Risks in the Carriage of Food Cargoes

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Introduction

A wide range of food cargoes are transported every year, mostly without any difficulties. However, when problems are caused by the failure or non application of management systems, these can result not only in financial losses but there can also be risks to food safety and associated public health issues.

Most foodstuffs are in a condition of prime quality and value at the time when they are harvested or produced. However, they are all inherently perishable and have a finite shelf-life. Therefore from that point onwards, during subsequent handling, processing, packaging, storage and transportation, activities that are designed to enhance value and market acceptability, they will inevitably deteriorate in quality until such time as they are no longer fit for purpose.

Almost all foodstuffs can be considered as belonging to one of three types:

Fresh Foods

These are foods that at the point of harvest are alive and hence in a condition of prime quality. Examples are fresh fish, newly picked fruit and recently harvest grain. These are the most obvious examples of inherent perishability. From the moment they are harvested they have a definite natural life after which they are either no longer edible or are unsuitable to eat or use as a food ingredient.

Many of the foodstuffs in this category remain alive after harvest and the nature of their life processes will define their natural life span. For example, an apple fresh from the tree is usually ready to eat. It will continue to respire, breathing in oxygen and breathing out carbon dioxide. Some fruits are harvested before they are ripe to meet handling, packaging and market requirements. However, at the point of ripeness fresh foods will be at peak quality. Thereafter, they will age progressively over time, becoming less pleasant to eat and eventually becoming inedible or unsaleable. An exception to this rule is rice which, in some markets, can increase in value with limited ageing. If foodstuffs become infected by micro-organisms such as fungi, e.g. become mouldy, then this merely increases the rate at which they age and become inedible.

Many people realise that this is the case with fish, fruit and vegetables, but they wrongly believe that grains are durable commodities. This is not the case and all grains will behave as perishables unless they are managed correctly.

On the other hand, some fresh foodstuffs are dead because they are killed at the point of harvest. One of the best examples is fresh fish; it is alive at the point of harvest but

dies very quickly thereafter and becomes subject to deterioration due to the enzymatic breakdown of major fish molecules. These reactions are catalysed either by the fish's own enzymes or by bacterial enzymes which ensure it spoils rapidly. This type of fresh food has a very short natural life usually measured in days rather than weeks or months.

Manufactured or Processed Foods

These are foodstuffs that undergo some kind of processing after harvesting but prior to being presented for consumption or other use. They are typically produced from an edible raw material often by a form of physical processing. Examples are flour from grain, edible oils from oilseeds, and sugar from cane or beet. In a sense these types of foodstuffs can be considered to have two distinct natural lives: that of the edible raw ingredient, e.g. wheat will store for a year or more, and that of the processed raw material, e.g. wheat flour which normally has a shelf life of around 6 months.

Formulated Foods

These may consist of many different ingredients brought together and processed to produce a final food. Examples are canned soups, baby foods and confectionery. The manufacturing processes tend to involve some form of preservation to prevent subsequent spoilage, e.g. high osmotic pressure solutions to protect sugar confectionery and heat processing of canned foods.

Seasonal Availability

The modern food industry depends on a plentiful all year round supply of ingredients for manufacturing processes or of the food itself for sale to consumers. A supermarket will be expected to have fresh fruit and vegetables available for the entire year irrespective of the local seasons. Therefore it is necessary to extend the natural life of foodstuffs so as to permit successful carriage and transportation to the end market.

Methods used to achieve this include:

> Control of temperature
> Control of moisture content
> Physical security from rodents, insects, birds, fungi, water and fire

However, all of these methods, and others, need to be employed with adequate knowledge and understanding of food science and a necessary level of skill and expertise. Otherwise they can present risks to the quality assurance of the cargo. If not undertaken effectively, the very procedures intended to extend the usable life of the food commodity can, and do, result in reduction of quality, market rejection and subsequent financial loss. This would be the very opposite of what was intended.

Control of Temperature

Life processes are dependent on temperature and can only exist within a fairly narrow range. At the extremes there are bacteria that can live at sub zero temperatures and other that can live at 100ºC. However, these are exceptions and for the large majority

of living things, and certainly for all multi-celled animals and plants life can only exist within the narrow range of around 0ºC to around 45ºC.

The rate of life processes varies with temperature. Living processes roughly double their speed with every 10ºC increase in temperature. The reverse is also true, i.e. cooling a food product slows down the life processes.

It is important to understand that these temperature effects relate to the rate of biological processes within the cells of the animal or plant. Hence they have a general applicability to the extension of the life of a particular foodstuff even if the food itself is dead. For example a dead fish can have its shelf life extended by cooling or freezing because the enzymic activity within the fish cells is slowed by the lowered temperature. Similarly, the oxidative processes that cause oily fish such as mackerel to rapidly become stale and inedible are slowed by lowering the temperature thereby increasing its shelf life from a matter of days at room temperature to several months at -23ºC.

Temperature reduction also influences the rate at which spoilage bacteria can grow on and in fish. Micro-organisms are also alive and subject to the general effects of temperature in the same way as larger organisms.

The effects of temperature on foodstuffs can be considered in two different ways; although the fundamental scientific process is the same its applicability to food commodities differs depending on their starting condition.

Fresh commodities such as fruit and vegetables are alive. Cooling them extends their natural life since it slows down life processes such as respiration without killing the fruit or the vegetable. It can provide a genuine extension of the natural life of the food, for example storing apples at 4ºC means they will keep in good condition for 3 months instead of the normal 4 to 6 weeks if stored at 20ºC. With certain long life varieties it means that the fruit can be available in good condition for as long as 6 months merely by cooling it to the appropriate temperature and then maintaining it at that temperature. Such long storage lives make it feasible to ship fruit over relatively long distances to supply distant markets often out of season for locally grown apples.

However, cooling food to extend its life brings potential hazards and these form part of the pattern of risk associated with the carriage and storage of food commodities. Many fresh foods, particularly those grown in warmer climates in the sub-tropics or tropics, are sensitive to cold temperatures. Thus the mere act of cooling them can result in deterioration, damage and loss of market value. For example, the chill damage of bananas is a well known phenomenon and can cause major damage to shipments.

Even with foods that are relatively non-sensitive to cooling it is important to ensure correct control of the temperatures to which they are cooled. In some instances, even quite minor variations in temperature can lead to significant quality variations.

When foods are frozen other risks emerge. Ice crystals will form within the food when it is frozen. Different parts of the food will freeze at different temperatures. For example, the inner part of a block of fish is still liquid and unfrozen when the

outside of the block is at -10ºC. Depending on how the freezing is achieved ice crystals of differing sizes will be formed. In many instances the crystals will be quite large and may rupture cell walls. When such frozen food is thawed it will have a different structure to that which it had before it was frozen and this will often be considered a quality deficiency. A clear example of this is that of frozen strawberries which can never be reconstituted after freezing into the same structure and texture as before it was frozen.

Even when food that has a strong texture and structure is deep frozen there is always some form of damage. Modern freezing techniques can minimise this to the extent that it is not noticeable in the thawed food but management is not always perfect and damage may occur.

Because some bacteria can continue to grow at sub-zero temperatures there is always a danger of deterioration and spoilage unless a food commodity is held consistently at temperatures below -10ºC. Thus it must not be assumed that just because a food has been frozen it cannot be damaged by microbial growth.

It should also be noted that freezing food will not remove or denature any microbial toxins that may be present. If the commodity had been attacked by micro-organisms before it was frozen then any toxic chemicals that they might have created in the food will remain and would still be capable of creating a health risk when the food is thawed and eaten.

Control of Moisture

The chemical reactions that we characterise as living processes all take place in water. Life developed on this planet in water and it was only late in evolutionary history that living animals were able to colonise the land. To do this, land-living animals carried with them their watery environment in their cells and inner tissues. This is why most living things are composed largely of water, e.g. adult human beings about 60%, baby human beings about 78%, fresh apples about 87% and green string beans about 91%.

The organisms that can spoil food are also bound by the same rules – they are living organisms and their life processes depend on the availability of water. Thus if insufficient water is available to a micro-organism it cannot grow in or on the food to damage it. This fact underlies one of the oldest and still very effective methods of extending the life of many foodstuffs: drying. For example, cereal grains at the time of harvest may have a moisture content sufficiently high enough to permit fairly rapid microbial spoilage. Rice is frequently harvested at over 20% moisture content before it is dried to a safe storage moisture content of around 12%. Obviously, inadequate drying creates a potential risk of microbial damage prior to or during shipment of rice cargoes.

The incorrect drying of cereals or the mixing of parcels with very different levels of moisture within a shipment of cereals is an ever present risk and the cause of many shipments being damaged by mould growth during carriage. This risk is always present because there will always be individuals who will be tempted to ship grain as wet as possible, irrespective of technical guidance because to do so they are selling water for the price of grain.

Most food commodities have a natural protection against attack by micro-organisms, for example fruits are often enclosed by a tough external rind or skin that protects the softer inner tissues from microbial attack. Some foods such as onions and garlic have developed the ability to synthesize chemicals such as thiosulphinates precisely to protect themselves from infection. Other foods are protected from attack by high levels of acidity within the tissues. However, once these defences are breached, e.g. by insects bites or physical damage, there is usually sufficient water in the tissues to permit microbial growth and subsequent damage and loss of quality and value.

There are other factors that protect food commodities against invasion by micro-organisms and some of these are vital to the safe carriage of food cargoes in the holds of ships. These generally relate to the conditions within a cargo stow that will permit or prevent the growth of micro-organisms.

All micro-organisms need water for growth and, if they produce spores, they need water for the spores to germinate. Generally the micro-organisms that need the least amount of water to germinate and grow are the moulds (fungi) followed by yeasts and bacteria. Moisture in a cargo will comprise the water in the commodity itself and the water held by the air within the cargo, e.g. between the individual grains. The water in the air can be described in terms of relative humidity (RH) which will vary depending on the temperature and the available water. However, it is generally more useful to use the term equilibrium relative humidity (ERH). The ERH of a food at a given moisture content represents the relative humidity of the air in equilibrium with the food – when there is a steady state condition with no net movement of water between air and food. The air between granules of food will usually be at an ERH except during forced ventilation. A food exposed to air with a RH higher than the ERH will gain moisture and vice versa, although the rate of change will vary according to the commodity.

Scientists often refer to the water activity (A_w) of a commodity. The A_w is the ERH expressed as a fraction rather than a percentage. Where food commodities are in granular form, e.g. grains or milk powder, it is more meaningful to be aware of the ERH or A_w, because susceptibility to deterioration is correlated with these terms, and not to moisture contents which vary at any given ERH or A_w between different commodities. For example, at 70% ERH at 25°C most cereal grains have a safe storage moisture content in the region of 14% whereas dried fruit has a much higher moisture content (dates 24%, sultanas 20%); in contrast to oil-rich foodstuffs which will have lower moisture contents (nuts 4 to 9%, cocoa 7 to 10%). In practice it is more common to measure moisture content because of the ready availability of electrical moisture meters.

As stated above, the RH of a given volume of air is temperature sensitive. When air is heated it can hold more water vapour. So if a volume of air saturated with water vapour at say 20°C is heated it ceases to be saturated because warmer air has the ability to hold more water vapour. The converse is also true. If a fixed volume of saturated air is cooled then it cannot hold so much water vapour and some of the vapour must come out (condense) from the air as liquid water. The point at which this phenomenon starts under a given set of conditions is called the Dew Point.

These basic laws of physics can have profound effects on the quality and condition of food cargoes. Measurements of Dew Point will provide guidance as to whether or not to ventilate a cargo. The purpose of ventilation is to minimise temperature gradients between the cargo and the atmosphere, and serves to minimise excessive moisture in the hold.

If there is a difference in temperature between different parts of a stow, conditions may be appropriate for a phenomenon called moisture migration to occur. Air in one part of the stow might be warmed by the cargo and, since warm air is less dense than cold air the warmed air will tend to move upwards through the stow. As warmer air meets colder conditions within the stow it will be cooled and its capacity to hold all its water vapour will decrease. It may change to the extent that it reaches Dew Point and liquid water actually condenses and wets part of the cargo. Even before that happens there will be an increase in the RH of the air surrounding the cargo leading to an increased ERH. This in itself may be sufficient to create conditions suitable for mould spores to germinate and grow. The result will be the binding together of the cargo into lumps or caking as a result of what is known as cargo sweat. See Figure 1 and Figure 2.

Figure 1   Soya beans that went mouldy and then caked following moisture migration

Figure 2   Caked refined sugar

If the temperature of the steel work falls below the dew point of the air in the hold there can be condensation on the ship's structure leading to ship's sweat running onto the surface of the cargo.

Physical Security

Rodents

Food cargoes are particularly vulnerable to attack by rats and mice. These rodents are believed to consume their own weight of food per week. Apart from the cargo that is eaten, it is common for rodents to be responsible for significant additional cargo spoilage and contamination by their hairs, faeces and urine. There are also other costs associated with replacement of packaging materials and re-bagging. Much of the spillage in breakbulk cargoes arises when rodents attack the packaging to obtain nesting material. Rodents also cause fire risks by gnawing electrical cables. However, the main concerns in food cargoes are the risks of rodent transmitted diseases, viz. Lassa fever, leptospirosis, and salmonella food poisoning.

Control of rodents in food cargoes is difficult because use of rodenticides carries the risk of cargo contamination. Additionally, full control of rodents by poisoning and/or trapping can never be guaranteed, even by the best operatives, because rodents as mammals have the ability to learn from experience and therefore modify their behaviour to evade control measures. Fumigation, as used to control insect infestations, provides the only sure means of controlling rodents in food cargoes, although it does leave the dead bodies in situ in the cargo. To avoid such contamination, ship and port management systems should aim to exclude the rodents from the vessel and the cargo, thereby obviating the need for control measures. This can be achieved by the effective use of full size rat guards on ships' lines and by

inspection of the cargo and its surroundings prior to loading, together with the vessel having a valid De Rat certificate. The effective use of rat guards is necessary because of the ability that rats have to climb ropes and wires (Figure 3).

Figure 3   Rats are very adept at accessing ships by climbing on unguarded wires and ropes

Insects

Insects, unlike rodents, do not have the ability to learn and it is normally possible to achieve full control by the conventional use of fumigation. The few exceptions will be where insects have developed resistance to the fumigant. However, fumigation remains an extremely valuable tool. This is just as well because trying to exclude them from grain is not achievable in practice. It should be noted that a successful fumigation requires the correct dosage of a fumigant such as phosphine, to be retained in the commodity for a period of 5 to 7 days. Shorter periods of exposure or non-gastight seals on the hatch covers can result in limited or cosmetic control. Cosmetic control occurs when there is sufficient gas present to kill the active and often very visible life stages such as adult and larva, but insufficient gas to kill the relatively inactive and frequently less observed stages such pupa and egg. The pupae and eggs remain alive to develop into adults during the weeks to follow. Repeated fumigations can be a lucrative source of income for fumigation companies in situations where they perceive there to be an advantage in under dosing. This is always a risk because fumigation is a specialised activity which cannot easily be monitored by the crew.

Some 30 species of insects commonly infest grain cargoes, although there are 200 to 300 species that may occur from time to time depending on the commodity, its condition and ERH. Most of these insects are cosmopolitan having been distributed around the world by trade in food commodities. A recent example of this phenomenon is the Larger Grain Borer which was transported from Central America to Africa in the 1980s in grain cargoes and is now well established in the grain trade in East and West Africa (Figure 4).

Figure 4   Adult Larger Grain Borer beetles infesting yellow maize

Insects infesting grain are small, have cryptic colouration and are often difficult to detect because they prefer dark situations, actively avoiding light. Additionally, the life stages of some insects, i.e. egg, larva, pupa are concealed within individual grains. In these situations, when a hole is observed in a grain it has often been caused by a developing adult exiting the grain rather than by an external insect biting a hole from the outside.

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Insect populations can multiply rapidly, going from a few individuals to several million in a matter of months if conditions are suitable. Insects in common with other life forms require water to survive. Those suited to commodities such as grain are able to metabolise the water they need from the starch in the grain. However, there is no doubt that a very dry cargo will be less conducive to insect development than one which has a higher moisture content.

When insects feed on grain, or other food cargoes, their metabolism produces heat and moisture. Large populations can produce 'hot spots' in the cargo. The result of these, as described above when there are temperature differences within the cargo, can lead to moisture migration and subsequent water damage and caking, generally above the 'hot spot'.

However, the presence of live insects, even in small numbers, often constitutes a phytosanitary constraint and can result in the shipment being rejected by port authorities or the receiver. Insect infestation leads to weight loss, downgrading, and contamination caused by the dead bodies, cast skins, waste products and metabolic secretions. The presence of the latter can give the cargo an unacceptable taint, e.g. the quinones produced by the thoracic and abdominal defence glands of the common flour beetle, *Tribolium castaneum*, have a disagreeable odour and flavour.

Specific mention needs to be made concerning the health risks associated with cockroach infestation. Cockroaches are mechanical carriers of many different diseases. These include bacterial and fungal related diseases and illnesses caused by protozoa and viruses.

Birds

Birds are occasional invaders of warehouses and loading ships, particularly those carrying grain. They can cause damage by spillage, consumption and contamination of cargoes. There is always a risk that their droppings and shed feathers might spread diseases such as salmonella food poisoning. However, birds are often seen as more of a problem than they actually present.

Moulds (Fungi)

All grains, fruit and horticultural commodities, are infected with mould spores at harvest and during subsequent transport and handling. The spores are commonly airborne and their presence in the food cargo is inevitable. However, with grain cargoes it is certainly not inevitable that the spores will germinate and infect the cargo. Spores on grain will not germinate so long as the commodity has a safe storage moisture content or water activity.

If grain does not have a safe storage moisture content it is likely that the mould spores will germinate and grow as hair-like filaments to bind the grain into lumps or mats which are often grey, green or black in colour, and create further moisture and heat by their own metabolism. An illustration of mould growth is at Figure 5.

Figure 5   Aspergillus mycelium visible as green mould on a laboratory culture

In addition to caking and discolouration, there is also a risk that mould growth can also result in heating and consequent damage, and toxin formation. The mycotoxins produced by specific moulds are listed in Table 1.

Table 1   Common mycotoxin producing species of fungi

Fungus	Mycotoxin produced
Aspergillus parasiticus	Aflatoxins B1, B2, G1, G2
Aspergillus flavus	Aflatoxins B1, B2
Fusarium sporotrichioides	T-2 toxin
Fusarium graminearium	Deoxynivalenol, Zearalenone
Fusarium verticillioides (moniliforme)	Fumonisins
Penicillium verrucosum	Ochratoxin A
Aspergillus ochraceus	Ochratoxin A

The metabolic processes can produce toxic metabolites known as mycotoxins on a range of commodities including cereals, dried fruit, spices, nuts, dairy products, animal feed, coffee, wine, beer and cocoa. Mycotoxins can be ingested, inhaled or

absorbed through the skin, causing lowered physical performance, sickness or death in man and animals, including birds. Ingestion of mycotoxins can result in both chronic and acute poisoning resulting in a range of health risks, e.g. liver and oesophageal cancers, haemorrhages, vomiting, headaches, cancer, renal and hepatic failure.

Some mycotoxins are the most potent carcinogenic substances known to science. Unfortunately, they are colourless, tasteless and odourless, and very difficult to detoxify even with heat. Cattle fed with mycotoxin contaminated grain will pass the mycotoxins through their bodies into their milk.

Spores on fruit and horticultural commodities are far less likely to germinate if the commodity is in good condition and particularly if the surface skin has no blemishes or damage. However, it is common practice to treat the surface of some fruits with a protective coating or use treated packaging material to protect against the growth of moulds.

Water Ingress

Any ingress of water from the air, rain, fog or hatch leakage will raise the moisture content of otherwise dry cargoes and render them susceptible to damage by moulds and possibly even bacteria if they are heavily wetted. This renders the cargo unstable and there can be considerable spoilage resulting in heavy damages, losses and possibly rejection.

If the ingress is dirty bilge water or seawater then there could be additional issues of contamination, loss of grade or change in the quality characteristics of the cargo.

Fire

Some food cargoes are susceptible to self-heating and possibly combustion, e.g. copra and oilseed expellers. Incorrect use of phosphine fumigation can be another source of fire, as can electrical spark ignition. Often fires cause more damage to the packaging than to the actual commodities. However, contamination with soot and smoke can be a serious problem because food commodities readily take up commercially objectionable taint or odours.

Acknowledgement

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