Marine transport of some tropical food cargoes to cold climates: maintenance of quality (NRI Bulletin 69)

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Maintenance of Quality

Overseas
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M. C. Gough

Bulletin 69

Natural Resources Institute

The scientific arm of the
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Summaries

SUMMARY

Problems of quality maintenance are encountered in the marine transport from tropical and sub-tropical to temperate climatic zones, of hygroscopic durable foods such as cocoa beans and similar commodities, particularly in winter in the Northern Hemisphere. Cargoes frequently display damaging mould formation and insect infestation on unloading. This publication indicates the likelihood of the incidence of these problems for different modes of transport by ship (bulk, bag and box container). Interpretations are based upon the principles of heat and moisture transfer and experimental observations of several shipments. The mould problem is usually interpreted as arising from the migration of moisture from the interior of the cargo to its sides. It occurs when a temperature difference develops between the cargo interior and the frame of the ship's hold. With bulk commodities, the moisture problem can occur at the sides of the cargo if this is in direct contact with the sides of the ship. With bagged commodities, similar difficulties can arise, but they are less pronounced because of the beneficial effect of air circulation around the bags, particularly if dunnage is present. For box-container transport, the major risk of quality deterioration occurs in winter following off-loading on the dockside. Dew can rapidly form on the underside of the container roof, and 'internal raining' with subsequent wetting and mould formation can occur with the associated risk of mycotoxin production. Closed box containers present the greatest hazard. Naturally ventilated and open-sided containers together with suitable modifications to handling practices are considered to be more suitable for the avoidance of this problem.

General recommendations for good practice are also included in the text.

RESUME

Il est observé des problèms au niveau du maintien de la qualité pendant le transport par voie maritime, entre les zones de climats tropicaux et sub-tropicaux et les zones de climats tempérés, pour les produits alimentaires hygroscopiques, par exemple les fèves de cacao et autres denrées. Il arrive fréquemment que les cargaisons présentent des formations indésirables de moisissures et des infestations d'insectes au déchargement. Cette publication indique la vraisemblance de l'incidence de ces problèmes pour différents modes de transport par bateau (en vrac, sacs et conteneurs). Les interprétations se basent sur les principes du transfert de la chaleur et de l'humidité et d'observations expérimentales de plusieurs expéditions par voie maritime. On interprète normalement le problème des moisissures comme étant le résultat du déplacement de l'humidité depuis l'intérieur de la cargaison vers ses côtés. Il intervient lorsqu'une différence de température se produit entre l'intérieur de la cargaison et le bâti de la cale du navire. Dans le cas des denrées en vrac, le problème peut se produire sur les côtés de la cargaison si elle est en contact direct avec les flancs du navire. Dans le cas des denrées dans des sacs, des difficultés semblables peuvent se produire, bien qu'étant moins prononcées en raison de l'effet bénéfique de la circulation de l'air autour des sacs et particulièrement si des dégâts sont présents. En ce qui concerne le transport par conteneurs, le principal risque de détérioration de la qualité se produit en hiver, après déchargement des denrées sur les quais. De la rosée peut rapidement se former sous le panneau supérieur du conteneur et une 'pluie intérieure', l'humidité ultérieure et la formation de moisissures peuvent se produire, ainsi que le risque connexe de production de mycotoxines. Les conteneurs fermés présentent les risques les plus élevés.

On estime que les conteneurs à aération naturelle et de type à côtés présentant des ouvertures et des modifications adaptées aux méthodes de manutention conviennent le mieux pour éviter que se produise ces problèmes.

Il est également indiqué dans le texte des recommandations générales concernant les méthodes correctes à observer.

RESUMEN

Desde las zonas tropicales y subtropicales a los climas templados, se encuentran problemas de mantenimiento de la calidad en le transporte marítimo de productos higroscópicos dura-

deros, tales como los granos del cacao y otros productos similares, particularmente en el Hemisferio Norte, durante la temporado invernal. Con frecuencia, al realizarse la descarga de los productos, se observa la presencia de mohos e infestación con insectos. En esta publicación se presenta la probable incidencia de estos problemas en los distintos modos de transporte marítimo (a granel, en sacos y en contenedores). Las interpretaciones están basadas en los principios de la transferencia del calor y la humedad y en observaciones experimentales realizadas con diversas cargas. Por regla general, se considera que el problema de los mohos surge de la migración de la humedad del interior a los lados de la carga, al producirse una diferencia de temperatura entre el interior de la carga y las cuadernas de la bodega. En productos a granel, el problema de la humedad puede producirse en la parte lateral de la carga, cuando se encuentra en contacto directo con los laterales del buque. Si bien pueden experimentarse dificultades similares con los productos ensacados, su impacto es menos pronunciado en este caso, como resultado del efecto beneficioso de la circulación de aire alrededor de los sacos, particularmente, en presencia de maderos de estiba. Por cuanto respecta al transporte de estos productos en contenedores, el principal riesgo de deterioro de la calidad se produce durante el invierno, tras su descarga en los muelles. En estas circunstancias, puede formarse rápidamente rocío en el interior de la tapa superior del contenedor, que resulta en 'lluvia interna', humedecimiento subsiguiente del producto y formación de mohos, con el peligro asociado de producción de micotoxinas. El mayor peligro se encuentra en los contenedores cerrados. Consiguientemente, se considera que, para evitar este problema, resulta más apropiado el uso de contenedores naturalmente ventilados con lados abiertos, en cuya manipulación se utilicen métodos convenientemente modificados.

El texto incluye asimismo recomendaciones de carácter general.

Part I

Principles and analysis

INTRODUCTION

Scope of this bulletin

The scope of this bulletin is confined to the marine transport from tropical and sub-tropical to temperate climatic zones of durable foods (such as raw cocoa and coffee beans), feed and similar commodities. Perishable foods or voyages from temperate to tropical climatic zones are not considered here (but *see* Boxall and Gough, 1993).

Overview

There are hazards to the maintenance of quality of durable commodities when they are transported by ship from tropical and sub-tropical to temperate climatic zones, particularly in winter. Cargoes frequently display 'wetting' and mould formation and insect damage at unloading. In this publication the likelihood of the incidence of these problems for different modes of carriage by ship is discussed. Interpretations are based upon the principles of heat and moisture transfer and experimental observation. Recommendations for good handling practice are provided. Detailed observations of actual shipments are provided in Part 2 of the bulletin.

Types of foods transported

The durable cargoes transported by sea from tropical and sub-tropical to temperate climatic zones include oilseeds, legumes, pulses, spices, beverages, cereals, and processed by-products such as copra expeller cake. They have a water concentration (moisture content) in the range 5-25 %. Their physical features can aid their deterioration in quality when surrounded by a hostile environment – they are hygroscopic (that is, they can absorb and desorb significant amounts of water in the liquid and vapour phase), and they have a large thermal capacity and poor thermal conductivity.

Food cargo configurations

Typically, the ships used in the transport of durable tropical and sub-tropical foods have cargo capacities ranging from about 10 000 to over 70 000 t, with some modern bulk carriers having capacities of more than 100 000 t. Box container ships frequently exceed 50 000 t in capacity. The ships used are usually less than 30 years old. Newer ships tend to be comparatively larger, and their cargo-handling equipment is either very efficient or virtually non-existent, relying solely on dockside facilities.

Food cargoes can be conveyed in ships' holds in three ways: bulk, bag, and box container.

Bulk cargoes are carried in ships with holds designed specifically for this purpose. The cargo can be loaded by conveyor belt or by lifting large buckets of the commodity by crane or derrick and tipping them into the holds.

Unloading is by pneumatic or mechanical ship unloader, or by a crane and grab system. With bag transport, the sacks normally have a 50-90 kg capacity and are made from jute or polypropylene. The holds are either filled as 'break bulk' (that is, the bags are randomly placed in the ship, or loaded onto pallets (about 25 bags to a pallet)) (*see* Figure 1). Pre-slung unit loads of sacks can be regarded as 'break bulk'.

Figure 1 A pallet of produce in polypropylene bags

Various types of box containers are in use; the basic designs are:

- general purpose, which are almost totally sealed;
- naturally ventilated, which have a series of natural ventilation grids near the top and the bottom of the two long walls; and,
- open-sided, which have metal-gates instead of the two long walls and which permit free air exchange between the cargo and the surrounding atmosphere when stored in a ship's hold. When off-loaded on to the dockside, the gates are covered with plastic curtains that prevent rain-water entering.

Box containers can be transported on board ship both above and below deck. These two methods of carriage can have different effects in terms of quality maintenance.

Climate and weather

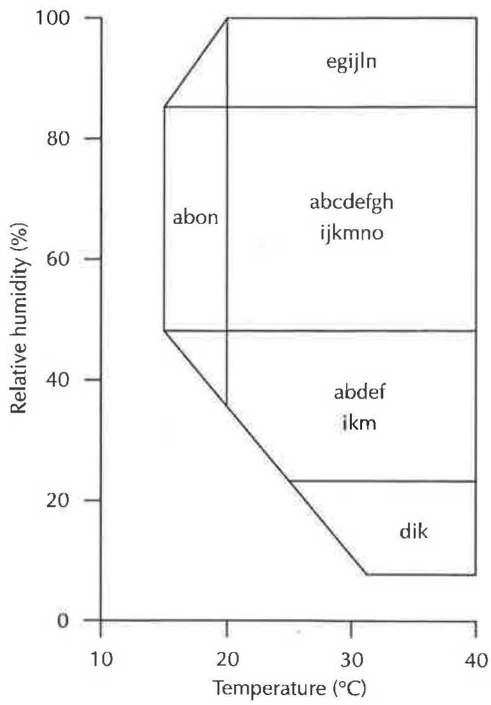
If hatch covers are properly maintained and correctly closed, cargo should not suffer liquid water damage even when stormy weather is encountered. Cargoes are, nevertheless, affected by climate and weather. This happens because of differences between ambient and cargo temperatures that induce undesirable water vapour – pressure gradients across cargoes.

HAZARDS TO FOOD CARGO QUALITY

Good-quality durable food can deteriorate both during and after marine transport. The particular type of deterioration depends upon the biological infestation agencies present, the mix of physical factors, and climate and weather during and after the voyage. Both existing physical condition and *changes* in physical condition can cause a food cargo to be in a potentially hazardous state from the point of view of quality maintenance.

Insects

Stored products insects (World Food Programme, 1992) increase in numbers and cause significant deterioration to many foods over a range of combinations of temperature and relative humidity. Some insect species can be a problem at almost any relative humidity (*see* Figure 2a), although most are adversely affected by low relative humidity (*see* Figure 2b). Significant growth of all species is limited to temperatures in the approximate range 15 °C to 40 °C, with a maximum around 30 °C. In tropical climates average storage temperatures are usually in the range 20 °C to 30 °C. While fumigation



a. *Sitotroga cerealella*
b. *Ephestia cautella*
c. *Plodia interpunctella*
d. *Trogoderma granarium*
e. *Lasioderma serricorne*
f. *Rhyzopertha dominica*
g. *Carpophilus dimidiatus*
h. *Cryptolestes ferrugineus*
i. *Oryzaephilus surinamensis*
j. *Ahasverus advena*
k. *Tribolium castaneum*
l. *Alphitobius diaperinus*
m. *Latheticus oryzae*
n. *Sitophilus oryzae*
o. *Sitophilus granarius*

Figure 2a Temperature and relative humidity conditions at which various insect species are important

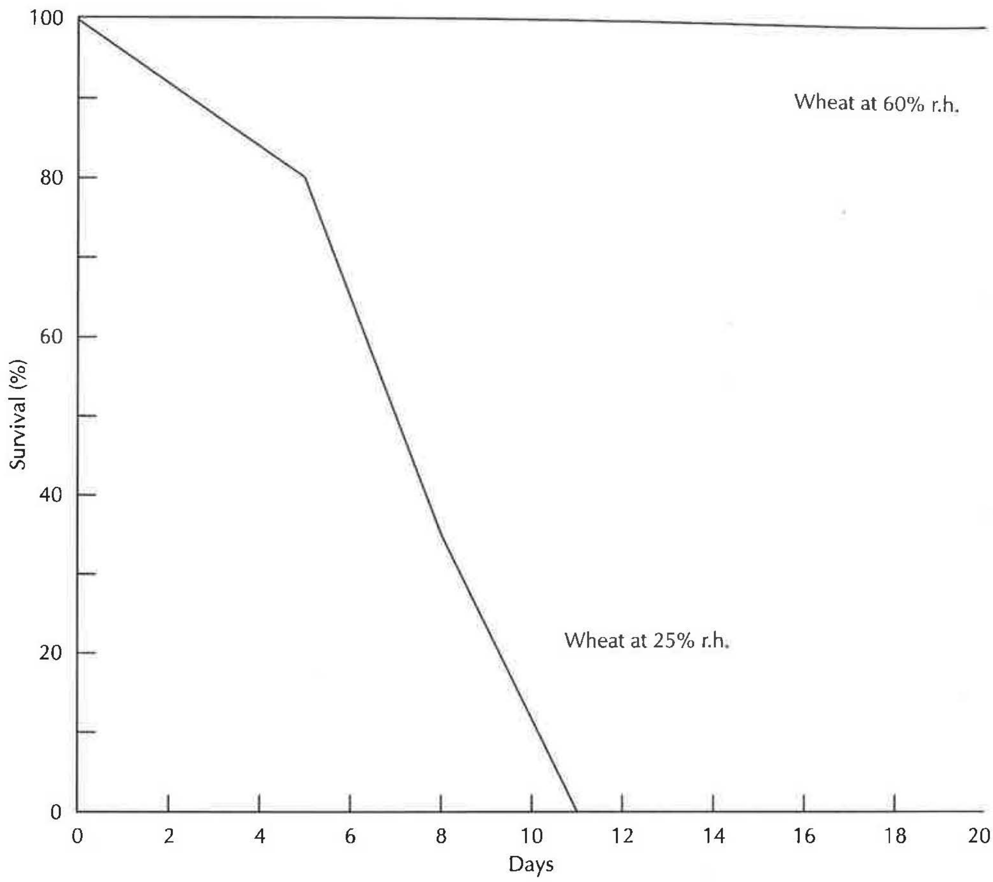


Figure 2b The period of survival of adult rice weevils in wheat with different relative humidities (after Moss and Szobnolotzky, 1960)

before or after loading may kill most insects, there will often be survivors that will develop during a voyage of several weeks if conditions are suitable.

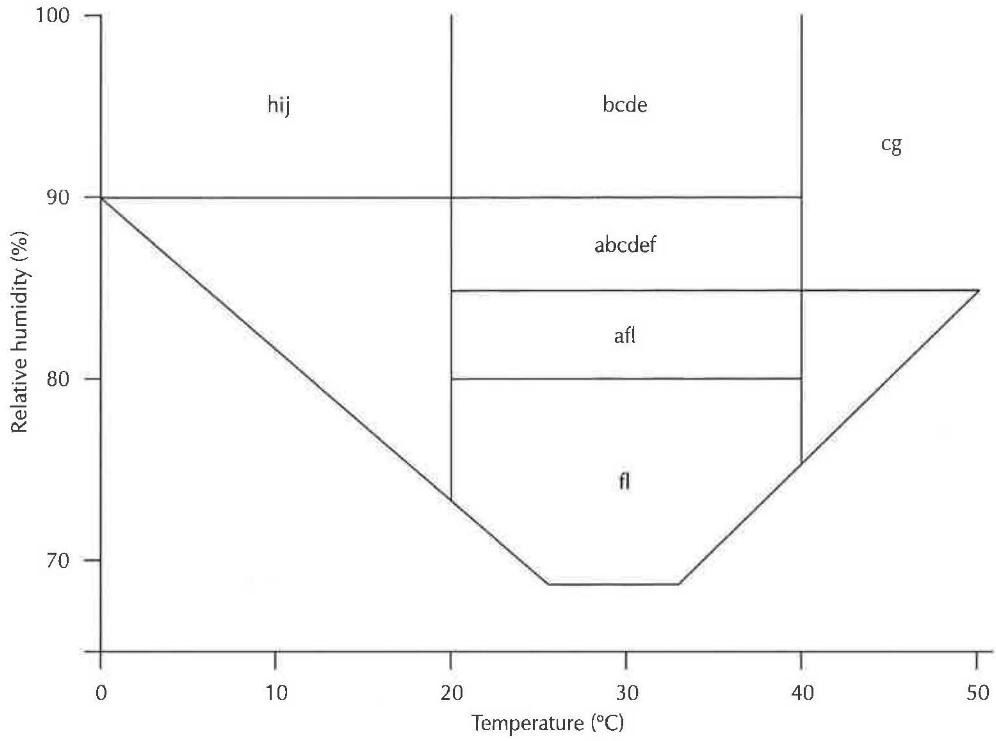
In old ships the holds frequently have metal support ribs and other structural projections jutting into the vacant space for cargo occupation. This is undesirable because it makes cleaning the empty hold difficult, with the risk that the work will not be done properly. Such lack of hygiene can act as harbourage for insect infestation from previous cargoes, resulting in a clean cargo becoming infested.

Moulds

Moulds (fungi) can reduce quality. If, for example, a climate change causes condensation droplets to fall onto the top surface of a cargo, large localized increases in moisture content will occur and this can lead to the growth of a mould such as *Aspergillus flavus* with concomitant production of aflatoxin (Diener and Davis, 1969). Mould propagates on the surfaces of the particles of a food and its rate of growth depends on the relative humidity and temperature at that location (World Food Programme, 1992). Mould can be significant over a wide range of temperatures (from 0 °C up to 50 °C), but only above a relative humidity specific for each species (*see* Figure 3). It is generally accepted that to protect durable food cargoes from mould, a relative humidity of 70% or less (Gough, 1975) should be maintained in the air in the voids between particles of the commodity (the interparticulate air). This is true only when temperature equilibrium has been established between the interparticulate air and the food itself. As will be explained later, the moisture content of the produce dictates the relative humidity of the interparticulate air and thus, if necessary, the food should be dried before despatch, to ensure a satisfactory relative humidity, particularly if temperature increases during or after the voyage are anticipated. It is important to note that mould growth is dependent upon the relative humidity and not the water content (absolute humidity) of the interparticulate air.

Respiration

Respiratory activity can be observed in all living cells and may be defined as the oxidation of food materials to supply energy for bio-chemical processes. Where a plentiful supply of oxygen and moisture is present, carbohydrates and fats are oxidized to carbon dioxide (*see* Figure 4) and water, and heat is liberated. In general, respiration is undesirable because it can reduce weight and quality.



a. *Aspergillus candidus*
b. *Aspergillus flavus*
c. *Aspergillus fumigatus*
d. *Aspergillus tamarii*
e. *Aspergillus niger*
f. *Aspergillus glaucus* group (including *A. restrictus*)
g. *Aspergillus terreus*
h. *Penicillium cyclopium*
i. *Penicillium martensii*
j. Some *Cladosporium* spp.
k. *Sporendonema sebi*

Figure 3 Temperature and relative humidity conditions at which various species of fungi are important

The total respiratory activity of commodities such as 'dormant' tropical food arises from three sources: the food itself, insect infestation and mould infestation. In dry foods, free from insects, the respiration rate is very low. As the moisture content and interparticulate air relative humidity increase, the growth of mould on the food leads to increased rates of respiration. In such damp material it is difficult to distinguish between that part of the respiratory activity associated with the mould and that part associated with the living food. Marked increases in respiratory activity are usually associated with produce in which the moisture content for safe storage from mould damage has been exceeded.

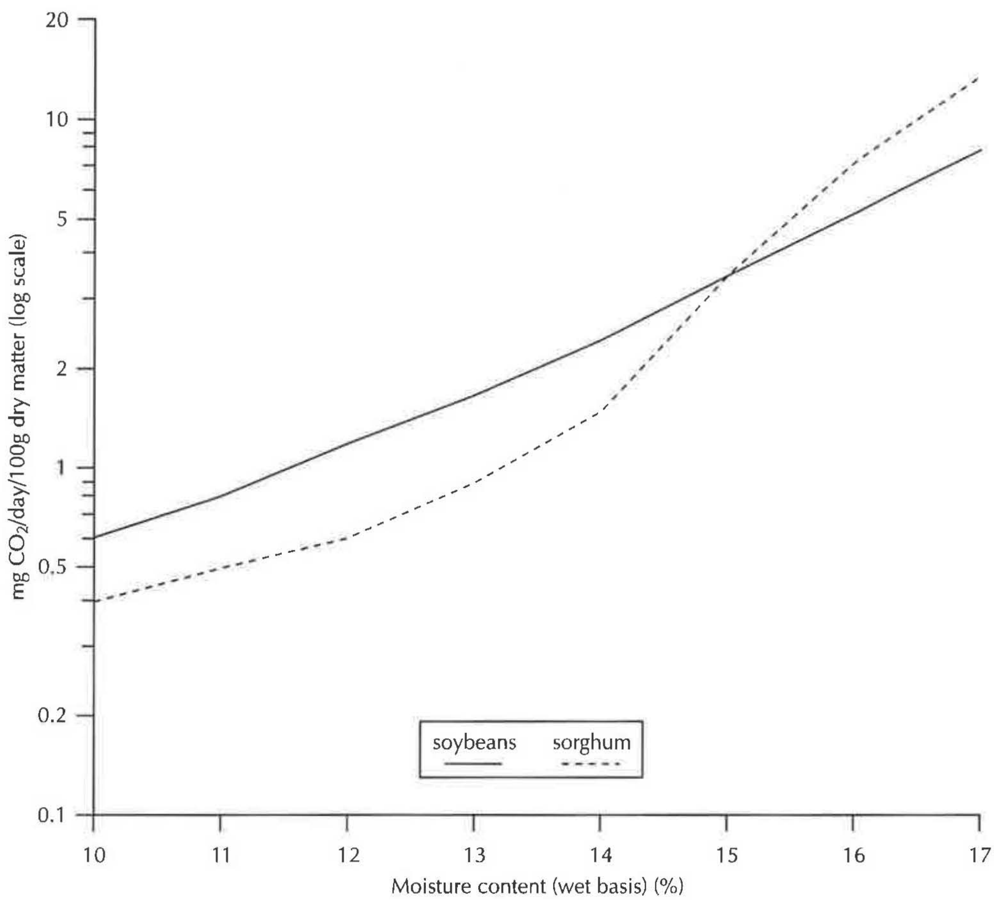


Figure 4 Production of carbon dioxide by two commodities at 38 °C (after Dr S. M. Henderson, University of California)

As in most chemical reactions, the respiration rate is accelerated by an increase in cargo temperature until the point is reached where the temperature becomes too high to allow further activity. Maximum respiratory activity in the commodities described here occurs at temperatures in the range 40 °C to 55 °C; it is, however, probable that at temperatures above about 40 °C, a great deal of the apparent respiration may be caused by chemical rather than biochemical oxidation. The effect of temperature is approximately to double the respiration rate for every 10 °C rise. Under tropical conditions, damp foods awaiting shipment suffer serious heating and consequent spoilage due to respiration.

A considerable contribution to the total respiratory activity can be made by insects present in a commodity. A great deal of heat is liberated as a result of the combined activity of the respiration of the food, the insects and the moulds it contains. The temperature of an infested food will therefore rise markedly during transport and subsequent storage. Moisture translocation may then occur, giving rise to local high concentrations of moisture and a further increase in the rate of respiration. Foods do not conduct heat very readily, so the heat produced will be dissipated very slowly, creating the conditions referred to as spontaneous heating. A good example of this is copra expeller cake, which has been known to self-ignite during transhipment. Where the heating is localized in origin, discernible 'hot spots' occur. It should be noted that the heat produced by insects can cause their eventual death or emigration from a heating commodity (Gough and Boxall, 1993).

THE RELATIONSHIPS BETWEEN PHYSICAL CONDITION AND HAZARDS TO FOOD CARGO QUALITY

Importance of the physical condition of the food

The physical conditions that can pose a danger to the quality of food cargo are: the temperature of the cargo and the surrounding air; the moisture content of the cargo; and the relative humidities of the interparticulate air and of the surrounding air. The growth of all food infestation is directly dependent upon these physical factors. Therefore knowledge of the physical factors is essential for quality maintenance. Control of losses depends to a great extent upon measuring and then controlling the physical condition of the cargo.

Temperature

The temperature is important in the transport of cargo in two ways. Firstly, when the food temperature is in the range 18 °C to 40 °C, all insect species can rapidly increase in population. They can then migrate through the cargo (subject to mechanical barriers such as the fabric of sacks, in the case of bagged commodity). The insect problem is greatest at about 30 °C. Secondly, if the sides of the cargo become significantly colder than the cargo interior, either through movement of the vessel into a cooler climate or because of a temperature rise in the centre of the cargo, a water-vapour pressure gradient will develop. If this is large enough, water vapour will diffuse from the cargo interior to its surfaces, raising the relative humidity at these surfaces. This can be serious because it can permit mould growth.

Relative humidity

If the relative humidity of the interparticulate air of a food cargo is 70% or more (when temperature equilibrium has been established between this air and the particles of the food), mould development can take place. This can occur if the cargo is too damp before it is loaded onto the ship or it can happen later as a consequence of temperature differences developing across the cargo.

If the cargo is ventilated either by mechanical or natural means, the incoming air can dry or wet the cargo. The relative humidity of the air when temperature equilibration has taken place is what is significant, not its value at the time of entry. Because of the enormous thermal capacity of the cargo compared to the incoming air (*see* below), the temperature of the incoming air changes to that of the cargo.

Moisture content and relative humidity/moisture content relationships

The moisture content (defined on a 'wet basis') of a sample of food is the ratio of the weight of water in the sample (determined by a standard method) to the total weight of the sample, expressed as a percentage. The relative humidity of the interparticulate air is more important than moisture content because the former dictates whether moulds will grow or not. In practice, it is seldom measured; the moisture content of the food cargo is measured instead. There are two reasons for this. Firstly, cargo consignments are bought and sold by weight and the most convenient way of checking how much climatically-induced weight gain or loss has occurred is to measure moisture content and make appropriate calculations. Secondly, instruments for measuring relative humidity in confined spaces (hygrometers) are often very expensive and fragile, and require frequent very careful calibration by skilled personnel. In contrast, moisture meters are reasonably cheap, relatively robust and seldom drift out of calibration significantly unless they are physically damaged. The moisture content can be linked to the relative humidity by means of an isotherm (*see* Figure 5). It should be noted that a properly calibrated and reasonably accurate hygrometer is a potentially useful tool since it does not require separate calibration for individual foods.

Relative humidity/moisture content isotherm relationships

At a specific temperature, there is a fixed relationship between the moisture content of a commodity and the interparticulate relative humidity. If a consignment of food is damp, the interparticulate relative humidity will be high and vice versa. The typical relationship between the moisture content of a commodity and the equilibrium relative humidity of the interparticulate air can be illustrated in graphical form as shown in Figure 5. The full characteristic curve is sigmoid. This relationship, at one temperature, is called a moisture content/relative humidity isotherm. Every commodity has a characteristic isotherm; even varieties of, for example, coffee beans, each have their own isotherms. The differences between varieties may be small, for example, a one-half per cent moisture content difference at 70% relative humidity. Nevertheless, if reliable recommendations for safe storage are to be made, it is important that the safe storage moisture content for each variety be known, because even a small increase over 70% relative humidity can put the cargo into a potentially hazardous condition. Some general examples of safe storage moisture contents are shown in Table 1.

Table 1 Safe storage moisture contents

Commodity	Moisture content (%)
Pepper	12
Green coffee	13
Palm kernels	7
Copra expeller cake	12

The values in this table are approximate and are not a complete range of common safe storage moisture contents. The effect of temperature on equilibrium relative humidity is relatively small within any 10 °C range (*see* below), so it is usually sufficient, for any one climatic zone, to refer to a single isotherm averaged within the appropriate temperature range, for each commodity or variety. A good example of the interaction between relative humidity and moisture content occurs when ships are travelling through warm tropical seas. In this instance, dry cargo can pick up moisture from the surrounding air. The converse can occur when a ship, with a warm cargo, is travelling through cold seas.

THE RELATIONSHIPS BETWEEN *CHANGES* IN PHYSICAL CONDITION AND HAZARDS TO FOOD CARGO QUALITY

Overview

When a cargo is subjected to a new ambient temperature and water vapour pressure (as a result of change in climate or weather), its physical condition changes. The response is slow. This is because the thermal conductivity and

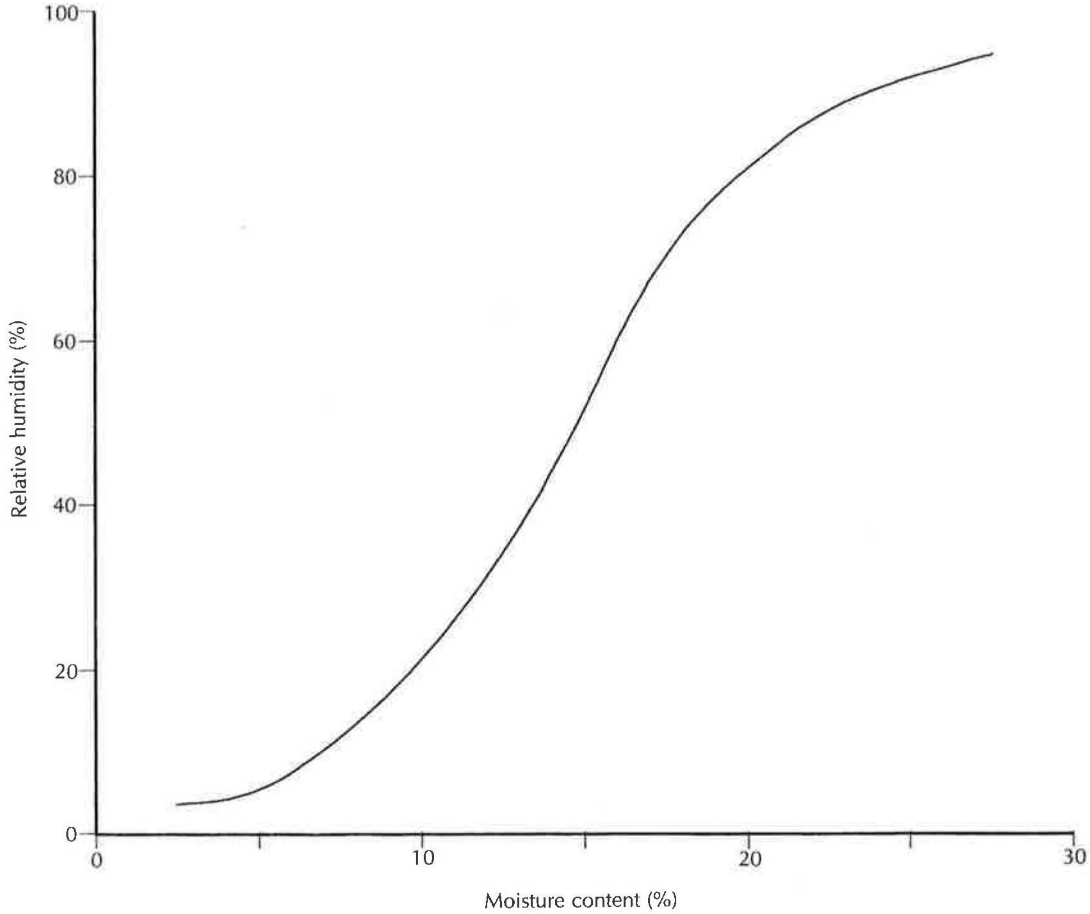


Figure 5 Hypothetical isotherm

capacity, and moisture conductivity and capacity of food and a comparable volume of air are very different. Nevertheless, eventually the changes can be significant and pervasive.

Thermal conductivity

Cargoes of durable tropical food are poor conductors of heat. Their conductivity is much lower than, for example, that of materials used in the construction of ships or box containers. Some examples for comparison are shown in Table 2. However, cooling by direct contact with the metal sides of a ship (and indirect contact with seawater) is slow because the heat mostly flows out of the cargo through air, which is a poor conductor. In practice, when a surface of a warm bulk is cooled, for example, as a ship enters temperate waters in winter, a cold temperature front will move across the bulk. The rate of movement is about 2 m per month through bulk grain (Gough *et al.*, 1987).

Table 2 Thermal conductivities of some cargoes and materials

Material	Thermal conductivity in arbitrary units
Wheat (12% moisture content)	3.6
Wheat (23% moisture content)	4.2
Glass	19
Cork (granulated)	1.1
Steel	1 100
Copper	9 600

In uniformly-stowed bagged cargo a front will move faster, at the rate of about 4 m per month; the increased value caused by air convection between the bags assisting the heat movement process.

Thermal capacity

Tropical durable foods have similar thermal capacities to metals and water, but the volume-to-volume ratio of the thermal capacities of food to air is about 1000:1. Any attempt to cool the cargo significantly by natural ventilation will be time-consuming because a large amount of air is required. Hence large bulks of, for example, cocoa beans will cool down slowly. Upon entering cool temperate waters, such bulks retain their tropical heat for some time.

Moisture conductivity

The movement of moisture by isothermal diffusion in bulk tropical foods, that is, the conduction of moisture when there are no temperature gradients, is very slow. For example, if bagged grain at 11% moisture content is exposed to 75% relative humidity for four months, moisture will diffuse into the bag stack raising the moisture content by 1% or more to a depth of only 0.3 m (Gough *et al.*, 1989). In spite of this small increase, it may be of financial significance for a high-value commodity such as green coffee, because it can increase the weight of the consignment slightly. The value of the ambient relative humidity is not specifically important, but the difference between the water-vapour pressure of the cargo and the external air is. Consequently, the exposed surfaces of a cargo may increase in weight as the ship travels through warm tropical seas, because the water vapour pressure of the air over the sea will normally be higher than that of the interparticulate air of the cargo. Conversely, the same cargo may lose weight as the ship travels through cold seas, where the water vapour pressure of the air over the sea will normally be lower than that of the air within the consignment. In both of these instances the **relative humidity** of the air over the sea will be similar in value.

The movement of moisture by non-isothermal moisture diffusion, when temperature gradients are present in bulk tropical food, can be significant (Anderson *et al.*, 1943). For example, if a ship which is coming from a tropical climate enters cool waters, a temperature difference develops between the sides and top surfaces of the cargo and its interior; this in turn induces this type of diffusion to that part of the cargo which is nearest to the metal sides of the ship, raising the relative humidity locally. The accumulated moisture usually cannot easily escape.

Moisture capacity

Compared to dry non-hygroscopic materials such as metals, dry tropical foods contain significant amounts of moisture when exposed to air at typical ambient relative humidities. For example, when surrounded by 60% relative humidity air, about one tenth by weight of green coffee beans will consist of water when equilibrium is reached between the air and the beans. Almost all of this water is absorbed inside the beans. The amount of water vapour in the voids between the beans is very small. When materials like cast iron and steel are exposed to 60% relative humidity, the quantity of water absorbed is negligible by comparison. The approximate amounts of moisture in one cubic metre of bulk tropical food and in ambient air are 80 kg and 0.012 kg respectively – a ratio of 6667:1. Hence, during aeration a large amount of air would be required to change significantly the amount of moisture in a batch of bulk food from a typical value such as 10% down to 5% (Bakker-Arkema, *et al.*, 1967).

Inter-relationships between physical factors

Knowledge of cargo moisture content and temperature, and the relative humidity of the interparticulate air is essential for good management, since these factors all affect safety in transport and subsequent storage. All three are related. Their relationships are difficult to understand if all three are changing simultaneously. It is easier to understand the subject by studying how one factor affects another by keeping the third constant; for example, investigating the effect of temperature on relative humidity whilst keeping moisture content constant.

Relative humidity/temperature relationships in air

Temperature has a marked influence on the water-holding capacity of air. In a closed non-hygroscopic receptacle (such as a glass jar) a fall of 10 °C can induce a large change, such as from 50% to 90%, in the relative humidity of the air inside. An example of the importance of the effect of temperature on relative humidity is the change which can take place just beneath the roof of a box container. If a commodity is placed in an enclosed box container, the moisture content of the commodity will govern the relative humidity of the air inside and a state of equilibrium will become established. The equilibrium value is constant at any given temperature and is called the equilibrium relative humidity. This will characterize the air around the produce and the interparticulate air so long as conditions remain constant. If the head space volume is large, this air is distant from the surface of the hygroscopic stow and may thus tend to behave like the air in an enclosed container containing no hygroscopic material. If the container is suddenly cooled down, for example when the container, stowed below deck, is offloaded from a ship at a temperate port in winter and left exposed to the weather, the relative humidity of the air just beneath the roof rises until it reaches 100% and water vapour then condenses on the underside of the roof. As explained previously, this can be hazardous to quality maintenance.

Relative humidity/temperature relationships in commodities

The relationship between moisture content and interparticulate relative humidity as expressed through isotherms was discussed previously. A change in temperature causes a corresponding change in the isotherm. With air in an airtight enclosure filled with green coffee, for example, a 10 °C temperature rise will raise the equilibrium relative humidity by about 3%. As mentioned above, the relative humidity of the air in the same airtight enclosure, with no commodity, would change by about 40% (or more) for the same 10 °C change. In general terms, the reason for the differing behaviour is that the commodity functions as a moisture reservoir to supply water vapour to the air, because the air's water-vapour carrying capacity increases rapidly with a temperature rise. But the commodity is itself affected by the increased temperature and this latter effect is responsible for the small *increase* in equilibrium relative humidity. While the effect of temperature upon equilibrium relative humidity is generally negligible in routine handling practice in any particular climatic zone, it is sometimes important when shipping from cold to warm climates (Boxall and Gough, 1993). The effect may also be important when, for example, inadequately dried rice is exported from a subtropical zone in the cool season following a wet harvest and the ship is travelling through warmer seas.

EFFECTS OF CLIMATE AND WEATHER

In bulk cargo transportation, climate (average weather conditions) and weather (abnormal climatic conditions) can be damaging to quality. Specifically, temperature in conjunction with relative humidity are responsible. As explained previously, non-isothermal moisture diffusion to that part of the cargo which is nearest to the metal sides of the ship raises the relative humidity locally. The same problem can arise in bag transport, but it is less significant because air circulating around and between the bags disperses excess moisture vapour. This process is aided if small groups of the bags are stacked on pallets throughout the cargo. Consequently, properly dried bagged cargo can usually be safely carried from tropical to temperate ports.

Temperature in combination with moisture can be a particular problem with box container shipments at the end of voyages when the containers placed below deck are lifted on to the dockside. In winter, the container can be subjected to a temperature difference between the metal frame of the container and the centre of the load of 20 °C, or more, within minutes of offloading (Gough and Green, 1993). Condensation (dew) can form on the underside of the container roof. If the condition is intensive enough, 'internal raining' occurs – water droplets fall onto the top surface of the load. This can set up an undesirable chain of events – the moisture content of a thin layer of commodity at the top surface is raised; this in turn may permit the growth of moulds, which in turn can produce mycotoxins. For example, in the transportation of black pepper by box container the development of aflatoxin is a known hazard (Gough and Green, 1993). Even concentrations of aflatoxin of 20 parts per billion (ppb) are considered excessive (see *Part* 2, *Bulk Cargo Study*). It could be argued that, provided that they are in good condition and weatherproof, containers should travel above deck if arrival at the importer is expected to be in winter. This would avoid the thermal shock that can occur when a container is suddenly removed from deep inside the interior of a container-ship's hold. However, transport on deck can expose the stow to undesirable effects of weather, such as solar heating on only one of the long walls, or to several days of unusually cold weather (a 'cold snap'). An increase in wind levels can also have a chilling effect on the warm cargo by increasing the thermal flow from the container structure. Problems are reduced if loads are stacked onto pallets placed on the floors of the containers, because this improves the ventilation around the commodity.

The effect of humid ambient air does not usually cause difficulties with unventilated cargoes. For example, when a ship is travelling through tropical seas where the water vapour pressure of the ambient air is comparatively high, the cargo does not experience large overall changes in moisture content. However, if the captain operates mechanical ventilation machinery in these circumstances, moisture increases can occur in exposed parts of the cargo. In the case of cargoes leaving sub-tropical ports in winter and subsequently entering warm tropical waters there will be an even greater increase in moisture content at the exposed surfaces. In extreme conditions condensation can occur if the cargo is in plastic (such as polypropylene) bags. Irrespective of the bag material, the moisture adsorption is only temporary and the process may reverse later in the voyage. The reason for this is that the incoming air warms the surfaces it makes contact with. The warming action eventually results in the relative humidity of the incoming air remaining unchanged when it impinges upon the exposed cargo. These instances are not as hazardous as those for a converse voyage (from a temperate to a tropical zone), where a large proportion of the moisture in the humid incoming air would be absorbed throughout the cargo and the food has an interparticulate relative humidity which will rise above 70% as the cargo warms up in the tropical waters.

The transportation of bulk powdery materials such as copra expeller cake can be particularly problematic in terms of cargo heating; this can be exacerbated by the climate and the weather. Like all fine granular foods, the cake has an extremely poor thermal conductivity, and thus there is no opportunity for significant convection to dissipate a build-up of heat due to respiration by the food itself, by insects or by moulds. An exothermic chemical reaction can also take place in copra expeller cake. The result is that even a small amount of heat generated will manifest itself in a high temperature rise that sometimes leads to spontaneous combustion of the cargo in a ship's hold. This problem is aggravated if the voyage is through tropical waters during summertime at the destination port.

For many years, importers of commodities in box containers in temperate climates have discovered deterioration of quality upon unloading the cargo. This includes:

- wetting – typically, dampness on the top layer of bags and on those in contact with the side walls of the container. In the most severe cases, bags have rotted and water has poured out of the container upon opening the doors, or the water has frozen the doors to the frame under winter conditions; and,
- visible mould formation on the commodity, usually found on the top layers of bags in the container.

These problems have been encountered most frequently with general purpose and other poorly-ventilated types of box containers in shipments from the tropics to the temperate climates of North America, Europe and Japan. Additionally, other non-visible problems can arise along with those listed above which are clearly related to 'sweating' or moisture vapour build-up within the container. If adequately dried to the appropriate moisture content for the particular commodity, growth of mould is inhibited. However, the moist conditions that can develop when spices are shipped in containers can favour localized mould growth and the formation of mycotoxins, which are invisible to the naked eye. While there are means of treating some feed commodities after import to inactivate certain mycotoxins, there is no effective method for the destruction of mycotoxins in food for human consumption once the mycotoxins have been produced.

SIMULATED TRIALS OF CONTAINER VENTILATION

The effect of ventilation has been investigated by Cambridge Refrigeration Technology. Several studies of simulated container shipments (some in collaboration with NRI) were undertaken and what follows summarizes the findings published by R. D. Heap (Heap, 1983).

In the trials a fully loaded container fitted with monitoring instrumentation (thermistors and Reethorpes (Gough, 1980)) was equilibrated in a controlled environment chamber at 20 ± 2 °C and $80 \pm 5\%$ relative humidity, to simulate cargo conditions observed when approaching Europe in winter. The external temperature was dropped over a few hours to 2 ± 1 °C and the response was observed.

As far as condensation on the underside of the container roof was concerned, one of three things happened in the simulation trials: there was no condensation at all (unusual except for containers of exceptionally large vent area); condensation formed but was removed by ventilation before large droplets built up (a common pattern); or condensation continued to build up until a potential danger to the cargo arose (observed in containers of limited vent area, particularly with cocoa as a cargo). This simulation procedure succeeded in producing conditions sufficiently severe to distinguish between different containers without being too severe to be realistic.

Predictive modelling

A mathematical model of ventilation in containers was produced (Heap,1983). It was found to be able to predict the number of air changes per hour and was experimentally validated with reasonable accuracy in a purpose-built ventilated empty container. Chimney-effect ventilation tests on a number of container designs showed that, even in well-ventilated containers, there would not be more than four air changes per hour.

Conclusions

It was concluded that vents should not intrude excessively into cargo space, and inlets should be effective, particularly when cargo loading is prone to block vent openings. Both theory and practice showed that the greater the vent areas, the wider the range of conditions under which naturally ventilated containers will succeed, but there are no established values for acceptable areas in particular trades. The effects of vent geometry and the interaction between vents and stowage patterns were not studied in detail.

RECOMMENDATIONS FOR GOOD PRACTICE

- The moisture content and temperature of cargo should be as uniform as possible.
- The maximum moisture content of the commodity should be such that the interparticulate air relative humidity never exceeds 70% during or after the voyage. This may mean that the consignment should be drier than is needed at the port of export, to counter the moisture – increasing effects of climate and weather during the sea journey, and afterwards when stored at the importer's warehouse. In addition, a somewhat lower specification value may need to be demanded to compensate for sampling error in moisture-content measurement.
- The value of the average temperature of the commodity at the time of loading ideally should be such as to incur the least thermal stress (temperature differences across the cargo) during and after the voyage.
- The time of year for shipment and subsequent storage should be chosen to minimize thermal stresses and moisture increases in the cargo, if practicable.
- Cargo should never be stowed directly against the sides of the ship, and the head space should be minimized without the cargo making contact with the deck or hatch cover.
- Attempts should be made to induce air circulation around and through the cargo where possible.
- Where there is a large difference in temperature between the cargo and the air above the sea, forced ventilation should be kept to a minimum.
- Cargoes such as pepper, cocoa and coffee should be transported in open-sided or naturally ventilated containers, and stowed below deck.

Part 2

Trials and observations

BULK CARGO STUDY

Quality changes in copra by-product during transhipment from the Philippines to Europe

Introduction

Background

Most of the oil from dried coconuts (copra) is extracted by physical compression using an expeller. Further extraction of oil can be achieved by the use of a solvent. The residues following physical compression and solvent extraction are called copra cake and copra meal respectively. Most residues are pelletized in the Philippines. Because the cargo described in this section was a combination of batches of pelletized and non-pelletized copra cake and copra meal, it will frequently be referred to as copra by-product.

Up to 1991 the European Union (EU) general limit for aflatoxin in imported copra by-products was 200 ppb. Consignments containing more than 50 ppb could only go to a registered feed compounder. In November 1991 the 50 ppb limit was reduced to 20 ppb (Official Journal of European Community, 1991), and it is probable that the general limit will be reduced to 100 ppb. It was anticipated that the Philippines Coconut Authority (PCA) might have difficulty in meeting the new standard and, therefore, risk losing valuable export markets in the EU.

NRI collaborated with the PCA in a study of the problem of aflatoxin contamination in copra by-product exports to Europe. As part of this investigation it was agreed that three shipments of the commodity in bulk form would be monitored for quality changes. These consignments were sampled for aflatoxin determination at loading in the Philippines and during discharge in Europe. In the first shipment the vessel was a 'tweendecker with five holds and it carried 2 000 t of copra cake and 8 800 t of copra meal, both in pelletized form. Loading took place at Tacloban, Roxas, Iligan and Davao in April 1991. The five-week journey was via the Suez Canal to Livorno, Italy. The second shipment was in a four-hold bulk carrier with a cargo of 12 600 t of non-pelletized copra cake loaded at Jose Panganiban, Tacloban and Manila in late May/early June 1991. The six week journey to Ravenna, Italy was via the Suez Canal.

The third shipment (the main subject of this section) was planned to take place when the weather was cold at the discharge ports. There is evidence from cargo surveyors that copra cake frequently arrives at European ports at temperatures exceeding 35 °C. In winter and spring when the average ambient temperature is frequently below 10 °C, there is a real risk that the difference in temperature between the cargo and ship's structure will induce significant convection currents in the holds, thus permitting condensation to develop on the undersides of the hatches. In the trial, monitoring sensors were installed in the cargo to record physical changes, which could allow the production of aflatoxin, during the voyage.

The third shipment and voyage

The vessel used for the investigation was a 16 year-old five-hold bulk carrier. It carried 21 000 t of bulk pelletized copra by-product loaded at Cebu, Iligan and Davao in the Philippines. The cargo was a mixture of batches of copra cake and meal. Except for 2 350 t in the upper part of Hold 2, all of the cargo was sampled for aflatoxin analysis during loading. Sensors were installed before, during and after loading at Davao; they were placed in or near the cargo in the upper regions of all five holds, to enable temperature, moisture content and condensation to be regularly monitored during the voyage.

The voyage across the Indian Ocean, round the southern tip of Africa to Lisbon took 43 days, when 3 500 t of the cargo were discharged there. Two days later the ship departed, arriving after a three-day voyage at Rotterdam where the rest of the cargo was discharged.

Arrival in Europe

At Lisbon, the top surfaces of the cargo, in the two holds that were opened, were dry and showed no signs of mould growth – even though heavy seas had flowed over the hatches when the ship sailed through a storm in the Indian Ocean. It was only possible to collect samples for aflatoxin determination from one of the two opened and partly discharged holds. The samples were collected from the cargo surface immediately following the removal of the hatches and then during discharge.

The remainder of the cargo was discharged in Rotterdam. The top surfaces of the three previously unopened holds were dry, with no evidence of mould growth. Samples were collected for aflatoxin determination from the surfaces of the cargo and then during discharge. Unfortunately, because of the unloading procedures, the high rate of discharge (about 20 t per minute), and the fact that discharge was continuous for 48 hours, it was not possible to follow the sampling regime used at loading, nor to obtain samples from every hold. Additional 100 g samples were obtained for moisture content analysis from alongside the moisture sensors on the surfaces of the cargo.

Monitoring physical changes during the voyage

Overview

Microclimatological changes in the cargo during the third voyage were monitored with electrical instruments. Sensors were installed before, during and after loading at Davao. They were placed in or near the cargo at the upper regions of all five holds but predominantly in Holds 1 and 4. Sensors were installed in these two holds: thermistors to monitor temperature; Reethorpes to measure moisture content (Gough, 1980); and Muratas to measure condensation. Wherever a Reethorpe was placed, a thermistor was positioned alongside, and a 100 g sample was collected at the time of installation for accurate moisture content measurement later. Hold 4 was the most heavily instrumented – it had 26 sensor places (*see* Figures 6a and 6b) compared to nine in Hold 1. Holds 2, 3 and 5 were fitted only with a small number of thermistors.

Measurement during the voyage

In Hold 4, Squirrel dataloggers collected temperature measurements automatically every hour throughout the voyage. In all the other holds, temperature measurements were collected manually by the Chief Officer at about 08.00 hours (local time) every other day. He connected each thermistor cable in turn to an Edale thermometer and recorded the measurement on a specially prepared data record sheet. He also took measurements of moisture content in Holds 1 and 4; each Reethorpe being connected by switchboxes to a Marconi moisture meter and the reading recorded on the data record sheet. He also collected meteorological data from the instruments on the ship's bridge throughout the voyage.

Copra by-product temperature and moisture content

Even if the interparticulate air relative humidity of a copra by-product cargo is acceptably low (70%), there is still the risk that the moisture content of the surface of the consignment could rise locally to dangerous levels because of 'internal raining' (Gough *et al.*, 1989).

In the description that follows, the changes in temperature and moisture content during the voyage refer to the readings obtained from the thermistors and Reethorpe sensors in the cargo, and standard oven moisture content determinations. For moisture content *changes* of about 2 or 3%, the Reethorpes have an accuracy of $\pm$0.2% with 95% reliability. Standard oven moisture-content determinations with an accuracy of 0.1% (or better) were obtained from samples collected at loading and discharge. It should be noted that the time shown on all graphs is Greenwich Mean Time (GMT). Davao is eight hours ahead of GMT.

Overview of physical changes during voyage

The temperature of the head space air and the top surface of the cargo remained in the region of 20-30 °C throughout the voyage across the Indian Ocean and around Africa. It started to decline on the approach to Europe, and after Lisbon the temperature dropped rapidly, falling to about 10 °C at the time of discharge at Rotterdam. In the interior of the cargo the temperature behaved differently – it rose steadily from 34 °C to 37 °C during the voyage. A thin layer of condensation formed on the undersides of the hatches during the last few days of the journey. It was not heavy enough to fall on to the cargo. The only moisture increases were at the sides and top surface of the cargo and these were generally not significant.

Temperature in Hold 4

Apart from bunkering at Singapore for one day, the vessel proceeded across the Indian Ocean towards Africa. During this time the average temperature of the top surface of the cargo remained virtually constant at 33 °C (*see* Figure 7). It dropped by about 10 °C as the ship rounded the southern tip of Africa, and it rose by about 10 °C as the ship passed the equator. It started to decline again a few days before the ship passed the westernmost part of Africa, and had dropped to 15 °C by the time the ship arrived at Lisbon. A further drop of 7 °C took place by the time of arrival at Rotterdam. The greatest diurnal change in temperature occurred at the top surface of the cargo, in response to the warming or cooling of the deck and hatch covers caused by the sun and by night radiation.

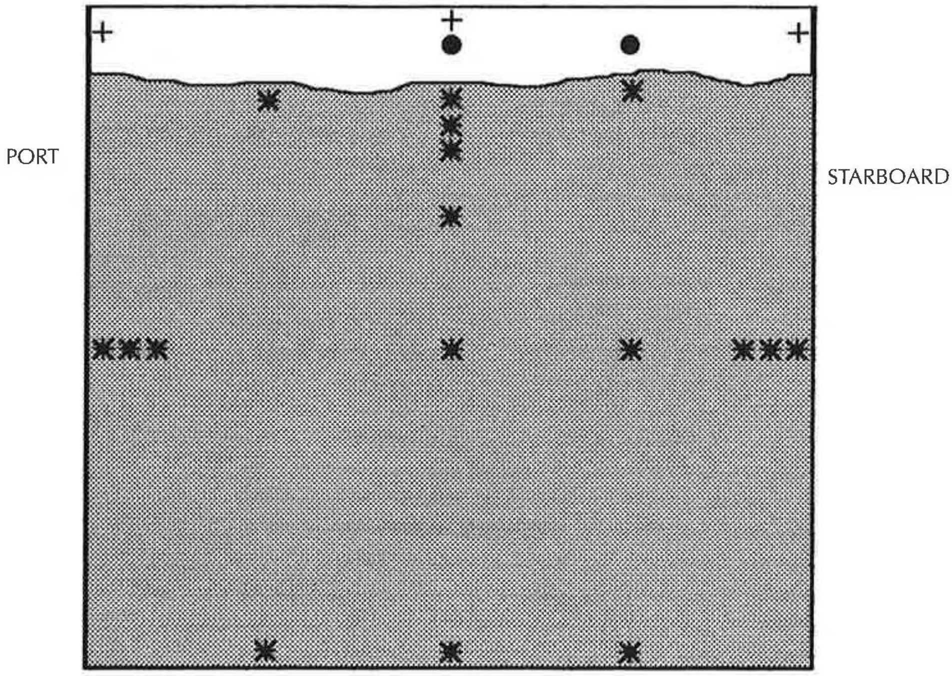


Figure 6a Central plane in Hold 4 across the ship

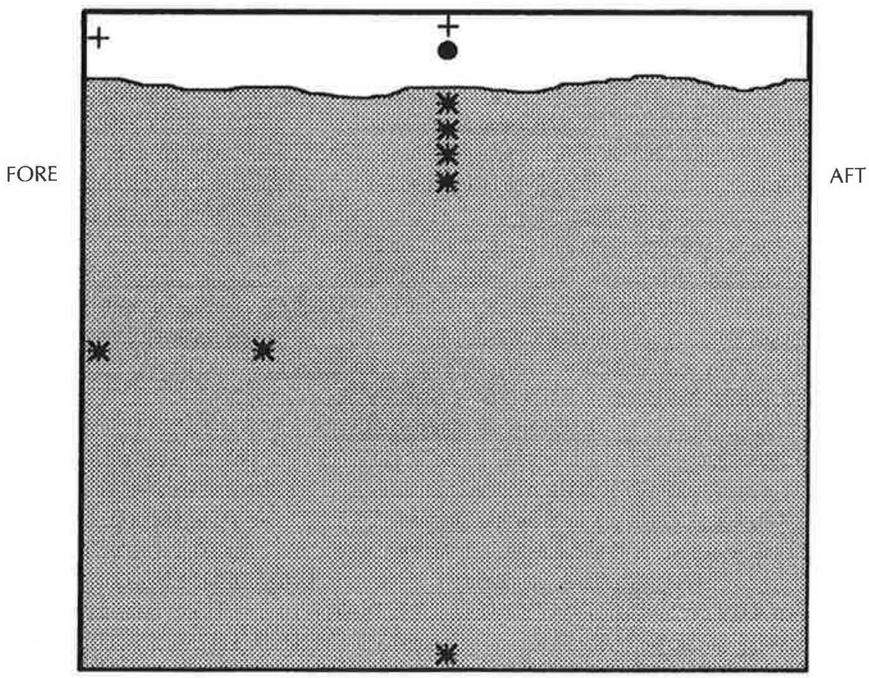


Figure 6b Central plane in Hold 4 along the ship

In the centre of Hold 4 the temperature was unaffected (in the short term) by the external conditions, and it gradually increased from 34 °C to 37 °C during the voyage.

The pattern of change at and near the surfaces of the consignment in Hold 1 was similar to that in Hold 4. However, the interior temperature (39 °C) was 5 °C higher at the start of the voyage. It rose by 3 °C during the voyage compared to a 5 °C increase in Hold 4.

In Holds 2, 3 and 5, temperature was measured 0.15 m below the top surfaces of the consignments in two places in each hold. In Hold 2 the pattern was similar to that in Hold 4. In Holds 3 and 5 the pattern was also similar until the start of discharge at Lisbon. The temperature rose by about 7 °C in both holds after discharge. This can readily be explained by the fact that the bulldozers used to discharge pushed large quantities of copra by-product from the central interior towards the fore and aft parts of the holds. The sensors would thus have been submerged more deeply and the covering material would have been comparatively warm. The implication is that the interiors of the consignments in Holds 3 and 5 were warm, probably at about 40 °C.

Condensation

During the six days before arrival at Rotterdam, condensation had formed continuously on the underside of the **deck** above the cargo in Hold 4. It was not possible to attach condensation sensors to the underside of the **hatches**. The extent of the condensation cannot have been significant because there was no evidence of condensation, 'internal raining', or mould growth when the hatch was opened.

Moisture

In Hold 4 there were localized increases in moisture content during the voyage; these were only at the top surface and sides of the cargo and they were not a threat to quality. There was a similar but greatly reduced pattern in Hold 1.

Mycotoxicological change in the cargo during the voyage

The aflatoxin B_1 concentration (Diener and Davis, 1969) was measured in the same laboratory before and after shipment and no evidence of an increase in value was found.

Discussion

Physical changes

As has been observed with other shipments, the copra cake warmed up during the voyage – even though the surrounding air temperature dropped by more than 20 °C. The data imply that the behaviour in the consignments of copra meal was similar. Since no insects were observed in any of the consignments, respiratory heating from this source was not responsible. Solar heating from the deck downwards could not have been a factor – the average temperature of the top surface of the commodity in Hold 4 did not rise above 35 °C during the voyage. Respiratory heating by moulds is also unlikely to have been the source of heating because the interparticulate relative humidity of the consignment was low (Gough,1975). The source of the heating may have been an exothermic chemical reaction in the form of the oxidation of unsaturated residual oils (although they are usually present at low levels).

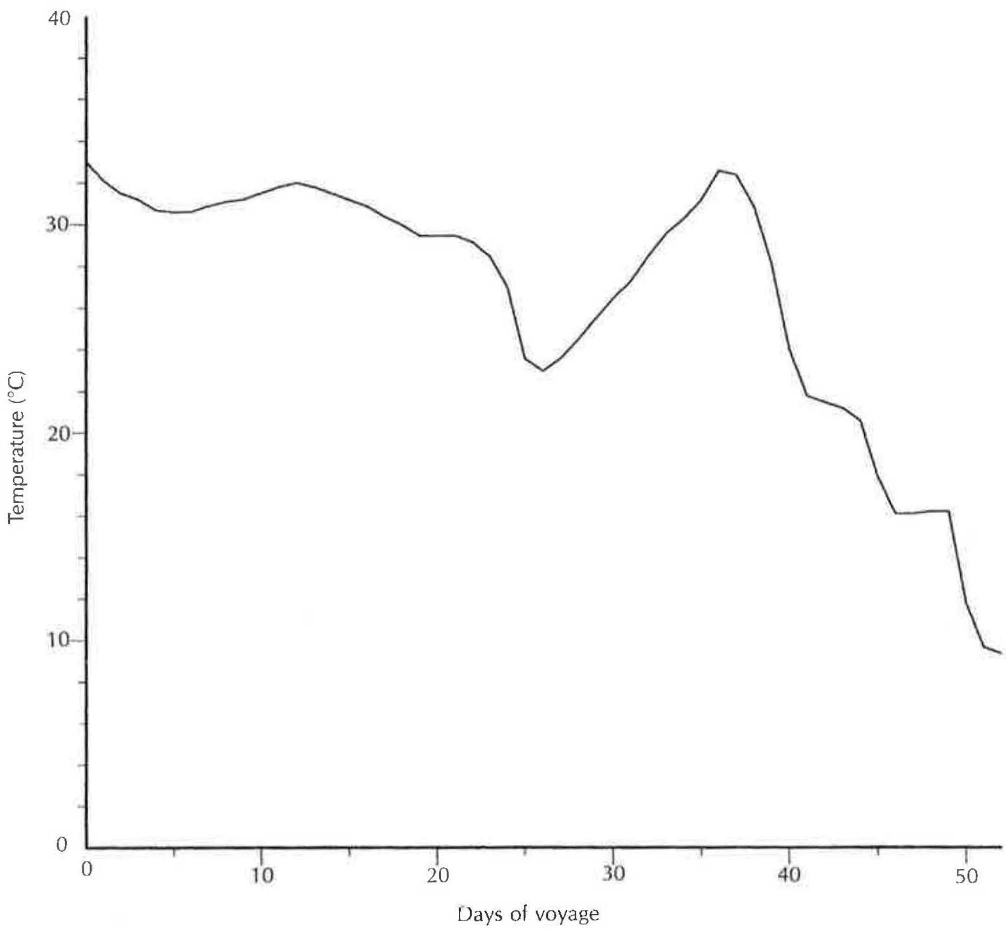


Figure 7 Average temperature at the top surface of the consignment in Hold 4

The consignments left the Philippines at a moisture content not exceeding 9%. There were localized moisture content increases of up to 3% at the top surfaces and sides of the consignments in Holds 1 and 4 by the end of the voyage. For both copra cake and meal the safe storage moisture content is about 13.5% (wet basis) at 30 °C (Gough, 1977); the value is influenced by the particular oil content of the consignment. There was, therefore, no risk of mould attack despite the increase in moisture content. The data highlight the need to ensure that the commodity is not exported at a moisture content much greater than 9% – at any higher value mould attack is likely to occur because of moisture content increases during the journey.

Consignments of copra by-product usually had a temperature of about 40 °C just below the top surface. If local high moisture content had been a result of 'internal raining', conditions would have been suitable for aflatoxin production. Only light condensation developed in this case because of the route taken and the weather in Europe. As it was summertime south of the equator, the ship sailed in warm ambient conditions for most of the voyage. Had the journey been via southern Africa or through the Mediterranean in winter the opportunity for prolonged condensation would have been much greater. Unfortunately, in this instance the decision to travel via southern Africa was taken at short notice, preventing study of a more appropriate shipment. In spite of this, the data show moisture increases at the top surface of copra by-product in one of the holds, implying that hazardous conditions could have developed had the ship taken a climatically less favourable journey.

The holds of this ship were not provided with ventilation. Generally, ventilation is beneficial in preventing moisture problems (Gough and McFarlane, 1984). When the cargo is comparatively warm, the relative humidity of the incoming ventilating air will decline to safe levels and will disperse the warm moist convective currents rising out of the cargo. Ventilation has the added advantage that, if it is gradually applied, it reduces thermal stress across the cargo as the ship enters a cool climate (Gough *et al.*, 1989).

Mycotoxicological changes

An examination of the results on a hold-by-hold basis showed that there was a large reduction in the aflatoxin level, except in the bottom of Hold 2 where the decline was only significant at the 5% probability level. In general, there was an estimated reduction in aflatoxin B_1 of 19% during shipment, and there was statistically significant evidence that the level of aflatoxin B_1 was lower on unloading in Rotterdam and Lisbon than when loaded in the Philippines. The reason for this decrease is unclear. Similar findings have been reported in some studies on aflatoxin levels during storage. It is recommended that further work on aflatoxin reduction during storage (and shipment) should be carried out to seek an understanding of this behaviour.

It is clear that, during this voyage, conditions did not allow growth of toxin-producing mould.

Conclusions

There was no evidence of an increase in aflatoxin B_1 concentration during shipment.

The initial moisture content of the commodity was just low enough to prevent the development of unsafe conditions.

The consignment did become vulnerable to moisture-induced deterioration towards the end of the journey. Potentially hazardous conditions are likely to have arisen had the ship sailed directly to Europe through the Suez Canal, because the cargo would have been cooled more rapidly by the surrounding atmosphere.

BOX CONTAINER STUDIES

A Studies of quality maintenance of black pepper shipped in open-sided box containers

Introduction

Background

Traditionally, black pepper has been transported as 'break-bulk', but the recent past has seen the growing use of box containers for shipment. This reflects a general trend on major trade routes where significant economies, particularly in labour for handling at ports, can be achieved by the use of containers. A particular weakness of this new mode of transport is the greater incidence of microbiological problems.

Microbiological problems

When box containers of hygroscopic commodities, such as pepper, are transported to temperate climate ports in winter, the temperature of the commodity slowly equilibrates with the surrounding air temperature. This process is slow because of the large thermal capacity and low thermal conductivity of the commodity. On arrival at the port the temperature at the centre of the load (in a consignment of bagged commodity) is frequently 20 °C warmer than the average ambient air temperature, for containers stowed below deck. When the container is removed from the hold of the ship, the metal structure of the container cools rapidly to a value close to that of the surrounding air. A large temperature difference then exists between the centre of the load and the metal walls and roof of the container. This difference induces convective air currents (Gough *et al.*, 1990) which transfer moisture upward, permitting condensation to develop on the underside of the roof. When sufficient condensation develops, precipitation occurs ('internal raining') on the top of the load, raising the moisture content of the commodity to high levels and permitting serious mould and bacteriological growth (Diener and Davis, 1969).

Avoidance of the problem

The obvious remedy, which has been adopted by some exporters and buyers, is to revert to traditional, open-hold ('break-bulk') shipment. This does not, however, confront the longer-term problem of a trend towards the use of containers on many important trade routes. If containers are to be used, then it is necessary to exercise care both in the selection of container type and management practices. Closed (general purpose box) containers present the greatest risk of consignment quality deterioration since there is no means of venting moisture vapour if it accumulates in the head space. Open-topped containers have a very limited geographical climatic range of application by virtue of their design, and they effectively revert to a closed-box character when their tops are shut in inclement weather. Occasionally, 'ventilated' containers have been found to perform poorly with spices, and further improvement of head-space ventilation is desirable before they can be regarded as risk-free for spices shipped from the tropics to temperate climates. The system of choice, amongst the units in commercial service, seems to be an open-sided container (*see* Figure 8) since this offers the greatest potential for the necessary head-space ventilation. This form of shipment, with modifications, was studied in three trial voyages, in order to identify a safe system of container transportation (Gough and Green, 1993).

The trials

Overview

Three trials (identified hereafter as the first, second and third trial) were undertaken. Each involved the transportation of 140 70-kg jute bags, filled with Fair Average Quality grade black pepper, in open-sided 5.8 m (20 ft)-long containers from Singapore to Southampton, United Kingdom, and thence overland to the importers' warehouses for discharge.

Filling and transporting the containers

The containers (*see* Figure 8) had wooden floors and internal dimensions of length, height and width of 5.8 m, 2.1 m and 2.3 m respectively. The bagged pepper arrived in Singapore in small coastal ships from Kuching, East Malaysia. The containers were each stuffed (filled) at the Singapore dockside. Before stuffing, the container curtain and gates on one side were kept closed while the curtain and the gates on the other side were rolled up and removed respectively, to enable bag loading through that side. The stow was hand-stacked six bag-layers high, the topmost layer being incomplete. The layout of the first five layers was identical (*see* Figure 9) so that the bags formed three 'walls'; two of these were adjacent to the open sides of the container with the long axes of the bags being at right angles to the container length. Bags in the central 'wall' were parallel to the length. Special marked bags which had been sampled in Kuching were placed in pre-arranged locations in the container. Monitoring instruments were installed before, during and after stuffing. The gates were then repositioned and the curtain rolled down and laced at the edges to the container frame. When the container ships arrived in Singapore, the side curtains of the trial containers were rolled up just before the containers were loaded into the ships. In all cases, the containers were placed at central positions in the ships' holds.

Each voyage was across the Indian Ocean, through the Red Sea and the Suez Canal, across the Mediterranean, then around Spain and France to Southampton. Limited ventilation was sometimes applied in the container hold during the voyage. Within one or two hours of containers being off-loaded at Southampton, the curtains were rolled down and laced to the frame. The containers stood in a container park near the dockside for a maximum of three days. They were then taken by train to another container park within a few miles of the importers. They stayed there for a maximum of three days, after which they were transported by truck to the importer's warehouses and unloaded immediately (subject to customs' inspection). The monitoring instruments were retrieved at this stage.

Improvements to containers and timing of the three trials

The first trial was in autumn. The main improvement to the container was the inclusion of wooden battens. These were fixed vertically at 0.7 m intervals against the outsides of the gates of the container. Their cross-section was 30 mm by 10 mm and one of the 30 mm sides was pressed against the gates. This introduced vertical air gaps between the gates and the plastic curtains when they were rolled down, thus improving airflow around and through the stow. As was normal practice, the top and bottom surfaces of the stow were lined with corrugated packing paper, to protect the stow from the entry of moisture. Although it would have been preferrable for the trial to be undertaken in winter, the autumn shipment was the only consignment that could be relied upon for the trial.

The second trial was in winter and the container was prepared identically to that in the first trial. The third trial was also in winter. For this trial it was decided to introduce several modifications in one half of the container and none in the other half. The partition between the container halves was made

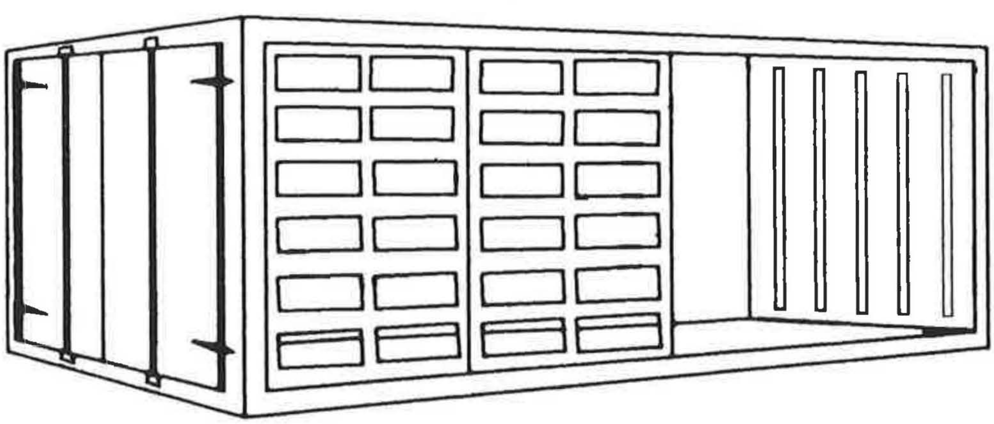


Figure 8 Standard open-sided box container showing two of the four removable retaining gates which compose each long wall. The plastic curtains that cover the gates are not shown

in the headspace only, using a sheet of polythene attached to the container ceiling and the stow. The position of the sheet was halfway along the length of the container and at right angles to the long walls. In the modified half of the container, the floor was covered with a specially constructed pallet to provide dunnage. Battens were placed outside the gates along this half of the container exactly as in the previous trials. Plywood (5 mm thick) was fixed onto the roof-strengthening girders so that a 15 mm air gap existed between the plywood and the roof. The stow was built as one complete stack exactly as in the previous trials.

Results

Phases in the voyages

In order to facilitate the interpretation of the results, it is useful to split the container voyages into three periods:

- the sea voyage from Singapore to Suez – the climate was warm and humid;
- the sea voyage from Suez to Southampton – the climate was cool and humid; and,
- the period on the UK mainland after container landing – the climate was temperate maritime.

Temperature

In all three trials the weather was close to normal during sea transit. For the second and third trials it was unusually cold from the time the containers were landed at Southampton – temperatures seldom rose above freezing. During the journeys across the Indian Ocean the stow interiors gradually warmed by about 3 °C from about 32 °C and then declined steadily during the rest of the journeys to about 26 °C at Southampton. Stow top surface and interior temperatures were similar only from Singapore to Suez. After landing,

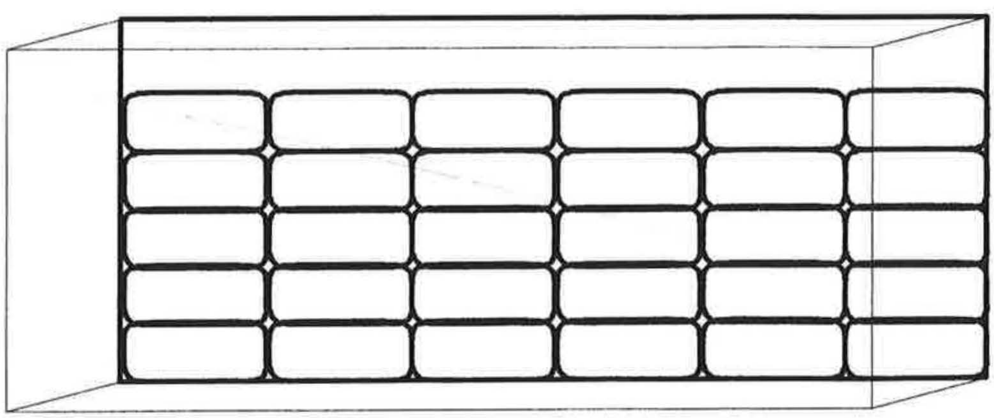


Figure 9 Elevation of the central vertical long plane through the container.

the metal structures of the containers cooled rapidly – the corresponding change at the stow surfaces followed by one hour, but the response of the stow interior was much slower (*see* Figure 10).

Moisture

From Singapore to Suez the stow interior moisture contents increased by about 1%, then gradually declined by a slightly larger amount during the remainder of the journeys (*see* Figure 11). The stow interior moisture-content losses over the complete journeys in the first, second and third trials were 0.5%, 0.8% and 2.6% respectively. Changes were even greater at the stow top and side surfaces. For example, in the third trial the stow top surface dried by 3% moisture content during the sea voyage. It then increased gradually by 3% in both halves of the stow following off-loading from the ship – the increase was more rapid in the unmodified half of the container.

Condensation in container headspaces

In the first trial, condensation developed on the underside of the roof within 4 hours of landing in the UK and persisted during the following day, but by the third day it had disappeared. When the container was opened at the importer's warehouse there were no visible signs of dampness on top of the corrugated paper covering the stow nor on the bags near the door.

In the second trial, condensation formed on the underside of the container roof central area in less than 30 minutes after landing and had spread across as far as the walls one hour later. Condensation was never detected on the metal sidegates of the container. There were no visible signs of dampness anywhere when the container was opened.

In the third trial, the weather was unusually cold and dry, with almost no wind during the first three days after container landing. Frost formed on the outside of the container roof each night. The amount was much greater over the insulated half of the container roof and took one hour longer to melt and disperse than on the uninsulated half. Condensation on the underside of the roof, in the unmodified half of the container, occurred within one hour of landing and was present almost continuously during the next five days. It froze at night and only melted after sunrise. By early afternoon each day the condensation had dispersed. No condensation was ever observed on the underside of the wooden panels on the insulated half of the roof. No condensation occurred on the uninsulated half on the fourth morning, but on that occasion wind levels were significant, causing the container curtains to flap, thus greatly increasing ventilation of the container. There were no visible signs of dampness or mould anywhere when the container was opened.

Conclusions

Fair Average Quality grade black pepper at 14% moisture content (wet basis) may be transported in open-sided containers with battening fixed to the gates in spring, summer and autumn with little risk of 'internal raining'. This is also true for winter shipments, but for these cases some further attempt at improving ventilation is advisable – the most practicable remedies are the use of pallets and roof insulation. The practice of placing corrugated paper on top of the stow is of doubtful value; it provides no protection to the commodity.

B Observations of the condition of bagged green coffee being unloaded from a prototype box container

Background

Green coffee in jute bags stowed in a prototype box container arrived in Tilbury Docks, London in June from the Côte d'Ivoire. The container was permanently ventilated, having a line of continuous vents along the long walls near the floor and roof. The purpose of the investigation was to determine whether there had been significant moisture accumulation in any part of the stow during the journey to the UK, in view of the difference in

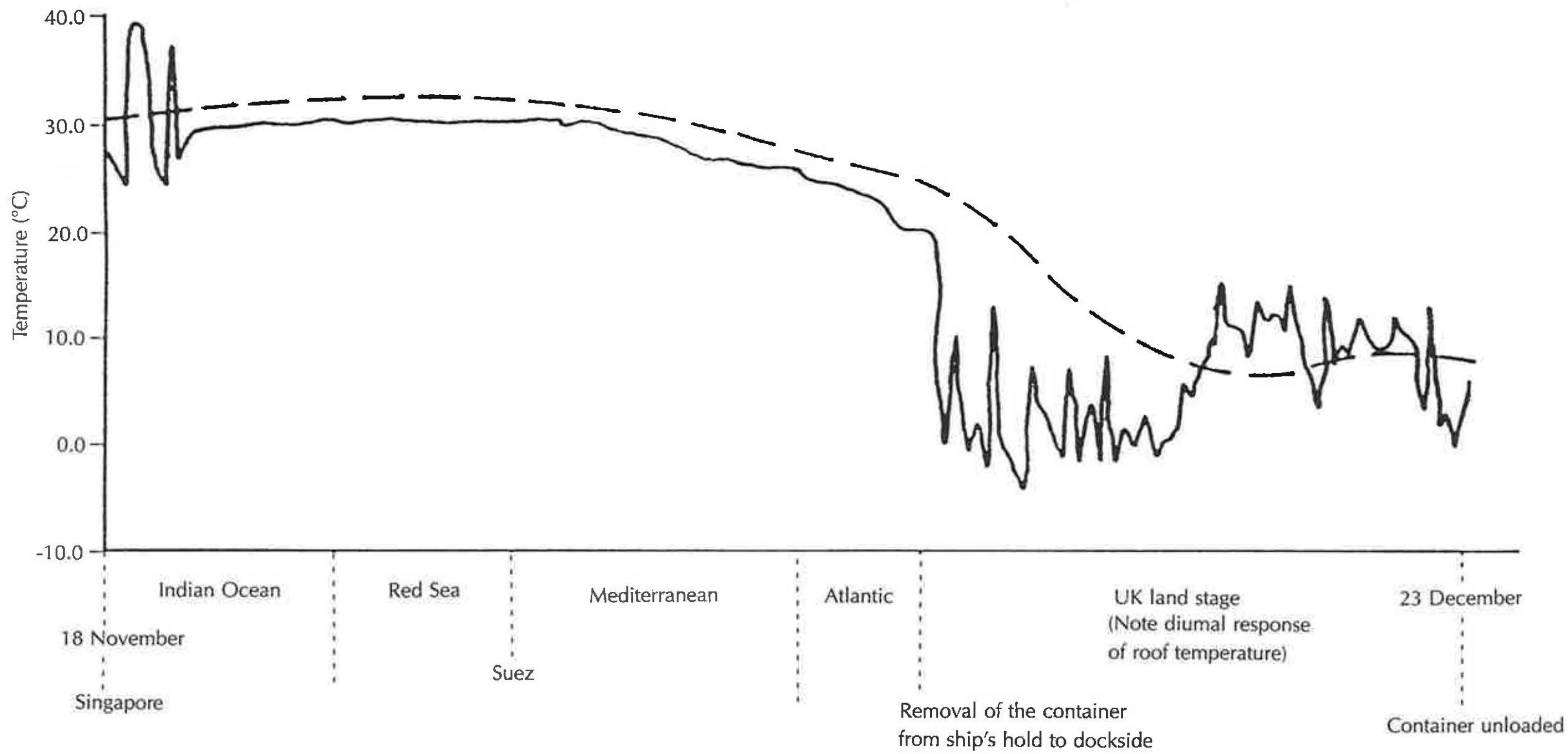


Figure 10 Temperature changes at the box container roof (——) and at the centre of the consignment (- - -) during the third trial

climates at the exporting port (Abidjan, Côte d'Ivoire), and at the UK dock-side (where the container stood for several days).

Observations

When the doors of the container were opened, no moisture problems were observed. The first surface sacks to be removed appeared dry. The undersides of the floor sacks, however, felt slightly damp—one in particular felt very damp and was put aside for drying by the receivers. The floor of the emptied container appeared to be damp at the places where sacks had been. The floor area between these places appeared dry. The difference between the

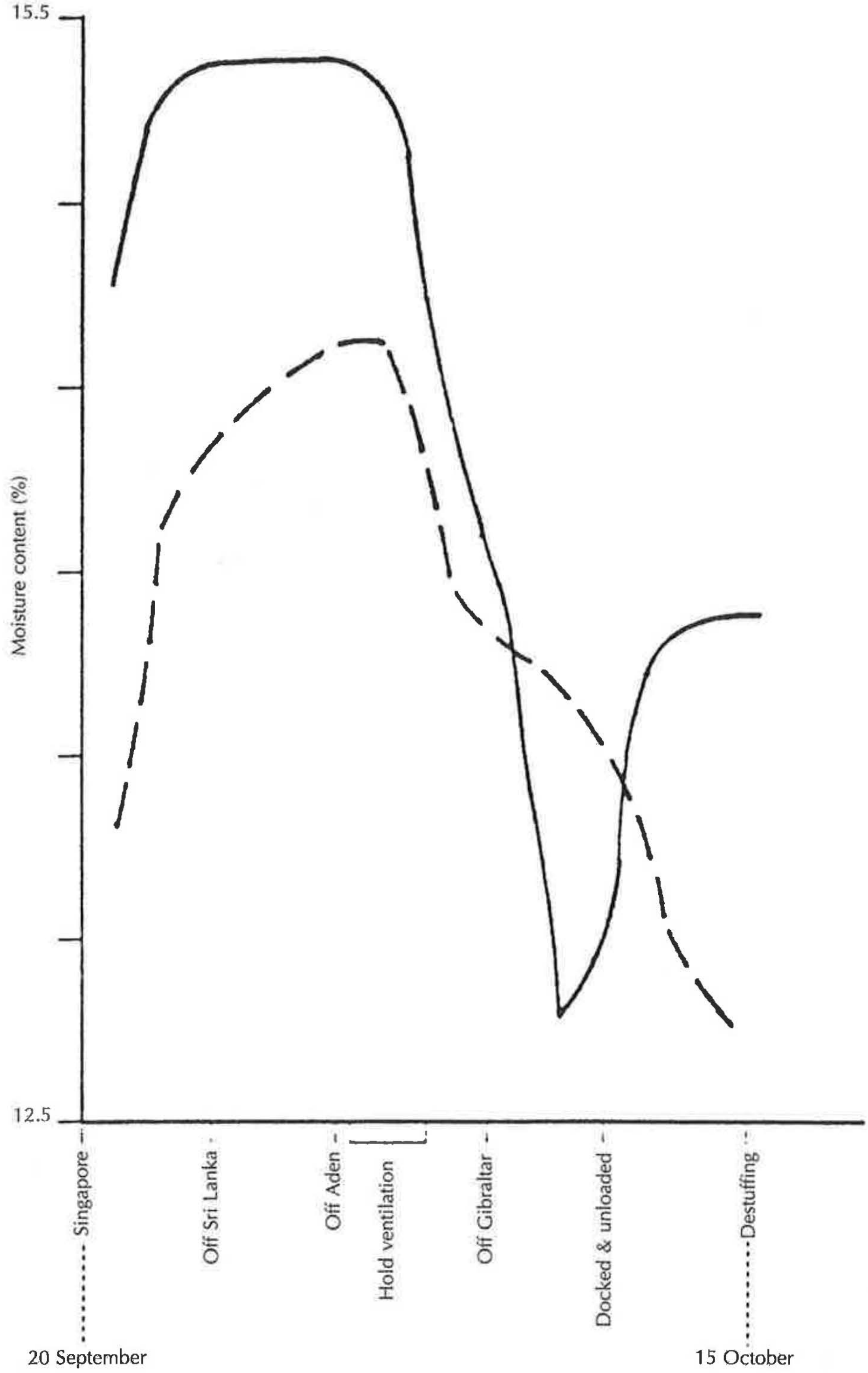


Figure 11 Moisture content changes at the stow top surface (——) and interior (- - -) during the first trial

two areas was so distinct that it was easy to count the number of sacks that had been transported on the floor.

Discussion

In the summer, the average temperatures in London, Abidjan, and the sea route between these ports are not greatly different. This is probably the reason why no moisture problems were observed at the top or side surfaces of the stow. In addition, because green coffee is generally not easily infested with insects/moulds and none was observed on this occasion, respiratory moisture did not develop. The surface samples were actually drier than a random sample from the interior of the stow. This may have been because of head space ventilation, since the average ambient relative humidities in May in Abidjan and June in London are about 85% and 76% respectively. No clear explanation can be offered for the damp patches on the floor. The drying effect of the ambient ventilating air experienced upon entering the UK region may explain the dry patches on the floor between sacks. The underside of the floor was coated in bitumen, but clear cracks were visible. It is possible that the washing of the container interior (which is a frequent practice) may have been a factor.

Conclusion

The container appears suitable for transporting green coffee from the Côte d'Ivoire to southern England during the summer.

C Observations of the condition of bagged cocoa in a prototype box container following a simulated trial

It had been reported that when bagged cocoa was transported in ventilated box containers from Nigeria to the UK in the winter, 'internal raining' occurred. There was a need to see whether this could be avoided with a new design of ventilated box container, with small vents in the long walls near the roof. Following a journey from Nigeria during the summer, this prototype box container was taken to a cold-storage room where the relative humidity was 85% and the temperature was 8 °C to simulate a voyage in winter.

Observation

During the first seven days in the cold room the bags of cocoa slowly cooled down to near 8 °C. The container was then opened. There was no visible moisture condensation, nor was there evidence that it had taken place earlier.

D Observations on the condition of palm kernels arriving from Papua New Guinea to the UK in box containers

Two 5.8-m (20-ft) box containers of palm kernels were transported from Papua New Guinea to the UK; in one the cargo was bagged and in the other it was in bulk. The containers had been stowed on deck. The ship arrived at Hull in July, and the containers were examined immediately they were lifted off the ship. The container loaded with bags was lined with polyethylene sheeting and the top surface of the jute bags was covered with thick paper. The only ventilation was through two close groups of 25 holes, each 6 mm in diameter, near the top of each long wall. The bulk container was lined with two layers of plastic sheeting which also covered the top surface of the cargo. In addition, paper lined the walls up to and across the ceiling. There were no ventilation apertures.

Observations and results

Container with bagged commodity

The weather on the day the containers were offloaded was cloudy, with a maximum temperature of about 20 °C. There was heavy condensation on the ceiling of the container loaded with the bagged commodity. Droplets of water were observed on the paper sheet that had been attached to the ceiling originally, but had fallen onto the cargo. It seemed to have fallen recently because the paper had not absorbed the moisture. The amount of water on the paper varied considerably, with puddles of water in the hollows where the surface was not flat. Some of the bag surfaces were very mouldy. The relative humidity and temperature were measured at several places in the commodity and the readings are shown in Table 3. Samples were removed for moisture content and free fatty acid (FFA) analysis (*see* Table 4).

Table 3 Temperature and relative humidity in the bagged stow container

Position in bag container	Relative humidity (%)	Temperature (°C)
Just beneath top centre of stow, 2 m from door (Position A, Table 4)	78	17
Middle of bag 0.3 m below position A (Position B, Table 4)	78	18

Container with bulk commodity

Condensation was observed on the ceiling of the container loaded with the bulk commodity, but much less than that observed in the container with the bagged commodity. It was also observed between the two layers of plastic sheeting lying on the top surface of the cargo. The kernels on the top surface were dark coloured for a distance of 0.4 m from the doors, and were light coloured and apparently mouldy elsewhere. The depth of mouldy kernels was about 35 mm. There was no visible moisture on the top surface of the upper layer of plastic nor on the paper by the walls. Relative humidity and temperature were measured at several locations (*see* Table 5). Samples of palm kernels were removed for moisture content and FFA analysis; the results are shown in Table 4.

Infestation

No evidence of insect infestation was found.

Discussion and conclusions

The safe storage moisture content of palm kernels is about 5.2% (Somade, 1955) which is lower than the values recorded at various levels in the bulk container (*see* Table 4). This is largely confirmed by the relative humidity readings in Table 5. Clearly, the condensation levels would be reduced if the palm kernels were drier, since there was no infestation to induce moisture migration by respiration. Because the cargo was not destined for human consumption, moisture content was not important in the importation of palm kernels except insofar as it might raise FFA levels and affect weight. Table 4 shows, however, that the FFA levels, even of very damp samples, were very low. These measurements were made three months after removal from the containers. If storage for longer periods before processing were required, it is possible that FFA levels would increase.

Table 4 FFA and moisture content values

Position no.	Acid value*	Moisture content %†	Container	Description
1	3.0	9.6	Bulk	Top surface, 0.1 m from the door
2	2.2	13.8	Bulk	Top surface, 0.2 m from the door, mouldy-looking kernels
3	3.3	23.3	Bulk	Top centre 2 m from front, dark-coloured kernels, coated with liquid water
4	3.8	13.8	Bulk	As in 3 except light-coloured kernels, no liquid water
5	2.5	7.1	Bulk	0.1 m deep, below 4
6	4.9	6.3	Bulk	0.15/0.2 m deep, below 5
7	3.5	6.4	Bulk	0.2 m deep, below 6
8	4.7	7.8	Bulk	0.5 m deep, below 7
A	7.5	7.1	Bag	Top centre, top surface of the bag
B	7.5	5.6	Bag	Middle of second bag from the top under Position A, but about 0.3 m down

Notes * acid value is free fatty acid and as % lauric acid in extracted oil. Method follows BS 684 Section 210 (1976). Accuracy is about ± 0.05

† moisture content accuracy is about 0.2%

Table 5 Temperature and relative humidity in the bulk stow container

Position in bulk stow container	Relative humidity (%)	Temperature (°C)
Top surface of load, near front of container on the long central axis	81	23
Just beneath surface of load at the middle of the long axis, by a long wall	86	20
0.25 m deep, 0.50 m from rear of the container on the central long axis	92	22
As above, except 2 m from front of the container	90	27
As above, 0.50 m deep	84	27
As above, 0.75 m deep	76	25
As above, 1 m deep	69	21

The condensation observed by the author was inordinately severe, given that the sea route was Lae, Singapore, Suez and the UK in July. That route could not have induced temperature differences of more than 20 °C within the produce. It is interesting to note that bagged coffee transported at about the same time from the Côte d'Ivoire to the UK showed no signs of moisture migration. The relative humidities of the air in the palm kernels was high, and as a result the level of moisture migration was high. This suggests that, as a general rule, palm kernel consignments should be dried to about 70% equilibrium relative humidity to avoid severe condensation occurring if transportation is in containers to the UK in summer. The corresponding value for winter shipments should be much lower. Good ventilation (absent in these containers), does reduce the need for extra drying. Table 4 shows that the moisture content values of the samples from the top surface of the bagged cargo were much lower than from the corresponding region in the bulk container. No clear explanation can be offered for this, except that the comparatively smaller convective air circulation expected in the bulk container would have permitted more convection-induced rising moisture to be trapped beneath the plastic sheet covering the top of the stow. In addition, condensation droplets can, in the author's experience, run off the tops of sacks of produce before the jute becomes wet. When water does enter the sacks, its progress is impeded by the absorption by the jute material. Since sampling of the top surfaces of the loads took place not long after the appearance of condensation, this may explain the lower moisture content values.

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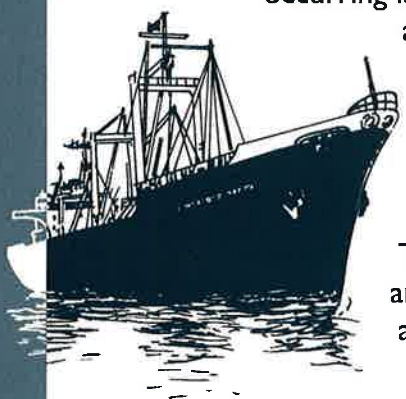
In the marine transport of hygroscopic durable foods such as cocoa beans, from tropical and sub-tropical to temperate climatic zones, quality can deteriorate due to climatically induced moisture increases.

In **Marine Transport of some Tropical Food Cargoes to Cold Climates: Maintenance of Quality** the likelihood of deterioration occurring is assessed for durable foods transported in bulk, bags and by box container. Interpretations are based upon the principles of heat and moisture transfer and also on experimental observations of several shipments. General recommendations for good practice are included.



This bulletin will be of interest to commodity exporters and importers, shipping agents, ships' officers, insurers and others involved with cargo claims, and scientists and engineers concerned with food quality.