OPTIMUM CONDITIONS FOR THE SAFE STORAGE OF DEHYDRATED FOODS

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Abstract

The stability of the food depends largely on its moisture content. It has been indicated that it is not sufficient to keep dehydrated foods free of fungi and insects because moisture levels that prevent their growth are high enough for chemical deterioration to proceed at a rate that reduces its nutritive value. It has been indicated that there is a mathematically predictable minimum optimum moisture level at which these chemical reactions either do not take place or are reduced to a low level. The indicated stability however depends on the control of the optimum environmental storage conditions.

Introduction

Most developing countries, though described as agricultural countries, are unable to feed themselves and rely on the importation of large quantities of food to an extent which their meagre resources cannot support. The solution popularly expressed by politicians and some famous international organisations is to campaign to step up agricultural production. But this approach presupposes that the increase in production will be fully utilised. It is estimated (Hall, 1970) that post harvest losses in some developing areas may take as much as 50% of the farmers farm produce. Such high rate of spoilage is the result of poor handling and storage conditions. A considerable quantity of food spoilage is caused by the destructive activities of insects and microorganisms while a good quantity of what is left may be nutritionally depleted as a result of the activities of enzymes present in the food.

Such high rate of waste of effort has perhaps taught the farmer in developing areas to produce in sufficient quantity only to feed his family with just a little surplus to be sold quickly because of the fear of certain spoilage. It is perhaps on account of this fear of certain spoilage that some peasant farmers in developing areas have in the main not bothered to improve on their cultivation equipment and have relied on such simple equipment as the hoe and cutlass which are grossly inadequate to feed their present large families.

Efficient storage fundamentally depends on the moisture content of the food and the oldest and most widely means of preserving agricultural produce is to reduce this moisture to a level that will minimise or arrest the deteriorative agents and processes that depend for their activity on water. The required optimum moisture content depends on both the food, the environment and the type of deteriorative process, chemical or biological, one wants to control. This paper will discuss the optimum moisture content and the conditions for the safe storage of dry agricultural produce.

Moisture relations of dehydrated foods

When a dehydrated material is placed in an environment higher than its aqueous activity, i.e. humidity that will equilibrate with its moisture content it rapidly absorbs moisture. The total amount of moisture a food material will absorb does not depend on only the surrounding humidity but on temperature and the composition of the food as well. The functional relationship between the total water absorbed by a food item and its corresponding equilibrium relative humidity or Aw at constant temperature is described as its moisture sorption isotherm. For foods this relationship is generally sigmoid (Fig.1). From this relationship certain critical moisture levels in storage as well as certain parameters of importance in dehydration may be derived.

Agents of food deterioration

Insects, microorganisms and enzymes are identified as the principal agents of food deterioration. Because of the low level of moisture in dehydrated foods fungi and yeasts are the microorganisms of importance in storage. Dehydrated foods may be infested with spores and eggs of fungi and insects respectively at the time of storage. They may also contain enzymes which may originate from the food itself or from microorganisms growing on the food before dehydration. All these agents are stimulated to activity by favourable moisture and physical environmental factors.

Insects and fungi may be broadly divided into field and storage fungi or insects. Of these groups the field fungi and insects require moisture levels higher than is normal in dehydrated foods before they can develop and are therefore not of much importance in storage.

Conditions for the growth of stored product insects and fungi

i) Stored product insects

By definition a stored product insect~~s~~ refers to an insect whose development is partly or wholly intimately associated with the product which it infests. All other insects such as ants, cockroaches, etc. found on food are considered as contaminants.

Though the majority of stored product insects are adapted to foods having low-moisture contents they survive and breed with difficulty in foods having between 8 to 11% moisture. In contrast the grain beetles, *Tribolium confusum* Duv, *T. castaneum* (Hbst) and *Oryzaephilus surinamensis* L, survive and breed in foods at any moisture content provided the grains are either broken or damaged during such processing operation as threshing.

These insects survive extremes of dessication because in addition to their ability to use metabolic water their bodies have been built to conserve water. Experiments nonetheless show that all types of storage insects are rather sensitive to the physical effects of heat and are only active between 10°C (50°F) and 60°C. They survive for only 10 minutes at 60°C and exposure for a few hours at between 48°C and 50°C is sufficient to kill them in all their stages of development (Cotton & Gray, 1948).

ii) Storage fungi

Christensen (1957) has divided the most common storage fungi into major and principal groups. Alternaria, Helminthosporium, Fusarium, Diplodia and Absidia Spp made up the major group and Aspergillus and Penicillium Spp formed the principal group.

These storage fungi unlike storage insects, are known to grow over a very wide range of temperature from below freezing to over 60°C. In contrast they are able to grow and develop over a relatively narrow range of Aw or humidity. Fungi generally in relation to insects have a high minimum Aw for growth in the neighbourhood of 0.70Aw ~~or 70% RH~~. This minimum Aw as may be seen from Table 1, represents foods at different water contents. This shows that it is the physical drying effect of humidity to which vegetative fungi may be sensitive rather than to the availability of water for their life processes at low Aw.

Though there is a general limiting minimum Aw, specific fungi have different minimum Aw at which they will grow. This minimum value however depends in part on the temperature to which a specific fungus might be exposed in storage.

Experiments indicate that the minimum Aw permitting either growth or spore germination of any species depends in part on the optimum temperature for either germination or growth of the specific organism.

Table 1

Moisture content Equilibrium values (at a temperature of about 27°C) for a range of produce at 70. RH, the maximum acceptable level for storage for any sample (After Hall, 1970).

Product	Equi. H_2O at 0.70 Aw
Maize	13.5
Wheat	13.5
Sorghum	13.5
Millet	16.0
Paddy	15.0
Rice	13.0
Cowpeas	15.0
Beans	15.0
Groundnut (shelled)	7.0
Cotton seed	10.0
Cocoa beans	7.0
Copra	7.0
Palm Kernels	5.0

Outside this optimum temperature the minimum Aw for either process tends to rise. Thus Stille (1948) found that the lowest Aw permitting the germination of Aspergillus glaucus spores was 0.70 at its optimum temperature of growth c. 30°C, 0.78 at 10°C and 0.85 at 40°C.

Generally the germination of fungal spores has a higher minimum Aw and moisture requirements than is needed for their later growth which refers more to mycelial development (Tilbury 1966). It is therefore theoretically easier to keep dehydrated foods contaminated by airborne spores, free of fungal growth than when they are contaminated by vegetative mycelia.

Hermetic Storage

Both insects and fungi are aerobic organisms and require oxygen for their development. Use is often made of this requirement to store food under atmospheres other than air in airtight or gastight containers. By such storage techniques it has been possible to store food free of both fungi and insects at moisture levels as high as 20% (Srinavasan and Majumder, 1961). Though foods may be stored free of insects and fungi at such high moisture levels experience shows that such foods soon deteriorate due to the activity of inherent enzymes or those secreted into the food by microorganisms.

The chemical stability and nutritive value of low moisture foods

Enzymes are not only active in foods at high moisture contents but they are known to react with liquid substrates or substrates dissolved and carried in the limited water contents of dehydrated foods (Duckworth & Smith, 1963).

By the activity of hydrolytic enzymes starches present in foods are hydrolysed to sugars, proteins to their constituent amino acids and fats and oils into fatty acids. These hydrolytic products may undergo secondary reactions resulting in products which often unfavourably change the physical and chemical characteristics of the food.

Except for liquid substrates like oils which can move on their own to the enzymes to be split even at very low Aw (Acker, 1969) all other substrates require an aqueous medium for their dissolution and transport to enzyme sites.

Thus the rate of enzyme activity, except the lipases, in dehydrated foods show a considerable dependence on available or liquid water. Experiments by Acker & Kaiser (1959, 1961) and Acker & Huber (1967a) indicate that the rate of hydrolase, oxidase and other moisture dependent chemical reactions which have been equilibrated at a low Aw increase immediately if the samples are transferred to an atmosphere of higher Aw and therefore higher water content.

For chemical activity in foods it is known (Rockland 1957; 1969) that there is an optimum moisture level above and below which deterioration occurs at a fast rate; the deteriorative reactions occuring below this optimum being generally different from those occuring above it. This conclusion supercedes the old idea that the lower the moisture content the more stable the product. The enzymic reactions discussed so far are typical of reactions above the critical optimum minimum moisture content.

Below the optimum moisture content autoxidative reactions predominate and the rate increases with decreasing moisture content. Such autoxidative spoilage reactions depend on atmospheric oxygen and they may thus be inhibited by storage at low oxygen partial pressures by vacuum packaging or by storage in an atmosphere of inert gas such as nitrogen under hermetic conditions.

It should be clear from this discussion that with the control of insects and microorganisms food items must be properly stored to prevent high chemical reaction rates outside an optimum moisture level which result in the loss of dry matter in the form of CO_2 as well as important nutrients such as proteins and vitamins, which are vital to health and normally present in foods in limited quantities, with all the serious malnutritional effects on those who will depend solely on such food for survival.

Optimum minimum moisture level of dehydrated foods

A mathematical definition of a minimum moisture content for the optimum stability of dehydrated foods has engaged the attention of scientists for many years. Salwin (1959) suggested the strongly bound monomolecular layer of Brunaeur, Emmet & Teller's (1938) multimolecular moisture absorption theory, popularly known as the BET theory, to be a satisfactory minimum for the stability of dehydrated foods in storage.

Subsequent application to foods and recent critical appraisal of its predictions indicate that the BET theory applies more to the absorption of non-polar gases on inorganic solid substances for which it was developed rather than to the absorption of polar gases including water vapour on organic food substances.

The work of Shaw (1944), Benson _et al_ (1953, 1954), Gur-Arieh _et al_ (1967a) show that organic substances absorb polar gases to a much greater extent than non-polar gases on which the BET theory was based. This suggested that the BET monolayer as applied to organic substances is likely to underestimate the monolayer moisture of organic food substances and thereby provide metastable conditions that do not completely satisfy Salwin's (1959) mechanism for storage stability of dehydrated foods.

A single layer moisture absorption theory for foods

Recognising the limitations of the BET model as applied to foods a model equation (Caurie, 1970) and corresponding single layer moisture absorption theory (Caurie, 1971b) have recently been developed to predict from sorption data a minimum safe moisture for the storage stability of dehydrated foods. The monolayer moisture level predicted by this single layer theory is higher and has been shown to provide a more stable product (Caurie, 1970) than is possible with the BET theory.

The functional relationship between this critical safe moisture level with its corresponding Aw forms an inverse linear isotherm whose gradient has been shown to depend on the class of food (Fig 2) (Caurie, 1971a); this inverse relationship is unique because normally increases in total moisture content of foods correspond to proportional increases in Aw on sorption isotherms.

It was demonstrated (Caurie 1971a) that the safe moisture was numerically identical to its bond energy expressed in Kcal units. This explained the unusual inverse functional relationship observed between the numerical value of the safe moisture content and corresponding Aw. The safe moisture isotherm was therefore in reality a relationship between bond energy and Aw.

It should be clear that each point on a linear safe moisture isotherm represents a point on a standard sigmoid isotherm. Since percent safe moisture and percent total moisture of food substances are expressed in the same numerical units when a standard sigmoid sorption isotherm is superimposed on a linear safe moisture sorption isotherm characteristic of the class of food the two curves will intersect at M (Fig 3) corresponding to the safe moisture content of the food in question and predicted by the model equation (Caurie, 1970). From Fig 3 as the standard sigmoid isotherm varies with varying ambient temperatures the point of intersection (M) moves up or down along the linear safe moisture isotherm AB. It is clear therefore that for the stable storage of dehydrated foods high storage humidities and temperatures, characteristic of tropical climates are associated with low safe storage moisture levels while low storage temperatures and humidities characteristic of temperate climates correspond to high safe moisture levels. This relationship between the safe moisture, humidity and temperature should be of great importance in tropical food storage because it removes the stigma around the tropical ambient, characterised by high humidities and high temperatures, and it explains why agricultural produce deteriorate quicker under tropical than under temperate climates when the correct storage conditions are not used.

The Moisture available for biological and chemical activity in dehydrated foods

It is generally recognised that the importance of water in biological and moisture dependent chemical changes in dehydrated foods depends on its availability.

In nature biological structure of seeds and grains are such that enzymes and substrate are kept separate from each other. The two are, however, brought more closely together after the destruction of the biological structure by grinding or damage to the cell tissue during handling, processing, and storage. In this respect a slight damage to the seed or grain by developing insect larvae is sufficient to start off a slight enzyme activity which can make itself felt in longterm storage.

In the ground or damaged state dissolved substrate is readily transported to the enzyme in a water medium and to reduce this mobility requires a restricted aqueous phase. It is for the reason of moisture unavailability that whole seeds and grains may be stored free of moulds and insects for years at moisture levels as high as given in Table 1, whereas the ground or damaged forms rapidly deteriorate at the same moisture levels; these may be safely stored by reducing their moisture content, which serves as a transport medium between the substrate and enzyme, to unavailable safe moisture levels.

This available moisture which determines the rates of biological and chemical activities is empirically and firmly believed to be measured in absolute units of Aw which are identical to the surrounding equilibrium humidity expressed as a fraction.

One of the early consequences of the single layer absorption theory was to show (Caurie, 1971b) that the use of absolute units of Aw as a measure of available moisture in dehydrated foods overestimates the parameter. It was shown instead that available moisture in dehydrated food items under specified conditions of equilibrium humidity and temperature may be precisely calculated as percent moisture.

Conclusion

We have discussed the effect of the environment on dehydrated foods as well as the development and activities of insects, fungi and enzymes in food deterioration.

It is clear from the discussion that it is not sufficient to just keep the food free of moulds and insects without considering its nutritive quality which is of much concern to the health of the consumer and which requires a much lower minimum moisture for retention.

It was also indicated that it is not only necessary to lower the storage moisture to a safe minimum but it is equally important to keep it there by the control of the storage environment. This means that a safe storage moisture does not necessarily guarantee safe storage unless uniform storage temperature and humidity conditions are maintained. Sorption data which are taken under uniform equilibrium conditions offer the best data for predicting the safe storage moisture level for the optimum stability of dehydrated foods.

Accurate methods for determining these sorption data especially at low Aw where interferring permanent gases reduce the sorptive capacities of foods to very low levels will greatly add to the accuracy of the parameters drawn from these isotherms.

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