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An overview of the principles and effects of intermediate moisture fruits and vegetables

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Abstract
Intermediate moisture foods are semi-moist foods that have some of their water bound by the addition of glycerol, sorbitol, salt or organic acids, thus preventing the growth of many microorganisms. It is now well recognized that fruits and vegetables are dehydrated to an intermediate moisture level (20-50%), that have enough moisture content to permit easy chewing with low water content to prevent spoilage. Production of IMF is based on an increased scientific understanding of chemical reactions involved in traditional food preservation methods. A number of humectants are available to reduce water activity to acceptable level without imparting any adverse effect on product quality. They are preserved by restricting the amount of water available for microbial growth, while retaining sufficient water to give the food a soft texture and can be eaten without further preparation. Water is removed or its activity restricted with a water-binding substance such as sugar or salt. IM foods usually range from 20-50 per cent moisture, but the water present is chemically bound with sugar or salt and is not available to support microbial growth. Dried peaches, pears and apricots are examples of such food. IMF from fruits and vegetables are gaining immense importance in these days as these are shelf-stable foods, which do not require refrigeration and freezing to prevent microbial deterioration, or any thermal treatment for further storage after processing. IMF does not even require any processing before consumption and also maintains flavour, taste and texture very close to that of fresh fruits and vegetables.

Keywords: Intermediate moisture food, fruits, vegetables, water activity, hurdle technology

Introduction
India is one of the leading producers of fruits and vegetables. In spite of the increase in production, about 30-40 per cent of the produce is lost due to improper post-harvest management practices like storage, packaging and processing. There is sustained demand from consumers for novel, value added products with enhanced quality, altered palatability and improved nutrition. Consumers are becoming more health conscious and nutritionally aware, owing to improved standard of living due to higher level of income. Intermediate moisture fruits and vegetables, minimally processed fruits and vegetables, osmotically dehydrated products, frozen fruits and vegetables, fruit juice powders and concentrates etc. are of great demand. These high qualities, value added products in suitable, convenient packages offer to impart quality and thus having ample scope in the processed food sector in the reducing of post-harvest losses. In order to minimize the loss of quality, and to control microbial growth and thus ensure product safety and convenience, a hurdle approach appears to be the best method. According to Alzamura *et al.* [1], hurdle technology can be applied several ways in the design of preservation systems for intermediate moisture foods.
Hurdle technology act as a synergist. According to Leistner [2], in food preserved by hurdle technology, the possibility exists that different hurdles in a food will not just have an additive

effect on stability, but could act synergistically. A synergist effect could work if the hurdle in a food hits different targets (*e.g.*, cell membrane, DNA, enzyme systems, pH, a_w, Eh) within the microbial cell, and thus disturbs the homeostasis of the microorganisms present in several aspects. Therefore, employing different hurdles in the preservation of a particular food should be an advantage because microbial stability could be achieved with a combination of gentle hurdles. In practical terms this could mean that it is more effective to use different preservatives in small amounts in a food than only one preservative in large amounts, because different preservatives might hit different targets within the bacterial cell, and thus act synergistically [3].

Intermediate moisture fruits and vegetables

Intermediate moisture fruits are semi-moist fruits that have some of their water bound by the addition of glycerol, sorbitol, salt or organic acids, thus preventing the growth of many microorganisms [4]. It is now well recognized that fruits and vegetables are dehydrated to an intermediate moisture level (20-50%). As the intermediate moisture product are characterized by a semi moist consistency so these foods have enough moisture content to permit easy chewing but low enough water content to prevent spoilage. Production of intermediate moisture foods is based on an increased scientific understanding of chemical reactions involved in traditional food preservation methods [5]. Development of different intermediate moisture fruits and vegetables by different scientist have been given below in the fig 1, 2 and 3 for different products.

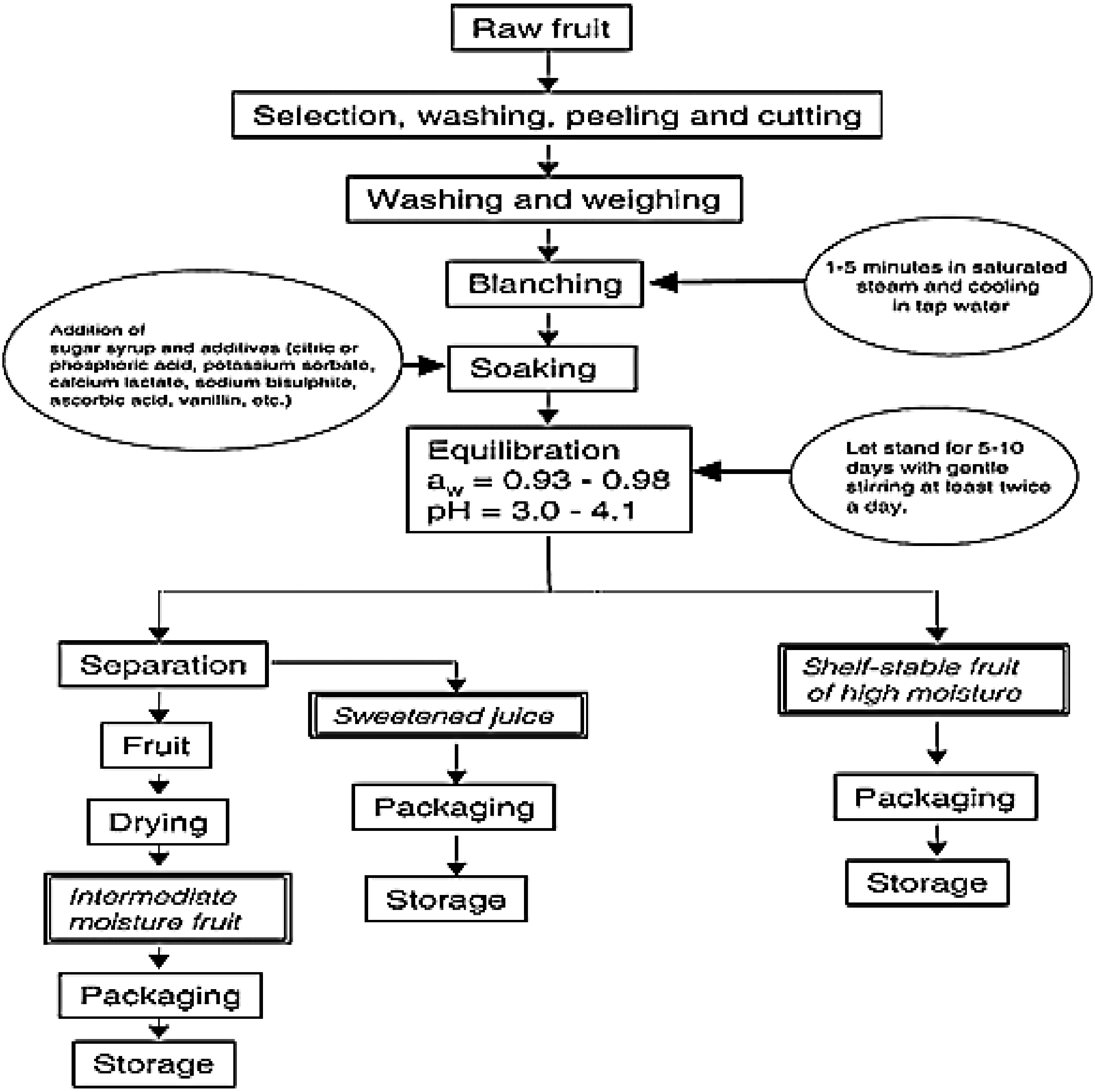

Fig 1: Development of IM foods from fruits and vegetables [6]

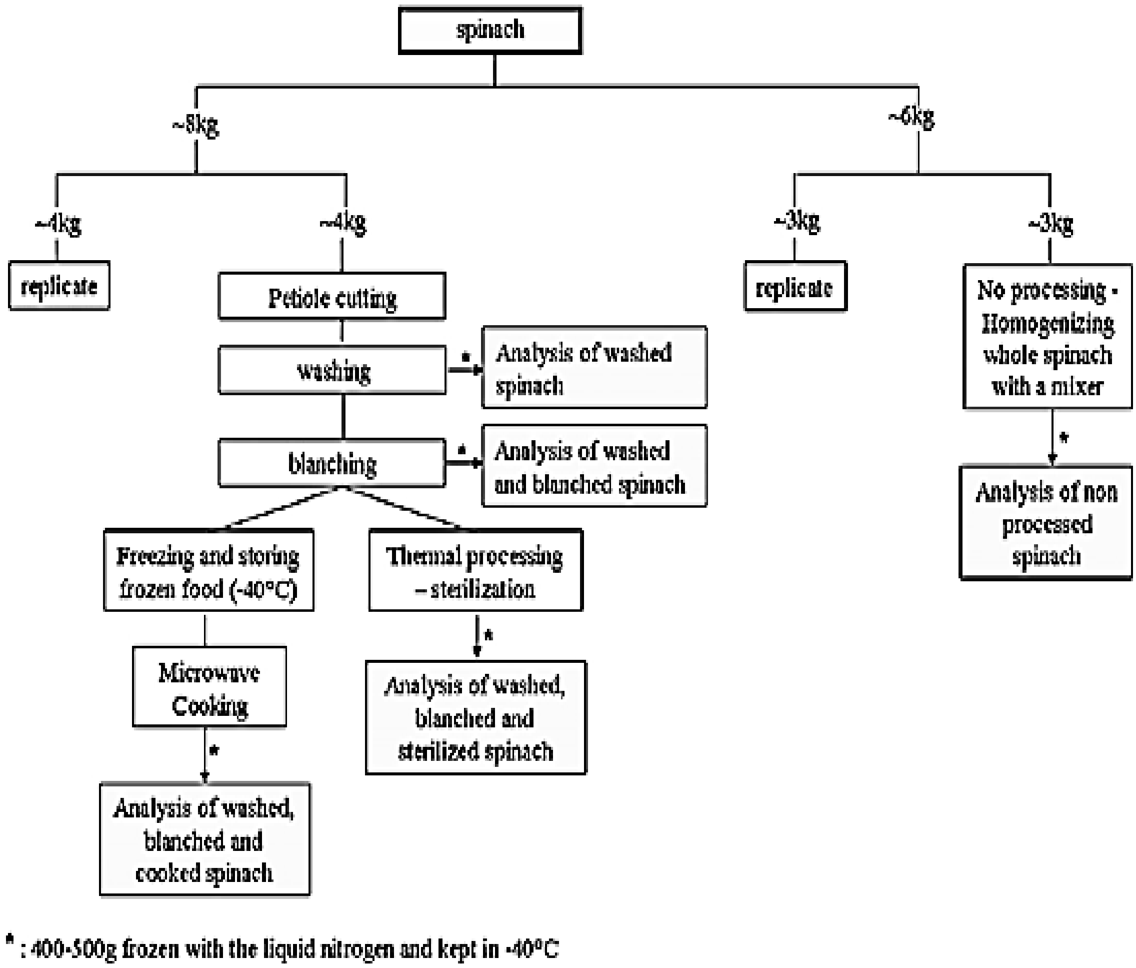

Fig 2: Preparation of shelf-stable IM Spinach and other leafy-vegetables [7]

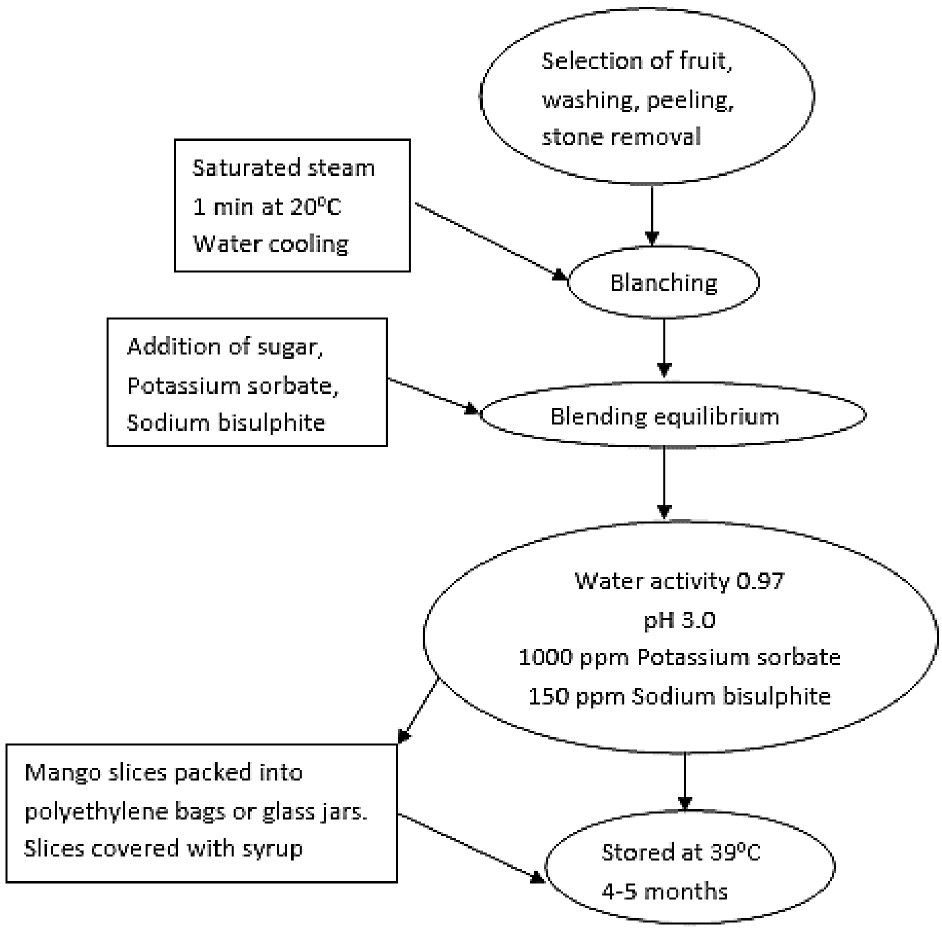

Fig 3: Preparation of stabilized Intermediate moisture mango slices [7]

Water Activity (a_w) concept and its role in food preservation

a_w concept

The concept of a_w has been very useful in food preservation and on that basis many processes could be successfully adapted and new products designed. Water has been called the universal solvent as it is a requirement for growth, metabolism, and support of many chemical reactions occurring in food products. Free water in fruit or vegetables is the water available for chemical reactions, to support microbial growth, and to act as a transporting medium for compounds. In the bound state water is not available to participate in these reactions as it is bound by water soluble compounds such as sugar, salt, gums, etc. (osmotic binding), and by the surface effect of the substrate (matrix binding). These water-binding effects reduce the vapour pressure of the food substrate according to Raoult's Law. Comparing this vapour pressure with that of pure water (at the same temperature) results in a ratio called water activity (a_w).

Microorganisms vs. a_w value

The definition of moisture conditions in which pathogenic or spoilage microorganisms cannot grow is of paramount importance to food preservation. It is well known that each microorganism has a critical a_w below which growth cannot occur. For instance, pathogenic microorganisms cannot grow at a_w <0.86; yeasts and moulds are more tolerant and usually no growth occurs at a_w <0.62. The so-called intermediate moisture foods (IMF) have a_w values in the range of 0.65-0.90.

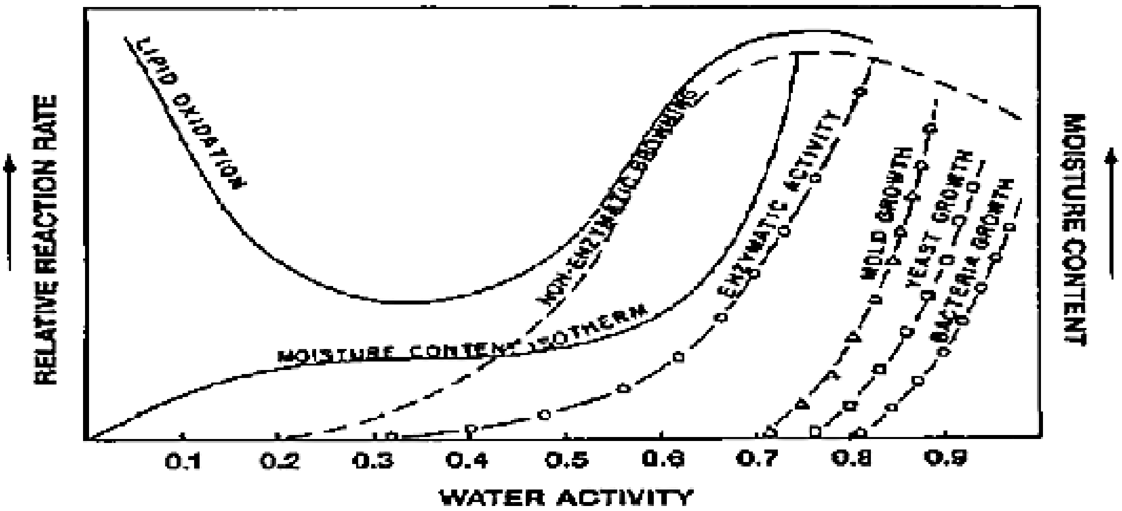

Fig 4: Relationship of food deterioration rate as a function of water activity

Enzymatic and chemical changes related to a_w values

The relationship between enzymatic and chemical changes in foods as a function of water activity showed in fig 4. With a_w at 0.3, the product is most stable with respect to lipid oxidation, non-enzymatic browning, enzyme activity, and of course, the various microbial parameters. As a_w increases toward the right, the probability of the food product deteriorating increases. According to Rahman and Labuza [8], enzyme-catalyzed reactions can occur in foods with relatively low water contents.

The authors summarized two features of these results as follows:

1. The rate of hydrolysis increases with increased water activity but is extremely slow with very low activity.
2. For each instance of water activity there appears to be a maximum amount of hydrolysis, which also increases with water content.

Recommended equipment for measuring a_w

Many methods and instruments are available for laboratory measurement of water activity in foods. Methods are based on the colligative properties of solutions. Water activity can be estimated by measuring the following:

- Vapour pressure
- Dew point and wet bulb depression
- Thermocouple Psychrometer
- Isopiestic method
- Electric hygrometers
- Hair hygrometers

Intermediate moisture Foods (IMF) concept

Traditional intermediate moisture foods (IMF) can be regarded as one of the oldest foods preserved by man. The mixing of ingredients to achieve a given aw, that allowed safe storage while maintaining enough water for palatability, was only done, however, on an empirical basis. The work done by food scientists approximately three decades ago, in the search for convenient stable products through removal of water, resulted in the so-called modern intermediate moisture foods. These foods rely heavily on the addition of humectants and preservatives to prevent or reduce the growth of microorganisms. Definitions of IMF in terms of a_w values and moisture content vary within wide limits (0.6-0.90 a_w, 10-50% moisture), and the addition of preservatives provides the margin of safety against spoilage organisms tolerant to low a_w. Of the food poisoning bacteria, *Staphylococcus aureus* is one of the organisms of high concern since it has been reported to tolerate a_w as low as 0.83-0.86 under aerobic conditions.

Fruits preserved under IMF concept

The application of IMF technology has been very successful in preserving fruits and vegetables without refrigeration in most Latin American countries. For instance, the addition of high amounts of sugar to fruits during processing will create a protective layer against microbial contamination after the heat process. IMF foods are those with a_w in the range of 0.65 to 0.90 and moisture content between 15% and 40%. Food products formulated under this concept are stable at room temperature without thermal processing and can be generally eaten without rehydration. Some processed fruits and vegetables are considered IMF foods. These include cabbage, carrots, horseradish, potatoes, strawberries, etc.; their water activities at 30°C follow.

Table: Fruits preserved under IMF concept

Foods	a_w
Cabbage	0.64
Carrots	0.75
Horseradish	0.64
Potatoes	0.75
Strawberries	0.75

Under these conditions, bacterial growth is inhibited but some moulds and yeast may grow at a_w greater than 0.70 [9].

Advantages and disadvantages of IMF preservation

Advantages

Intermediate moisture foods have an a_w range of 0.65-0.90, and thus water activity is their primary hurdle to achieving microbial stability and safety. IMF foods are easy to prepare and store without refrigeration. They are energy efficient and relatively cheap. They are not readily subject to spoilage, even if packages have been damaged prior to opening, as with thermostabilized foods, because of low a_w. This is a plus for many developing countries, especially those in tropical climates with inadequate infrastructure for processing and storage, and offers marketing advantages for consumers all over the world.

Disadvantages

Some IMF foods contain high levels of additives (*i.e.,* nitrites sulphites, humectants, etc.) that may cause health concerns and possible legal problems. High sugar content is also a concern because of the high calorific intake. Therefore, efforts are been made to improve the quality of such foods by decreasing sugar and salt addition, as well as by increasing the moisture content and a_w, but without sacrificing the microbial stability and safety of products if stored without refrigeration. This may be achieved by an intelligent application of hurdles [2].

Fruit products from intermediate moisture foods (IMF) appear to have potential markets. However, application of this technology to produce stable products at ambient temperature is limited by the high concentration of solutes required to reduce water activities to safe levels. This usually affects the sensory properties of the food.

Combined methods for preservation of fruits and vegetables: a preservation concept

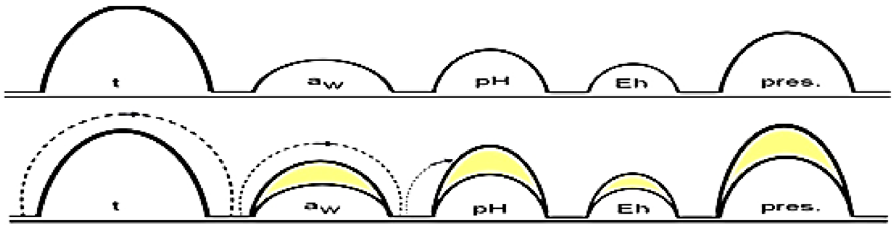

Fig 5: Hurdle technology

Why combined methods?

Food preserved by combined methods (hurdles) remains stable and safe even without refrigeration, and is high in sensory and nutritive value due to the gentle process applied. Hurdle technology is the term often applied when foods are preserved by a combination of processes. The hurdle includes temperature, water activity, redox potential, modified atmosphere, preservatives, etc. The concept is that for a given food the bacteria should not be able to “jump over” all of the hurdles present, and so should be inhibited showed in fig 5. If several hurdles are used simultaneously, a gentle preservation could be applied, which nevertheless secures stable and safe foods of high sensory and nutritional properties. This is because different hurdles in a food often have a synergistic (enhancing) or additive effect. For instance, modified foods may be designed to require no refrigeration and thus save energy. On the other hand, preservatives (e.g., nitrite in meats) could be partially replaced by certain hurdles (such as water activity) in a food. In general, hurdle technology is now widely used for food design in making new products according to the needs of processors and consumers. For instance, if energy preservation is the goal, then energy consumption hurdles such as refrigeration can be replaced by hurdles (a_w, pH, or E_h) that do not require energy and still ensure a stable and safe product.

The hurdle effect is an illustration of the fact that in most foods several factors (hurdles) contribute to stability and safety [10]. It is the combination treatments for food stability, safety and quality. This hurdle effect is of fundamental importance for the preservation of food, since the hurdles in a stable product control microbial spoilage and food poisoning as well as undesirable fermentation.

General description of combined methods for fruits and vegetables

Increasing consumer demand for fresh quality products is turning processors to the so-called minimally processed products (MP), an attempt to combine freshness with convenience to the point that even the traditional whole, fresh fruit or vegetable is being packaged and marketed in ways formerly reserved for processed products [11]. According to these authors, the widely accepted concept of MP refrigerated fruits involves the idea of living respiring tissues. Because MP refrigerated products can be raw, the cells of the vegetative tissue may be alive and respiring (as in fruits and vegetables), and biochemical reactions can take place that lead to rapid senescence and/or quality changes. In these products, the primary spoilage mechanisms are microbial growth and physiological and biochemical changes, and in most cases, minimally processed foods are more perishable than the unprocessed raw materials from which they are made.

Minimal processing may encompass pre-cut refrigerated fruits, peeled refrigerated whole fruits, sous vide dishes, which may include pre-heated vegetables and fruits, cloudy and clarified refrigerated juices, freshly squeezed juices, etc. All of these products have special packaging requirements coupled with refrigeration [11].

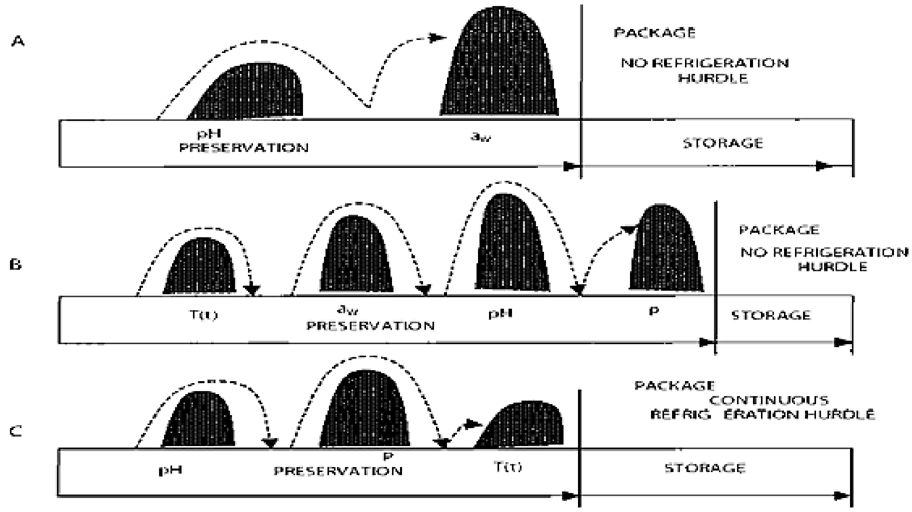

Fig 6: Schematic representation of hurdles: water activity (a_W), pH, preservatives (P), and slight heat treatment, T(t), involved in three fruit preservation systems. (A) an intermediate moisture fruit product; (B) a high-moisture fruit product; (C) a minimally processed refrigerated fruit product. (Adapted from Tapia *et al.* [11])

An example of the hurdle technology concept is presented in Figure 6, in which a comparison of HMFP, IMF and MPR fruits in terms of hurdle(s) involved is made. Example A represents an intermediate moisture fruit product containing two hurdles (pH, and a_w). The microorganisms cannot overcome (jump over) these hurdles, thus the food is microbiological stable. In this case, a_w is the most relevant hurdle exerting the strongest pressure against microbial proliferation of IMF. In the preservation system of HMFP (example B), it is obvious that a_w does not represent the hurdle of highest relevance against microbial proliferation; pH is the hurdle exerting the strongest selective pressure on microflora. As in example A, HMFP does not require refrigerated storage. In example C, the mild heat treatment T(t) is applied and the chemical preservative, P, added affects the growth and survival of the flora.

Recommended humectants to reduce a_w in fruits

The recommended humectants are given below in the table 1

Table 1: Water activity reduction capacities of sugars and salts

Anhydrous						Amorphous		
Sugars	a_W = 0.60	0.70	0.80	0.90	0.60	0.70	0.80	0.90
Sucrose	3.0	5.0	10.0	-	14.0	20.0	35.0	65.0
Glucose	1.0	3.5	7.5	12.5	1.0	3.5	8.0	22.0
Fructose	14.0	22.0	34.0	47.0	18.0	30.0	44.0	80.0
Lactose	0.01	0.01	0.05	0.10	4.5	4.7	4.7	-
Sorbitol (adsorption)	17.0	22.0	37.0	76.0	2 5.0	3 5.0	5 5.0	110.0
Corn syrup	-	-	-	-	1 4.0	2 0.0	3 0.0	54.0
Salts								
NaCl (adsorption)	0.1	0.1	130.0	5 85.0	-	-	-	-
NaCl (desorption)	-	-	385.0	5 90.0	-	-	-	-
KCl (adsorption)	0.1	0.1	0.1	0.1	-	-	-	-

Recommended substances to reduce pH

These are some of the substances used to reduce pH eg. Citric acid, malic acid, tartaric acid, benzoic acid and propionic acid [8].

Table 2: Classification of IMF and their humectants used for preservation

Foods	Water activity (a_w)	Principal humectants
Figs	0.65-0.83	S, OH (Naturally occurring)
Apricots, peaches	0.73-0.81	S, OH (Naturally occurring)
Candied papaya	0.7	S, OH
Candied pineapple	0.8	S, OH
Prunes	0.77	S, OH (Naturally occurring)
Dehydrated banana	0.62	S, OH (Naturally occurring)

S-sucrose, OH-other humectant (glucose, fructose)

Recommended additives to inhibit microorganisms

Some of the additives are used to inhibit microorganism like Potassium sorbate, sodium benzoate, vanillin (4-hydroxi-3-methoxybenzaldehyde), allicin, cinnamon, eugenol etc.

Water content vs. a_w relationship

Figure 7 represent typical curves that can be applied to most food systems for equilibrium water content (g water/g solid) versus water activity (% ERH). The graphs indicate the range in which foods can be adjusted. In general, dehydrated foods have less than 0.60 a_w; meanwhile, intermediate moisture foods (IMF) have water activity ranging between 0.62 and 0.92. A decrease in water activity or water content can be accomplished by drying, and by the addition of humectants, which reduces water activity through the effects of Raoult's law, or by the addition of dried ingredients such as starch, gums, or fibres, which interact with water through several mechanisms.

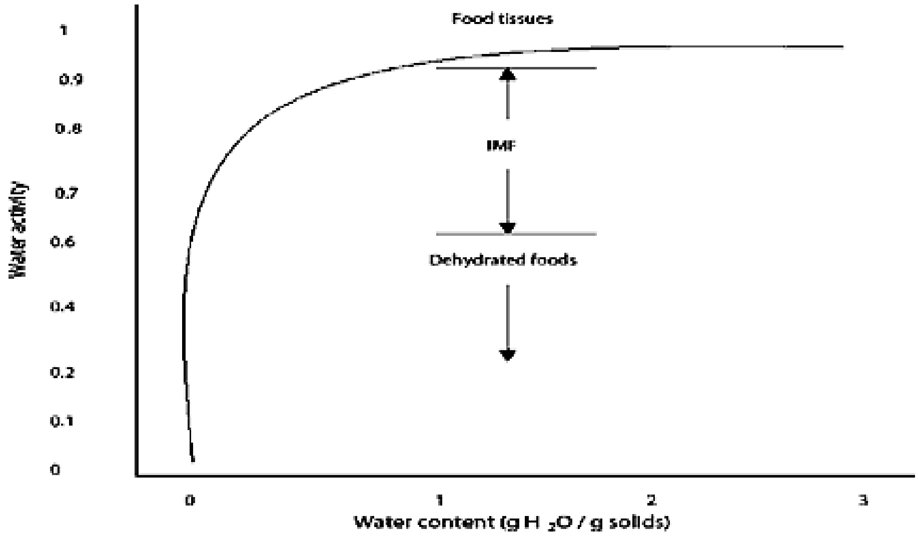

Fig 7: Classification of food level on a_w

Predicting safety and stability

Water activity predicts safety and stability with respect to microbial growth, chemical and biochemical reaction rates, and physical properties. Figure 8 shows stability in terms of microbial growth limits and rates of degradative reactions as a function of water activity. Therefore, by measuring and controlling the water activity, it is possible to:

a) predict which microorganisms will be potential sources of spoilage and infection.
b) maintain the chemical stability of products.
c) minimize non enzymatic browning reactions and spontaneous autocatalytic lipid oxidization reactions.
d) prolong the activity of enzymes and vitamins.
e) optimize the physical properties of products such as moisture migration, texture, and shelf life.

Table 4: Water activity-foods and their associated microbial spoilage

a_w ranges	Microorganisms	Types of foods
1-0.95	Some yeast, gram negative bacteria	Fresh fruits, canned fruits and sausages
0.95-0.91	Most coccid, lactobacilli	Fruits (50% sucrose or 12% salt)
0.86-0.80	Most moulds	Fruit cakes
0.80-0.75	Most halophilic bacteria	Prunes, salted fish
0.65-0.60	Osmophilic yeasts	Dried fruits, honey

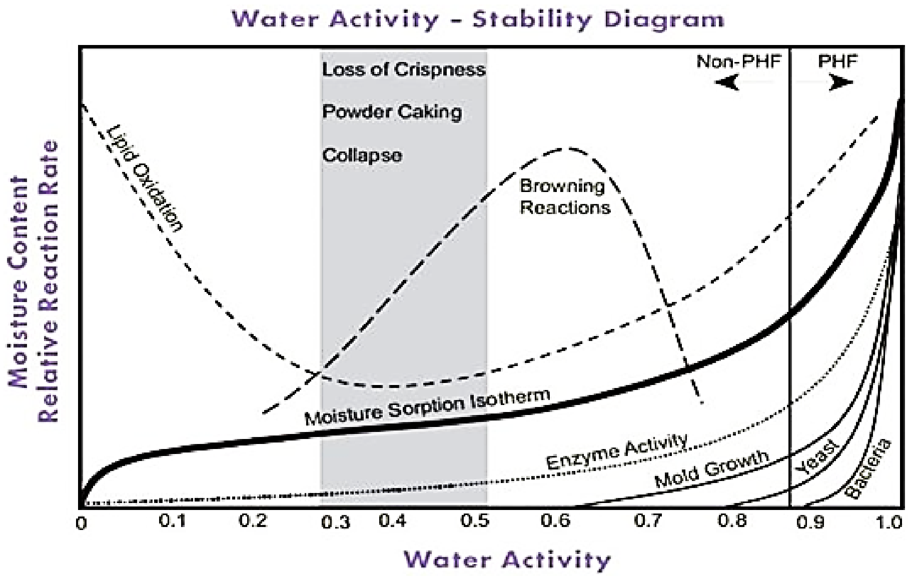

Fig 8: Relationship between a_w and extent of food deterioration

Microbial growth

Microorganisms have a limiting water activity level below which they will not grow. Water activity, not moisture content, determines the lower limit of "available" water for microbial growth. Water may be present, even at high content levels, in a product, but if its energy level is sufficiently low the microorganisms cannot remove the water to support their growth. This 'desert-like' condition creates an osmotic imbalance between the microorganisms and the local environment. Consequently, the microbes cannot grow and its numbers will decline until it eventually dies.

Limiting microorganism growth

While temperature, pH, and several other factors can influence whether an organism will grow in a product and the rate at which it will grow, water activity is often the most important factor. Water activity may be combined with other preservative factors (hurdles), such as temperature, pH, redox potential, etc., to establish conditions that inhibit microorganisms. The water activity level that limits the growth of the vast majority of pathogenic bacteria is 0.90a_w, 0.70a_w for spoilage moulds, and the lower limit for all microorganisms is 0.60a_w.

Chemical/biochemical reactivity

Water activity influences not only microbial spoilage but also chemical and enzymatic reactivity. Water may influence chemical reactivity in different ways; it may act as a solvent, reactant, or change the mobility of the reactants by affecting the viscosity of the system. Water activity influences nonenzymatic browning, lipid oxidization, degradation of vitamins and other nutrients, enzymatic reactions, protein denaturation, starch gelatinization, and starch retrogradation

Physical properties

Besides predicting the rates of various chemical and enzymatic reactions, water activity affects the textural properties of foods. Foods with high a_w have a texture that is described as moist, juicy, tender, and chewy. When the water activity of these products is lowered, undesirable textural attributes, such as hardness, dryness, staleness, and toughness, are observed. Low a_w products normally have texture attributes described as crisp and crunchy, while these products at higher a_w levels change to soggy texture.

Caking, clumping, collapse and stickiness

Water activity is an important factor affecting the stability of powders and dehydrated products during storage. Controlling water activity in a powder product maintains proper product structure, texture, stability, density, and rehydration properties. Knowledge of the water activity of powders as a function of moisture content and temperature is essential during processing, handling, packaging and storage to prevent the deleterious phenomenon of caking, clumping, collapse and stickiness.

Moisture migration

Because water activity is a measure of the energy status of the water, differences in water activity between components is the driving force for moisture migration as the system comes to equilibrium. Some foods contain components at different water activity levels, such as filled snacks or cereals with dried fruits. By definition, water activity dictates that moisture will migrate from a region of high a_w to a region of lower a_w, but the rate of migration depends on many factors. Undesirable textural changes can result from moisture migration in multi component foods.

Conclusion

The countries share in the global trade stands at nearly 1.3%. Therefore, it is necessary to focus on the marketing of intermediate moisture foods. Intermediate moisture (IMF) developed from fruits and vegetables are gaining immense importance in these days as these are shelf-stable foods, which do not require refrigeration and freezing to prevent microbial deterioration because of their lower water activities. IMF does not even require any processing before consumption. In intermediate moisture products developed from fruits and vegetables, the flavor, taste and texture remain intact and they will be very close to as that of fresh fruits and vegetables.

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