31) QUALITY OF DRIED FOODS AND DETERIORATIVE REACTIONS DURING DRYING

Consumer demand has increased for processed products that keep more of their original characteristics. In industrial terms, this requires the development of operations that minimize the adverse effects of processing. The effect of food processing on finished product quality ultimately determines the usefulness and commercial viability of that unit process operation. In the particular case of food drying this indicates that loss of volatiles and flavours, changes in colour and texture, and a decrease in nutritional value. Furthermore, residual enzyme activity and microbial activity in dried foods are essential parameters that effect product quality and shelf life.

The quality of dried foods is dependent in part on changes occurring during processing and storage. Some of these changes involve modification of the physical structure. These modifications affect texture, rehydrability and appearance. Other changes are due to chemical reactions, but these are also affected by physical structure, primarily due to effects on diffusivities of reactants and of reaction products.

The most commonly examined properties of dried products can be classified into two major categories, engineering and quality properties. The engineering properties of the dried products involve effective moisture diffusivity, effective thermal conductivity, drying kinetics, specific heat, and equilibrium moisture content. In addition there are properties related to product quality. These properties are necessary for the determination and the characterization of the quality of dried products can be grouped into:

- Thermal properties : state of product; glassy, crystalline, rubbery,
- Structural properties : density, porosity, pore size, specific volume,
- Textural properties : compression test, stress relaxation test, tensile test,
- Optical properties : colour, appearance,
- Sensory properties : aroma, taste, flavour,
- Nutritional characteristics : vitamins, proteins and
- Rehydration properties : rehydration rate, rehydration capacity.

During the last decades, much attention is paid on the quality of dehydrated foods. The specific drying method as well as the physical-chemical changes that occur during drying seems to affect the quality of dehydrated products. More specifically, drying method and process conditions affect significantly the drying constant, colour, texture, density and porosity and sorption characteristics of materials. The increasing need for producing efficiently high quality and convenient products at a competitive cost has led to the employment of several drying methods in practice.

Conventional air-drying is the most frequently used dehydration operation in food and conventional chemical industry. Dried products are characterized by low porosity and high apparent density. Significant colour changes occur during air-drying, and most frequently the dried product has low sorption capacity.

Microwave drying is an alternative drying method that has recently been used in food industry. Applying microwave energy under vacuum combines advantages of both vacuum drying and microwave drying as far as improved energy efficiency and product quality are concerned. Vacuum dried materials are characterised by higher porosity, depending on level of vacuum, and less deterioration of colour and volatile aroma.

Osmotic dehydration minimises the heat effects on colour and flavour, prevents enzymatic browning and thus limits the use of sulphur dioxide, increasing in this way the retention of nutrients during subsequent convective drying. Osmotic dehydration greatly affects apparent density and porosity.

Freeze drying is one of the most sophisticated dehydration methods. It provides dried products of porous structure and little or no shrinkage, superior taste and aroma retention, better rehydration properties, compared to products of alternative drying processes. However, its advantages are directly weighed against its corresponding high treatment cost. The factors that influence quality during drying have been identified briefly as in table 1.

Table 1. Factors that influence during drying (Heldman, 1992).

Chemical	Physical	Nutritional
Browning reactions	Rehydration	Vitamin loss
Lipid oxidation	Solubility	Protein loss
Colour loss	Texture	Microbial survival
	Aroma loss	

All food products deteriorate at some rate or other in a manner that depends on food type, composition, formulation, packaging and storage regime. The potential for deterioration may occur at any of the stages between the acquisition of raw materials and the eventual consumption of a finished product, and may therefore be accelerated or minimised at any of these stages also. The complete preservation systems for food and dairy products are therefore usually multi-component in that they seldom rely on one factor alone. The major deteriorative reactions, which are the major targets for preservation, are well known and relatively few (Table2). They include some that are essentially physical in their mode of action, some that are chemical, some that are enzymatic and some that are microbiological. When preservation fails and these reactions escape control, the consequences range broadly. At the one extreme, these may be trivial though undesirable, such as loss of colour or flavour, or texture change within a food. At the other extreme, the most serious forms of deterioration are those associated with the presence or multiplication of micro-organisms, and these range from the reactions that cause undesirable spoilage to the transmission of life-threatening diseases caused by the most hazardous of the food-poisoning, micro-organisms, such as *Clostridium botulinum, Salmonella*, enteropathogenic *Escherichia coli, Listeria monocytogenes.*

Table 2. Major Food Deterioration Reactions (Gould, 1995).

Basis of reaction	Example and consequence
Physical	*Moisture movement*, causing drying and toughening of texture, hydration and softening of texture, aggregation
Chemical	*Oxidation*, causing oxidative rancidity, loss of colour
	Maillard reactions, causing discolouration, change in texture
Enzymatic	*Polyphenoloxidase*, causing enzymic browning
	Lipoxygenase, causing oxidative rancidity
	Lipase, causing lipolytic rancidity
	Protease, causing gelation and flavour and texture changes
Microbial	*Growth of spoilage organisms,* causing quality deterioration
	Growth of toxigenic organisms, causing food poisoning
	Presence of infectious organisms, causing food poisoning

Reactions occurring during drying can result in quality losses, particularly nutrient losses and other deteriorations caused by browning reactions. Reactions during drying may be classified as browning reactions and nutrient losses. Moreover, there occur also structural changes, which affect quality of dried fruits and vegetables.

A. CHEMICAL FACTORS

1. BROWNING REACTIONS

Browning reactions, which are some of the most important phenomena in food during processing and storage, represent an interesting research area for the implications in food stability and technology, as well as in nutrition and health. They can involve different compounds and proceed through different chemical pathways. Browning reactions in foods are of widespread occurrence, and become evident when food materials subjected to processing or to mechanical injury. They are important in terms of the alteration of appearance, flavour, and nutritive value. Browning is considered to be desirable if it enhances the appearance and flavour of a food product in terms of tradition and consumer acceptance like in the cases of coffee, maple syrup, beer, and in toasting of bread. However, in many other instances, such as fruits, vegetables, frozen and dehydrated foods, browning is undesirable as it results in off-flavours and colours. Therefore it is important to know the mechanisms and inhibition methods of browning reactions. Another significant adverse effect of browning is the lowering of the nutritive value of the food article.

Rate of browning reactions depends on temperature of drying, pH and moisture content of the product, time of heat treatment, and the concentration and nature of the reactants. Rate increases with increasing temperature, and the increase is faster in systems high in sugar content. For moisture contents above 30 %, a decrease in reaction rate is caused by dilution, whereas below 30 %, decrease is caused by the intrinsic ability of sugars to lower water activity.

Browning reactions change colour, decrease nutritional value and solubility, create off-flavours, and induce textural changes. There are two important forms of browning, enzymatic and non-enzymatic (Maillard reactions, caramelization, ascorbic acid oxidation). This colour development is usually undesirable, but with knowledge of the type of reaction involved, it is easier to work out methods for controlling this change.

1.1. Enzymatic Browning

A group of enzymes, collectively called "phenolase" is responsible for browning of some fruits and vegetables, such as potatoes, apples, and banana. When the tissue is bruised, cut, peeled, diseases, or exposed to any number of abnormal conditions, the colour of the fruits or vegetables is changed. The injured tissue rapidly darkens on exposure to air, due to the conversion of phenolic compounds to brown melanins. This enzyme group includes such diverse enzymes as phenoloxidase, cresolase, dopa oxidase, catecholase, tyrosinase, polyphenoloxidase, potato oxidase, sweet potato oxidase, and phenolase complex.

Phenolase is extensively distributed in plants such as roots, citrus fruits, plums, bananas, peaches, pears, melons, olives, tea, mushrooms, and others. It has a molecular weight of

128.000 and a copper content of 0.2 %, amounting to 4 Cu molecules to each enzyme molecule. The freshly prepared enzyme contains cupper in the cuprous form, but it slowly oxidizes to the cupric form on aging. This change thus not results in any loss of activity. Phenolase in the pure form is colourless. Concentrated solutions of phenolase are most stable at the neutral pH. But, heating for a short time at 60?C inactivates enzyme. Phenolase is also inhibited by substances, which form stable complexes with copper such as H_2S, KCN, CO or p-aminobenzoic acid.

In plants, there are a large number of naturally occurring o-diphenolic compounds, which are oxidizable by phenolase. Actually the mechanism of action of phenolase on o-diphenolic compounds is very complicated. Since the copper is the prosthetic group of the enzyme, it has been postulated that the activity of phenolase is based on the change of the copper from the cupric to the cuprous state. Simply phenolase catalyse the oxidation of colourless phenolic compounds into o-quinones, which are red to brown in colour. O-quinones are precursors of the brown colour in cut fruits and vegetables. When they combine with amino acid derivatives, highly collared complexes forms.

The initial reaction, involving the conversion of the phenolic compound to the corresponding quinone, is dependent upon the presence of the phenolase, its copper prosthetic group, and oxygen. Advantage may be taken of this in order to control or prevent enzymatic browning in foods. This type browning is a serious problem during the dehydration process where any injury to the plant tissue, sustained through the use of heat or through poor handling procedures, can result in phenolase activation.

The enzymatic browning of foods is usually undesirable because it cuts down the acceptability of the food in question for two reasons: (1) the undesirable development of off-colour and (2) the formation of off-flavours.

1.1.1. Control Methods of Enzymatic Browning

1.1.1.1. Heat

The application of heat to the food article at a high temperature for an adequate length of time will inactivate phenolase and all other enzymes present. Several problems may arise through the use of heat. The fruit or vegetable becomes cooked, and this in turn leads to unfavourable texture changes and the development of off-flavours. Such problems may occur for instance in the processing of pre-peeled potatoes, apples, pears, and peaches.

There is a close relationship between temperature and time with respect to the heat-treatment of foods. These factors themselves depend upon the amount of enzyme. It is therefore essential to control the heating time very carefully at high temperatures, so that the enzymes are inactivated w hile avoiding significant changes in flavour and texture. A balance should be worked out in terms of each particular raw material and desired food product.

1.1.1.2. Sulphur dioxide and sulphites

Sulphur dioxide and sulphites, usually sodium sulphate, sodium bisulphate and sodium metabisulphate, are the chemical inhibitors of phenolase that has been used for years in the food industry. It can be applied by gaseous sulphur dioxide or dilute aqueous solutions of the sulphites. The gas will penetrate at a faster rate into the fruit or vegetable, but the sulphite

solutions are easier to handle, as in the form of a dip in the processing plant, or as a spray. There are advantages and disadvantages in the use of sulphur dioxide or su1phites. They can be used in cases where the application of heat would result in undesirable textural changes and the development of off-flavours. The internal atmosphere of the product in question must be considered when using SO_2. Apple slices, for example, have a fair amount of oxyge n in the internal tissue, which can cause browning. It is necessary, therefore, that SO_2 penetrate the entire slice, to effectively control browning. They have antimicrobial properties and also assist in preserving vitamin C. However, their use in food material may result in an objectionable flavour and odour, or may bleach the natural colour of the food. It is toxic at high levels, and can be detected organoleptically. Perhaps the most serious disadvantage of using sulphur dioxide or sulphites in foodstuffs is their adverse destructive effect on vitamin B or thiamine. In spite of these drawbacks, this group of phenolase inhibitors is widely used in food processing, due mainly to the effectiveness and low cost of these substances.

1.1.1.3. Acids

This is a widely used method for controlling enzymatic browning. The acids employed are among those, which occur naturally in tissues, particularly citric, malic, phosphoric and ascorbic acids. In general their action is to lower tissue pH and thus to decrease the rate of enzymatic browning. The optimum pH of phenolase lies within the range 6-7, and below 3 there is virtually no enzymatic activity.

Citric acid, often in conjunction with ascorbic acid or sodium bisulphite, has long been used as a chemical inhibitor of enzymatic browning. Cut fruit, such as peaches is often immersed in dilute solutions of these acids prior to processing. Citric acid possesses a double inhibitory effect on phenolase, not only by lowering the pH of the medium, but also by chelating with the copper moiety of the enzyme.

A much more significant inhibitor of phenolase is ascorbic acid. It does not have a detectable flavour at the concentration used, nor does it possess a corrosive action upon metals; in addition, its vitamin value is well known. Ascorbic acid reduces the o-quinones formed by phenolase to the original o-dihydroxphnolic compounds, which in turn prevents the formation of brown substances.

1.1.1.4. Dehydration in sugar

The fruit is partially dehydrated by reducing to 50% of its original weight by osmosis in sugar or syrup. After draining, the fruit is either frozen or dried further in an air or vacuum dryer. The sugar or syrup inhibits enzymatic browning through the complete dehydration. In addition, it has a protective effect on flavour.

1.2. Non-Enzymatic Browning

During manufacturing process changes in the structure of derivative fruit products are produced, therefore these modify the colour and final aspect of the product. Although most non-enzymatic browning in food materials is undesirable because it indicates deterioration in flavour and appearance of the product involved, the development of brown colours in some products is entirely acceptable. Examples of this are the development of brown colours in baked goods during the baking process, in beer, molasses, coffee and substitute cereal beverages, many breakfast foods, and the roasting and other forms of heat preparation of

meat. However, the brown colours developing in most other products are not desirable, and methods to prevent or retard such changes are in use.

There are three main non-enzymatic reaction pathways: (i) Maillard reaction, (ii) Caramelization, (iii) Ascorbic acid oxidation.

1.2.1. The Maillard reaction

For as long as food cooked, the Maillard reaction has played an important role in improving the appearance and taste of foods. It has been a central and major challenge in food industry, since the Maillard reaction is related to aroma, taste and colour, in particularly in traditional processes such as the roasting of coffee and cacao beans, the baking of bread and cakes, the toasting of cereals and the cooking of meat. Moreover, during the Maillard reaction a wide range of reaction product is formed with significant importance for the nutritional value of foods. This can be reduced by decrease of digestibility and possibly formation of toxic and mutagenic compounds, but can also be improved by the formation of antioxidative products.

The chemistry underlying the Maillard reaction is very complex. It encompasses not one reaction pathway but a whole network of various reactions. The Maillard reaction is notoriously difficult to control. Various factors involved in food processing influence it and they can be considered as food processing variables.

The Maillard reaction has been named after the French chemist Louis Maillard (1912) who observed the formation of brown pigments or melanoidins when heating a solution of glucose and glycine.

The Maillard reaction is the action of amino acids and proteins on sugars. The carbohydrate must be a reducing sugar because a free carbonyl group is necessary for such a combination. The end product is the melanoidins, which are brown pigments. The mechanism of reaction has three stages:

(i) Initial stage (colourless)
  a. sugar-amine condensation
  b. Amadori rearrangement
(ii) Intermediate stage (colourless to yellow)
  c. sugar dehydration
  d. sugar fragmentation
  e. amino acid degradation
(iii) Final stage (highly coloured)
  f. aldol condensation
  g. aldehyde-amine polymerisation, formation of heterocyclic nitrogen compounds.

The carbonylamino reaction can occur in acidic or alkaline media, although it is favoured under the more alkaline conditions. A number of studies have demonstrated an increase in reaction rate with a rise in pH. The relationship between the reaction rate and pH would therefore render those foods of high acidity less susceptible to this reaction, e.g., pickles.

Furfural and hydroxymethylfurfural (HMF) are the most important chemical substances produced in non-enzymatic browning processes. The HMF content is important because it indicates the degree of heating of the treated products during processing.

The role of buffers in non-enzymatic browning has been shown to increase the rate of browning for sugar-amino acid systems as a result of their influence on the ionic environment in which the reaction takes place. The temperature dependence of this reaction has been demonstrated in a number of quantitative studies, where increased rates were reported with a rise in temperature. This reaction proceeds readily in aqueous solution, although complete dehydration of the reactants results in a rapid halt in the process.

Reducing sugars are essential ingredients in this reaction, providing the necessary carbonyl groups for interaction with the free x-amino groups. The reaction, itself, is not confined to monosaccharides but can also proceed in the presence of reducing disaccharides, i.e. maltose and lactose. Non-reducing sugars, however, cannot participate unless the glycosidic bond is cleaved, thereby liberating its constituent reducing monosaccharides capable of entering the reaction. The order of reactivity appears to be greater for aldopentoses than for aldohexoses, whereas reducing disaccharides exhibit considerably less activity.

1.2.2. Caramelization

This process is another example of non-enzymatic browning involving the degradation of sugars in the absence of amino acids or proteins. When sugars are treated under anhydrous conditions with heat, or at high concentration with dilute acid, caramelization occurs, with the formation of anhydrous sugars.

Caramels for commercial use are made from glucose syrups, but usually caramelization is the result of reactions that take place when sucrose is heated. There are three stages during this process (at $200\ ^0C$), during which water is lost and first isosacchrosan and then other anhydrides are formed. The first stage starts with the melting of sucrose, followed by foaming, which continues for 35 min. during this period one molecule of water, is lost from a molecule of sucrose. The foaming then stops. Shortly after this, a second stage of foaming starts which lasts 55 min. During this stage about 9% of the water is lost, and the compound formed is caramelan, a pigment with the average formula of $C24H36O18$. Caramelan melts at $138\ ^0C$, is soluble in water and ethanol, and is bitter in taste. The pigment caramelen is formed during the third stage of foaming which starts after about 55 min. the formula of this pigment is $C_{36}H_{50}O_{25}$. Caramelen melts at $154\ ^0C$ and is soluble in water.

The main disadvantage of this reaction is the production of unpleasant, burned, and bitter products, which can arise if this process is allowed to proceed uncontrolled. This reaction may be slowed down by bisulphites, which react with sugar to decrease the concentration of aldehydic form.

1.2.3. Ascorbic acid oxidation

A further mechanism appears to operate during the discoloration of dehydrated vegetables in which ascorbic acid is involved. The formation of dehydroascorbic acid and diketogluconic acids from ascorbic acid is thought to occur during final stages of the drying process and is capable of interacting with the free amino acids, nonenzymatically, producing the red-to-brown discoloration. This reaction may involve Strecker degradation.

1.2.4. Inhibition of non-enzymatic browning

Several of factors can affect the formation of coloured complexes in food products. Among these are pH, temperature, moisture content, time, concentration and nature of reactants.

The rate of browning increases with rising temperature. Since these reactions have been shown to have a high temperature coefficient, lowering of the temperature during the storage of food products can help to minimize these processes.

Reducing the moisture content through dehydrating procedures can inhibit those reactions being moisture dependent for optimum activity. In attempting to carry out these procedures one must ensure that the dehydrated product is suitable for sale in that form, and that the product is suitably packaged so as not to permit moisture uptake during storage.

Since the Maillard reaction is generally favoured at the more alkaline conditions, if this type of browning is involved, lowering of the pH might provide a good method of control.

Gas packaging is extremely useful in excluding oxygen by using an inert gas. This reduces the possibility of lipid oxidation, which in turn could give rise to reducing substances capable of interacting with amino acids. While this reaction does not appear to influence the initial carbonylamino reaction, exclusion of oxygen is thought to effect other reactions involved in the browning process.

Chemical inhibitors have been used to advantage in limiting browning reactions during the production and storage of a variety of foods. Among those widely used are sulphites, bisulphites, thiols, and calcium salts.

Sulphites proved successful in controlling a variety of browning processes. Bisulphites inhibit the conversion of D-glucose to S-hydroxymethyl- furfural, as well as the conversion of ascorbic acid to furfural by complexing through the reducing group. Consequently the formation of furfurals is blocked, thus preventing the production of the coloured pigments. They can also block the carbonyl group of the reducing sugars involved in the carbonylamino reaction.

Calcium chloride was reported to be a possible inhibitor of browning. Its inhibitory effect is due to the chelating of calcium with the amino acids.

Although the various inhibitors discussed can prevent to varying degrees of success browning from occurring, it is important to realise that the nutritional value of the foods could still have been seriously reduced. The initial stages of the Maillard reaction, for example, the carbonylamino reaction could still have rendered the amino acids unavailable even though no browning is visible during this stage. However to be certain that this stage is the one inhibited is extremely difficult to ensure.

2. LIPID OXIDATION

Lipid oxidation is responsible for rancidity, development of of-flavours, and the loss of fat-soluble vitamins and pigments in many foods, especially in dehydrated foods. Factors that affect oxidation rate include moisture content, type of substrate (fatty acid), extent of reaction, oxygen content, temperature, presence of metals, presence of natural antioxidants, enzyme

activity, ultraviolet light, protein content, free amino acid content, other chemical reactions. Moisture plays an important part in the rate of oxidation.

The elimination of oxygen from foods can reduce oxidation, but the oxygen concentration must be very low to have an effect. The effect of oxygen on lipid oxidation is also closely related to the product porosity. Freeze-dried foods are more susceptible to oxygen because of their high porosity. Air-dried foods ten to have less surface area due to shrinkage and thus are not as affected by oxygen. Minimizing the oxygen level during processing and storage, and addition of antioxidants as well as sequesterants, have been recommended in the literature to prevent lipid oxidation.

3. COLOUR LOSS

The colour of foods is dependent upon the circumstances under which food is viewed, and the ability of the food to reflect, scatter, absorb, or transmit visible light. Drying changes the surface characteristics of food and hence alters the reflectivity and colour. Carotenoids are fat-soluble pigments present in green leaves and red and yellow vegetables. Chemical changes to carotoneoid and chlorophyll pigments are caused by heat and oxidation during drying. In general, longer drying times and higher drying temperatures produce greater pigment losses. Oxidation and residual enzyme activity cause browning during storage. This is prevented by improved blanching methods and treatment of fruits with ascorbic acid or sulphur dioxide. Many studies indicate that the bulk of carotene destruction occurs during storage rather than as a result of the dehydration process. Pigment retention in dried foods decreased as temperature and moisture increased. Thus it was found that the beet pigments were most stable in the powders, then slices, and least stable in solution.

The natural green pigment of all higher plants is a mixture of chlorophyll *a* and chlorophyll *b*. The retention of the natural greenness of chlorophyll is directly related to the retention of magnesium in the pigment molecules. In moist heating conditions, the chlorophyll is converted to pheophytin by losing some of its magnesium. The colour then becomes an olive green rather than a grass green.

The interaction of amino acids and reducing sugars (Maillard reaction) occurs during conventional dehydration of fruits. If the fruits are sulphured, enzymatic browning can be inhibited, and the Maillard reaction retarded.

There are certain different methodologies for analysing the colour. The most common methods are the RGB (red, green, blue), LAB (lightness, redness-greenness, yellowness-blueness) and XYZ scales that analyse the colour into three parameters, so that each composite colour can be easily quantified by a set of three numbers.

B. PHYSICAL FACTORS

1. Rehydration, Shrinkage and Food Porosity

Rehydration is a complex process aimed at the restoration of raw material properties when dried material is contacted with water. Pre-drying treatments, subsequent drying and rehydration *per se* induce many changes in structure and composition of plant tissue, which result in impaired reconstitution properties. Hence, rehydration can be considered as a

measure of the injury to the material caused by drying and treatments preceding dehydration. Rehydration of dried plant tissues is composed of three simultaneous processes: the imbibition of water into dried material, the swelling and the leaching of soluble.

It has been shown that the volume changes (swelling) of biological materials are often proportional to the amount of absorbed water. It is generally accepted that the degree of rehydration is dependent on the degree of cellular and structural disruption. There are a large number of research reports in which authors measure the ability of dry material to rehydrate. The ratio between the dry material mass and water mass varies from 1:5 to 1:50, temperature of rehydrating water is from room temperature to boiling. Time of rehydration varies from 2 min. to 24 h.

The degree to which a dehydrated sample will rehydrate is influenced by structural and chemical changes caused by dehydration, processing conditions, sample preparation, and sample composition. Rehydration is maximised when cellular and structural disruptions such as shrinkage are minimised.

Several researchers have found that freeze-drying causes fewer structural changes and fewer changes to product's hydrophilic properties than do other drying processes. Most of the shrinkage occurs in the early drying stages, where 40 to 50 % shrinkage may occur. To minimise shrinkage, therefore, low-temperature drying should be employed so that moisture gradients throughout the product are minimised.

Many drying techniques or pre-treatments given to food before drying are aimed at making the structure more porous so as to facilitate mass transfer and thereby speed drying rate. Porous sponge-like structures are excellent insulating bodies and generally will slow down the rate of heat transfer into the food. Porosity may be developed by creating steam pressure within the product and a case hardened surface through rapid drying. Porosity also can be developed by whipping or foaming a food liquid or puree prior to drying the porous product has the advantages of quick solubility or reconstitution and greater volume appearance, but the disadvantages of increased bulk and generally shorter storage stability because of increased surface exposure to air, light, etc.

2. Solubility

Many factors affect the solubility, including processing conditions, storage conditions, composition, pH, density, and particle size. It has been found that increasing product temperatures is accompanied by increasing protein denaturation, which decreases solubility. A low bulk density is required for good dispersibility of non-fat dry milk. It was found that particle agglomeration, which increases particle size, increased sinkability. However, some scientists found that larger particles were less soluble. This was attributed to the longer drying time required to dry large particles. Thus more protein was denatured and solubility decreased. This shows that the heat treatments as well as the particle size must be considered when determining solubility.

3. Texture

Texture is one of the most important properties connected to product quality. Changes to the texture of solid foods are an important cause of quality deterioration. Factors that affect texture include moisture content, composition, variety, pH, product history (maturity), and sample dimensions. The chemical changes associated with textural changes in fruits and vegetables include crystallization of cellulose, degradation of pectin, and starch gelatinisation. Texture is also dependent on the method of dehydration. High air temperatures (particularly with fruits, fish and meats) cause complex chemical and physical changes to the surface, and the formation of hard impermeable skin. This is termed "case hardening". It reduces the rate of drying and produces a food with a dry surface and a moist interior. It is minimised by controlling the drying conditions to prevent excessively high moisture gradients between the interior and the surface of the food.

On rehydration the product absorbs water more slowly and does not regain the firm texture associated with the fresh material. There are substantial variations in the degree of shrinkage with different foods (Table 3).

Drying is not commonly applied to meats in many countries owing to the severe changes in texture compared with other methods of preservation. These are caused by aggregation and denaturation of proteins and a loss of water-holding capacity, which leads to toughening of muscle tissue.

Table 3. Approximate ratios for drying, shrinkage and rehydration of selected vegetables (Fellows, 1988).

Vegetable	Drying Ratio	Overall shrinkage ratio	Rehydration ratio
Cabbage	11.5	21.0	10.5
Carrots, diced	7.5	12.0	7.0
Onions, sliced	7.0	8.0	5.5
Peppers, green	17.0	22.0	8.0
Spinach	13.0	13.5	5.0
Tomato flakes	14.0	20.0	5.0

The rate and temperature of drying have a substantial effect on the texture of foods. In general, rapid drying and high temperatures cause greater changes than do moderate rates of drying and lower temperatures. As water is removed during dehydration, solutes move from the interior of the food to the surface. Evaporation of water causes concentration of solutes at the surface.

In powders, the textural characteristics are related to bulk density and the ease with which they are rehydrated. These properties are determined by the composition of the food the method of drying, and the particle size of the product. Low-fat foods 8for example fruit juices, potato and coffee) are more easily formed into free-flowing powders than re whole milk or meat extracts. Powders are 'instantised' by treating individual particles so that they form free-flowing agglomerates or aggregates, in which there are relatively few points of contact. The surface of each particle is easily wetted when the powder is rehydrated, and particles sink below the surface to disperse rapidly through the liquid. These characteristics are respectively termed *wetability, sinkability, dispersibility*, and *solubility*. For a powder to be considered 'instant', it should be complete these four stages within a few seconds.

The convenience of instantised powders outweighs the additional expense of production, packaging and transport for retail products.

Textural properties are usually related to mechanical stress, which examine the viscoelastic behaviour of the material. The viscoelasticity is strongly related to complex quality characteristics perceived by people as mouth feeling, etc. Characterising the viscoelastic behaviour of materials is usually done by the measurement of relaxation modulus *E(t)* and Poisson's ratio *v(t)* from a simple uniaxial tension or compression test, creep test, dynamic test and the Hertz and Boussinesq technique were explained as to their principles and data analysis.

Compression tests are the most common techniques for the estimation of the texture. The simplest approach is to measure the maximum applied force or stress at fracture of the material. The quantification of difficult terms such as hardness, chewiness, has been made by a methodology called Texture Profile Analysis.

The model for compression test involves four parameters: the maximum stress ($?_{max}$), the corresponding strain ($?_{max}$), the elastic parameter (E) and the viscoelastic exponent (p). The maximum stress ($?_{max}$) and the maximum strain ($?_{max}$) are related with moisture content through simple equations. The elastic parameter (E) and the viscoelastic exponent (p) are related to moisture content through exponential equations.

The maximum deformation and maximum strain are significantly affected by the drying method. Osmotic dehydration seems to prevent the breakage of samples due to gain of solids that cause a plasticisation of structure. On the contrary vacuum and freeze drying seem to make apple samples more fragile due to higher values of porosity that they develop compared to that of convective dried materials.

4. Aroma Loss

There is often decrease in the quality of the dried products because most conventional techniques use high temperatures during the drying process. Processing may also introduce undesirable changes in appearance and will cause modification of the natural "balanced" flavour and colour. The dehydration technologies should be focusing on the production of dried products with little or no loss in their sensory characteristics together with the advantages of added convenience.

The properties of dried vegetables are influenced by chemical and physical changes. Chemical changes mainly affect sensory properties such as colour, taste and aroma, whereas physical changes mainly influence the handling properties such as swelling capacity and cooking time.

Heat treatment of fruits and vegetables often reduces the number of original volatile flavour compounds, while introducing additional volatile flavour compounds through the autoxidation of unsaturated fatty acids and thermal decomposition, and/or initiation of Maillard reactions. Volatile organic compounds responsible for aroma and flavour have boiling points at temperatures lower than water. Volatiles, which have a high relative volatility and diffusivity, are lost at an early in drying. Fewer volatile components are lost at later stages. Control of drying conditions during each stage of drying minimises losses. Foods that have economic value due to their characteristics flavours, herbs and spices, are dried at low temperatures.

A second important cause of aroma loss is oxidation of pigments, vitamins and lipids during storage. The open porous of dried food allows access of oxygen. The storage temperature and the water activity of the food determine the rate of deterioration.

In dried milk the oxidation of lipids produces rancid flavours owing to the formation of secondary products including ?-lactones. Most fruits and vegetables contain only small quantities of lipid, but oxidation of unsaturated fatty acids to produce hydroperoxides, ketones and acids, causes rancid and objectionable odours. Vacuum or gas packaging, low storage temperatures, exclusion of ultraviolet or visible light, maintenance of low moisture contents, addition of synthetic anti-oxidant, or preservation of natural anti-oxidants reduce these changes.

The technical enzyme, glucose oxidase, is also protecting dried foods from oxidation. A package, which is permeable to oxygen but not to moisture and which contains glucose and the enzyme, is placed on the dried food inside a container. Oxygen is removed from the headspace during storage. Flavour changes, due to oxidative or hydrolytic enzymes are prevented in fruits by the use of sulphur dioxide, ascorbic acid or citric acid, by pasteurisation of milk or fruit juices and by blanching of vegetables.

Other methods that are used to retain flavours in dried foods include:
   (1) Recovery of volatiles and their return to the product during drying,
   (2) Mixing recovered volatiles with flavour fixing compounds, which are then granulated and added back to the dried product (for example dried meat powders), and
   (3) Addition of enzymes, or activation of naturally occurring enzymes, to produce flavours from flavour precursors in the food (for example onion and garlic are dried under conditions that protect the enzymes that release characteristics flavours). Maltose is used as a carrier material when drying flavour compounds.

C. NUTRITIONAL FACTORS

1. Nutrient Losses

In drying, a food loses its moisture content, which results in increasing the concentration of nutrients in the remaining mass. Proteins, fats, and carbohydrates are present in larger amounts per unit weight in dried foods than in their fresh counterpart. Large differences in reported data on the nutritive value of dried foods are due to wide variations in the preparation procedures, the drying temperature and time, and the storage conditions. In fruits and vegetables, losses during preparation usually exceed those caused by the drying operation. The water-soluble vitamins can be expected to be partially oxidized. The water-soluble vitamins are diminished during blanching and enzyme inactivation. Vitamins during drying proceeds, some (for example riboflavin) become supersaturated and precipitate from solution. Losses are therefore small (See Table 3). Others (for example ascorbic acid) are soluble until the moisture content of the food falls to very low levels and react with solutes at higher rates as drying proceeds. Ascorbic acid is sensitive to high temperatures at high moisture contents. Several studies have shown that the maximum rate of ascorbic acid degradation occurs at specific (critical) moisture levels. The critical moisture level appears to vary with the product being dried and/or the dehydration process. Short drying times, low temperatures, and low moisture and oxygen levels during storage, are necessary to avoid large losses. To optimise ascorbic acid retention, the product should be dried at a low initial temperature when the moisture content is high since ascorbic acid is most heat sensitive at high moisture contents. The temperature can then be increased as drying progresses and ascorbic acid is more stable,

due to decrease in moisture. Thiamin is also heat sensitive, but other water-soluble vitamins are more stable to heat and oxidation, and losses during drying rarely exceed 5-10%.

Fruits can be sun dried, dehydrated, or processed by a combination of the two. Sun drying causes losses in carotene content. Dehydration especially spray drying, can be accomplished with loss in this nutrient. Vitamin C is lost in great proportions in sun-dried fruits. Freeze-drying of fruits retains greater portions of vitamin C, and other nutrients. The retention of vitamins in dehydrated foods is generally superior in all counts than in sun-dried foods.

Vegetable tissues dried artificially or in the sun tend to have losses in nutrients in the same order of magnitude as the fruits. The carotene content of vegetables is decreased as much as 80 per cent if processing is accomplished without enzyme inactivation. The best commercial methods will permit drying with losses in the order of five per cent of carotene. Thiamin content reduction can be anticipated to be in the order of 15 per cent in blanched tissues, while unblanched may lose three-fourths of this nutrient. With ascorbic acid, rapid drying retains greater amounts than slow drying. Generally the vitamin C content of vegetable tissue will be lost in slow, sun drying processes. In all events the vitamin potency will decrease on storage of the dry food.

With milk products, the nutrient level of the raw milk sand the method of processing will dictate the level of vitamins retained. Vitamin A is retained in good proportions in drum-dried and spray-dried milk. Vacuum packed dry milk can be stored with good retention of vitamin A. Thiamin losses occur during both spray and drum drying, but losses are of a lower order of magnitude than with fruit and vegetable drying. Similar results are obtained with riboflavin. Ascorbic acid losses occur during the drying of milk. Being sensitive to heat and oxidation, vitamin C may be totally lost in a drying process. With careful processing, vacuum drying and freeze-drying, ascorbic acid values can be retained in the same order of magnitude as fresh raw milk. The vitamin D content of milk is generally greatly decreased by drying. Fluid milk should be enriched with vitamin D prior to drying. Other vitamins such as pyridoxine and niacin are not materially lost.

Usually dried meat contains slightly less vitamins than fresh meat. Thiamin losses occur during processing, greater losses occurring at high drying temperature. Vitamin C is in most part lost in dried meat. Small losses of riboflavin and niacin occur.

Oil-soluble nutrients (for example essential fatty acids and vitamins A, D, E and K) are mostly contained within the dry matter of the food and they are not therefore concentrated during drying. However, water is a solvent for heavy metal catalysts that promote oxidation of unsaturated nutrients. As water is removed, the catalysts become more reactive, and the rate of oxidation accelerates. Fat-soluble vitamins are lost by interaction with the peroxides produced by fat oxidation. Losses during storage are reduced by low oxygen concentration and storage temperatures and by exclusion of light.

Table 3. Vitamin losses in selected dried foods (Fellows, 1988).

Food	Vit. A	Thiamin	Vit. B$_2$	Niacin	Vit. C	Folic acid	Biotin
					Loss (%)		
Fruits[a]	6	55	0	10	56		
Fig (sun-dried)	–	48	42	37	–	–	–
Whole milk (spray-dried)	–	–	–	–	15	10	10
Whole milk (drum-dried)	–	–	–	–	30	10	10
Pork		50-70					
Vegetables[b]	5	< 10	< 10				

[a] Fruits mean loss from fresh apple, apricot, peach and prune.
[b] Vegetables mean loss from peas, corn, cabbage and beans (drying stage only)

Influence of Drying on Protein: The biological value of dried protein is dependent on the method of drying. Prolonged exposures to high temperatures can render the protein less useful in the dietary. Low temperature treatments of protein may increase the digestibility of protein over native material. Milk proteins are partially denatured during drum drying, and these results in a reduction in solubility of the milk powder, aggregation and loss of clotting ability. At high storage temperatures and at moisture contents above approximately 5%, the biological value of milk protein is decreased by Maillard reactions between lysine and lactose. Lysine is heat sensitive and losses in whole milk range from 3-10% in spray drying and 5-40% in drum drying.

Influence of drying on fats: Rancidity is an important problem in dried foods. The oxidation of fats is greater at higher temperatures than at low temperatures of dehydration. Protection of fats with antioxidants is an effective control.

Influence of drying on carbohydrates: Fruits are generally rich sources of carbohydrates, poor sources of proteins and fats. The principal deterioration in fruits is in carbohydrates. Discoloration may be due to enzymatic browning, or to caramelization types of reactions. In the latter instances, the reaction of organic acids and reducing sugars causes discolorations noticed as browning. The addition of sulphur dioxide to tissues is a means of controlling browning. The action is one of enzyme poisoning and antioxidant power. The effectiveness of this treatment is dependent upon low moisture contents. Carbohydrate deterioration is most important in fruit and vegetable tissues being dried. Slow sun drying permits extensive deterioration unless the tissues are protected with sulphates, or suitable agents. Burning sulphur is the least expensive method of obtaining such protection, and is done prior to drying.

2. Microbiological quality

In as much as micro organisms are widely distributed throughout nature, and foodstuffs at one time or another are in contact with soil and dust, it is anticipated that micro organisms will be active whenever conditions permit. One obvious method of control is in the restriction of moisture for growth. Living tissues require moisture. The amount of moisture in food establishes which micro organisms will have an opportunity to grow. Reducing the water activity of a product below 0.85 inhibits growth but does not result n a sterile product. The heat of the drying process does reduce their numbers, but the survival of food-spoilage

organisms may give rise to problems in the reconstituted food. Recommendations for the control of micro organisms during processing are often very basic. The highest possible drying temperatures should be used to maximise thermal death even though low drying temperatures are best for maintaining organoleptic characteristics. If a process is optimised for other quality factors, there are constraints on the maximum allowable water content.

Sodium chloride is commonly employed in conjunction with drying. Salt is useful in controlling microbial growth during sun drying and dehydration processes, i.e., meat and fish drying.

The most positive control would be to start with high quality foods having low contamination, pasteurise the material prior to drying, process in clean factories, and store under conditions where the dried foods are protected from infection by dust, insects, rodents and other animals.

3. STORAGE STABILITY

When discussing storage stability, one is concerned with the organoleptic, physical, and chemical changes that take place in the dried fruit and vegetables during storage and the rates at which these changes occur. Darkening and loss of flavour are the major types of deteriorations of dried fruits and vegetables in storage.

Sulphur dioxide content, storage temperature, light, packaging material, moisture content, antimicrobial treatment and trace elements are major factors affecting storage stability. Only free sulphite is effective in retarding the formation of pigment materials. During storage, the loss of sulphur dioxide determines the practical shelf life of the dried product with respect to spoilage through non-enzymatic browning. Storage of products at semitropical or summer temperatures requires residual sulphites to prevent darkening and flavour bittering, and to make the dried fruit less favourable medium for growth of micro organisms. Sulphur dioxide helps to maintain a light, natural colour during storage. Darkening rates during storage is inversely proportional to sulphur dioxide content. Therefore, any condition accelerating sulphur dioxide loss, in turn, accelerates the darkening of the product. One way to retard sulphite loss, thereby darkening, is the addition of oxygen scavenger pouch to the sealed packed sulphured dried fruit.

Storage temperature is of vital importance in relation to maintenance of quality. Storage of dried fruits and vegetables should be at relatively low temperatures to maximize storage life. There is an important effect of temperature on loss of sulphur dioxide from the dried product during storage. A 20?F increase in temperature increases the rate of sulphur dioxide loss approximately 3 times. Moreover at higher temperatures, the rate of change in flavour also increases.

Light, during storage, is detrimental for quality. It causes a reduction in carotene content, increases the rate and amount of sulphur dioxide loss, and thereby increases the rate of darkening. In addition, it also affects riboflavin content.

Packaging material used and the package environment is another major factor in terms of storage stability. The type of package used varies with expected storage conditions. Packaging may be done under vacuum, nitrogen or atmospherically.

Dried foods have moisture content below 20 % and a water activity 0.7 or below. They are hard and firm, resistant to microbial deterioration. There are critical water activities for some products below which browning is minimized. Storage stability increases with decreasing moisture content. But, it was also reported that the maximum rate of deterioration of dried fruits occurs at a moisture content of 5-8 % moisture.

Dried fruits and vegetables must be protected from rodents and insects during storage. Fumigation is often used to prevent insect infestation during storage and before packaging. In addition to fumigation, antimycotic agents (fungistats) are used to stabilize most prunes and figs against mould growth at 30-35 % moisture. Sorbic acid and sorbate salts are used as dips or sprays to prevent melding; sulphur dioxide or sulphite salts are used to preserve fruits during drying from colour changes and browning, and to ward off insects. Potassium sorbate dip is the most effective one. The effectiveness depends on pH of the product.

Some salts and metals are detrimental to nutritive value, flavour and storage quality. Raw materials may be exposed to these trace elements during washing or pre-treatment. Calcium has a firming effect on texture; iron and copper combine with tannins to cause blackening and may accelerate degradation of ascorbic acid. Sodium, magnesium and calcium sulphates impart bitter flavour. Certain salts of zinc, cadmium and chromium have toxic effects.

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