may thus be discernible. In post-harvest infestation, the threshold of economic damage is, technically, zero because any visible or measurable damage caused by a pest is, potentially, of economic significance. The harvested commodity has little or no ability to repair or compensate for the damage. However, in practice and depending upon consumer sensitivity, it is sometimes justifiable to consider economic damage thresholds, for storage pests, above zero. For example, a very low percentage of insect-damaged grains may have no measurable effect upon food value and may thus have no economic significance unless consumer standards put a financial value upon complete freedom from pests and pest damage.

Economic control threshold This is the level of pest damage which justifies, in cost/benefit terms, the expenditure of resources on pest control actions (Hebblethwaite, 1985). It is a variable threshold because the costs and the benefits, for any particular action, are situation-specific. An analysis of costs and benefits, including those upon which it may be difficult to set a monetary value, is necessary in each different case.

Integrated control This term is used here to describe cost-effective pest control procedures, which may or may not involve several techniques, that are integrated into the storage management system and fully suit the objectives for storage as well as the technical capability of that system.

Integrated pest management (IPM) This means the application of integrated control, as defined above, based upon scientific and cost-effective pest monitoring procedures which permit judicious adjustments to the timing, choice and intensity of control actions so as to maximize economic benefits. IPM should be demonstrably cost-efficient and must be subject to appropriate, periodic evaluation. It implies the existence of a commodity (or crop) management system that incorporates a sufficient and cost-effective input of specific pest control techniques. In some situations the specific pest control techniques may be minimal.

PEST MANAGEMENT OBJECTIVES

In storage pest management the pragmatic objective is to prevent or reduce losses of quality and quantity in stored commodities, thereby increasing the availability and acceptability of, for example, essential foodstuffs.

Technical objectives are:

(i) to reduce the status of a pest or pest complex, in a particular storage management system, to an economically acceptable level by compatible control measures;

(ii) to ensure that the control measures, including any pest monitoring procedures, are cost-effective in the particular system;

(iii) to ensure that negative environmental effects are minimized.

To achieve these objectives, the introduction of improved pest control procedures within an existing storage system may be insufficient. Modification of the scale and location of storage facilities and, in some cases, of the intended period of storage may also be needed. Pest management methodology may need, therefore, to influence storage management decisions.

Chapter 2

Factors affecting pest management

DEVELOPMENT PLANNING

Norton (1986) has drawn attention to the need for a 'strategic approach' to pest management problems in agricultural development planning. Such an approach should take account of post-harvest pest problems. Crop production and marketing policies greatly affect national storage requirements, but development plans do not always sufficiently consider the problems of storage management; especially the questions of storage pattern and period. If these aspects are taken into account, then definitive decisions on the techniques of storage, including integrated pest control, should be more easily made.

No particular storage or pest control technique is necessarily more efficient and cost-effective than any other. Choices between techniques, if they are intended to select those that are most appropriate and potentially cost-effective for particular situations, should be made on the basis of comprehensive analysis and long-term planning.

THE STORAGE SYSTEM

The efficiency of storage management, both in centralized storage and in storage at the farm level, generally determines the magnitude of the losses which occur. Efficient management will keep losses within a range that is economically acceptable to the particular purposes of the storage system. It will rarely try to reduce them further unless a clear economic benefit becomes apparent.

The storage system itself will largely determine the extent to which losses are susceptible to reduction. Loss reduction in practice requires management decisions on the probable cost-effectiveness of technical improvements. The decisions will be influenced by any actual or predictable changes in the immediate management objectives. Such changes may occur within the system or may originate elsewhere: a requirement for an improvement in product quality is commonly extrinsic; a decree that economies must be made may be intrinsic or extrinsic. These are factors of change which are often crucial to the implementation of enhanced pest management.

In both on-farm storage and off-farm storage a key issue for management decision is the pattern (location and scale) of storage. The pattern is commonly determined by the purpose of storage which may also determine the required storage period. However, if the purpose of storage is speculative trading, then the period will be less clearly defined.

CUSTOMARY PRACTICES

Pest control methods should also relate to the purpose, pattern and period of storage, but they are commonly chosen on the basis of past experience. This will include, in many cases, traditions which may be more or less obscure: commercial storage traditions being, sometimes, no less obscure than those which influence domestic storage. Thus, a conventional reluctance to use impermeable packaging or stack covers, as a protection against reinfestation by insect pests, may stem from past experience of practical problems which might now be overcome. The common domestic practice of storing maize cobs in cribs over the cooking hearth may be beneficial, both for drying purposes and for the control of insect infestation, but whether or not it gives any significant benefit when large quantities of cobs are so stored is rather doubtful.

OTHER FACTORS

Storage techniques, including pest control methods and the form of storage structures and containers, are much influenced by the local availability of suitable materials, manpower and investment capital. In this respect, on-farm storage is commonly more tightly constrained than centralized storage; whether this be in the public or private sector. Centralized storage facilities are commonly located near urban centres, where materials, labour and skills may be more readily available. They are often financed, directly or indirectly, from resources that are more substantial than those available to the average farmer.

THE IDENTIFICATION OF RELEVANT FACTORS

Attainment of pest management objectives will generally require an analysis of all the interacting factors which affect the target situation: that is the particular storage system, its objectives and its circumstantial constraints. Figure 1 indicates in general terms the common key factors and their range of interactions.

Figure 1

Factor interactions and key issues for pest management and loss reduction in grain storage

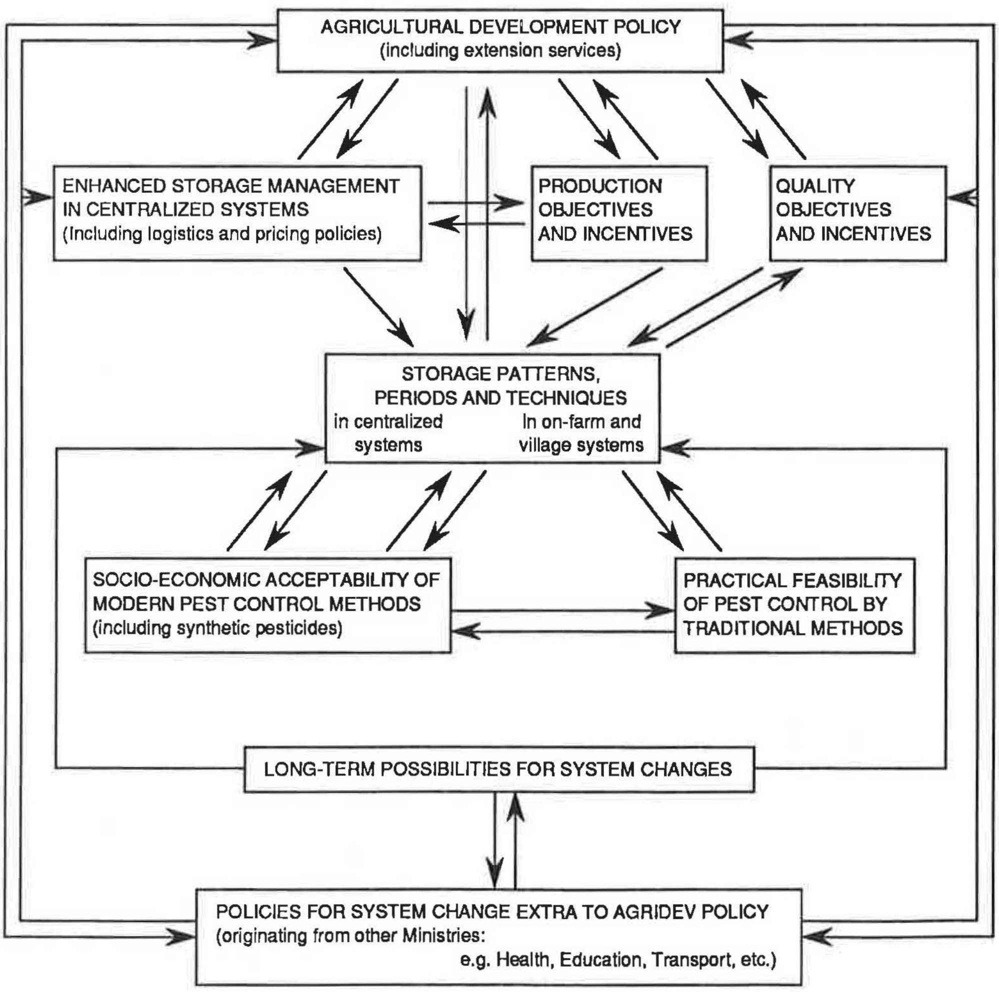
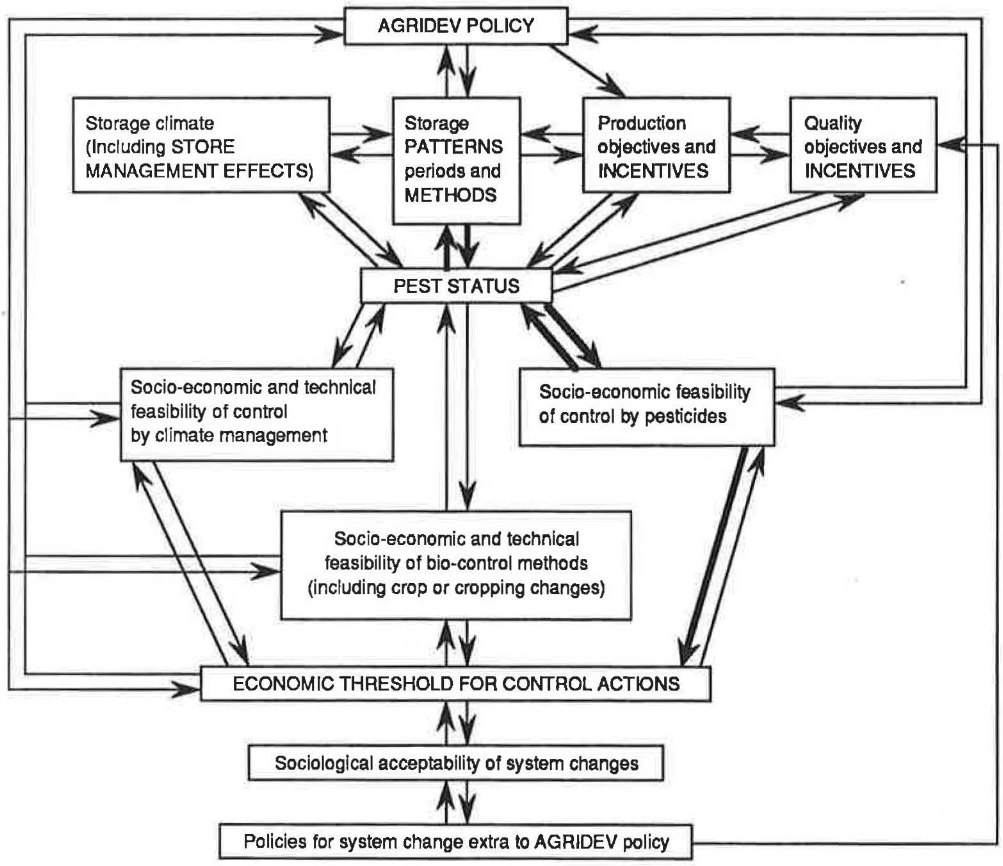


Figure 2 includes some more particular factors in a specific case, and draws attention to pest status and the economic threshold for control as major issues which also interact as factors in the analysis. These pest management issues may strongly influence other factors. Figure 2 relates to the larger grain borer (*Prostephanus truncatus*) control programme in East Africa, where the economic threshold for control actions, by smallholder farmers, was exceeded by the damage levels that occurred when this new pest became established. The pest status of this insect appears to have influenced Tanzanian farmers towards the adoption of modified techniques, including the use of suitable contact insecticides. Elsewhere, or in the future, storage patterns also may be affected by the status of this pest. A move away from on-farm storage to more centralized storage, where feasible, could considerably increase the options for pest management. Whether or not the current control strategy for *P.truncatus* will prove cost-effective in the long term remains to be seen. The probable need for a more broadly-based pest management strategy has been indicated (Hodges, 1986; McFarlane, 1988).

Figure 2

Factor interactions and key issues in pest management for *Prostephanus truncatus* in Africa



Source: McFarlane (1988)

INTERACTIONS BETWEEN PEST STATUS AND THE INTENSITY OF CONTROL

Pest status is itself affected by any significant change in storage technique and by the intensity of the applied pest control measures. The socio-economic feasibility of control by pesticides (*see* Figure 2) is often a crucial factor.

It is clear, for example, that the pest status of *P.truncatus* in East Africa has been somewhat reduced by the current campaigns. Although still officially regarded as a major threat, with the continuation of preventative control measures still being actively encouraged (Golob, 1988), it has already been observed (P. Golob, personal communication) that where farmers do not see the pest at the start of the storage season they are reluctant to apply the recommended measures. This illustrates the balance between pest status, as an incentive, and the intensity of control actions, as a response: an effective response will reduce pest status and may thereby diminish the incentive.

THE SIGNIFICANCE OF MAJOR DEVELOPMENT ISSUES

Many broad development issues warrant thorough analysis within the framework indicated in Figures 1 and 2. Two that are of common interest to most countries are:

(i) the choice between increased centralized storage and the maintenance of substantial on-farm storage;

(ii) the balance between increased staple food crop production, aiming at national self-sufficiency, and increased export crop production, aiming to achieve an enhanced national economy and a stronger trading position.

Such issues have a major bearing on long-term economic development and are also key issues affecting possibilities for pest management improvements.

RESOLVING THE PROBLEMS OF IMPLEMENTATION

A simple basic approach to the problems of implementing improved pest management procedures in developing countries is outlined in Figure 3. Full liaison with all those concerned (planners, executive agencies and even labour unions) is very important (Hindmarsh and McFarlane, 1983).

More sophisticated analytical processes may be developed to explore fully the various factors and to resolve conflicting issues. However, the identification of relevant factors, feasible options and significant constraints should always be the first step. The next step is to explore those factors of change which might create necessary incentives or eliminate avoidable constraints. Research that might produce preferable control strategies must be included.

The existing storage and pest management system must itself be examined to identify those elements which are of unproven or marginal cost-effectiveness. The conventional use of repetitive surface treatments with contact insecticides, on the fabric of stores or on grain in bagstacks, is but one example. Efficacy is commonly assumed but rarely monitored.

ECONOMIC CONTROL THRESHOLDS

Pest status is shown in Figure 2 as a central issue which, through its interactions with other factors, will determine the economic control threshold (ECT) for a specific pest or pest complex in a particular set of circumstances. The available options for pest control are outlined in Chapter 3 and some of the characteristics of existing control systems, including possibilities for their improvement, are described in Chapter 4. Research objectives are considered in some detail in Chapter 5, but at this stage it should be clear that:

(i) ECTs are situation-specific rather than pest-specific;

(ii) research is needed to establish the ECT in each particular set of circumstances;

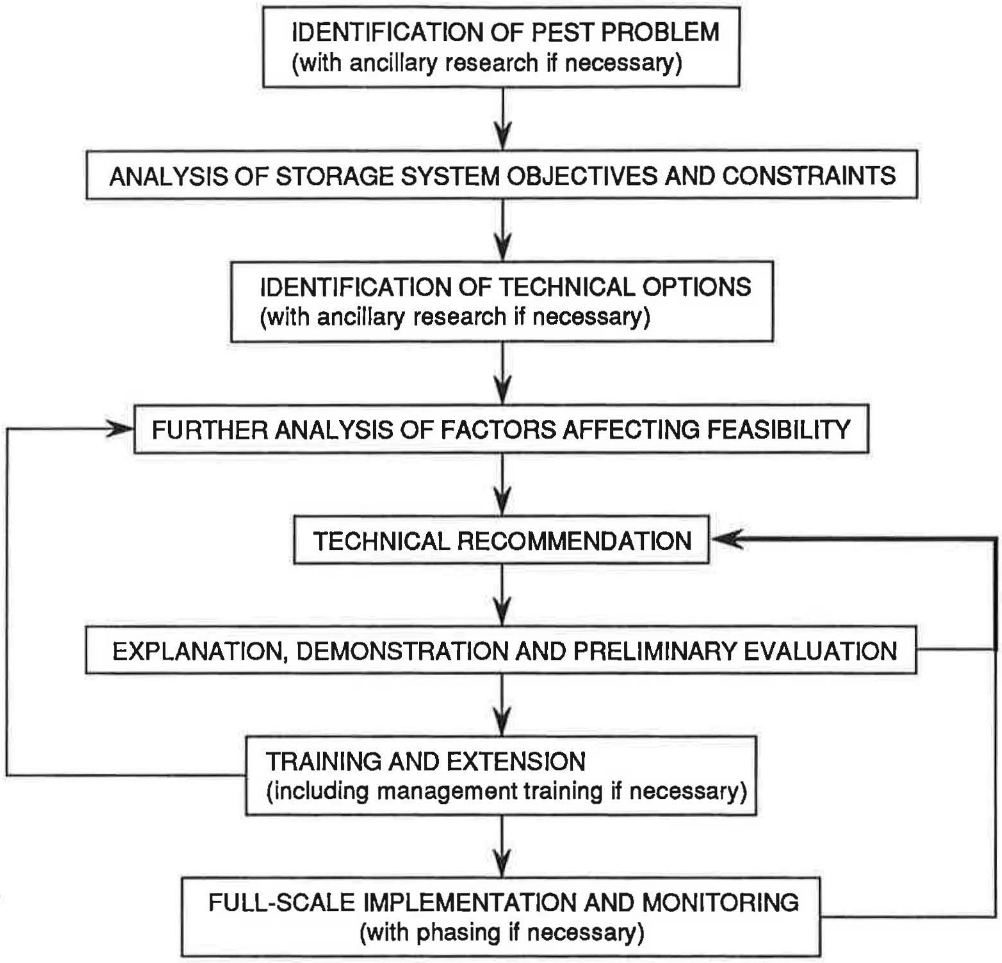
(iii) while the establishment of an ECT is a key objective in pest management resea [illegible] must be approached with a great deal of circumspection and a [illegible]

(iv) o [illegible] must be seen as susceptible to change in respo [illegible]

As [illegible] bblethwaite, 1985) there can be no uniqu [illegible] post-harvest pest; nor can any partic [illegible]

Figure 3

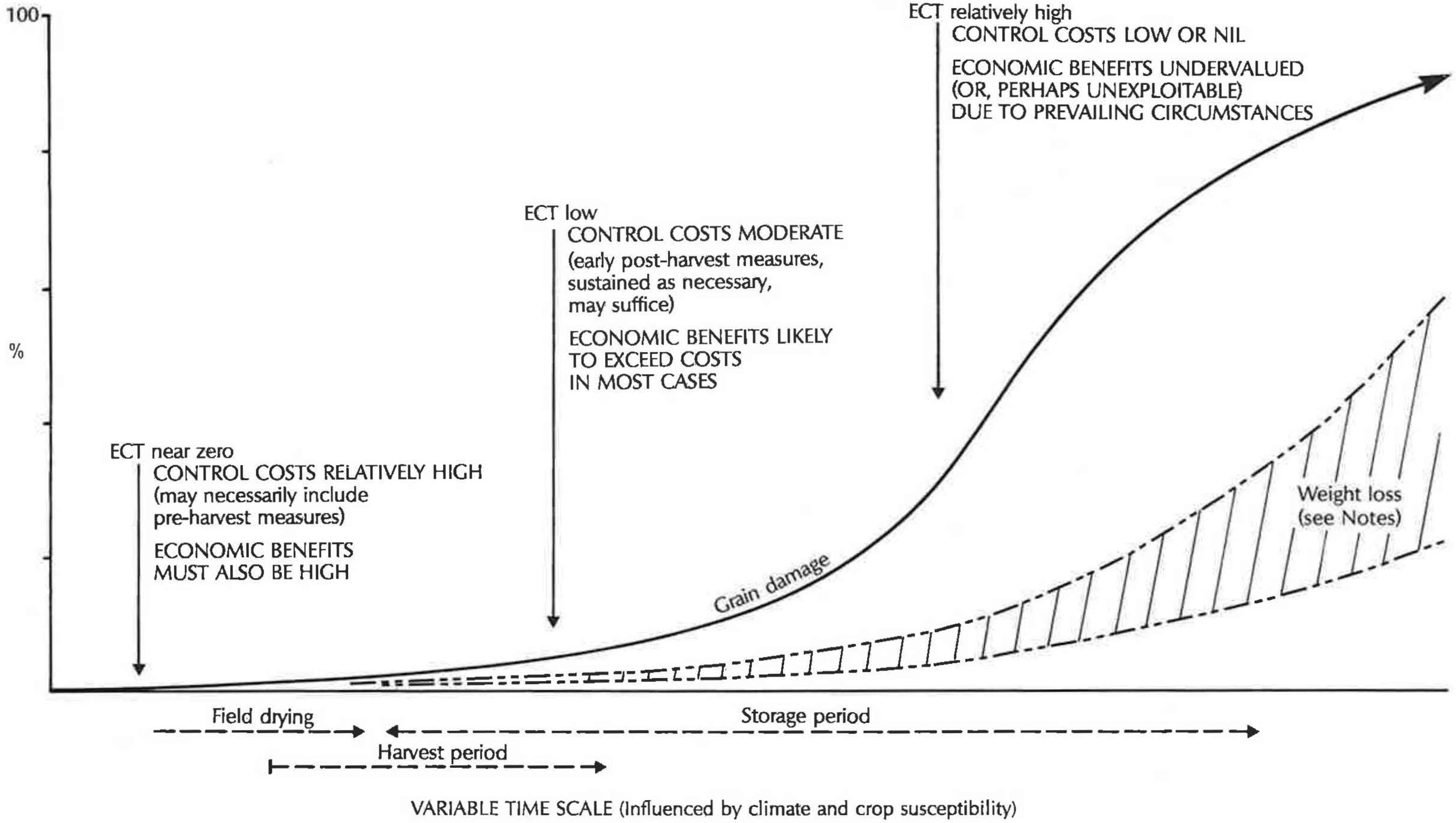
A structured approach to pest management improvements



Source: Adapted from Hindmarsh and McFarlane (1983)

Figure 4

Conceptual control thresholds for insects on stored grains



Notes: Weight loss per damaged grain is dependent upon pest species and grain type: e.g. 90% grain damage by weevils and secondary pests is equivalent to about 20% weight loss in maize (McFarlane, 1975) but substantially more in wheat and rice.

Loss in market value is dependent upon consumer requirements and grain type.

Chapter 3

Available control methods

CURRENT OPTIONS

All pest control techniques need careful management as a part of the storage system whether it be small scale or large scale. Storage systems, including any pest control methods, have usually been developed to suit particular commodities and handling procedures. They can be broadly classified as bulk or bag handling systems (*see* Table 7). Storage structures and containers have been similarly developed but, in a few instances, they have been designed or modified to meet the special requirements of a particular pest control technique. Welded steel bins, for use in controlled atmosphere storage systems, are an example. Storage buildings designed and maintained to permit efficient in-store fumigation would be another example, but such buildings are uncommon and, in many circumstances, they may be too costly. The various available techniques are listed in Table 8 with indications of their relative efficacy and cost. The main categories are further described in the following sections.

Table 7

Storage techniques: current options

Storage container	Associated pest control methods*
Small-scale bulk storage	
Cribs: – in open air:	– 'smoking' over an open fire – admixing a grain protectant
– inside a dwelling place:	– as above
Underground pits:	– self-disinfesting if sufficiently airtight
Small storage bins:	– as above – admixing a grain protectant
Large-scale bulk storage	
Sealed bunkers:	– admixing a grain protectant – disinfesting by fumigation
Unwelded metal bins:	– as above – cooling by aeration
Flexible (collapsible) bins:	– as above
Concrete bins or pits:	– self-disinfesting if sufficiently airtight – admixing a grain protectant – disinfesting by fumigation or controlled atmospheres
Welded steel bins:	– as above
Storage in bags or small containers	
Sealed pots, gourds, etc.:	– self-disinfesting if sufficiently airtight
Conventional bags, (stacked or unstacked):	– admixing a grain protectant – fumigating under sheets; with or without protection against reinfestation – partially self-disinfesting if tightly stacked
Wrapped bags in sealed pits or bunkers:	– self-disinfesting if sufficiently airtight
Insect-proof packages:	– fumigation or irradiation

Note: * New biological methods have unconfirmed potential.

Table 8

Pest control techniques: current options

Control method and major uses	Advantages	Disadvantages
*Fumigation** with penetrating gases: for disinfestation in storage or prior to export	Pest mortality is almost immediate and can be total	No residual protection. No control of pests outside the enclosure
*Space treatments** with contact insecticide: to control flying insects especially moths	Spectacular effects. Can be useful as an adjunct to fumigation	Affect only a small part of the total population
*Residual treatments** with contact insecticides: for long-term protection of food stocks	Effective protection for some time after treatment: especially with insecticide admixture; less effective with surface treatments	Effectiveness varies with circumstances. Highly dependent upon the availability of suitable, high quality formulations
Heat treatment for disinfestation before storage or export	Pest mortality is almost immediate and can be total	Relatively advanced technology needed to ensure success and to avoid adverse effects. Solar dryers may offer a cheaper alternative
Cooling for sustained pest control during storage	Highly effective and economic in some situations	Not usually feasible in the low-altitude tropics without expensive equipment
Entoleters to disinfest flour before storage or despatch	Convenient in modern processing systems	Not practical in some circumstances
Physical barriers to protect uninfested or disinfested goods in storage and transport	Can be cheap and very effective if well designed and managed	Enclosed goods may need to be drier than usual or specially aerated if the barriers impede moisture vapour movements
Trapping to control rodents or monitor pest populations	Can be inexpensive, simple and effective	Ineffective for control unless combined with other methods
Controlled atmospheres for long-term storage	Potentially highly effective	Suitable storage structures are usually expensive
Pheromones to monitor pest populations or reduce them by behavioural disruption	Very effective for monitoring low-density populations	Currently available for relatively few pests. Rather expensive
Food attractants to monitor or reduce pest populations	Simple and effective for population monitoring	Ineffective for control unless combined with other methods
Growth regulators: for long-term control by the reduction of population growth	No proven advantages in storage control	Currently experimental and few available for use
Pest pathogens to eliminate or reduce populations	Relatively pest specific	Pests may show high natural tolerance
Predators and parasites to reduce populations	Natural occurrence	Ineffective until pest populations are well established
Resistant varieties to reduce the rate of population growth	Effective throughout the storage period	May conflict with other plant-breeding objectives
Sterile insects to reduce population growth rates	No proven advantages in storage pest control	Technique requires sophisticated equipment and management

Source: Adapted from Dobie (1984)

Note: * All chemical methods are relatively cheap and can be highly effective, but have the disadvantage of eventually causing pest resistance.

CLIMATIC CONTROL

All techniques (including construction methods, *see* Table 9) that reduce temperature or humidity within storage structures and containers provide a degree of climatic control of storage pests. Examples are: pre-store and in-store drying, in-store ventilation, forced aeration for grain cooling (with or without refrigeration), insulation or shading from the heat of the sun and the more sophisticated cool storage systems. Thermal disinfestation treatments are considered separately because their influence upon the commodity microclimate is essentially short term.

Those techniques which influence humidity in the storage microclimate, such as ventilation and aeration, are commonly used also to reduce the moisture content of stored crops. The extent to which they can remove

Table 9

Effect of roof insulation on storage temperature in a hot-humid climate

Wall cladding	Roof cladding	Resultant T (°C)	Acceptable mc%*	Costs**
Concrete blocks (hollow)	Rusty steel	39.5	8.8	6.3
Concrete blocks (hollow)	Clean steel	36.4	9.6	4.9
Concrete blocks (hollow)	Aluminium/fibreboard	31.3	11.0	4.0
Concrete blocks (hollow)	Aluminium/polyurethane	31.0	11.1	4.3

Source: Adapted from O'Dowd *et al.* (1987a)

Notes: * Acceptable moisture content for seed grain.
** Costs (£/tonne stored) are for cladding materials plus the costs for drying to the acceptable moisture content.

moisture, in the absence of equipment for drying or heating the air artificially, will depend upon the ambient climate. The times of day selected for aerating the commodity are important and there are considerable possibilities for exploiting controlled aeration, for grain drying and cooling, in many tropical regions. Target temperatures for cooling to control infestation in stored grain are indicated elsewhere (*see* Chapter 1, page 8).

With the exception of sophisticated cool storage systems, climatic control techniques can be reasonably inexpensive and all are potentially very effective aids to the management of insects and mites in stored commodities. Detailed information on meteorology and grain storage is contained in *WMO Technical Note* No.101 (Smith, 1969). Cooling and drying applications in storage pest management are discussed by Evans (1987a).

AIRTIGHT STORAGE AND CONTROLLED ATMOSPHERE (CA) STORAGE

The airtight storage and controlled atmosphere (CA) storage techniques require storage structures or containers that are sufficiently gas-tight. For CA storage complete gas tightness is particularly necessary in most cases. Both are, technically, highly efficient and intrinsically complete pest management systems for stored, dry grains. Containers that are sufficiently sealed for these purposes will serve also as physical barriers against reinfestation (*see* p. 21).

In airtight storage the intergranular air is depleted of oxygen by the activity of insects, mites and other organisms present in the grain. This leads ultimately to the death of all stages of insects and mites and, in completely hermetic conditions, this will happen with relatively little increase of grain damage. The quality of dry grain, including its germinative power, is well maintained. CA storage achieves disinfestation more immediately by the introduction of carbon dioxide or nitrogen and the maintenance of the gas at a concentration sufficient to prevent biological activity. A high level of management efficiency is essential.

Airtight storage is potentially inexpensive, even where sophisticated structures are used, especially where the grain is to be stored for long periods. CA storage is more expensive, because of the need for more complete gas-tightness and the extra cost of the introduced gas, but it can be cost-effective in many situations.

Extensive information on CA storage is now available: see, for example, Anon. (1984). Evans (1987a) particularly discusses the implications for stored products pest management. A comprehensive account of airtight grain storage is given by Hyde *et al.* (1973).

Traditional underground storage

Semi-airtight storage, in earth-walled underground pits, is common in many parts of the world. In Africa, for example, it is commonly used for the storage of sorghum (in Ethiopia, Sudan and Somalia) at the farm level or by grain traders. The nature of the losses associated with traditional pits is indicated by Gilman and Boxall (1974) who also draw attention to the mycotoxin hazard. However, this relatively simple storage technique, when applied to reasonably large bulks of grain, can effectively minimize insect damage over long periods and may considerably restrict other forms of damage, including mould damage (McFarlane, 1988b). Some moisture infiltration, or redistribution within the pits, is almost inevitable and consequent peripheral mould damage is to be expected. For this reason, large storage pits are generally more efficient, for grain quality maintenance, than small pits where the surface/volume ratio is relatively high. Moisture problems may be increased by ambient temperature fluctuations which will affect the upper parts, especially when pits are incompletely filled.

Semi-underground, concrete grain bins

Large, semi-underground concrete grain bins have been used in some countries. These, in concept, provide a good means of long-term storage, but their operational management may pose problems. While it is technically possible to store grain hermetically for very long periods, with negligible loss of food value, such grain is likely to show some reduction of quality and will therefore lose market value except when released at times of acute grain shortage. Since such events are highly unpredictable it may be considered necessary that the grain reserve should be renewed at relatively frequent intervals. This may lead to major problems in the provision of additional grain-handling equipment to facilitate the loading and unloading of the bins and may greatly increase the cost of the enterprise.

Small-scale airtight storage

The use of sealed clay pots or gourds for small-scale airtight storage is quite common but rarely fully effective unless the degree of airtightness is increased by suitable external coatings (McFarlane, 1970a). A more sophisticated form of small-scale storage, using metal drums, is sometimes used and may be cost-effective in some circumstances; especially for seed storage which can be done safely in airtight conditions provided that the grain is dry and the containers are kept reasonably cool. Cost-effective airtight storage for food grains is more likely to be obtained with improved pits.

THERMAL DISINFESTATION TECHNIQUES

Evans (1981, 1987b) has confirmed that short exposures to temperatures above 60°C are generally effective for the disinfestation of grain. His method, based upon fluidized-bed grain drying techniques (Dermott and Evans, 1978), permits rapid heating of individual grains. With less sophisticated methods, a rapid heat rise is less easily achieved. Direct exposure to the heat of the sun, which is a traditional grain drying procedure in many parts of the tropics, is of doubtful efficacy for thermal disinfestation. This is especially so when the target grain is maize on the cob.

Solar dryers present one possibility for enhanced disinfestation by the heat of the sun. Doe *et al.* (1977) have shown that temperatures in a polyethylene tent-dryer can be high enough to kill insects attacking fish during the drying process. Lethal temperature/time combinations sufficient for the disinfestation of grain, including maize on the cob, can be achieved by the use of simple cabinet dryers (McFarlane, 1989a). The procedure would be impractical for large grain stocks but might be of use at the farm or village level for the disinfestation of residual grain stocks; or for maize cobs segregated at harvest-time as being evidently infested. Solar cabinets are unlikely to be constructed for this purpose alone but their capabilities for disinfestation should not be overlooked. Field trials are needed to confirm practicability and reliability and to determine the extent to which this technique might be usefully combined with grain drying operations.

IRRADIATION TECHNIQUES

Various forms of electromagnetic energy are technically available for use in the disinfestation of foodstuffs including stored products. Watters (1972) includes a useful review of possible applications for radio-frequency heating, infra-red, ultraviolet and ionizing radiation. There has been much further research, especially to determine suitable dosage rates and operational procedures with regard to safety in use as well as efficacy, but the use of these techniques for stored products pest control is still limited by the basic problems of capital cost, running costs and other aspects of practical feasibility (*see* also Banks, 1976). The need for exceptionally careful operational management appears to be a major constraint.

With regard to technical efficiency, it has been shown, for example, that gamma radiation produced by radio-active materials such as cobalt-60 is effective against a wide range of insect pests. Mites are generally more resistant and may require dosages higher than the 50 krad that would achieve satisfactory control of most storage insects. At practical dosage levels mortality is not instantaneous, although sterility may be immediate. The time interval between treatment and death, up to 4 weeks or longer depending on the dose applied and the insect species, was noted by Watters (1972) as an apparent disadvantage of this disinfestation method, especially in comparison with fumigation treatments. The method shares with fumigation the further disadvantage that it confers no protection against reinfestation. For this reason insect-resistant packaging would be a logical adjunct. In countries where socio-economic circumstances may appear to favour the use of irradiation techniques their inclusion in IPM systems will depend primarily, as with the use of other techniques, upon their relative cost efficiency.

THE USE OF PHYSICAL BARRIERS

Physical barriers to protect commodities from rodents and birds are well known. Barriers against insects and mites are more difficult to effect, but they are possible, and deserve more attention. The barrier may be a bag, carton, drum or some other unit container, a protective stack-cover, a bin or even the building itself. However, the complete and effective insect-proofing of a building is far more difficult to achieve than effective rodent-proofing or bird-proofing.

Sacks as barriers to infestation

A woven sack is seldom proof against storage insects and mites because these pests are mostly small enough to penetrate the weave. Cotton sacks are less easily entered than jute or sisal sacks if the mouth of the bag is tightly closed. Woven plastic provides better protection than jute or sisal against some insects, but not against all.

Multi-wall paper sacks provide very good protection, but this is considerably reduced if the end closures are not specially treated to prevent or repel entry by insects and mites through the stitching holes. Film-plastic sacks, or other sacks with film-plastic liners, provide good protection if they are carefully sealed. Paper and plastic can be penetrated by many of the common storage insects (Davey and Amos, 1961; Wohlgemuth, 1979) but they are most likely to do this when a dense population is confined in the bag or against it; small numbers of wandering insects are less likely to do so, but crevices or folds in packaging materials provide refuges which may attract wandering insects and encourage penetration.

Stitching holes in paper and plastic sacks are probably penetrated mainly by first instar insects and mites which are very small. The stitching holes can be sealed using waxed paper or plastic tapes impregnated with pyrethrins or pyrethroids. The repellency of the insecticide appears to be the main factor responsible for the increased protection. Multi-wall paper sacks, treated with synergized pyrethrins, have been recommended for the protection of protein-fortified cereal flours in prolonged storage (Highland, 1974).

Two advantages of unlined paper sacks are that they do not greatly restrict natural aeration and the contents can be disinfested by conventional fumigation under gas-proof sheets. Commodities packed in film plastic must be sufficiently dry, as well as being free from infestation, and fumigation of the contents will be more difficult and will necessitate extended aeration periods. The retention of gases by plastic sacks or liners does, however, permit their use as effective fumigation chambers (Proctor and Ashman, 1972) if the mouth of the sack is tightly closed and the fumigant dose is sufficient.

Commodity stack covers

Hyde and Kockum (1964) tested a variety of stack covers as physical barriers to prevent insect invasion following fumigation. These were sealed at the base with lindane dust. The results were promising but problems were experienced with impermeable stack-covers, especially where the store climate favoured moisture condensation. The trials were carried out in Kenya at Kisumu, Nairobi and Eldoret. Table 10 gives relevant data on temperature, relative humidity and altitude for these sites. Large daily fluctuations in temperature greatly influence the likelihood of moisture condensation on the inside of impermeable stack covers. At low altitude sites, condensation is unlikely to be significant unless the commodity is infested and heating, or has a moisture content above the safe level. Work elsewhere (McFarlane, 1980) supports this conclusion.

The stack covers tested by Hyde and Kockum included close-weave cotton sheets which were shown to be effective and without condensation problems. More recently, cotton sheets have been used successfully, for routine protection of security grain stocks in Mali, with an insecticidal treatment to seal the barrier at floor level.

Table 10

The effect of altitude on diurnal climatic fluctuations in a tropical country

Location (Kenya)	Altitude (m)	Temperature (°C)		Relative humidity (%)	
		Mean	Range	Mean	Range
Mombasa	15	26.1	5.6	74.5	9
Kisumu	1100	23.1	10.5	57.5	21
Nairobi	1700	18.1	10.5	67.0	32
Eldoret	2100	16.9	15.0	56.5	56

THE USE OF PESTICIDES

The proven and commonly available fumigants, phosphine and methyl bromide, and a considerable range of contact insecticides with low mammalian toxicity are undoubtedly of great value in the control of storage insects and mites. Their judicious use, in the control of these pests, is likely to remain essential in the foreseeable future. Storage pesticide treatments, when timed and applied efficiently, are generally highly effective, reasonably inexpensive and safe in practice. Their main limitations in effectiveness arise from misuse, which may create hazards and accelerate the development of pest resistance, or from logistical or formulation problems which may lead to the marketing of poor quality products.

Recommendations for the use of contact insecticides are usually based on experimental trials in which good quality formulations are accurately applied with reliable equipment. In routine use, efficacy commonly declines through the use of poor quality formulations or unsuitable equipment. The physical properties of formulations (for example the ability of concentrates to form stable, uniform dispersions in the diluent) are as vital to efficacy as the content of active ingredient. Sub-standard materials are sometimes marketed and, even when formulators have provided a good quality product, physical and chemical properties can deteriorate in transit and storage. The efficient use of pesticides requires quality checks by competent analysts, routine bioassays in practical storage situations to test efficacy and supplementary monitoring, by standard 'discriminating dose' tests, to identify real instances of pest resistance. Treatment failures due to faulty materials or application techniques are then more likely to be identified and distinguished from failures due to acquired resistance.

The problem of pest resistance to toxicants provides a major reason for the development of improved pest management strategies that are less completely dependent upon pesticide use. This should permit increased selectivity in the choice and timing of pesticide treatments, where they remain necessary, and a reduction in the extent and frequency of such treatments. Further research is needed to reveal more completely the ways in which pesticide treatments, including fumigation, influence the development of resistance in pest species and to determine optimal application methods and treatment regimes. Other biotic effects, genetically linked to resistance, may also warrant further investigation.

Problems in pesticide use are especially common at farm level and, for this reason, alternative control techniques may be particularly needed in such situations.

Efficacy and safety in pesticide use

The most definitive pesticide applications for storage pest control are fumigation with penetrating fumigants and insecticide admixture treatments. All other applications are, at best, protective treatments and therefore have real value only on commodities that are initially free of infestation. Many are not always completely effective even as protective treatments, especially in tropical conditions.

Both fumigation and insecticide admixture, if correctly applied, will disinfest the treated commodity. An essential difference is that the admixture of a pesticide will always produce a residue in the commodity which will be more or less persistent depending upon the chemical nature of the pesticide used. So long as it persists relatively unchanged, the residue has positive value in providing protection against reinfestation. However, it may also create a potential hazard or, at least, a source of possible anxiety to the user of the commodity. Fumigation treatments may or may not produce significant persistent residues. This will depend upon the fumigant used (*see* Table 11) and, to a considerable extent, upon the dosage required and the frequency of application. Fumigant residues do not provide protection against reinfestation.

Most other forms of pesticide application, including residual surface treatments and space treatments, may also give rise to chemical residues in commodities stored in bulk or in permeable containers that are exposed to such treatments or come into contact with treated surfaces. Such residues may or may not contribute usefully to insect control, but they will always present a possible hazard to the consumer and may also accelerate the development of insect resistance. The significance of these various effects will depend upon the insecticide used and the rate and frequency of application (*see* Appendix 2).

Choice of treatment

In practice, neither effectiveness nor the relative significance of chemical residues will necessarily determine the choice of treatment. Practical con-

Table 11

Phosphine and methyl bromide as fumigants: *advantages* and disadvantages

Phosphine	Methyl bromide
Easy to transport	Refillable cylinders are expensive to transport
Easy to apply	Difficult to apply, requiring special equipment and skill
Good penetration and distribution	Distribution rather poor
Taint, residues and loss of viability in treated seeds are generally negligible	Sorption occurs and may cause taint, bromide residues and loss of viability in treated seeds
Very toxic to insects but slow acting, particularly at low temperatures and humidities*	*Rapidly toxic and widely effective even at lower temperatures*
Flammable; spontaneous explosive ignition can occur in some circumstances	*Non-flammable*
High acute mammalian toxicity *but low chronic toxicity*	Dangerous acute and chronic poison with delayed symptoms
Fairly easy to detect	*Very easy to detect*
Rapidly lost by leakage unless fumigation space is well sealed and gas tight soon after application	Needs very good sealing before application

Source: Adapted from *Pest Control for Food* Security
FAO Plant Prod^n^& Prot^n^ Paper 63
Prepared for FAO by ODNRI (TDRI)
FAO, Rome (1985).

Note: * Not recommended for use at temperatures below 12°C.

venience, including the availability of materials and equipment, is often the deciding factor. Many fumigants, for example, are difficult to use, and at the farm level in developing countries suitable fumigants may not be available. If stored grains need insect control treatment, the admixture of a dilute insecticidal powder may be the only chemical treatment that is possible and also likely to give satisfactory results, including the continuing protection that a fumigation treatment would not provide. Conversely, disinfestation of a commercial stock of bagged grain in large stacks is more likely to be done by fumigation, because of the practical difficulties and handling costs that would arise if an admixture treatment were to be done.

The choice of treatment can be made on purely technical grounds, especially at the time when the storage and handling facilities are being planned. In such cases, the decision should provide for more than one option because, in the long term, the availability of particular pest-control materials, or their effectiveness, may change. Silo storage facilities for bulk grain, including vertical bins and some flat bulk stores, may provide the opportunity for either fumigation or insecticide admixture by liquid spray treatment. When one of these options is preferred the eventual decision may rest on such considerations as the gas-tightness of the storage structures and the cost of improving these if necessary, the cost and availability of equipment needed, the reliability of local maintenance services and pesticide supplies, the operational capacity of the storage facility and consumer attitudes towards freedom from pesticide residues. All such considerations may have more immediate practical relevance than the question of treatment effectiveness in terms of actual pest control, except where consumer requirements, either locally or in the countries to which the commodity may be exported, give paramount importance to freedom from infestation.

Choice of pesticide

Pesticides used in places where foodstuffs are stored or handled, especially when used for admixture with foodstuffs, should always be chosen from those that have international and local approval, for the particular purpose, and established maximum residue limits that allow effective application rates (*see* Appendix 2, Table 2/3).

In the absence of insect resistance, which may affect any chemical insecticide, the choice between the various organophosphates relates mainly to marginal differences in toxicity, specificity (*see* Table 12) and persist[illegible] excepting dichlorvos, which is much more toxic, but also much more volatile and much less stable. A main use for this compound has been in the treatment, by admixture, of grain that is about to go into transit. Its main advantage is that residues will decline to acceptable levels within a reasonable period, depending mainly upon the temperature and moisture content of the grain (Desmarchelier, 1977). Another possible advantage is that this insecticide is effectively toxic to many insects at very low concentrations in the vapour phase and has effective mobility in aerated bulks of treated grain (Desmarchelier *et al.*, 1977). The high vapour activity of dichlorvos makes it useful also as a vapour phase space-treatment which can be used cost effectively for the control of tropical warehouse moths (McFarlane, 1970).

Table 12

Comparative toxicities of contact insecticides

The following table gives a general guide to the comparative toxicity of insecticide groups to different species

	Malathion	Other organo-phosphates	Lindane	Pyrethroids
Sitophilus spp.	X	X	O	O
Oryzaephilus spp.	X	X	O	O
Tribolium spp.	X	X	O	O
Callosobruchus spp.	—	X	X	X
Ephestia spp.	—	O	O	X
Trogoderma granarium	X	X	X	
Rhyzopertha dominica	—	—	X	X
Lasioderma serricorne	X	X	X	X
Stegobium paniceum	X	X	X	
Cryptolestes ferrugineus	X	X	X	
Carpophilus hemipterus	—	X	X	
Dermestes maculatus	—	X	X	
Ptinus tectus	—	O	X	
Mite spp.	—	O	X	

Source: *Pest Control for Food Security*
FAO Plant Prod^n& Prot^n Paper 63
Prepared for FAO by ODNRI (TDRI)
FAO, Rome (1985).

Notes: X effective
O moderate
— ineffective

Few other organophosphates exhibit significant vapour activity. Pirimiphos methyl is known to migrate in the vapour phase and individual grains may absorb a sufficient amount of this insecticide to become toxic to insects feeding on them. For such insecticides an initially dispersed dose may be preferable to a completely uniform treatment provided that the eventual distribution of insecticidally active grains is regular.

Cost effectiveness of contact insecticides

In general, pyrethrum and the synthetic pyrethroids are much more expensive than the organophosphates, but their relative efficacy against the bostrichid beetles *R. dominica* and *P. truncatus* makes them cost effective. Pyrethrum itself, bioresmethrin, permethrin and phenothrin have all been used on grain for control of bostrichids. However, malathion or pirimiphos methyl are ? commonly still regarded as the economic choice for grain protection where *Sitophilus* and *Tribolium* or *Oryzaephilus* species are the main pests, so long as acquired resistance does not invalidate this choice.

Effectiveness against particular pests

Warehouse moths, in particular *Ephestia* species and *Corcyra cephalonica*, are not effectively controlled in practice by many of the surface spraying or dusting treatments commonly recommended for the protection of bagged grain. Malathion has been noted as being particularly ineffective. Graham (1970) has [redacted] suggested that the particular association between malathion sprays and poor control of warehouse moths may be due to the relatively high levels of control achieved with malathion against beetle pests and acarina, including the common predatory mite *Blattisocius tarsalis*. This mite has been shown to be a significant predator of *E.cautella* (Haines, 1981) and it may be that malathion in particular has favoured the increase of *Ephestia* populations by selectively suppressing competitors and predators.

The control of insect infestation in maize stored on the cob also presents special problems. Unless the sheathing leaves are removed, any insecticidal spray or dust may fail to reach the insects on the grains. If the sheath is removed, insecticides like malathion may be more rapidly degraded since the grain is likely to be relatively moist at this stage. Some control of infestation is possible with insecticides like pirimiphos methyl (Golob and Muwalo, 1984), but the control achieved will depend upon many factors including grain moisture content, ambient humidity, the condition of the cob sheath, the type of storage structure used and the pattern of infestation. In general, the best solution is to dry the cobs as quickly as possible and then shell the grain so that an admixture treatment can be applied more effectively. This is certainly the best insecticidal treatment where *Prostephanus* is a serious pest (Golob *et al*., 1985), provided that natural drying in the crib does not take more than 1-2 months and that initial infestation levels are not exceptionally high.

Other considerations

Varietal differences in the susceptibility of grains to insect infestation also affect the need for chemical pesticides. Traditional varieties are generally less susceptible to insect infestation than the high-yielding varieties produced by modern plant-breeding programmes. Some of these new varieties are particularly susceptible. Where they are introduced there may be need to improve upon the levels of insect control obtainable by traditional methods. This could require the introduction of storage insecticides where, previously, such treatments may have been unnecessary. Wherever local circumstances prevent the effective supply or use of chemical pesticides, or warrant the prohibition of such materials, the introduction of high-yielding varieties should be approached with great caution unless the local grain marketing system can provide adequately for the rapid movement of surplus grain from the farms to well-managed regional storage centres.

High value commodities, such as tobacco, cocoa and coffee, where intrinsic flavours are particularly valued and the risk of taint is consequently of increased importance, invite alternative control measures. Moreover, the high commercial value of such commodities quite commonly justifies the use of more expensive control measures and protective packaging techniques. These may be justified also for processed foods, dried fruit and nuts where there is special need to minimize the risk of excessive pesticide residues. This might apply to processed animal feeds, but economic considerations usually prohibit expensive control and packaging procedures for these commodities and higher levels of infestation are generally tolerated.

Comprehensive guidance on the use of fumigants and synthetic contact insecticides for the control of insects and mites in stored food grains is given in an FAO publication prepared for FAO by the Storage Department of ODNRI(TDRI) (Anon., 1985).

A recent review of the potential uses of the more modern synthetic pesticides, in particular the juvenile hormone analogues, is given by Edwards (1986).

THE USE OF OTHER ADDITIVES

Traditional grain protectants, including wood ash, vegetable oils and abrasive powders such as diatomite, are of considerable value in on-farm storage, but they are generally much less effective than the synthetic grain protectants (Golob, 1984).

They are mostly chemically inert materials which may be abrasive, absorbent or obstructive. They act as insecticides by damaging the surface of an insect's body, so that it dies by loss of moisture, or by impeding an insect's movements in the commodity. The use of such materials, especially wood ash or a locally available mineral dust or sand, appears to be widespread. Amongst rural communities in tropical countries they may be of considerable value even when not completely effective.

More recently, in addition to the traditional materials, some very effective synthetic compounds (such as silica aerogels) with non-chemical insecticidal action have been developed as grain protectants or proposed for use as insecticide carriers (Shawir *et al.*, 1988). These are less likely to be suitable for rural use, despite their effectiveness, because they would be more costly. The use of inert silica dusts has been usefully reviewed by Ebeling (1971).

In India, activated kaolins and vegetable oils are recommended for control of bruchid beetles. Coulon and Barres (1966) have recommended the use of levilite (amorphous aluminium pentasilicate) for protecting beans, with rates of application up to 0.4%. Diatomite mixed with wheat at the rate of 0.35% was found to be effective for at least one year (La Hue and Fifield, 1967 and La Hue, 1970). Rice husk ash has been tested as an insecticide, mixed with stored grains, by Krishnamurthi and Rao (1950) and is used by farmers in Japan and India. Powdered rice husk has been recommended for the protection of wheat against *Sitophilus oryzae* (El Halfawy, 1976).

The action of silica dusts and the ashes of materials like rice husk, which contain at least 90% silica, is abrasive. Their effectiveness for insect control is consequently influenced by the grain moisture content and the ambient relative humidity. The drier the conditions, the more likely it is that a high level of control will be achieved. Silica aerogels are non-abrasive powders that damage the insect by absorbing surface waxes and moisture. They also absorb other oily substances and are therefore less effective when used on commodities of high oil content. Kane (1967) demonstrated that dermestid beetles were less effectively controlled by silica aerogels on dried fish when the oil content of the fish was high.

Vegetable oils such as palm oil and groundnut oil are particularly effective as protectants against bruchid beetles. Adult beetles are little affected by the presence of oil admixed at 5ml/kg, but egg mortality is increased. The oil may inhibit oviposition or it may obstruct the entry of oxygen into the egg and it may also enter the eggs and prevent development (Singh *et al.*, 1978; Schoonhoven, 1978).

The effect of sand as a stored grain protectant may be largely obstructive. Sand is sometimes used to cover completely the exposed surface of grain in a storage vessel, thus reducing access by insects. Where it is admixed throughout the grain, so that the intergranular spaces are filled, the movements of the insects amongst the grains are impeded and this may reduce or prevent both feeding and breeding. Wood ash and very small cereal grains, such as millet, are also sometimes used in this way.

The effectiveness of inert materials as grain protectants, particularly the abrasive materials, depends greatly upon the conditions of use. Relatively high application rates are needed (Golob, 1984). For wood ash, in particular, this may be a considerable constraint.

A number of other naturally occurring materials (*see* for examples Golob and Webley, 1980), which have been used or suggested as grain protectants and may also be particularly useful in rural storage, are more correctly described as chemical protectants. These include plant materials, that are aromatic and may be repellent to insects, such as the dried fruits of *Capsicum* species, the powdered roots of *Derris elliptica* ('derris dust') and the leaves and seeds of the neem tree, *Azadirachta indica*. Derris dust contains the toxin rotenone while azadirachtin, in neem, has antifeedant properties.

It is often assumed that 'natural' plant extracts are safer than synthetic chemicals, but this is not always true. Plant fragments or extracts should not be recommended for admixture with stored foodstuffs until appropriate tests have proved them to be safe.

BIOLOGICAL CONTROL

The use of resistant crop varieties

The rate of increase of a pest population is influenced by the qualities of the food available to the pest. Most crops have some varieties that are less suitable than others for insect development. These are described as *resistant* (or *less susceptible*) to attack. The existence of varietal resistance to storage insects, as well as to pre-harvest pests, is now well known.

If an insect feeds on a relatively resistant variety then its rate of population growth will be reduced. This may reduce control costs by extending the period between pesticide treatments or may extend the period for safe storage without the use of pesticides. The latter benefit may be of special value in on-farm storage.

To reduce the rate of population increase a resistant variety should:

- reduce insect fecundity (effective egg production); and/or
- extend the development period; and/or
- cause high insect mortality.

The rate of egg-laying can be reduced by:

- varieties with effective natural barriers (e.g. husks, cob-sheaths, pods) that restrict access to the insect's food material, thus reducing the number of eggs laid and the insect's productivity;
- varieties that repel the insects or are unattractive to them;
- varieties that are unsuitable for oviposition, e.g. too hard for species that chew holes in which to lay eggs, or too rough for species that stick their eggs onto a smooth surface.

The development period can be extended by:

- hard-textured varieties that are difficult to ingest or digest;
- varieties that are partially toxic to the insect pests;
- varieties that are nutritionally inadequate for the development of the pest.

The death rate can be increased by:

- varieties that cannot be penetrated by the larvae which hatch from the eggs, so that the larvae are unable to feed;
- varieties that are nutritionally inadequate for, or toxic to, the feeding insects.

In general, the indigenous crop varieties traditionally grown by small-scale farmers are at least moderately resistant to attack by stored products pests and may have been selected for that reason. Unfortunately, the introduced varieties of some crops, especially cereals which have been selected by plant breeders for high yield, have commonly proved to be highly susceptible to pest attack during storage (Schulten, 1976).

Improved crop varieties with the potential for high yield will undoubtedly be used extensively in the future in order to increase food production. It is vital that storage entomologists should work in collaboration with plant breeders to ensure that newly developed varieties are generally suitable for storage and that the varieties recommended for particular situations are chosen with regard to local storage requirements and capabilities. The current status of research and development has been reviewed (Dobie, 1984). It is clear that the use of resistant varieties can contribute effectively to the safe storage of food crops. Most crop species that have been investigated have shown a certain amount of variation in resistance to major storage pests and plant breeding programmes could be designed to exploit such variation.

The use of pheromones

A pheromone is a chemical released from the body of one individual that affects the behaviour of another of the same species. Many of the mites, beetles and moths associated with stored products are known to produce pheromones which stimulate specific responses such as alarm, dispersal, aggregation or attraction of the opposite sex.

There may be some interaction between the pheromones of different species. For instance, in large populations of *Plodia interpunctella* the resultant high level of *P.interpunctella* pheromones may inhibit and even eliminate competing populations of *Ephestia cautella* (Read and Haines, 1979).

Pheromones are extremely potent in their action: for example *P.interpunctella* males respond to as little as 1 x 10^{-17}g per cm^3 of the major component of the female sex pheromone (Mankin *et al.*, 1980). They thus provide powerful tools with which to manipulate insect behaviour. Synthetic pheromones are produced by several commercial companies and by other organizations including the Overseas Development Natural Resources Institute.

Conventional insect traps, e.g. refuge traps or sticky traps, may be baited with pheromones. This increases trap efficiency and affords an improved means of monitoring pest populations. The pheromones used may be sex attractants or aggregation pheromones. Pest population monitoring, with pheromone-baited traps, has played an important part in the campaigns to control *Prostephanus truncatus* in Africa (Dendy *et al.*, in press).

Pheromones may be used in three ways to control pests.

(i) Traps baited with pheromones may be used for mass trapping. Such traps are unlikely to provide effective control when sex attractants are used. The traps would have to be extremely numerous, or more attractive than the female, if they were to collect all the males before a significant degree of mating had occurred. The problem may be overcome if mass trapping is integrated with other compatible control measures (Burkholder, 1981). Alternatively, the use of aggregation pheromones, attracting both sexes, may prove more effective.

(ii) Sex attractants or aggregation pheromones may be used to lure insects to a source of insect pathogen or chemosterilant.

(iii) The air of a store may be perfused with sex pheromone to disrupt normal courtship behaviour and prevent mating.

With further development, pest monitoring or control by pheromones will provide definite opportunities for improved pest management in tropical stored products. In particular, monitoring may ensure the more timely application of other control measures and mass trapping could perhaps help to suppress pest populations. The use of high levels of pheromone to reduce mating success could be used to slow down the growth of pest populations and hence reduce the need for conventional pesticide treatments. The technique might also be integrated with other biological control methods to keep pest populations at acceptable levels.

Control by predators and parasites

Most animal species are subject to attack by natural enemies: that is, organisms that kill them or impair their health by acting as predators, parasites or pathogens. Insect predators usually kill their prey more or less immediately. The effects of insect parasites on their hosts are much more variable, but most feed, as larvae, upon their host during its pre-adult life and eventually cause its death. Insect pathogens are discussed separately.

In complex natural communities, animal populations usually follow moderate, cyclical fluctuations in which population growth is limited and stabilized by several factors, including competition and the effects of a wide range of natural enemies. Such stability is rare in environments that are wholly or substantially man-made, such as fields of crops or food stores. In such situations, with the abundance of a particular food and the absence or ineffectiveness of natural enemies, certain species tend to increase dramatically and become serious pests.

The failure of natural enemies in man-made environments is caused by a number of factors. These can be divided into four broad categories, each of which is described below together with an appropriate biological control strategy.

(i) An absence of effective natural enemies often occurs when a pest species invades a man-made environment from another area. A possible biological control strategy is the artificial introduction of one or more natural enemies to the new environment. The most successful natural enemies for this purpose are usually those that were associated with the pest in its natural habitat.

(ii) If, in its original environment, the pest species were substantially limited by factors other than its natural enemies (e.g. by food availability), then its population growth in the new environment may be too rapid for its natural enemies to be effective. In such cases it may be possible to augment the natural enemy populations by making regular additions to the existing populations. The effectiveness of this strategy depends on the timing of augmentation in relation to the pest's life-cycle and population growth. It is likely to be expensive in practice.

(iii) Natural enemies may fail to be effective if one or more aspects of a man-made environment interfere with their normal ecology and behaviour. For example, the physical structure of the environment may make it more difficult for a predator or parasite to locate the prey or host species. The appropriate strategy in such situations would be modification of the environment to remove the limiting factors or lessen their effect.

(iv) It is often found that natural enemies are more susceptible than pests to conventional control methods. This is particularly common in relation to pesticides, especially if the pest species shows natural tolerance or has acquired resistance. The effectiveness of natural enemies can often be at least partially restored by modification of control measures so that they have less effect on the beneficial species: for example, by altered timing, by the use of more selective measures or by changes in application procedures. If the conventional control method is non-residual (e.g. fumigation) an alternative strategy is augmentation of natural enemies after the control treatment.

The current status of research in these areas has been reviewed by Haines (1984).

The use of insect diseases

Insect pests of stored products are subject to a number of diseases caused by pathogenic bacteria, viruses or protozoa. These diseases are frequently fatal to the pests, especially the larval stages. However, they do not infect man nor apparently do they kill the more useful storage insects such as predatory Hemiptera or the parasitic Hymenoptera. Transmission of the pathogens may occur in several ways: by the larvae feeding on the bodies of infected larvae or adults; by the consumption of infected stored food; during mating; or from the female to its progeny during oviposition.

Severe outbreaks of disease can occur even under natural circumstances, especially when populations are dense. For example, heavy infestations of the storage moths *Ephestia cautella* (Walker) and *Plodia interpunctella* (Hubner) (Burges and Hurst, 1977) have been severely reduced by the disease-causing bacterium *Bacillus thuringiensis* Berliner. The larvae of storage moths are also affected by two types of virus. These pathogens have little or no effect on beetles but strains of the bacillus which are active against some beetles have now been identified (McPherson *et al.*, 1988). In contrast, most beetles are known to be severely affected by several types of protozoa.

Insect pathogens may be cultured in the laboratory. With viruses and protozoa this can only be achieved in living insects, but for bacteria a nutritive medium is sufficient. It may thus be possible to provide a supply of all these organisms for the control of pests in stores. Pathogens may, in fact, be more suitable for use in stores than in open fields where they run the risk of being inactivated by high temperatures and excessive exposure to ultraviolet light. However, the only diseases that are likely to be effective in the management of stored products pests are those that have hardy, long-lived, dormant stages capable of infecting insects in dry conditions.

Owing to their rather specific nature, it is almost inevitable that the use of pathogens would have to be integrated with other control procedures. Possibilities for combining control by pathogens with conventional control practices have received some attention. It is known that treatment with the granulosis virus of *P.interpunctella* may be combined with malathion to produce a higher level of mortality of this moth than would be achieved if either was applied separately (Hunter *et al.*, 1975). *P.interpunctella*, like all moth secondary pests, is particularly resistant to malathion, which may still be used for the control of many stored products beetles. Consequently, the combination permits the continued use of malathion against those pest complexes that contain *P.interpunctella* together with insects susceptible to this insecticide. The effects of fumigation upon granulosis virus and *B.thuringiensis*, when used to control *P.interpunctella*, have also been studied (McGaughey, 1975). Four fumigants were tested: methyl bromide, phosphine and mixtures of carbon tetrachloride with carbon disulphide and of carbon tetrachloride with dichloroethylene. Only one important effect was found: methyl bromide inactivated the granulosis virus. The same fumigant also affected *B.thuringiensis*, so that when cultured it failed to produce colonies, but despite this a bioassay showed that the bacterium was still potent against *P.interpunctella*.

Insect pathogens offer distinct possibilities for the control of stored product pests. They may be admixed with bulk grain or disseminated by insects lured to a source of pathogen by an attractant. The bacillus, *B.thuringiensis*, is already commercially available for use against moths. It may be especially useful in situations where the moths are particularly tolerant to insecticides or where insecticide application is either not permitted or cannot be carried out effectively. However, before this pathogen is brought into more widespread use, further testing of its efficacy under tropical conditions is necessary.

Considerable research is needed on the potential use of protozoa and viruses. For example, the use of pheromones and other attractants in pathogen dissemination would seem a promising, yet almost unexplored, field. It would also be valuable to discover a single virus that would control all storage moths.

Research on insect diseases for use in stored products pest control has been reviewed by Hodges (1984a).

The use of sterile insects

The most obvious method of applying the technique of sterilizing insects would be to release sterile or cytoplasmically incompatible insects into and/or around storage facilities. In many instances, this would require the introduction of several species to combat all the important pests infesting the produce. The level of organization needed might make this impractical. The technique would be more suited to situations concerning only one or two pest species or where the control of a primary pest necessarily limits the populations of secondary pests. In both circumstances, an understanding of the insect ecology of the particular storage system is essential. However, even if only one or two species need be released it may still be necessary to introduce large numbers of insects into a store to reduce the pest population within a reasonable period. This would generally be both difficult, owing to the problems of rearing large numbers of insects, and undesirable since, with few exceptions, (e.g. moths and bruchid beetles) the adults would feed on the stored commodity. Furthermore, their dead bodies and excrement may be an unacceptable contamination.

Consequently, this type of control is only feasible when relatively few insects need to be introduced, that is, when the pest population is low. Such is the case when the commodity is barely infested or when it has just been disinfested. Under such circumstances the frequent release of small numbers of sterile insects may either reduce the rate of reinfestation so that fumigation and insecticide spraying are required less frequently, or it may keep the pest population at a permanently low level. The number of sterile insects required may be further reduced by the integration of this technique with other compatible types of pest control, such as the use of insect growth regulators, larval pathogens, or resistant varieties.

It may be possible to avoid release altogether if some of the insects in the pest population can be lured to a source of chemosterilant by a pheromone or food attractant. There would be three important considerations with such a method:

(i) it might have to be integrated with other compatible control techniques because mating and oviposition, in at least a small proportion of the population, is always likely to occur before chemosterilization;

(ii) the chemosterilants, which are usually highly toxic, would have to be kept from contact with the stored food;

(iii) the lures would have to be set up in such a way that the insects would leave them after contact with the chemosterilant. This might be achieved by using an attractant source that faded out fairly quickly or by placing the lure in an exposed region where the insects would be unlikely to settle for long.

It remains to be seen whether or not the sterile-insect method can eventually be used as an alternative method for control of tropical stored products pests. However, it is important that the more feasible possibilities should be thoroughly tested. The status of research in this area has been reviewed by Brower (1974) and, more recently, by Hodges (1984b).

LEGISLATIVE CONTROL

Statutory regulations affecting the control of storage insects and mites are not uncommon. They include food quality standards, food warehousing regulations, other legally enforceable codes of practice for the storage, handling and transportation of foodstuffs and a few quarantine measures.

Regulations enacted for public health purposes may be quite frequently invoked, but the enforcement of other pest control legislation is rarely seen to be fully cost-effective. In some countries such legislation (as distinct from pesticide legislation) has tended to fall into abeyance.

General improvements in standards of pest control for storage insects and mites are more likely to be achieved by the introduction of cost-effective management procedures, stimulated by economic incentives. Improvements in pest management are part of a socio-economic development process which is not usually responsive to direct legislation. However, realistic food quality standards, in the food processing industry and in the marketing of primary products, can provide a powerful management incentive if rewards for high quality are introduced alongside penalties for non-compliance.

Quarantine regulations against storage insects and mites are relatively rare. Many countries, following the actions taken in temperate regions where the khapra beetle (*Trogoderma granarium*) has been a very serious pest of malting barley, have imposed quarantine restrictions against this insect. However, in several of those countries, the pest is already present but is of low status for climatic reasons. The significance of *T. granarium* as a pest is primarily due to its unusual ability to attack and severely damage very dry grain. The ability of the larvae to survive for long periods, without food, and to withstand normal fumigant dosages when in this resistant state (diapause) is a further problem. The regions in which this insect is a serious general threat are those in which the climate, and therefore the stored grain, is exceptionally dry. The greater part of the Sudan and some other parts of North Africa are examples. In these regions *T. granarium* is the major primary insect pest of stored grains and heavy infestations in sorghum and millet are common. In more humid regions this insect is generally of importance only as the dominant scavenger on grain stored for long periods and previously damaged by other insects. The cost-effectiveness of quarantine procedures against this insect in the humid tropics is questionable.

Recent introductions of the larger grain borer (*Prostephanus truncatus*), which have resulted in the establishment of this pest in several African countries, pose another question: that is, whether or not quarantine inspection procedures, in practice, can ever be sufficiently reliable to ensure the interception of a grain pest at all points of entry. The costs of intensified control measures against *P. truncatus*, once it has become established in countries with substantial dependence upon small farm maize production, are enormous. Quarantine measures, if practicable, would almost certainly be judged cost-effective as an insurance against the risk. However, the likelihood of an adventitious occurrence, despite expensive quarantine measures, reduces the benefit/cost ratio. Decisions may have to be based upon an assessment of the extent to which quarantine actions can be expected to delay such an occurrence.

Chapter 4

The development of pest management systems

LOSSES IN EXISTING SYSTEMS AND POSSIBLE LOSS REDUCTIONS

Selected data on storage losses in developing countries were presented in Tables 1, 2 and 3 (*see* pp. 1 and 2) which indicate the nature and levels of storage losses associated with various commodities in existing sytems.

Clearly there is some scope for loss reduction, especially in centralized storage where there are many more technical options (*see* Tables 13 and 14) and greater possibilities for technical efficiency. However, losses vary in magnitude from place to place and from time to time. In general, variations in storage losses are more closely related to climate and to the presence or absence of incentives for loss-reduction than to the particular form or technique of storage.

There are, however, some fundamental differences between different storage systems in the socio-economic significance of storage losses. For example: economic thresholds for pest control will generally be relatively high in on-farm storage systems, especially in developing countries. Weight losses up to about 5% may commonly prove acceptable to the farm-level storekeeper and these losses may not be susceptible to economic reduction without substantial progress in local agricultural development. In contrast, the common level of acceptable storage loss in centralized storage systems is 1-2% or less. Although this level of control is not always achieved in practice there are technical grounds for considering it economically feasible.

Table 3 revealed the relative shortage of precise information on losses in centralized storage. This shortage is partly due to the difficulty of ensuring the satisfactory completion of studies that involve large-scale operations. Nevertheless, there is now sufficient knowledge to justify a more positive approach to loss reduction in centralized (collective) storage. This is also true for on-farm storage, where the data base is more substantial. However, at farm level, the constraints are usually different and the possibilities for cost-effective loss reduction are generally more limited.

Further work should be directed to programmes which aim to reduce losses where they are susceptible to reduction. The first aim should be to assess the losses in relation to the total costs of the modifications and possible innovations required to bring about their reduction. In the past, programmes to assess losses have sometimes been followed by speculative and possibly over-optimistic plans for nation-wide campaigns to reduce losses by a desirable but rather unrealistic percentage. Until it is demonstrable, to those responsible for grain storage, that loss reductions are both technically possible and clearly cost-effective, in all respects, no voluntary campaign is likely to succeed. The storage threat posed by the larger grain borer (*Prostephanus truncatus*) in Africa provides a valuable example of the successes which can be achieved where the storekeepers, farmers in this case, are predisposed to innovations by their own recognition of a material threat.

Table 13

Prerequisites and options for on-farm storage pest management

Essential	Optional
Basic IPM *Site and store management* (protection from birds, rodents and weather plus basic hygiene) *Commodity management* (cleaning, drying, etc.)	**Additional measures** Maintenance of conditions favourable to natural control: – by cooling (where feasible) – by insect parasites, pathogens, etc. *and/or* Thermal disinfestation by solar heat. *and/or* Treatment with traditional additives (if sufficiently available and effective) *or* Treatment with synthetic insecticides (if suitable formulations sufficiently available and effective) *or* Hermetic storage (pits or metal drums, etc.)

Table 14

Prerequisites and options for storage pest management at main depots

Essential	Optional	
Basic IPM	Disinfestation	Prevention of reinfestation
Site and store management (protection from birds, rodents and weather plus basic hygiene)	Insecticide admixture*!	Provided by the treatment
	Fumigation!	Residual insecticide sprays?! *or*
	Thermal*!	Physical protection! (Sheeted stacks or packaging) *or*
	Irradiation*!	Insecticidal space treatments!
Commodity management (cleaning, drying, etc.)	Hermetic!	Provided by the system
	Controlled atmosphere!	Provided by the system
	Grain cooling!	Provided by the system

Notes: *May entail double handling for in-bag storage.
?Efficacy doubtful.
!Extra management skills and/or other inputs required.

THE IMPORTANCE OF INCENTIVES AND OPPORTUNITIES

In the absence of a new pest problem, some other external change is generally needed as an incentive to pest management improvements. The introduction of reliable price incentives for quality improvements or increased opportunities to market the commodity profitably are possible examples. In practice, however, financial incentives for quality improvements are lacking in many marketing systems. The development of new and more cost-effective pest management strategies could also induce change so long as they are made available to potential users and are sufficiently understood.

POSSIBLE IMPROVEMENTS TO EXISTING SYSTEMS

Integrated control of storage pests requires the use of compatible techniques that can be integrated cost-effectively with particular storage systems. The control of insects and mites on stored products currently depends heavily upon the use of fumigants and residual pesticides. Such treatments can be integrated into many storage and handling systems but they are not always used compatibly and cost-effectively. Nor are they always entirely compatible with management objectives and consumer preferences. Four fairly typical existing systems are described in Examples 1-4. These also indicate some technically feasible pest management improvements and the constraints which may inhibit their adoption.

EXISTING SYSTEMS: EXAMPLE 1

Conventional commodity management in the pre-processing storage of wheat grain in the upland tropics

Production of grain: on small- and large-scale farms at altitudes ranging from 2000-3000 m; grain usually harvested at 14-18% mc; mechanical drying uncommon.

On-farm storage: for 2-6 months, often in ventilated bagstacks, with earliest movements generally from low altitude farms; mould damage unusual except where grain tightly stacked before it is sufficiently dry (14% mc); storage insects and mites common but grain damage usually minimal.

Storage in buffer depots: for 6-12 months, traditionally in large bagstacks but with increasing use of bulk storage facilities; commonly disinfested by fumigation; reinfestation by warehouse moth usually rapid but consequent kernel damage usually considered acceptable for milling purposes; reinfestation by other insects and mites rarely severe.

Terminal storage at mills: usually for less than 6 months; fumigated (or re-fumigated) when necessary, with occasional ancillary treatments to reduce moth populations; severe reinfestation (by weevils, other insects and mites) not a common problem except in stores at low altitude.

Technically feasible pest management improvements are:

- prompt initial fumigation, at buffer depots and at mill stores when grain is received direct from the farm, to prevent predictable damage by grain weevil;
- effective ancillary measures to control warehouse moth (which causes relatively little weight loss but a considerable percentage reduction in whole grain, due to the consumption of grain embryos by the larvae, and a consequent reduction in milling offals) and to avoid the need for refumigation;
- tighter management of grain movements to mills at low altitudes to ensure minimal storage periods at those sites.

Constraints are: reluctance to interfere with a system that is already tolerably satisfactory and, perhaps, insufficient technical information on ancillary control measures.

Source: Adapted from McFarlane (1989b).

EXISTING SYSTEMS: EXAMPLE 2

Conventional commodity management in the pre-processing storage of maize

Production of grain: on small- and large-scale farms in the tropics, mostly at low or intermediate altitudes; grain stored, on the farm, as stripped or unstripped maize cobs in ventilated cribs for 6-12 months; sometimes with 'mudding' of the cribs, at the end of the dry season, to reduce the reuptake of moisture; insecticide treatments, layer-by-layer on the cobs or applied to the outer surfaces of ventilated cribs, sometimes used (with varying degrees of cost-effectiveness).

Storage of marketed surplus: as shelled grain at buffer depots in bagstacks; insects and mites controlled by fumigation when judged necessary; reinfestation by warehouse moths and other secondary pests generally rapid and rarely deliberately controlled except by refumigation. Storage periods variable.

Terminal storage: at grain mills or export godowns, usually for relatively short periods; insect infestation commonly recognised as a serious problem but further control largely dependent upon refumigation prior to export or processing.

Technically feasible pest management improvements are:

- limitations on the production of new varieties that are more susceptible to storage pests (except where on-farm storage can be minimized, by efficient marketing, or facilitated by suitable and cost-effective control measures);
- restriction of on-farm insecticide use to treatments that are of proven efficacy and local cost-efficiency;
- effective ancillary measures, at mills and depots, to control secondary pests and to reduce the need for refumigation;
- better planning for food-security reserves so as to permit cost-effective use of alternative long-term techniques such as hermetic or controlled atmosphere storage.

Constraints are: low quality-control standards in local marketing; inadequate financial incentives at the farm gate and, probably, insufficient certainty of maize price and availability in the international market.

EXISTING SYSTEMS: EXAMPLE 3

Conventional commodity management in raw rice storage from production to milled grain distribution

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Production: on small- and large-scale farms; on-farm storage as rough rice in cribs or rice barns, commonly with some ventilation to reduce moisture content; infestation by the grain moth *Sitotroga cerealella* generally significant but rarely evaluated; infestation by other insects and mites (and mould damage) more variable and often of uncertain significance.

Storage at buffer depots: as rough rice in bulk or in bagstacks, after further drying if judged necessary; insect and mite infestation a relatively minor problem except for lesser grain borer in long-term storage; disinfestation by fumigation when judged necessary.

Temporary storage at mills: as rough rice in bulk or bagstacks; cross-infestation of milled grain stocks occurs commonly but is rarely evaluated.

Storage of milled, raw rice: for short or long periods (dependent upon the procurement and distribution programme) usually in bagstacks; insect and mite infestation generally a major problem if the period exceeds 2-3 months; control commonly dependant upon repetitive fumigation, with or without ancillary insecticide treatments of doubtful efficacy and unproven cost-effectiveness.

Technically feasible pest management improvements are:

- assessment of losses due to grain moth infestation in on-farm storage, especially where the grain may be drawn upon for seed, and the introduction of cost-effective control measures where necessary;
- situation-specific cost/benefit analyses of rough rice storage, in comparison with milled rice storage, and suitable policy changes where appropriate;
- adoption of better-regulated pest control programmes for milled rice, with improved pest monitoring procedures and proper evaluation of conventional treatments; wider use of physical methods for the protection of disinfested stocks.

Constraints are: lack of incentives and/or management skills.

EXISTING SYSTEMS: EXAMPLE 4

Conventional commodity management in the production and pre-processing storage of copra

Production: under-dried or marginally-dry copra produced in kilns or mechanical dryers.

Initial storage: short-term storage in makeshift premises; with initial bacterial and/or mould damage, infestation by mould feeding insects and shrinkage due to natural drying.

Medium or long-term storage: in processors' godowns; with further shrinkage losses, mould damage and increasing infestation by copra beetle (*Necrobia rufipes*), warehouse moths, silvanid beetles (*Oryzaephilus* spp. and *Ahasverus advena*) and miscellaneous other insects and mites; periodic disinfestation by fumigation and/or occasional depression of infestation by space or surface applications of contact insecticides.

Outcome: substantial loss of purchased weight due to shrinkage, loss of dry weight due to insects and moulds, loss of oil quality due to insect and mould damage; oil quality may be restored by refining processes and losses are generally off-set by low purchase prices. The by-product (copra cake) is of poor quality but is usually marketable.

Technically feasible pest management improvements are:

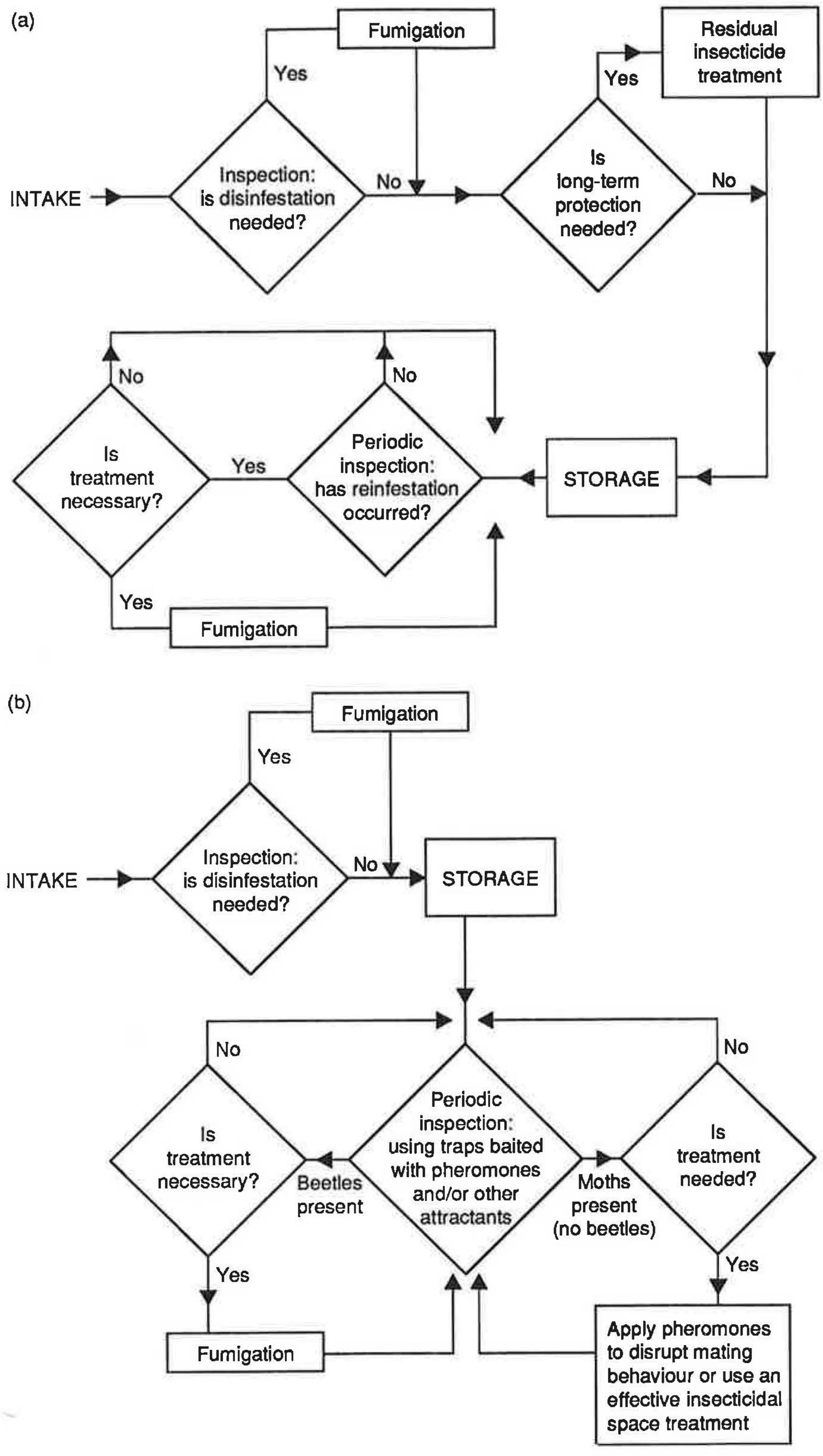
- production of well-dried copra (in equilibrium with 65-70% relative humidity: i.e. moisture content 5-6% rather than the 7-8% commonly accepted commercially;
- subsequent storage as before: well-dried copra is virtually immune to damage by micro-organisms and of the wide range of common insect pests only *Oryzaephilus mercator* is able to persist: insect damage will be relatively little.

Constraints are: inadequate marketing incentives

Figures 5 and 6 suggest ways in which the dependence upon pesticides might be somewhat reduced in two types of storage system. The first (Figure 5a/b) is concerned with the warehouse storage of bagged commodities and the second (Figure 6a/b) relates to maize storage on small farms.

Figure 5

Management patterns for the storage of bagged grain



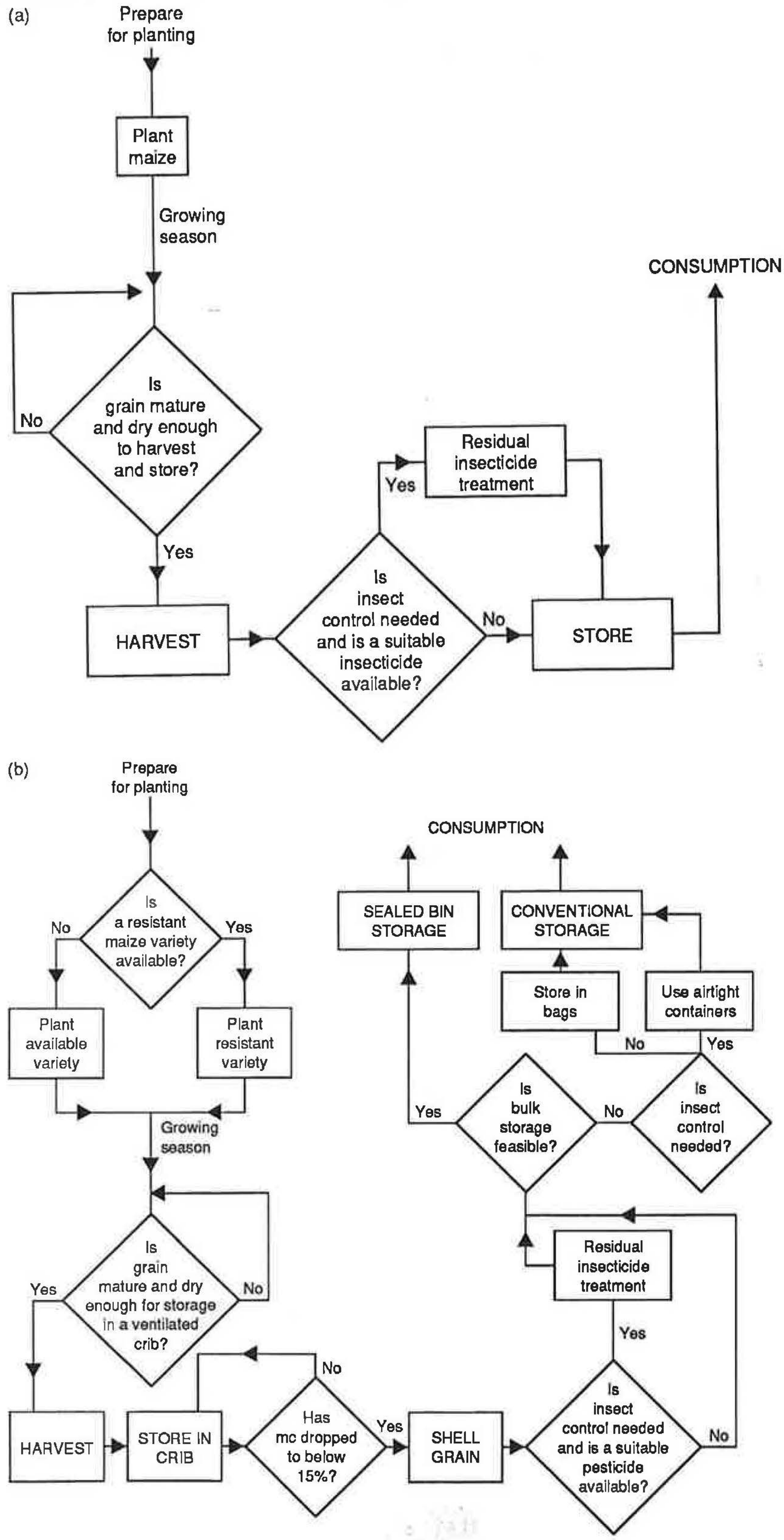
(a) A common management pattern, for the storage of a bagged commodity in a medium-large warehouse, with depedence upon chemical pest control and conventional inspection methods.

(b) Some possible modifications to the management pattern shown in Figure 5a to include certain alternative procedures.

Source: Dobie (1984)

Figure 6

Management patterns for on-farm storage of maize



(a) A common management pattern for the production and on-farm storage of maize in the tropics.

(b) Modifications to the management pattern shown in Figure 6a to include some alternative options for pest control.

Source: Dobie (1984)

Figure 7

Possible savings at three stages in the development of stored products insect control

Infestation:	latent	evident	heavy	→	extreme
Damage:	negligible	minor	major	→	extreme

STAGE	LOSSES					SAVINGS
1	Nil plus	1–2%	plus	10–20%	(!)?	Doubtful
2	Nil plus	1–2%	(!)	10–20% less control costs		
3	Nil (!)	1–2%	plus	10–20% less control costs		

Source: Adapted from McFarlane (1965).

Notes: (!) Control action.
Development stages

Stage 1: Control action only as a last resort when damage becomes very evident and if the commodity cannot otherwise be utilized.

Stage 2: Control action triggered by observed infestation level with regard to the expected storage period.

Stage 3: Pre-emptive action based upon scientific prediction of likely damage with regard to the expected storage period.

Potential savings under various pest management regimes, including the least-input regime which still operates wherever commodity value is not clearly linked to true quality, are roughly indicated in Figure 7. The least technically efficient regime (Stage 1) relies, for profit, upon the likelihood that losses in quantity and quality may be off-set by opportunistic marketing; or, for domestic food security, it serves well enough in situations where the losses sustained during a customary storage period are regarded as unavoidable. The development and extension of more cost-effective pest management systems could change such attitudes.

PROSPECTIVE PEST MANAGEMENT SYSTEMS

Some immediately feasible improvements to existing systems are indicated, as possible options, in Figures 5(b) and 6(b) (*see* pp. 40 and 41). Feasibility nevertheless depends upon the reduction or removal of various identifiable constraints (*see* Existing systems: examples 1-4, pp. 36–39). Longer-term possibilities depend more heavily upon the progress of socio-economic developments, especially in agriculture, marketing and agro-industry. These in turn are dependent upon sound and progressive development policies.

Progressive economic development, where it includes the rural sector, could, for example, lead to increased centralization of the storage and processing of maize, similar to that which often already exists for wheat. Clearly, this would only be sensible and viable if most maize users, in both rural and urban sectors, were able to afford the purchase of processed products. In the long term, this may be a possiblility in some regions of most developing countries. The necessary centralization might need to be relatively dispersed, that is with district centres rather than national or regional centres; but whatever the case, the standards of quality control and pest control, including protective packaging for finished products, would need to be high in order to gain any practical pest management advantage.

PRODUCT PROCESSING AS A FACTOR IN PEST MANAGEMENT

The processing of primary products may facilitate the management of storage insects and mites. The effects and potential benefits of drying, to remove excess moisture, and cleaning, to remove imperfect or damaged grains and foreign matter, are generally well known. The following aspects of processing are also relevant.

- Milled grains, excepting rice are generally less susceptible, sometimes virtually non-susceptible, to attack by primary pests, but they are generally highly susceptible to infestation by secondary pests.
- Processing techniques can be designed to deliver an infestation-free product and re-infestation by secondary pests can be prevented or substantially reduced by protective packaging (including the use of protective covers on bagstacks).
- Processed products are generally likely to be at a reasonably uniform moisture content, which may be sufficiently low to permit impermeable packaging.
- Processed products are likely to have sufficient 'added value' to warrant extra protection, but those which are of relatively low value (e.g. animal feed ingredients) may not always justify expenditure on pest management improvements.
- In all cases, the effective protection of processed products against insect and mite infestation in storage and subsequent distribution requires careful and efficient management; it is not an easy option but it may offer possibilities for pest management improvements in some situations.

THE DEVELOPMENT AND IMPLEMENTATION OF IMPROVEMENTS

In order to develop and implement pest management improvements it is necessary that all the important factors, in every particular situation, should be identified and sufficiently analysed. Interactions between pest status and control intensity, which also affect storage patterns, periods and techniques, are an obvious target for analysis and the influence of agricultural development policies must also be considered. Other socio-economic factors may be more peripheral, but nonetheless influential. They may be instrumental, through their success or failure in the creation of incentives, in determining whether or not a proposed pest management strategy will prove feasible and cost-effective. Factors of change, especially marketing incentives, are generally of crucial importance in the implementation of all agricultural developments including pest management.

Agricultural marketing organizations have a key role in the development of pest management improvements through grading standards and farm-gate pricing policies. National governments can influence such developments indirectly through policy planning in various ministries including Health, Education, Trade and Transport as well as Agriculture. International organizations and bilateral aid agencies can positively assist through the better and more co-ordinated support of agricultural development programmes that have economically feasible, long-term development objectives as well as clearly defined short-term goals.

Extension services are also important and their role may be critical. Extension workers are sometimes over-committed in their efforts to arouse local awareness of a supposed general need for better control of insect pests in stored products. They should, perhaps, direct their energies more deliberately to locally identifiable problems. In this way they might assist more in the realistic assessment of options, including the costs and benefits which can accrue from technically feasible improvements. Regular losses, of marginal immediate significance to the storekeeper, might sometimes be more positively assessed where the long-term feasibility of a proposed technical improvement has been clearly demonstrated. Sporadic losses, which are sometimes regarded as inescapable in both on-farm storage and centralized storage, are rarely entirely unpredictable and might often be prevented by informed management.

THE INVESTMENT OF RESOURCES

In most cases, the investment of resources in pest control measures has been based upon predictive assessments of the pest damage that would otherwise be sustained. In some cases the predictions may have been substantiated by research data but, in general, preventive control measures are largely based upon traditional, practical experience. They may be regarded as an insurance against a known high risk.

This approach to investment in pest control is reasonably valid for the maintenance of sensible, basic measures against known major pests: that is, those with potential high status. The weakness is that unproven control measures are sometimes included, either because they have become customary, or because they are deliberately promoted by agencies with vested interests.

The refinement of preventive control measures into fully cost-effective, integrated pest management procedures requires further applied research under practical storage management conditions. There is scope here for further work to assess costs and benefits (in terms of actual loss reduction or prevention), to develop applicable pest population-growth models alongside improved population monitoring techniques and to devise improved pest control procedures.

IPM strategies may be devised on the basis of scientific research. They will only be considered for practical application in situations where there is a perceived need for modifications to existing procedures. Where this perception can be strengthened by the revelation of possible, realistic, economic benefits there is a likelihood that suitable IPM strategies will be adopted and implemented.

Chapter 5

Targets for pest management

RESEARCH FRAMEWORK: THE STARTING POINT

A basic approach to the implementation of pest management improvements has been indicated (*see* p. 15). This begins with the identification of a pest problem because, very often, this is the point at which a pest management specialist is called in. Furthermore, it can be argued, on scientific and socio-economic grounds, that there is a need for improved pest management wherever a pest, or pest complex, is significantly reducing the quality or quantity of stored food products. However, the influence of the total production-marketing system, its objectives and constraints, should not be overlooked. The need for storage entomologists to take account of planning and management objectives and for development planners and storage managers to take account of storage pest management opportunities is crucial.

A joint appraisal of the fundamental issues is therefore needed, at the outset, to identify the particular production or marketing objective and the consequent commodity management requirements. This preliminary analysis should proceed as follows.

Step 1: identification of primary objective.

This may be to increase the availability of a particular commodity but the underlying purpose must also be identified.

It may be
- to achieve rural self-sufficiency;

or
- to achieve total self-sufficiency, with opportunities for stock-piling and the export of possible surpluses;

or
- to create an exportable surplus in response to a world market demand.

Step 2: determination of storage management policy and commodity management requirements including pest management.

For example:

- how, where and by whom is the commodity to be procured, stored, processed (if necessary) and transported (where necessary)?
- what are the targets for quantity and quality?
- will infestation be a constraint? – in particular, will insects and mites cause or contribute to direct or indirect losses of quantity and/or quality?
- what are the commodity management requirements in terms of staffing and equipment?
- should pest control operations be conducted by existing staff, extra staff or a specialist agency?

PROBABLE TARGETS FOR RESEARCH

A number of probable targets for improved pest management can be indicated (*see* Table 15). Where such commodity/pest complexes call for research in a

Table 15

Commodity/pest complexes targeted for IPM improvements in tropical developing countries

Maize *Sitophilus* spp., *Prostephanus truncatus, Sitotroga cerealella, Tribolium castaneum* and other tenebrionid beetles, *Ephestia cautella* and other warehouse moths, *Blattisocius tarsalis* and other predacious mites and insects, parasitic Hymenoptera.

Sorghum *Trogoderma granarium, Rhyzopertha dominica,* plus other spp. as for maize excepting *P. truncatus.*

Rice *Sitophilus* spp., *Rhyzopertha dominica, Sitotroga cerealella, Corcyra cephalonica* and other warehouse moths, *Tribolium castaneum* and other tenebrionids, *Oryzaephilus* spp. and other silvanid beetles, *Liposcelis* spp. and other psocids, *Blattisocius tarsalis* and other mites, parasitic Hymenoptera.

Dry beans *Acanthoscelides obtectus, Zabrotes subfasciatus,* parasitic Hymenoptera (rare).

Cowpeas and grams *Callosobruchus* spp., *Bruchidius* spp., *Spermophagus* spp., parasitic Hymenoptera (frequent).

Copra* *Oryzaephilus mercator* and other silvanids, *Necrobia rufipes,* warehouse moths, *Carpophilus* spp. and other mould feeders.

Cassava* *Araecerus fasciculatus, Prostephanus truncatus, Rhyzopertha dominica,* tenebrionid beetles, *Carpophilus* spp. and other mould feeders.

Dried fish *Dermestes* spp.

Note: * Attention to associated problems due to moulds and mycotoxins will be especially necessary in these two cases.

particular country there will be need for an analysis of the matters outlined in Steps 1 and 2 above. This should lead to a clear definition of the particular pest management situation.

Possible situations include:

- staple food production, on smallholder farms, for on-farm storage and domestic or local consumption;
- cash-crop production (which might be for a staple food crop or another commodity), on smallholder farms, for central marketing and export or redistribution;
- cash-crop production (including food crops), on estate farms, for central marketing, etc.;
- commercial importation of foodstuffs or other commodities for storage, processing (if necessary) and distribution.

Each situation will need to be approached with the same research objectives but the eventual IPM solutions may be very different.

RESEARCH OBJECTIVES

In general terms, research objectives should be:

- to reduce losses, of quantity and/or quality, and any other developmental constraints due to infestation by storage insects and mites;
- to ensure that recommended procedures for pest control are mutually compatible, can be cost-effectively integrated with the production/marketing system and do not favour the development of resistance to pesticides;
- to provide means whereby the procedures can be monitored, evaluated and modified when necessary so as to maintain their overall cost-effectiveness.

THE RESEARCH PROGRAMME

In most cases the research programme should include the following steps:

(i) analysis of commercial objectives and constraints;

(ii) identification of the underlying socio-economic development objectives;

(iii) identification of any possible developments that might provide relevant incentives or reduce existing constraints;

(iv) investigation of the perceived pest problem in actual or realistically simulated situations;

(v) assessment and evaluation of actual losses;

(vi) adaptive research to test the efficacy, cost-efficiency and compatibility of available pest control techniques;

(vii) analysis of benefit/cost ratios and practical constraints for the various IPM options;

(viii) innovative applied research to develop alternative pest-control techniques if the available options are insufficient or if potentially feasible and preferable possibilities are identified.

Steps (i)-(vii): all of these are contributory to the establishment of an economic control threshold (*see* Table 16).

Step (iv): laboratory studies of pest biology should be undertaken only if published information is inadequate; the basic biology of many cosmopolitan storage pests has been intensively studied and many of the results are generally applicable.

Step (v): predictions of potential losses (i.e. in the absence of control) may sometimes be useful but must be clearly distinguished from actual losses. For many primary pests there are sufficient published data on which to base reasonable predictions but further research on local strains may be needed.

Table 16

Questions concerning economic control thresholds

Is there a motive for improved pest management?
What are the possible gains/benefits?
Will additional incentives be needed and if so can they be found or created?
What are the technical options for improved pest management?
Which are potentially the most cost-effective?
How will infestation and/or damage be monitored?
What are the local costs for control actions and monitoring?
What are the extra demands on management? (Part of the local costs.)
Is there sufficient management capability and if not what will be the cost of increasing the capability? (Part of the local costs.)
What benefit/cost ratio is required to justify the necessary investment of money, materials and manpower?
What, therefore, are the economic thresholds for control actions?

Note: The fourth question may be the focus of technical interest (*see* Tables 12 and 13 for some examples) but the successful implementation of improvements will require attention to all other questions also.

ALLOCATION OF RESEARCH RESPONSIBILITIES

Several different kinds of organizations and institutes may be able to collaborate in the research programme. These may include:

- in-country agricultural research stations;
- in-country development planning institutes;
- universities, in-country or overseas;
- in-country agricultural training colleges;
- in-country storage and marketing organizations;
- international agricultural research institutes;
- natural resources development institutes, in-country or overseas.

In some cases, especially if the research relates to a large-scale agricultural development programme, it may be advisable to distribute research responsibilities amongst the collaborators. Thus, university post-graduate departments or leading natural resources development institutes might be called upon to undertake innovative research (item (viii) in the programme) and a local storage organization might undertake the necessary loss assessment work (item (v) in the programme) if it has the necessary expertise or is willing to accept appropriate programme direction and supervision from others. Experienced technical direction of all the work, including adaptive research and extension, will be essential.

PARTICULAR ASPECTS OF THE RESEARCH NEEDED TO IMPROVE IPM IN THE STORAGE OF TARGETED COMMODITIES (*SEE* ALSO TABLE 15)

Maize

The benefits, especially to smallholder farmers, of growing maize varieties that are relatively resistant to storage insect pests are well known (Schulten, 1976; Golob, 1984). More work by plant breeders to provide suitable varieties that are also sufficiently high-yielding is undoubtedly necessary, but further research is also needed to define more clearly the 'break-even' levels of resistance in relation to the yield characteristics. Furthermore, while it is currently advisable to restrict high-yielding susceptible varieties to developed production systems, with adequate marketing and storage infrastructure, this may be seen as a non-progressive policy. In the long term, the better solution will be the development of improved varieties that have resistance to storage pests as well as other desirable agronomic characteristics (Dobie, 1984).

Whatever the level of pest susceptibility, the storage of shelled maize leads to accelerated damage by grain weevils (*Sitophilus* spp.), other grain beetles and warehouse moths; whereas the storage of sound, dry cobs in traditional cribs generally retards damage by these insects, while permitting rather more damage by the grain moth (*Sitotroga*). Retention of the cob sheath gives added protection against weevils but makes it more difficult to identify infested cobs for segregation at the outset of storage. This may be one reason why some farmers prefer to remove the sheath before storage.

Where the larger grain borer (*Prostephanus truncatus*) is also present the storage of maize on the cob is less advantageous and, in consequence, the potential benefits of storing shelled maize, with admixed insecticide, have been clearly demonstrated (Golob, 1988). The provision of more dependable supplies of reliable, cheap insecticides, in powder formulation suitable for admixture with grain, together with appropriate grain marketing incentives, might allow the wider use of this well-tried, simple control technique. Control by the use of synthetic pesticides is not necessarily a bad thing where it can be cost-effectively integrated with the production system.

The modified storage management system outlined in Figure 6b takes account of existing knowledge and offers a practical basis for IPM in on-farm maize storage. Segregation of cobs with evident infestation, for immediate use or separate disinfestation, is another simple technique which might be incorporated. However, there is little information on the cost-effectiveness of this procedure, although it is reported (Hoppe, 1986) as a common practice in Honduras.

In centralized maize storage systems there is considerable scope for research into the cost-effective use of control measures, supplementary to fumigation, that will reduce the common tendency towards repetitive fumigation. Frequent refumigation is generally undesirable, for reasons of safety and because it may promote insect resistance. Furthermore, it is known to be antagonistic to the natural suppression of warehouse moth populations by the predatory mite *Blattisocius tarsalis* (Haines, 1981). In Figure 5b, which applies to the storage of bagged maize as well as to other bagged commodities, the suggested use of pheromones to disrupt insect mating behaviour (in warehouse moths especially) and the use of insecticidal space treatments are both rather speculative. There is research evidence, including some practical trials (Haines and Read, 1977; McFarlane, 1970b), to indicate that either technique might provide better and more compatible control than the use of insecticidal surface treatments or repetitive fumigation. However, more work is needed to evaluate these alternative options and to devise suitable and cost-effective management systems for their practical application.

There may also be scope for research into the cost-effectiveness of various packaging systems for the protection of processed products during distribution and retail handling. This would need to be allied with research to test and evaluate, in practice, suitable techniques for the disinfestation of packaged goods during the production process. There are a number of possibilities, including the various irradiation techniques, and the research objective should be to identify the most appropriate and locally cost-effective procedure that will also suit production management objectives.

IPM research needs for maize storage and the available farm storage data have been reviewed (McFarlane, 1988; Dick, 1988), with special regard to the situation in Africa following the introduction of the pest *Prostephanus truncatus*.

Sorghum

The general pattern and spectrum of infestation on sorghum is similar to that for maize. Varietal differences in susceptibility occur (Giles, 1965) with traditional varieties commonly more resistant to damage by storage insects and to pre-harvest damage by birds. Sorghum is often stored unthreshed at the small farm level and the advantages and disadvantages of this practice, in particular situations and circumstances, may warrant more investigation. As with maize and rice, infestation by *Sitotroga cerealella* is reduced by storing the threshed grain, but infestation by other species may be favoured (Giles, 1965).

In central storage there is a particular challenge to pest management in arid regions where *Trogoderma granarium* is the major pest and sometimes causes very great losses to bagged sorghum in commercial warehouses. There is a clear need, in some cases, for changes in the conventional storage and marketing system to promote higher standards of pest and quality control. Adaptive research to devise and demonstrate appropriate systems, for the cost-effective use of available control techniques, is also needed. Fumigation is likely to remain as an essential component, but physical barriers, for protection against reinfestation, could displace the use of residual spray treatments which are commonly ineffective. Hermetic storage systems, cooling by aeration, or controlled atmosphere storage might also be considered. The natural dryness of the stored grain, in these arid regions, would favour the adoption of these various techniques (Calderon *et al.*, 1989).

Rice

The most commonly abundant pest on rough rice at the on-farm level is *Sitotroga cerealella.* In large stacks of bagged grain and in large-scale bulk storage this pest is of low status because it is generally limited to the surface layers of the stacks or bulks. In the storage of rough rice on the panicle, however, and in small bulks or bagstacks, *Sitotroga* may cause substantial losses. Situation-specific studies, in practical farming circumstances, are needed to evaluate such losses, to determine economic control thresholds and to devise suitable pest management strategies.

In centralized storage *Rhyzopertha dominica* is commonly the main pest on rough rice, while *Sitophilus* spp. and a complex of secondary and tertiary pests are important on milled rice. Pest management for *R. dominica* may require little more than sensible store hygiene and occasional fumigation. For milled rice the problems are greater. Some technical possibilities for improved insect pest management on milled rice have been indicated (McFarlane, 1980; Annis *et al.,* 1984). The consequent requirements for enhanced warehouse management will be an important determinant of cost-effectiveness. The need for improved pest monitoring procedures has also been recognized and extensive studies have been carried out in Indonesia (C. P. Haines, private communication). These have confirmed, amongst other things, the potential significance of psocids as pests of milled rice (*see* also McFarlane,1982a).

Dry beans

On-farm storage of dry beans (*Phaseolus vulgaris*) for domestic use or local marketing is a major problem in the tropics. The storage insects which attack them (bruchid beetles) can be very effectively controlled by suitable admixed insecticides (McFarlane, 1969) but these are not always sufficiently available nor are they widely accepted for this purpose. Admixed vegetable oils are a traditionally acceptable alternative in some countries and can be very effective (R. W. Taylor, private communication). Airtight storage is another option, but the availablity of low-cost containers, that are sufficiently airtight, is a problem (McFarlane, 1970a). Plastic sacks, which can serve this purpose, are particularly prone to penetration by bruchid adults emerging from infested seeds in contact with the plastic. This requires the use of another sack, of woven material, inside the plastic sack (as for cowpeas: Caswell, 1973) which will add to the cost. The use of airtight bunkers (semi-underground pits) for collective storage at the village level has been suggested and investigated in Brazil (Sartori, 1987) and Rwanda (F.Dunkel, private communication).

There is need for more applied research and well-directed extension work to correlate these various options with particular situations and management circumstances. There is also considerable scope for the development of varietal resistance to bean bruchids and some progress has been made. (Gatehouse *et al.*, 1987).

Dry beans are also produced in the tropics for local canning or for export to overseas food processors. For these purposes the presence of even a very low percentage of holed beans is likely to be unacceptable so that insecticide admixture treatments may not suffice. Rapid local procurement and prompt fumigation may achieve the required degree of freedom from damage, but this cannot be relied upon where the beans are produced on small plots in densely farmed areas. Pre-harvest infestation by bruchids, in such situations, is common and a considerable percentage of the beans may be infested or holed at the time of first marketing. There is some evidence that the percentage of infested beans is considerably reduced where the crop is aggregated into larger plots or, at least, that high infestation levels are restricted to peripheral areas of the crop (J. A. McFarlane, personal observation). This possibility should be further investigated with attention, also, to ways and means of exploiting the effect.

Other pulses (dry cowpeas, grams, dolichos beans, etc.)

Pest management problems for these commodities are comparable, at the farm level, to those for dry beans. The main primary pests are also bruchid beetles (several *Callosobruchus* spp.) but the pattern of infestation is complicated by the common occurrence of other bruchids (notably *Bruchidius* and *Spermophagus* spp.) which also infest the seeds before harvest but do not usually persist throughout storage. However, the bruchids which attack cowpeas and grams are all much more commonly subject to parasitism than those which attack beans. The partial suppression of infestation by parasites, especially in on-farm storage, may therefore be of some significance where artificial controls are not applied.

Prompt harvesting can reduce bruchid infestation in cowpeas (Prevett, 1961b) and, probably, in most other pulse crops, but the suitability of this practice to small-farm systems has not been sufficiently studied. Labour availability is one uncertainty. Another is the impact of earlier harvesting and storage upon parasite populations. If this exceeds the impact upon bruchid populations the overall effect might be disadvantageous in situations where other control methods are not used. The development and adoption of resistant varieties (Redden *et al.,* 1983) may provide a more generally reliable solution.

The advantages and disadvantages of storing unthreshed pulses may also require further investigation. There appear to be some pest management benefits with cowpeas (Caswell, 1968) but these may not apply in all cases. More attention should perhaps be given also to possible varietal differences in the degrees of resistance to bruchid infestation found in the pods of stored pulses (Caswell, 1984).

Copra

Very substantial improvements in the management of storage insect pests on copra could be achieved simply by the firm application of basic commodity management principles (*see also* Existing systems: Example 4 in Chapter 4). The potential benefits of improved production procedures, whereby the copra is sufficiently dried at the outset, have been demonstrated (McFarlane, 1962). The problem is that the economics of marketing for this commodity, and the consequent grading standards, seem to be permanently influenced by traditional commercial practice. Some further research may be needed to establish whether or not commercial refinement of a poor quality product is really the most economic approach to the utilization of coconut oil; especially since it has a place as a locally popular cooking oil as well as in soap-making.

Cassava

Storage pest management improvements for cassava are constrained by its world market value as an animal feed ingredient. However, the considerable concern in the animal feeds industry over mycotoxin levels may generate more interest in the possibilities for improving the quality of marketed, dry cassava and, in particular, for promoting better drying procedures. A study of insects and mites infesting stored, dry cassava chips in Malaysia (Parker *et al.*, 1981) has shown that insect damage, which is commonly substantial, could be considerably reduced by correct, initial drying and subsequent measures to prevent moisture reabsorption. The observed spectrum of infestation, in this study, included 30 recognized storage pests of which 12 were species usually associated only with underdried commodities.

Table 5 includes some but not all of the species listed by Parker *et al.*, 1981. These authors discuss pest management and, in noting the striking similarity between the observed spectrum of infestation and that generally associated with stored cereal grains, they suggest that storage pest management procedures for this latter commodity might be applied, with benefit, to the storage of cassava chips. However, the market value of the commodity will inevitably determine the level of investment in storage management. As with other such commodities there may be scope for research to demonstrate more clearly the economic value of the losses, in food quality as well as quantity, that arise from insect and mite infestation. Storage management, including insect control measures, for dried cassava products is discussed also by McFarlane (1982b). The introduction of *Prostephanus truncatus* to Africa, however, has considerably increased the problem in that continent.

Dried fish

When hard-dried, that is with a water activity below 0.7, dried fish stores quite well, if carefully handled, but like other durables it remains susceptible to insect damage. However, it is commonly infested only by those species which prefer a protein-rich diet: notably the dermestid beetles and especially *Dermestes maculatus* and *D. frischii*. Salting is a traditonal control method but to be successful it generally requires heavy salting which makes the product less acceptable to some consumers. Insecticidal treatments have been used, mostly by dipping the pieces of dried fish in a solution or emulsion of the insecticide, but until recently only pyrethrum was regarded as suitable for this purpose. For the control of blowflies, during drying, pirimiphos-methyl has been approved subject to appropriate residue tolerances.

The essential requirements for integrated pest management, as for other durables, are adequate drying and good hygiene throughout drying, storage and distribution. It has been shown (Doe *et al.*, 1977) that enhanced solar drying can serve also as a means of thermal disinfestation during the drying process and suitable protective packaging, immediately after drying, could provide protection against both reinfestation and moisture uptake. Such an approach to improved pest management would make adequate drying still more essential. Cooling, before packaging, might also be needed where the product is to be packed into large baskets or bales. A sufficient and dependable premium payment for better quality would certainly be necessary.

Dried fish, like other stored products, can be disinfested by fumigation (Friendship, in press). Phosphine is the preferred fumigant since most others, including methyl bromide, are likely to leave undesirable chemical residues, especially in oil-rich fish.

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Appendices

APPENDIX 1 CATEGORIES OF STORAGE INSECTS AND MITES

Storage insects and mites can be categorized according to the state in which a particular crop or crop product is susceptible to infestation by them. **This appendix explains the categorization using commonly accepted terms (primary pest, secondary pest, etc.) which do not equate with pest status.**

A primary pest may sometimes be of minor importance. Thus, grain weevils (*Sitophilus* spp.) cause little concern in grain that is exceptionally dry, especially if the grain temperature is high. In the hot, dry regions of North Africa these insects occur, but are of low status as pests. Conversely, the well-known flour beetles (*Tribolium* spp.), which are categorized as secondary pests, are often of major importance on cereal products and on grain that contains a high proportion of broken kernels. On these commodities and a number of others their pest status may be very high. The same is true of the warehouse moths (*Ephestia* spp.), the rice moth (*Corcyra cephalonica*) and the Indian meal moth (*Plodia interpunctella*); all are usually secondary in their occurrence during the progress of infestation but they may be of considerable importance, in some situations, and they can all inflict damage, to the grain embryo, on whole grains as well as broken grains.

Primary pests are able successfully to attack dry, intact cereal grains or pulses. Many of them attack the grains before harvest and most of these are able to persist as storage pests.

Examples Grain weevils (*Sitophilus* spp.)
Bean 'weevils' and other bruchid beetles
Grain moth (*Sitotroga cerealella*)
Grain borers (*Prostephanus truncatus*, *Rhyzopertha dominica* and *Dinoderus* spp.)

The persistence of primary pests in store depends upon the storage conditions. Most are able to persist unless the grain is exceptionally dry. A few (e.g. some *Dinoderus* spp.) are less persistent.

Secondary pests typically become established as significant pests only after previous damage, due to primary pests or other causes, or on milled grain products. Some may occur on the crop before harvest and may damage grains that are not yet mature and dry.

Examples Flour beetles (*Tribolium, Palorus, Gnatocerus* spp.)
Silvanid grain beetles (*Oryzaephilus* spp. and *Cathartus quadricollis*)
Flat grain beetles (*Cryptolestes* spp.)
Warehouse moths (*Corcyra cephalonica*, *Plodia interpunctella* and *Ephestia* spp.)
Dust lice (Psocoptera)
Grain mites

Many secondary pests may successfully attack the embryos of undamaged cereal grains.

Tertiary pests are not associated with the crop before harvest. They typically become significant pests only after prolonged storage infestation by other insects or moulds.

Examples Fungus beetles (*Alphitobius* spp.)
The cadelle beetle (*Tenebroides mauritanicus*)

The khapra beetle, *Trogoderma granarium*, sometimes occurs as a tertiary pest but, on very dry grain, in the absence of competition from weevils, it can be a major primary pest.

Predators and parasites Predators in stores may be general predators (such as carabid beetles and some staphylinid beetles). Spiders also occur. General predators are of little importance in the control of pests. Storage predators, specifically adapted to the environment, are often associated with particular pest species or complexes and may contribute, sometimes significantly, to the natural control of the pests. Parasitic insects found in stores will always be associated with particular pests or complexes. They contribute to natural control but are rarely of practical importance.

Examples *Thaneroclerus buqueti*: a clerid predator commonly associated with the pest *Lasioderma serricorne*;
Blattisocius tarsalis: a predatory mite commonly associated with the pest *Ephestia cautella*;
Teretriosoma nigrescens: an histerid predator associated with *Prostephanus truncatus*;
Predatory hemipterans: commonly associated with heavy infestation by a complex of pest species;
Anisopteromalus calandrae: a hymenopteran parasite commonly associated with weevils and bruchids;
Bracon hebetor: a hymenopteran parasite of moth larvae.

APPENDIX 2 PESTICIDE DATA TABLES

Table 2/1

Average concentrations of phosphine (mg/l) required to give 100 per cent mortality of all developmental stages of insects under experimental conditions

Temperature	15°C		25°C			30°C	
Duration of exposure (days)	4	8	2	4	7	2	7
Sitophilus spp.		>1.50	>3.0	1.65	0.32	>0.36	0.05
Rhyzopertha dominica			1.6	0.18	0.02		
Lasioderma serricorne	0.36	0.04	1.6	0.32	0.15	>0.36	0.17
Trogoderma granarium	>1.30	0.77	0.8	0.32	0.08	>0.36	0.17
Acanthoscelides obtectus			3.0	0.32	0.15	0.36	0.09
Caryedon serratus				0.32	0.20	0.36	0.05
Ephestia elutella		>1.50	3.0	0.09	0.05	0.15	0.05
Ephestia cautella	>1.30	0.77	1.6	0.03	0.02	0.05	
Ephestia kuhniella	>1.30	0.77	1.6	0.03	0.02	0.05	
Plodia interpunctella	1.30	0.18	1.6	0.03	0.02	0.05	
Tribolium castaneum	0.03		0.16	0.08	0.04	0.02	
Oryzaephilus surinamensis	0.03		0.04			0.05	
Cryptolestes pusillus			0.16	0.08	0.01		
Cryptolestes ferrugineus				>0.08	0.04	0.36	0.05
Ptinus ocellus (=P. tectus)	1.30	0.18	0.40	0.08	0.04		

Source: Ministry of Agriculture, Fisheries and Food, Agricultural Science Service, Slough Laboratory, Slough, UK.

In: Pest Control for Food Security FAO Plant Production and Protection Paper 63 Prepared for FAO by ODNRI(TDRI) FAO, Rome (1985).

Table 2/2

Dosage schedules for fumigation with methyl bromide where the enclosed volume is filled, e.g. stacks under gas-tight sheets

	Stowage factor (m^3/tonne)	Dosage rate—g/tonne		Dosage rate—g/m^3		Exposure period (hours)
		Temperature (10–20°C)	*Temperature (Above 20°C)*	*Temperature (10–20°C)*	*Temperature (Above 20°C)*	
Rice (milled), peas and dried vine fruits	1.4	36	23	25	16	24
Barley	1.7	40	26	23	16	
Beans	1.8	42	27	23	15	
Paddy rice	1.9	44	28	23	15	
Cocoa beans	2.5	53	34	21	14	
Wheat, lentils	1.4	51	34	36	24	
Maize	1.6	54	36	34	23	
Sorghum, millet and figs	1.4	81	54	58	39	
Dates	1.1	74	55	70	50	
Cased, shelled nuts	2.0	90	60	45	30	
Empty sacks	1.4	81	54	58	39	
Flour	1.5	82	55	55	36	
Oilseeds	1.7	85	57	50	34	
Pollards	1.8	87	58	48	32	48
Groundnut kernels	1.9	88	59	46	31	
Groundnuts in shell	3.1	106	71	34	23	
Oilseed cakes	1.6	144	96	90	60	
Oilseed meals	1.7	145	97	85	57	

Source: Pest Control for Food Security FAO Plant Production and Protection Paper 63 Prepared for FAO by ODNRI(TDRI) FAO, Rome (1985).

Notes: The dosage rate per tonne can be read directly from the table according to the commodity. Recommended dosages are also given as g/m^3 for situations where the volume, but not the weight, of the commodity is known. The volume dosages have been obtained by dividing the dosage per tonne by the stowage factor. As the stowage factor is only approximate, it is better to use weight dosage; but in some cases, only the volume of a stack can be estimated of measured. The figures are *alternatives* and should *not* be added together. Temperatures refer to that of the commodity. Where *Trogoderma spp.* are present, dosage rates should be increased by 50 per cent. Where mites are present dosage rates should be increased by 50 percent. If the exposure period is reduced from 48 to 24 hours the dosage rate should be increased by 50 per cent. If the exposure period is increased from 24 to 48 hours the dosage rate can be reduced by 30 per cent. Where stacks of less than 30 m^3 (approximately 20 tonnes) are treated under sheets, dosages should be calculated as if the volume were 30 m^3 (20 tonnes).

Table 2/3

Maximum residue limits (mg/kg) recommended by the FAO/ WHO Joint Meeting on Pesticide Residues (as at January 1985)

Insecticides	Grain	Rice in husk	Bran (raw)
Dichlorvos	2	2	–
Malathion	8	–	20
Bromophos	10	–	20
Chlorpyrifos methyl	10	–	20
Fenitrothion	10	–	20
Pirimiphos methyl	10	–	20
Carbaryl	5-10	5	20
Lindane	0.5	0.5	–
Pyrethrins	3	–	–
Bioresmethrin	5	–	–
Piperonyl butoxide	20	–	–
Phenothrin	5	–	15
Fenvalerate*	5	–	10
Permethrin	2	–	10
Fumigants	**Raw cereals**	**Milled cereals**	**Cooked cereals**
Methyl bromide	5	1	0.01
Carbon tetrachloride	50	10	0.01
Ethylene dichloride	50	10	0.1
Ethylene dibromide	20	5	0.01
Carbon disulphide	10	2	0.5
Inorganic bromide	50	50	–
Phosphine	0.1	0.01	–

Source: Pest Control for Food Security FAO Plant Production and Protection Paper 63 Prepared for FAO by ODNRI (TDRI) FAO, Rome (1985).

Note: * Provisional.

Table 2/4

Recommended insecticide application rates

Insecticide	Dust admixture with cereals (ppm)	Surface treatments (g/m^2) Walls	Surface treatments (g/m^2) Bags	Space treatment (mg/m^3)
Malathion	8-12	1-2	1-2	–
Pirimiphos methyl	4-10	0.5	0.5 (3 months)	50-100 at 1 ml/m^3 (fog) 35-40 (smoke)
Fenitrothion	4-12	0.5	0.5-1	–
Bromophos	6-12	0.5-1	0.5-1	–
Chlorpyrifos methyl	4-10	0.5-1	0.5-1	–
Dichlorvos	2-20*	0.5		Simple fogging or aerosol 35-70 mg. Daily fogging or aerosol 10 mg. Strip changed every 2-3 months 1 per 30 m^3.
Methacrifos	5-15	0.2	0.4*	50-150
Iodofenphos	–	1-2	–	–
Tetrachlorvinphos	–	1-2	1-2	–
Lindane	1-2.5	0.5		40-80 (fog), 25 smoke
Pyrethrin/piperonyl butoxide (1:5)	3	–	0.075-0.1	1-2 (applied at 1 ml 0.3% for 1.5 to 3 m^3)
Bioresmethrin (resmethrin)	2	–		0.5-1
Phenothrin	5	–		–
Permethrin	–	0.5-0.10	0.5-0.10	–
Carbaryl	5-10	1-2	–	–
Bendiocarb	–	0.1-0.2	–	–
Dioxacarb	–	0.4-0.8	–	–
Propoxur	–	0.5	–	–

Source: Pest Control for Food Security FAO Plant Production and Protection Paper 63 Prepared for FAO by ODNRI (TDRI) FAO, Rome (1985).

Notes: * Short persistence.
– Generally signifies that the compound is not used in that type of treatment.

Table 2/5

Application rates for space treatments

Insecticide	Type of treatment	Recommended application rate (active ingredient)
Dichlorvos*	Single or occasional misting	35 to 70 mg/m^3
	Weekly or twice-weekly misting	15 to 30/mg/m^3
	Daily misting	5 to 10 mg/m^3
	Strip dispenser	1 per 30 m^3 space
Pirimiphos methyl (actellic)	Fogging	50 to 100 mg/m^3
	Misting every 2 weeks	20 mg/m^3
	Smoke (every few weeks)	35-40 mg/m^3
Pyrethrins synergized with piperonyl butoxide (1:5)	Occasional misting or fogging	1.5 to 3 mg/m^3 applied as 1 litre of 0.3% to 1,000 to 3,000 m^3
	Daily application by automatic misting	1 mg/m^3
	Treatment to obtain a residual deposit	25-45 mg/m^3 applied as 15 litres of 0.3% to 1,000 m^3
Bioresmethrin or synthetic pyrethroid mixtures	Misting	0.5 to 1mg/m^3
Lindane	Smoke for residual protection against beetles	100 mg/m^3
	Smoke for immediate effect on moths and flies	25 mg/m^3

Source: Pest Control for Food Security FAO Plant Production and Protection Paper 63 Prepared for FAO by ODNRI (TDRI) FAO, Rome (1985).

Note: * Formulation obtainable as 7 per cent w/v to 100 per cent w/v solution for direct application without dilution.

Table 2/6

Acute mammalian toxicity (LD_{50} – mg/kg body weight)

Insecticide	Rat (oral)	Dermal	Hen (oral)
Bromophos	4,000-8,000	2,000	9,700
Chlorpyrifos	135- 155	202	32
Chlorpyrifos methyl	950-1,100	>2,000	>2,000
Dichlorvos	56- 108	75- 110	15
Fenitrothion	250- 500	3,000	35*
Iodofenphos	2,100	>2,000	>2,000
Malathion	1,000-1,400	4,100	–
Methacrifos	700	3,100	–
Pirimiphos methyl	2,050	2,000	30-60
Tetrachlorvinphos	4,000-5,000	>2,500	2,500
Chlordane	450- 600	700- 850	–
Lindane	90	1,000	30-60
DDT	110	2,500	
Bendiocarb	34- 48	600-1,000	–
Carbaryl	500- 850	4,000	2,000*
Dioxacarb	60- 80	1950 (3,000)	–
Propoxur	90- 130	800-1,000	20*
Bioallethrin	500- 860	3,000-5,000	–
S-biol	800-1,500	1,500	–
Bioresmethrin	7,000	10,000	10,000
Resmethrin	1,400	3,000	–
Piperonyl butoxide	10,000		
Pyrethrum	580- 900	2,000	
Tetramethrin	4,600-6,500	>4,000	5,000
Cypermethrin	250	>1,600	
Deltamethrin	130- 140	>2,000	
Fenvalerate	450	>4,300	
Permethrin	1,500-4,700	>4,000	
Phenothrin	>10,000	>5,000	

Source: Pest Control for Food Security FAO Plant Production and Protection Paper 63 Prepared for FAO by ODNRI (TDRI) FAO, Rome (1985).

Notes: The figures for oral toxicity are for rats or as specified. Dermal figures are for rats, rabbits or unspecified.
* Pheasants

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