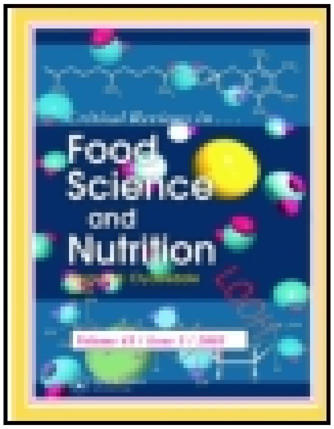

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Foam-mat Drying Technology: A Review

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Foam-mat drying technology: A review

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Abstract

This article reviews various aspects of foam-mat drying such as foam-mat drying processing technique, main additives used for foam-mat drying, foam-mat drying of liquid and solid foods, quality characteristics of foam-mat dried foods and economic and technical benefits for employing foam-mat drying. Foam-mat drying process is an alternative method which allows the removal of water from liquid materials and pureed materials. In this drying process, a liquid material is converted into foam that is stable by being whipped after adding an edible foaming agent. The stable foam is then spread out in sheet or mat and dried by using hot air (40 -90^{0}C) at atmospheric pressure. Methyl cellulose (0.25 - 2%), egg white (3 - 20%), maltodextrin (0.5 - 05%) and gum Arabic (2 - 9%) are the commonly utilised additives for the foam-mat drying process at the given range, either combined together for their effectiveness or individual effect. The foam-mat drying process is suitable for heat sensitive, viscous and sticky products which cannot be dried using other forms of drying methods such as spray drying because of the state of

product. More interest has developed for foam-mat drying because of the simplicity, cost effectiveness, high speed drying and improved product quality it provides.

Keywords

Foam-mat drying, spray drying, freeze drying, microwave drying, dehydration, preservation

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Introduction

Dehydration is the oldest and most frequently used method of food preservation. The removal of water has been used for centuries to preserve foods. In the food industry it is currently a versatile and extensive technique and is a subject of continuous interest in food research (Arayaï Farras & Ratti, 2008). Primary objective of food dehydration is to reduce microbial activity and product deterioration for extended shelf life. In addition to preservation, the reduced weight and bulk of dried products decreases packaging, handling, and transportation costs (Okos *et al*., 2006; Karel & Lund, 2003). Liquid-solid foods are dried for improved milling or mixing characteristics in further processing. Beforehand, drying processes were traditionally associated for specific food material whereby fruits were sun dried, smoking of fish and meat. Drum drying was applied to whey and buttermilk, soup mixtures, and tomato powder while spray drying was used particularly in milk products and eggs (Arayaï Farras & Ratti, 2008). However at present a variety of food materials can be dried using most if not all the drying processes. In this review foam-mat drying will be discussed in comparison to other forms of food dehydration such freeze drying, spray drying, microwave drying, vacuum drying, sun drying, solar drying. These varieties of food dehydration methods will be reviewed with regards to their food quality benefits, economic benefits and types of food commodities to which meets the quality specifications suitable for consumers. The following diagram is a depiction of drying methods for a variety of food materials.

Foam-mat drying is a simple process of drying liquid - solid foods by being mixed with stabilising agent and or foaming agent to produce stable foam, which undergoes air drying temperatures ranging from 50-80^{o}C (Kandasamy *et al*., 2012; Febrianto *et al*., 2012). The foam-mat drying process can be used to dry juice, milk, fruits, beverages, jams (Widyastuti & Srianta, 2011). The foam dried product is then further ground to produce a powdered product. Foam-mat drying is the simplest forms of drying compared to other methods such as freeze drying, spray drying, as it is less expensive, less complicated and is less time consuming (Febrianto *et al*., 2012). This review article mainly focuses on the different aspects of foam-mat drying. Figure 1 depicts a variety of drying technologies.

Foams

Theory of foam formation

Foam is a system with two phases (dispersed and continuous phase) separated by a thin film liquid layer known as the lamellar phase (thin wall of bubble). In the case of food and beverages, foam is a complex system formed by gas, liquids, solids and surfactants (Eisner *et al*., 2007). Foams have gas bubbles surrounded by plateau border. Given that foam development is an significant step, understanding the factors contributing to its appearance or disappearance is crucial Such factors includes the number, size and distribution of bubbles, will determine the foam texture, uniformly distributed tiny bubbles further results in softer foams. Foams accumulates and builds up at the air ï liquid interface but is naturally unstable because the surface tension go against the forces needed for its maintenance, thereby leading to collapse of the foam.

Proteins and surfactants are other factors that influences foam texture and are involved in retaining or improving stability of foams. Surfactants migrate rapidly against a gradient towards thinner regions of the bubble walls (lamella), while proteins will bind to interface and further interact with the lamella by means of electrostatic or hydrophobic forces, hydrogen bonds or

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covalent linkages. These interaction leads to the formation of viscoelastic films that is resistant to tension and able to withstand the filmôs thickness. Proteins interact with one another, to a point that no free molecules will be present, thereby producing foam (Blasco *et al*., 2011). Formation of foam depends on many parameters such as properties of the liquid being foamed, method of foaming and foaming condition. Figure 2 depicts the general structure of foam system. Indrawati *et al*, 2008 further explains that foams are thermodynamically unstable; therefore a surface active agent such as protein can be used to provide kinetic stability during foaming formation. Protein reduces surface tension which enables foam formation and stabilizes the foaming system by modifying the inter-particle forces between foam bubbles and improving the interfacial rheology.

Foam stability

Foams are thermodynamically unstable because of their high interfacial energy. The instability can be classified into two types; (1) unstable or transient foams with lifetimes of seconds and (2) metastable or so called permanent foams with lifetimes measured in hours to days. Collapsing of the foam is because of the bubble coalescence, which is defined as merging or combining of two bubbles in a fluid to form a larger bubble. It occurs in a three step process: bubble approach and creation of thin film, film drainage and film rupture. It is difficult to form a stable film in pure water as its surface tension is large and coalescence takes only a few seconds, whereas with addition of surfactants, will stabilise against coalescence leading to foam that will last longer (Henry, 2010).

Gravity is another obvious force that acts on the formation of foam, causing drainage of the liquid between the air bubbles. Drainage can be reduced by either adding particles or increasing the viscosity of the bulk liquid. Systems like these will then give very stable foam.

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The influence of solid particles on the formation and stability of foam is dependent on the surfactant type, the particle size and the concentration. Hydrophilic particles present in an aqueous phase of foam films can enhance foam stability by slowing the film drainage process. Whereas hydrophobic particles that penetrate the air-water surface of foam can cause destabilisation (Schilling & Zessner, 2011). Indrawati *et al*, 2008 investigated the effect of processing parameters (mixing speed, type of protein, temperature, and flow rate of the protein solution, and mixing geometry) on the stability of foam. The authors reported that volume fraction of foam increases as mixing speed is increased because of the more air that is incorporated and the liquid fraction also increases due to more entrainment of liquid in the foam resulting from small bubbles. Lower liquid flow rate of the protein also increases the foam stability.

Various foam generating methods

Foaminess of aqueous liquids is characterised by the volume of foam that can be formed either by bubbling air through liquid or by using any mixing method (Eisner *et al*., 2006). One of the foam generation classifications is the static method. The most common static methods of generating foam are known as whipping, shaking and bubbling.

Whipping

Whipping or beating can be carried out with different devices such manual and automatic blenders, vortex mixers, and homogenizers that agitate the liquid in order to form an interface with a gas phase. Blenders and homogenizers are used to blend all kinds of food material from liquid to solid including baking ingredients and mixes, drink mixes, powdered spices, snack foods, vitamins, coffee, and tea. They are effective in providing some diffusive mixing and in breaking up agglomerates, while vortex mixers can only be used for liquid suspension (Prescott & Clement, 2005). In this method, gas is introduced into the liquid. The volume of air incorporated into the foam usually increases with an increase of beating intensity (Arzhavitina & Steckel, 2010). Air is trapped inside the liquid because of the action of the agitator. When trapped inside the liquid, the size of the air bubble will be large and is subsequently broken into small bubbles because of the mechanical agitation. Every air bubble undergoes severe mechanical stress throughout whipping; therefore, a more fast coalescence happens during foam generation than in standing foam. The final size of bubbles depends on speed of the agitator, the geometry of the apparatus and rheological properties of the liquid (Arzhavitina & Steckel, 2010).

Shaking

In the method, agitating liquid vigorously results in the formation of foam and it is rarely used. The rate at which the bubbles are formed depends on the frequency and amplitude of shaking, volume and shape of the container, the volume and viscosity of the liquid. Only low foam volumes at longer generation time can be produced by this method (Arzhavitina & Steckel, 2010). .

Bubbling

This bubbling method of generating foam involves the injection of gas through narrow openings into a known quantity of liquid. This method is reproducible and produces uniform bubble sizes. The size of bubble formed highly depends on the viscosity of the liquid. This method has a greater control over the size of bubble achieved by adjusting diameter of the opening. Foam volume produced here depends on the total amount of foaming agent in the solution or liquid being bubbled (Arzhavitina & Steckel, 2010). .

Foam-mat drying processing technique

Foam mat drying is a process where liquid foods are whipped into stable foams and then air dried. During the heated air drying it is required that the foams remain stable and retain typical open structure to simplify rapid drying and detraying. Should foams collapse during drying, this unwanted feature increases drying rate, reduces the quality of the product and prevents detraying (Sankat & Castaigne, 2004).

Degree of drying in the foam-mat drying process is reasonably very high because of the massive increase in the liquid-gas interface, even though the heat transfer is hindered by a large volume of gas present in the foamed mass. Drying occurs in more than one constant rate periods because of the periodic bursting of successive layers of foam bubbles, thus exposing new surfaces for heat and mass transfer as the drying progresses (Kandsamy *et al*., 2012).

However it is recognised that pure liquids do not foam and the foaming solutions depict an obvious relationship with the surface activity of the solute. Foaming is not distinct in mixtures of liquids with the same chemical type, it is also not pronounced in aqueous solutions of highly hydrophilix solutes, glycerol or sucrose. Transient foams are caused by solutes that lower the surface tension moderately for example the short chain aliphatic alcohols and acids and persistent foams arise only with solutes which lower the surface tension in dilute solutions , for example proteins. For foaming to take place a ñforeign compoundò must be added to produce a stable gas-liquid dispersion. This type of compound is normally an existing or added active agent that reduces the surface tension of liquid and therefore encourages a surface layer of a composition that differs from the rest of the liquid. This layer performance as a buffer that hinders the natural coalescence of gas bubbles dispersed in a liquid (Tayeb, 1993).

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Drying foamed material enables a high speed of drying because of the open structure of foam. Foam-mat dried materials have desirable properties such as favourable rehydration and the retention of volatiles (Jakubczyk *et al*., (2011)).

Krasaekoopt & Bhatia, 2012 further reported that the collaboration of air bubbles into foam is important and affects the drying speed. Drying rate of the foam-mat drying process is relatively high because of the huge surface exposed to the drying air ensuring fast moisture removal. The foam stability during drying is critical, if the foam collapses, breaking of cellular will occur which can cause serious damage of the drying process. The foams become stable when high viscosity and low surface tension occurs at the air/aqueous interface. However there are a lot of factors that affect the foam characteristics and foam properties such as; food composition, type and concentration of the foaming agent as well as the mixing time. Small bubbles in the foaming mass are exposed to an enormous surface for removal of moisture. The fast drying is due to the movement of moisture by capillarity in the liquid films separating foam bubbles. The foaming makes the mass undergoing drying extremely porous and submissive or compliant to drying its inner layers (Rajkumar *et al*., 2007).

Economic and technical purposes for employing foam-mat drying

Foam-mat drying has the ability to process hard to dry materials to produce products of the desired and required properties, retaining volatiles that otherwise would be lost during drying of non-foamed materials (Wilson *et al*., 2012)

Foam-mat drying process produces end product with favourable rehydration, controlled density and retain volatiles that would be lost when using other forms of drying (Kudra & Ratti, 2006). Foam-mat drying process provides the advantage of lower temperature and shorter drying times compared to non-foamed material in same type of dryer and conditions (Widyastutu & Srianta, 2011).

The foam-mat drying process is suitable for heat sensitive, viscous, sticky and high sugar content food products (Rajkumar *et al*., 2007), which cannot be dried using other forms of drying methods such as spray drying because of the state of product. Foam-mat dried products contain improved reconstitution characteristics due to their open structure. More interest has developed for foam-mat drying because of the simplicity, cost effectiveness, high speed drying and improved product quality it provides. Foam-mat drying does not comprise a large capital outlay, product is reduced into light and porous form, which when packaged allows great stability (Kandasamy *et al*., 2012).

Foam-mat drying offers the advantage of air drying, affordability and accessibility. Foamed structures offer irregular advantages in spreading, in drying, in surface removal, in crinkling and rehydration of the product sample. Foaming assists in the difficulty of thickness control of a product (Tayeb, 1993). The foam-mat drying technique has the advantage of using lower temperatures and also the foaming system incorporated speeds up the evaporation of water, it is low cost and easy to do. With foam-mat drying method, expected drying time can be faster, which makes it cheaper and easier when compared to other usual methods of drying (Febrianto *et al*., 2012).

Most common additives/gums/hydrocolloids used in foam-mat drying process, Introduction

A food additive is any substance that becomes part of a food product, either directly or indirectly, during phase of processing, storage, or packaging. Direct food additives, are those intentionally added to food for a functional purpose, in controlled amounts, normally at low levels and

Indirect or incidental food additives, are those that enter the food product in small quantities as a result of growing, processing, or packaging (Janssen, 1996; Somogyi, 2005). The difference between food ingredients and additives is primarily in the quantity used in a formulation. Food ingredients can be consumed alone as food (e.g., sucrose), while food additives are used in small quantities, relative to the total food composition (Somogyi, 2005). Some intentional additives include nutrients, preservatives, colors, and antioxidants, and incidental additives include packaging material, metals, veterinary drugs, and pesticides (Stanley, 2004).

Food additives can be grouped into five categories; texturizing agents such as gelling agents, thickeners and emulsifiers; colourings; flavoring agents: such as flavors, flavor enhancers and non-nutritive sweeteners; preservatives: such as antioxidants and antimicrobials and miscellaneous additives, such as anticaking agents, catalysts, clarifying agents, filter aids, and solvents (Janssen, 1996). Functions of food additives include preservation, process improvement, appeal and convenience and nutrition enhancement. Table 1 is a depiction of various common food additives, and their functions. Food preservation by chemical additives includes the use of antioxidants and antimicrobial agents. Preservatives are added to decrease the degradation rate of foods during processing and storage. They include antioxidants, antimicrobials and anti-browning agents. Antioxidants prevent or inhibit lipid oxidation of fatty acids in food products and, development of rancidity and off flavours. Antimicrobials are used to prevent or inhibit the growth of microorganisms. They play a major role in prolonging the shelf life of foods. Antibrowning agents are chemicals used to prevent browning of food, especially dried fruits and vegetables (Janssen, 1996)

Process improvement additives include food emulsifiers, stabilizers and thickeners. Emulsifiers maintain mixtures and improve food textures, whereas stabilizers provide product appeal with consistent texture. And humectants such as Sorbitol and maltodextrin are used to retain moisture and enhance flavour. Appeal and convenience of a food product is provided by food additives such as gums, flavouring agents, colourants and sweeteners added by the processors for food to looks and taste good demanded by consumers. Colorings are used to improve the overall attractiveness of food. Nutrition can be enhanced by added vitamins, antioxidants, proteins and minerals to food materials (Somogyi, 2005).

Egg albumen foams/gels

Foam ability and foam stability are one of the most important functionalities of egg albumen. Proteins in egg albumen act as amphiphilic (can process both hydrophilic and liphophilic) emulsifiers between the continuous and dispersion phase to stabilize foam. However the use of commercially available egg albumin for foaming poses a few disadvantages such as limited pH and ionic strength variety for adequate performance. Therefore technologies that can improve the foaming properties of egg white are desired. Mleko *et al*. (2006) stated that; the quality of protein-based foams depends on the structural arrangement characteristics of the emulsifier. Basically, proteins open structure with both hydrophobic and hydrophilic groups and great flexibility is required in order for a protein to produce much better foams.

Egg albumin contains up to 40 different proteins and is complex. The major proteins involved in the foaming of agitated egg albumin are; ovalbumin, globulins and ovomucoid. Ovalbumin forms a single layer at the airï water interface; lysozyme creates films that are much thicker than the protein monolayer. Nevertheless, ovalbumin foaming properties are superior to those of lysozyme, due to the weak foaming capacity of the latter in its native state at pH 7.0. When egg white, which can be considered a solution of efficient surfactants, is compared with other proteins, it usually provides the best foaming properties. Since egg white is composed of many proteins that have different surface tensions and foam abilities, it is difficult to predict foaming properties of particular mixtures of egg white proteins. The foaming properties of isolated egg white proteins are lower than those of eggwhite as a whole, confirming the existence of interactions between proteins. Foam stability decreases when egg whites liquefy during storage. Moreover, egg whiteȏsfoaming properties increase upon addition of sucrose and sodium chloride. A combination of physical measurements and artificial vision has made possible an apparent and applicable evaluation of the foaming properties of protein-based foams and illustrating their modifications due to changes in protein conformation. Controlled thermal treatment of solutions drastically increased the foaming quality of lysozymeand improved that of ovalbumin, both of which gave very stable foams after being heated to 90°C (Nussinovitch & Hirashima, 2013).

Partial unfolding of these globular proteins exposes more hydrophobic groups on the surface, thereby increases their amphiphilic nature and flexibility to improve foaming properties (Liang & Kristinsson, 2005). The foaming properties of partial unfolded egg albumin are reported, where egg albumin foams are subjected to different pH treatments. The different conditions involves unfolding and refolding at different ph treatments. Initially egg albumin unfolding occurs at extreme pH values such as pH 1.5, 2.5, 3.5, 10.5, 11.5 or 12.5 and then partially refolding of proteins by adjusting pH back to pH range where most food systems fall under (4.5-8.5). Both the stability and foaming capacity of egg albumin foam can be improved by the unfolding and refolding conditions/regime, by choosing the proper pH values. Inducing pH increases sulfhydryl and hydrophobicity surface content and correlates well, improving foaming properties (Liang & Kristinsson, 2005). Egg white proteins coagulate upon heating, except for ovomucin and ovomucoid. The denaturation temperatures at pH 7.0 for ovalbumin, lysozyme, and ovotransferrin are 84.5, 74, and 65°C, respectively. Ovotransferrin is the most sensitive of theseproteins and as such is regarded as a gelation initiator and limiting factor in the jellification. Thus ovotransferrin elimination has been suggested to improve egg white gelling properties (Nussinovitch & Hirashima, 2013).

Rheological properties, foam stability and foam development of egg albumen foams has been investigated by Kampf *et al*. (2003). The authors recognized that testing the rheological characterization of egg albumen edible foams using a conventional shear viscometer results in problems. Placing the sample into a narrow gap alters the foamǒs properties and resting the sample prior to its testing results in drainage and further damage to foam structure, compared to the original properties of the foam. The authorsô further state that this problem is avoidable, by evaluating the foam properties using different testing method equipment (lubricated squeezing flow viscometry). Egg albumins foams of 8% concentration on wet basis formed by whipping at 3 different periods of time (1, 3 and 5 minutes). Figure 3 shows the structure of 8% egg albumen foam after 1, 3 and 5 min of whipping immediately after formation and after being let to stand for 10 minutes. Figure 4 further shows the size distribution of the egg albumen foams after 1, 3 and 5 minutes of whipping. According to Kampf *et al*. (2003) continuous increasing whipping time, increase the number of small bubbles and decreases the number of larger bubbles, without much effect on their sizes. The whipping time has effect on consistency of the foam or its mechanical strength.

Methyl cellulose in foam-mat drying, Methyl cellulose origin and food uses

Cellulose is a linear, nonbranched polysaccharide that contains glucosyl units. Cellulose molecules can combine to form fibrous crystalline bundles that are highly insoluble and impermeable to water. Cellulose is commercially sourced from wood pulp and cotton linters. Cotton linters are the shortfibers remaining on cottonseeds after the long fibers have been removed. Cotton fibers contains 98% cellulose; while, wood is 40%ï50% cellulose, 30% hemicellulose, and 20% lignin. Wood requires great processing to solubilize and remove the hemicellulose and lignins (Manthey & Xu, 2009). The quality of cellulose is measured by the content of Ŭ-cellulose. Powdered food grade cellulose is not required to reach 99% purity because all cellulosic cell wall materials occur naturally in food stuff such as; fruits, vegetables, and cereals. Methyl cellulose is derived from highly purified forms of cellulose (over 99% Ŭ-cellulose); and is made by reacting cellulose with methyl chloride. Methyl cellulose is a popular food additive and is widely used in food processing industries (Manthey & Xu, 2009).

Cellulose has many food uses. It is added in juice used as a processing aid in the filtration of juice, as an anticaking agent for shredded cheese, as a fat substitute and a bulking agent in low calorie foods. Cellulose requires physical or chemical modification before used in food systems. The use of powdered cellulose is limited since it results in poor mouth feel. Powdered cellulose is used in cake batters to help foam stability. It can be used to reduce fat and increase the moisture content of fried foods. Cellulose limits water movement by fat during frying due to strong hydrogen bonding with water (Manthey & Xu, 2009). In agreement with this theory

Salvador & Fiszman . (2007) studied the performance of methyl cellulose in coating batters for fried different foods. Four different food matrices (port pastries, cheese, marrow and squid) were prepared using different methods (processing using pre-frying and process without pre-frying). One batch was prepared by being immersed in batter containing MC and further fried (pre frying process) and other batch was prepared by being immersed in batter also containing MC and was further immersed in hot water (75^{o}C), once coagulated, further placed in a microwave oven for 30 s. The authors reported that, regardless of the food matrix, the inclusion of MC in batter reduces the amount of fat absorption during frying in comparison to batter which does not contain MC. The lower fat content in the MC batters is associated with the higher moisture content. This result is anticipated since oil absorption occurs as moisture is removed from the food during the frying process (Salvador & Fiszman, 2007). MCøs heat gelling ability makes it possible to eliminate pre-frying from manufactured process of battered foods. The addition of MC in a batter formula allows the replacement of pre-frying by immersing in hot water followed by short time microwave or other short heating treatment. The lowest oil content was visible in the process without pre-frying in all the food matrices and the process without pre-frying has the same worldwide acceptability. Therefore the use of MC is a suitable alternative to producing a wide variety of good quality healthier battered foods (Salvador & Fiszman, 2007).

Temperature and pH do not significantly affect the water retention of powdered cellulose. Methylcellulose is nonionic, active molecules that have no electric charge (not affected by the hardness of water), but can act as an emulsifier, because it contains both hydrophilic and hydrophobic groups. Methylcellulose functions as an emulsifier and as a stabilizer in low oil and in no oilsalad dressings and can be applied to fried foods to reduce oil absorption. Methyl cellulose is used in baked goods to prevent boil over of pastry fillings and to aid gas retention during baking. Methylcellulose can form gel at high temperatures due to hydrophobic interactions between highly substituted regions that stabilize intermolecular hydrogen bonding (Fernandez *et al*., 2005).

Gum arabic in foam-mat drying, Gum arabic origin /economic importance / characteristics/Uses

Gum Arabic is also known as gum acacia, Turkey gum, gum Senegal and has many other local names such as; Sudanese gum Arabic, three-thorn acacia, *gommierblanc* (French). This gum is the dried sticky exudation obtained from stems and branches of certain Acasia trees, specifically Acasia Senegal, which grows in the semi-arid region in Africa, dried in the sun to form hard glassy, different coloured exudates. The gum is also considered a valued source of income for farmers, as the trees also protect and improve the soils and provides animal feed (Williams & Phillips, 2001). Gum Arabic is composed of 45% galactose, 24% arabinose, 13% rhamnose, 16% glucuromic acid, 3.8% ash, 0.34% nitrogen, 0.24% methoxyl, 17% uronic acid and 15% 4-O-methyl glucuromic acid. The acid is normally in the mixed calcium, magnesium and potassium salt form. Gum Arabic also contains small amounts of protein, which is the important part of the structure (Williams & Phillips, 2001). Gum Arabic readily dissolves in water to form high concentrated solutions of low viscosity and it is surface active, therefore can stabilize oil-in-water emulsions. Gum Arabic is widely used in the industry as an emulsifier. The gum can form thick viscoelastic films at the oil-water interface and the emulsion stability and rheological properties depends on the protein content and molecular mass of the gum. The gum contains 10

00 microbes per gram, but after processing (Spray-drying), it contains no more than 40% (4 x 10^2) (Nussinovitch & Hirashima, 2013) of the common count. Heating of the gum during processing precipitates the arabinogalactan-protein complex, this enables and supports stabilization and emulsification (Ward *et al*., 2005). Gum Arabic is highly branched and has a dense structure. Solutions with 10% of gum Arabic have low viscosities and Newtonian characteristics. Solutions with 30% of gum Arabic and above result in a higher viscous solution and increasing pseudoplastic behavior. The gum can be used to prepare solutions at very high concentrations; therefore elevated levels of the gum can be used in numerous foods. The gum is stable in acid solutions, which makes it useful for destabilization of citrus oil emulsions. Viscosity of a solution can be changed by addition of acid or alkali. A lower ph leads to lower viscosity, while a higher ph results in higher viscosity (Manthey & Xu, 2010).

Gum Arabic is used in important food areas such as: confections, beverages, emulsions, flavour encapsulation, baked goods and brewing. Traditional chewy gums are prepared using gum Arabic alone at concentrations between 40 ī 55% of total solids. It is also used to prepare concentrated flavour oil emulsions for use in cola and citrus-based soft beverages. Gum Arabic is used as an encapsulating flavour agent that added to dry foods such as soups, dessert mixes and beverages (Ward *et al*., 2005). Combination of gum Arabic and other gums such as (tragacanth gum) at certain ratio can produce a thin emulsion, with minimum viscosity of high quality, shelf and stability. Gum Arabic is reported to contribute to the maintenance of the mucosal wall and produces a decrease in blood plasma cholesterol levels. It is said that when gum arabic is combined with apple fibre, it lowers total and low density lipoprotein cholesterol levels in men (Williams & Phillips, 2001).

Additives in foam-mat drying methods

In production of papaya pulp powder, methyl cellulose was incorporated as a foaming agent at different concentrations (0.25%, 0.50%, 0.75% and 1%). The maximum stable foam formed was 83% for the 0.75% concentration (Kandasamy *et al*., 2012). In the development of functional drink of foam-mat dried papaya, egg white was used as the foaming agent at different concentrations of (10%, 15% and 20%). Egg white contains good foaming properties, which is because of the proteins found in egg white, which has the ability to encapsulate and retain air. Increasing concentration of egg white, results in rapid drying, due to the surface area that is high. The finest concentration of egg white depends on the type of fruit being dried (Widyastuti & Srianta, 2011).

Sankat & Castaigne. (2004) reported that during the drying of ripe banana pure, soy protein was employed as the foam inducer. However, other foaming agents were employed such as Glyceryl monostearate, which did not induce any foam. Dream whip and gelatine produced foam, but the foams produced were not suitable for successive drying. Soy protein foaming agent reduced the density of the initial ripe banana product from 0.93 g / ml to 0.50 g / ml after being whipped for 12 min by adding 10 g / 100 g of the soy protein (Sankat & Castaigne, 2004). Some foods naturally contain soluble proteins and monoglycerides and produce foams when whipped; however the foams produced are not adequate enough for drying process. Therefore the addition of foaming agents and stabilisers are necessary to induce foaming and give proper stability during drying. Glyceryl monostearate (GMS) and solubilised soy protein (SP) are the most often reported foaming agents. Mango pulp was foam-mat dried using egg white at varying concentrations of 0, 3, 5, 7 and 9% as a foaming agent (Wilson *et al*., 2012).

The bulk density and reconstitution rate of citrus powder was studied using the method of foam-mat drying. For the experiment, GMS foaming agent and soya albumin foam stabiliser with Methocel (10 cps) also known as MSA/MC (Wagner *et al*., 1964)

Foam-mat drying of mango pulp using egg 10% albumin as a foaming agent combined with 0.5% of methyl cellulose as a stabiliser gave the optimum results (Rajkumar *et al*., 2006). The two combined together retain significantly high amounts of biochemical content.

Papaya pulp powder was foam-mat dried to optimize the concentration fruit pulp and level of foaming agents, to study the drying characteristics of foamed papaya concentrate and also to analyse the nutritive value of the foam mat dried papaya powder. Papaya pulp was foamed with methyl cellulose at different concentrations (0.25, 0.5, 0.75 and 1%), glyceryl monostearate (1, 2, 3 and 4%), and egg white at (5, 10, 15 and 20%) as foaming agents. The maximum stable foam formed was 72%, 90% and 125% at 0.75% methyl cellulose, 3% glyceryl mono-stearate and 15% egg white respectively (Kandasamy *et al*., 2012)

Apple puree which contained no additives was foam-mat dried using different foam-mat drying methods to study the physical properties and the aroma of the apple puree powder. Egg albumin (Fluka) with the concentration of 2% was employed as a foaming agent and 0.5% of the methylcellulose (Methocel, 65HG, and Fluka) (Jakubczyk *et al*., 2011).

Febrianto *et al*.(2012) reported the drying of milk powder with foam mat drying method. In this particular method a filler material was used combined with an emulsifier. Tween 80 was used as an emulsifier at a concentration of 1% combined with the two filler materials gum arabic at concentration (2, 4, and 6%) and maltodextrin at concentrations (5, 10, and 15%) (Febrianto *et al*., 2012). Foaming agents commonly used are enzymatically hydrolized soya protein (0.1-5%

by weight of the dry solids), glycerides or sucrose fatty acid ester, lecithin and poly glyceryl stearate other used foaming agents are Hyfoama (prepared by hydrolysis of casein), powdered egg white, vega foam and milk protein concentrate. Foaming stabilisers that are hydrophilic colloids are; soluble starches, sodium carboxyl methyl cellulose, agar, methyl cellulose, gum arabic, sodium alginate, pectin, dextrin, sodium carboxyl methyl starch, sodium carboxyl methyl amylose, pentosans, albumin, gelatin and dried egg white. Monostearate is a surface active agent acting as a foam stabiliser. Mono glycerides such as glycerol mono palmitate, glycerol mono myristate, glycerol mono laurate, glycerol mono stearate and glycerol mono oleate are well known foam stabilisers in aqueous systems. There are also some well-known emulsifiers, thickeners and consistency developers. Albumin acts as an emulsifier for syrups, while guar gum is added as a thickening agent and sodium alginate is used t raise viscosity of syrups. Consistency may also be elevated by adding hydrophilic colloids; such as methyl cellulose in juice, gelatin in meat pure, pectin in berry juice and guar gum in lemonade (Tayeb, 1994).

Drying of liquid and solid foods using foam-mat drying methods

Commercial yoghurt was foam-mat dried using two types of foaming agents; methyl cellulose and egg albumin. They were added at different concentrations as 0.5, 1.0, 1.5 and 2% for methyl cellulose and 1, 2, 3 and 4% for egg albumin respectively. Yoghurt foam was produce by mixing the foaming agents with the yoghurt and blended for 12 min. The yoghurt foam was then poured into Teflon trays and dried in an oven at 50^{o}C, 60^{o}C and 70^{o}C for 3 h. It was observed that the appropriate conditions for producing the optimum yoghurt powder is by using 3% egg albumin, dried at 60^{o}C for 3 h (Krasaekoopts & Bhatia, 2012). Alphonso mango pulp was foam-mat dried using egg albumin (5%, 10% and 15%) with methyl cellulose of 0.5% as foaming agents. The foamed pulps were dried at 60, 65 and 75^{o}C (Rajkumat *et al*., 2007). The optimum results were obtained using 10% egg albumin foaming agent with 0.5% methyl cellulose stabilising agent, dried at 60^{o}C.

Febrianto *et al*. (2012) reported drying of liquid milk using foam-mat drying process. Fresh milk was measured to a volume of 200 ml and cooled to 0^{o}C optimum temperature for treatment. The fresh milk was then mixed with an emulsifier Tween 80, 1% v/v of fresh milk (2ml) in plastic and glass containers and further homogenised using a mixer speed of 1 and increased to 2 and 3, respectively. The fresh milk with the emulsifier was then added to filler materials used at different concentrations; maltodextrin (5%, 10% and 15%) and gum arabic (2%, 4% and 6%). The mixtures were stirred using a mixer at speed 1 and then increased to 2 and 3 alternately for 5 min. The foamed mixture was poured to stainless steel pans which were coated with plastic. The pans containing foamed mixture were placed in the vacuum dryer and dried at temperature of 70^{o}C for 7 h. Best milk results were obtained using the treatment of 1% of emulsifier with 15% of maltodextrin.

Foam-mat drying and other forms of drying, Spray drying introduction and food selection

Spray drying is a processing operation that has the ability to transform feed from a fluid state into a dried form, by spraying the feed into a hot drying medium. The product can be a single part or clusters. The feed can either be a solution, suspension or a paste. Spray drying is a well-known suitable method for food dehydration. The development of spray drying has been previously closely associated with dairy industry; however the technology has been now developed and expanded to cover a variety of food groups, which can be successfully, spray dried. It is now used for a wide range of products; biotechnological products, fine and heavy chemicals, dairy products, foods and pharmaceuticals (Xin & Mujumdar, 2009). It is mostly suitable for liquid and semi-solid foods, such as beverages, coffee, milk and yoghurt.

Food quality benefits of spray drying

By decreasing water content, the process provides advantages of minimizing microbial deterioration of spray dried foods, reduction of lipid oxidation and preserving original emulsion structure (Gaiani *et al*., 2010). In the drying of yoghurt, spray drying allows the preparation of stable and functional products. However it has been reported that most of the aroma compounds and rheological properties of yoghurt are not retained during the spray drying process (Kumar & Mishra, 2004). This however can be improved by the addition of hydrocolloids (carrageenan, xanthan, gellan) to retain the aroma (acetaldehyde) as well as solubility and dispersability of spray dried yoghurt. Retention of acetaldehyde is affected by the feed total solids, atomizer speed and outlet temperature during spray drying.

It is reported that modifying the spray drying outlet temperature can alter or adjust surface composition (lipids, lactose) of protein milk powders. The lipid surface content decreases as the outlet temperature is increased. Higher drying temperatures stimulate the appearance of lactose over protein at the surface of the particle. Therefore spray drying can assist in formulating powders with controlled surface composition, which will lead to a better control of powder functionalities (Gaiani *et al*., 2010).

Common food commodities for spray drying process

Spray drying can handle heat sensitive foods and also simultaneously retain their nutritive value. The different systems of spray drying enable powders to be produced in a variety of forms necessary for the consumer and the industry. The different forms include agglomerated and agglomerated (ordinary, instant) powders, containing the exact particle size, residual moisture content and bulk density.

Milk is a nourishing food product, rich in high quality protein offering the essential amino acids. Milk is most commonly commercially available in two forms; liquid and /or dried powder form. Powdered form is now in high demand due to its longer shelf life. Milk can be spray dried using two forms of spray drying systems; one stage spray drying system and multistage spray drying system. Multistage system is found to be advantageous due to its higher capability of air drying each unit, has a better economic due to low outlet temperatures that can be used, gives better product quality (good solubility, flow ability and high bulk density) (Xin & Mujumdar, 2009).

Spray drying can also be applied in the drying of fresh vegetable juices (tomato juice). Fresh ripe tomatoes are soaked, washed, sorted and crushed into pulp. The tomato fruit can be prepared using two different methods such as; ñhot break and ñcold breakò. In hot break, tomatoes are heated at 85^{o}C ï 90^{o}C before being crushed and cold break, once the tomatoes are crushed, the pulp must be held for few seconds to obtain pectin decomposition, which will enable an easier to spread paste. It is however reported that powder obtained using the hot break method is more desirable. Cold break tomato pastes are spray dried at higher concentrations, than hot break tomato pastes. To obtain adequate drying, outlet temperature should range from 40^{o}C ï 50^{o}C and inlet temperature of 140^{o}C ï 150^{o}C. Such low drying temperatures employed during spray drying process, denote that the system has a slow evaporation rate. However the current volatile compounds in the paste will be preserved as well as the tomato solids. The initial moisture content of the tomato powder from the drying chamber is 10% and further reduced using fluidized bed attached at the bottom of the drying chamber (multi stage spray drying system) to get the required moisture content of 2%. To obtain a lump free product during storage, proper cooling time should be monitored. Lumpiness decreases as cooling powder increases, however the favourable powder temperature to obtain a lump free product also depends on the type of tomato. Lumpiness, can however be further aided, by using atmospheric packaging (nitrogen and carbon dioxide atmosphere packaging), noncaking agents (Food gel silica gel) (Xin & Mujumdar, 2009).

Coffee is one of the most commonly known beverages in the world. The process of making coffee includes roasting, grinding, extraction, spray drying and agglomeration. Due to the demand of instant coffee by the public with similar flavour and aroma quality as regular coffee, spray drying is one of the processes employed to produce instant powdered coffee. A multiī stage spray drying system is most favourably employed for drying coffee. The preconcentrated coffee extract should contain total solid content of 40 ī 50%. The inlet and outlet temperatures are 220^{o}C ï 240^{o}C and 105^{o}C ï 115^{o}C respectively. Non-agglomerated coffee powder with the moisture content of 3% is usually obtained, with particle size range 100 ï 400 µm (Xin & Mujumdar, 2009).

Economic advantages and disadvantages of spray drying

Spray dried products improves storage stability, minimizes packaging requirements and reduces shipping weights, hence it ensures a reduction of storage, transport cost and easier handling of the material (Sliwinskiet *et al*., 2003; Gaiani *et al*., 2010). Cost of spray drying is directly linked to the use of its energy.

Spray drying is an intensive energy process simply because, it is necessary to supply specific heat for evaporation in a short time. Change in temperature across drying chamber is comparatively low, due to sensitive materials spray dried. To be able to get a fine quality product; the use of low outlet air temperature and high inlet air temperature is disapproved. Due to the exhaust air, an amount of heat can be lost, which leads to the loss of dry product, because of the poor powder collection system. However to overcome these difficulties and promote saving of energy, the following can be done; removal of water from the feed prior to drying, because pre-concentration of feed leads to major energy savings. This can be done by mechanical dehydration as long as the feed is pumpable. Also increasing the inlet air temperature or either decreasing the outlet air temperature, will allow fine quality product, as both temperatures are effective. Using a wet scrubber (hot scrubber liquid used as feed process water) to clean the exhaust air and to escape losses of large amount of dry product can be achieved. However a good and hygienic energy and product saving method is to lead the exhaust air from cyclone into bag filter, where the product can be recovered (Filkova *et al*., 2006)

Freeze drying Introduction and food selection

Freeze drying process, is a methods that involves three continuous stages; the freezing stage, primary drying stage and the secondary drying stage. The principle of this method is that a portion of the product will be frozen at a temperature range of 10^{o}C or lower. Thereafter the frozen foodstuff will be placed under vacuum of pressure range 2mm Hg or less. Through the vacuum the frozen liquid sublimates. The ice immediately changes into vapour, without initially defrosting, this is also known as sublimation. The outside of the product will be the first to undergo the moisture loss; subsequently the water is removed till the core of the product (Liapis & Bruttini, 2006). Freeze dryers work on the principle of direct evaporation of the ice in the product to be dried (Sokhansanj & Jayas, 2006). This Freeze drying process is employed only for most heat sensitive and high valued foods in different form such as solids, pastes (fish, meat, chicken and coffee) (Fissore *et al*., 2014; Sokhansanj & Jayas, 2006). Because drying is accomplished at low temperatures, heat degradation of the food nutrients is minor, and therefore the product obtained is of high quality. Spray drying methods is also employed for the dehydration of vegetables.

Food quality benefits of freeze drying

Freeze drying allows retention of morphological and biochemical properties. It provides high viability levels; the product undergoing freeze drying is subjected to low temperatures, oxygen and less shear conditions, compared to other conventional drying methods. Freezeī dried products have high chances of retaining product structure, recovery of the volatiles, producing high yield and producing product with long shelf life (Liu *et al*., 2008; Quiroga *et al*., 2012). It has been reported that freeze drying of yoghurt improves the digestibility of the yoghurt, but also causes some loss of vitamins and flavour. Freeze drying results in better survival of starter culture when compared to other drying methods used such spray drying (Kumar & Mishra, 2004). Jayaraman & Das Gupta. (2006) further stated that freeze drying minimizes shrinkage, as well as the movement of the solids within the foodstuff. Permeable structure of a food material induces fast rehydration and retention of volatiles and compounds are significantly high.

Economic advantages and disadvantages of freeze drying

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Freeze drying reduces weight for storage, shipping and handling as the product will be transformed into a powder form. Freeze dried products have reduced preparation times, the structure or shape of the product stays intact. The product properties are retained because the drying process occurs at low temperatures. As a rule freeze drying produces the highest quality food product obtained by any drying method (Liapis & Bruttini, 2006).

One of the drawbacks of this process is the fact that, it is an expensive form of dehydration because of the slow drying rate and the use of vacuum. The amount of energy required and utilized is large (Fissore *et al*., 2014). This is due to the large amount of energy consumption and high costs of both operations as well maintenance of the system (Liu *et al*., 2007). The high capital and processing cost are also accompanied by the need for special packaging which assists in avoidance of moisture gain and oxidation (Jayaraman & Das Gupta, 2006).

Microwave drying introduction and food selection types

Microwave drying process is one of the few very fast conventional heating/drying processes. The drying temperature and microwave power are the two most critical factors comprising the microwave drying system. These two factors affect the drying parameters such as drying time, drying speed, drying curve, drying efficiency and final product quality. During a typical microwave drying process, throughout the processing system, a fixed microwave power level is applied; however temperature control is non-existent (Li *et al*., 2010; Kone *et al*., 2010). The microwave drying system is divided into three period stages according to the temperature alterations. The initial period is where by the sample temperature increases with little moisture removal, second stage is when most of the drying occurs and the last stage period is when the drying rate decreases and sample temperature increases quickly. This could lead to a very high

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unwanted temperature value, causing hot spots to the product, resulting in diminished product quality. In the first two drying stages, the drying efficiency is favourable, however moving forward to the final stage problem commences. The issue can be resolved by controlling the microwave power (Li *et al*., 2010; Kone *et al*., 2010). In microwave drying, heat is produced within the food material, due to the interactions of the food constituents (proteins, fats, moisture) and the radio frequency energy (Jayaraman & Das Gupta, 2006). Microwave heating elevates temperature of the internal, fluid areas of the solid food material. The transportation of moisture away from the food material to an evaporation state is improved by the internal pressure gradient (fluid movement rate and direction, within the material) (Ratti & Mujumdar, 2005). Microwaves are commonly used to dry pasta and macaroni products, onions and potato chips (Schiffmann, 2006).

Food quality benefits of microwave drying

It is reported that microwave drying reduced the drying period of potatoes, compared to other drying methods and produced a rather good quality of potatoes. Thin layered carrots had showed good product quality and accomplished within a decreased drying time, during drying process (Jayaraman & Das Gupta, 2006). Li *et al*. (2010) reported the aiding of temperature and power control of microwave drying application in a food material. The authors found that employing different attributes of microwave power and temperature control combined during drying of apples, provides optimal temperature control and product quality (Li *et al*., 2010). It is reported that microwave drying offers improved quality and longer shelf life of dried fruits and other solid food (Maskani, 2001)

Economic purposes, advantages and disadvantages of microwave drying

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Microwave drying like any other drying method has its downfalls and advantages. The desired ends of microwave drying are its significant penetrating capability, which results in uniform heating of the food material, owed to the introduced heat waves of the system. Microwave drying allows specific absorption of the heat waves within the moisture food material and provides simple management, for heat to be altered to the desired state (rapid, slow). Microwave drying can reduce the drying time of an irregular food material, with regards to the size and shape of the material, that which for a conventional drying method is impossible (Jayaraman & Das Gupta, 2006; Ratti & Mujumdar, 2005).

However this type of equipment is complicated and expensive, therefore no industry uses it for fruit dehydration (Ratti & Mujumdar, 2005). Microwave heating results in undesirable discolouration on food material (tomatoes), this is because of the elevated temperatures levels. The colour damage is an indication of deteriorated caretonoids pigments (lycopene), chlorophyll, oxidation of ascorbic acid and browning reactions (Kone *et al*., 2013)

Drying of meat, fish and seafood and other forms of drying, Introduction

Meat and fish is composed of animal muscle tissue. These food materials are an important source of high quality protein required in the human diet. They form part of the group of highly perishable foods and have a very short span of shelf life, if not properly stored and monitored under favourable conditions (Darvishi *et al*., 2013). Therefore to extend the shelf life of these foods groups, drying techniques are incorporated

Drying of fish is essential because it preserves the fish by deactivating the enzymes and as well as moisture removal, that facilitates bacterial growth and spoilage (Darvishi *et al.*, 2013).

Forms of drying fish and meat

The ways in which fish and meat are dried are similar. The food groups, prior to dehydration undergo pretreatment. Fish and meat can be salted, which is known as curing. Sodium chloride, sodium and potassium nitrites or nitrates are the curing salts. Salting reduces the moisture content of the food material and acts as a preservative, which makes the foods more shelfī stable. The food material can either be smoked, which another pretreatment process to ensure adequate is drying. The main purpose of smoking is to impart desirable flavours and colour the food material, it is not particularly used to reduce moisture content (Rahman & Perera, 2007).Cooking before drying is another recommended step, because it has the capability to reduce bacterial load and once cooked, it allows easy even distribution and spreading of fish and meat, prior to drying (Rahman, 2006). Table 2 represents the critical quality characteristics of dried foods grouped in categories taken into account during drying applications of the final product.

Sun drying and or solar drying are one of the most ancient drying applications. In the sun drying process, food materials are directly exposed to the sun, by being placed on land or left hanging in the air (Rahman & Perera, 2007). The temperature of the food material throughout the sun drying application should range from 5 ï 15^{o}C, above ambient temperature and drying time may extend up to 3 ï 4 weeks, depending on the product (Sokhansanj & Jayas, 2006). When climate is particularly suitable, drying can take 4 ï 5 days (Santchurn *et al.*, 2007). Sun drying is the cheapest method of drying foods, and it has become more popular nowadays. However the main disadvantage about this kind of drying is that it is highly susceptible to contamination from the environment, the food material may undergo loss and contamination due to insects and birds.

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It is a complex process to control and brings bad odour within the environment (Rahman & Perera, 2007).

Comparison of different drying methods

Drying of food materials is a type of preservation commonly used by the food processing industry. There are multiple different types of drying methods used worldwide, depending on the desired final product outcome required. Several drying applications have been discussed in this review, to clearly identify the economic difference, technical differences, cost and benefits associated with each drying application, which can assist suitable selection, regarding type of drying application. The initial cost of microwave drying system is costly. There is few food materials containing dielectric properties that will accommodate the use of microwave drying system. This can complicate the robust heaters of a microwave drying system (Rao *et al*., 2012). Thus microwave drying is not commonly used. During spray drying a huge heat and mass transfer occurs within short time, this requires intensive energy use. Maintenance of spray dryer can be considered as complex because of the nozzles utilized, which are fragile, likely to undergo clogging and abrasion at nozzle mouth. During spray drying process powders have the potential of sticking to the internal walls of the heating chamber, which will contribute to maintenance cost. The Freeze drying process reaches very low temperature. The equipment needed for this purpose can be costly. Freeze dried food material require specific packaging which helps eliminate any moisture gain and assists in retaining the shape of the food material. On the other hand foam-mat drying provides simplicity, as it utilizes air drying at medium temperature conditions. Table 3 depicts the economic and technical benefits of different drying methods. Each drying processes caters for a variety of food materials, depending on the form of

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the initial product and on the equipment. They depict different results, of the quality of the final product. Table 4 represents the different drying applications.

Conclusion

Drying of foods remains a critical step in the food production sector for food preservation and foam-mat drying process can be used to expend food preservation. The most crucial aspect of food dehydration is obtaining a high quality food material. The food material should display optimum desired nutritional, physical, chemical and microbial aspects. Meaning there should be minimal or insignificant loss of nutrients, such as proteins, vitamins and fatty acids. Food drying techniques should provide absence of colour loss, oxidation, spoilage of pathogens and toxins on the final product. The preferred physical aspects, which manly include texture, aroma, rehydration and shrinkage, should be achieved. Foam-mat drying possesses more economic and technical benefits compared to the other commonly used forms of drying methods. It provides simplicity during process operation; it is affordable as it requires less intense energy supply. Foam-mat drying like other drying methods delivers uniform heating, rapid drying and good quality product as well as storage reliability. Therefore the foam-mat drying process is recommended to be more commonly utilized as a drying and food preservation processing method.

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Table 1 Food additives, their food uses and functions

Food additive	Major food additives	Major food uses	Preservation	Process Improvement	Appeal and convenience	Nutrition
Antioxidant	Ascorbic acid, BHA	margarines	x		x	x
Anticaking agent	Salts of fatty acids	Milk powder		x	x	
Colouring agent	Dyes, lakes, caramel	Dressings			x	
Enzyme	Pectinase, amylase	Dietic products		x	x	
Emulsifier	Lecithin, esters	Dry beverages		x	x	x
Flavour	Methanol,	Dairy products			x	
Humectants	Maltodextrin, sorbitol	Honey			x	
Preservative	Sorbic acid,	Dessert	x			

s	sulfites	mixes				
Sweeteners	Saccharin, aspartame	Chewing gum, candy	x	x	x	
Thickeners and Stabilizers	Gum Arabic, gelatin, carrageenan	Baked goods	x		x	x
Vitamins and minerals	Vitamin C, D, K,A,	Breakfast cereals				x
pH control agents	Phosphoric, citric, malic acid	Citric juices	x	x		

Table 2: Quality characteristics of dried foods

Nutritional	Physical	Chemical	Microbial
Vitamin loss	Texture	Oxidation	Spoilage
Functionality loss	Aroma	Colour loss	Pathogens
Protein loss	Solubility	Aroma development	Toxin
Fatty acids loss	Shrinkage		
	Porosity		
	Rehydration		
	Pore characteristics		

(Rahman, 2006; Rahman & Perera, 2007)

Table 3: Economic and technical benefits of different drying methods

	Simplicity	Product quality	Rapid drying	Uniform heating	Storage reliability	Affordability
Foam-mat drying	ã	ã	ã	ã	ã	ã
Freeze drying		ã	ã	ã	ã	
Spray drying		ã	ã	ã	ã	
Microwave drying		ã	ã	ã	ã	

Table 4: Drying applications varieties

Drying methods	Food commodities	Initial feed	Desired form
Foam-Mat Drying	Milk,fruits (apples, papaya), yoghurt	Liquid, paste, semi-liquid	Powder
Spray Drying	Milk,coffee, beverages	liquid	Powder
Freeze Drying	Meat,fish, chicken, coffee, fruit (berries)	Solid, liquid	Dried solid
Microwave Drying	Potatoes,Pasta	Solid, paste	Dried solid
Solar/Sun Drying	Meat, fish, fruits (peaches)	Solid,	Dried solid

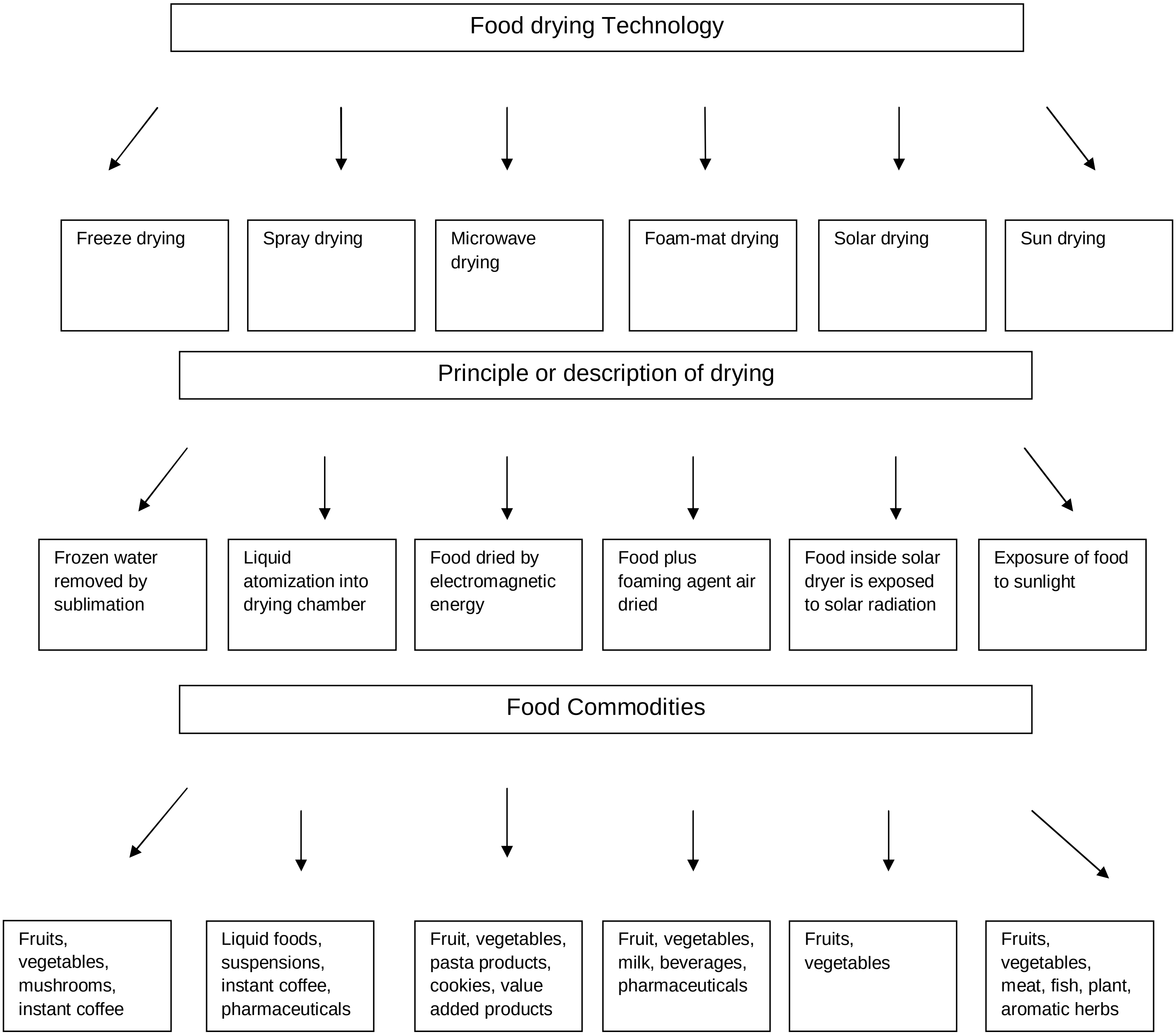

Figure 1 Various food drying technologies

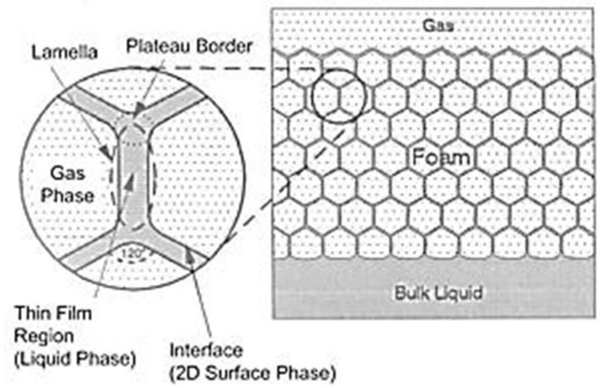

Figure 2 Generalized 2D foam system. (Anon, 2012)

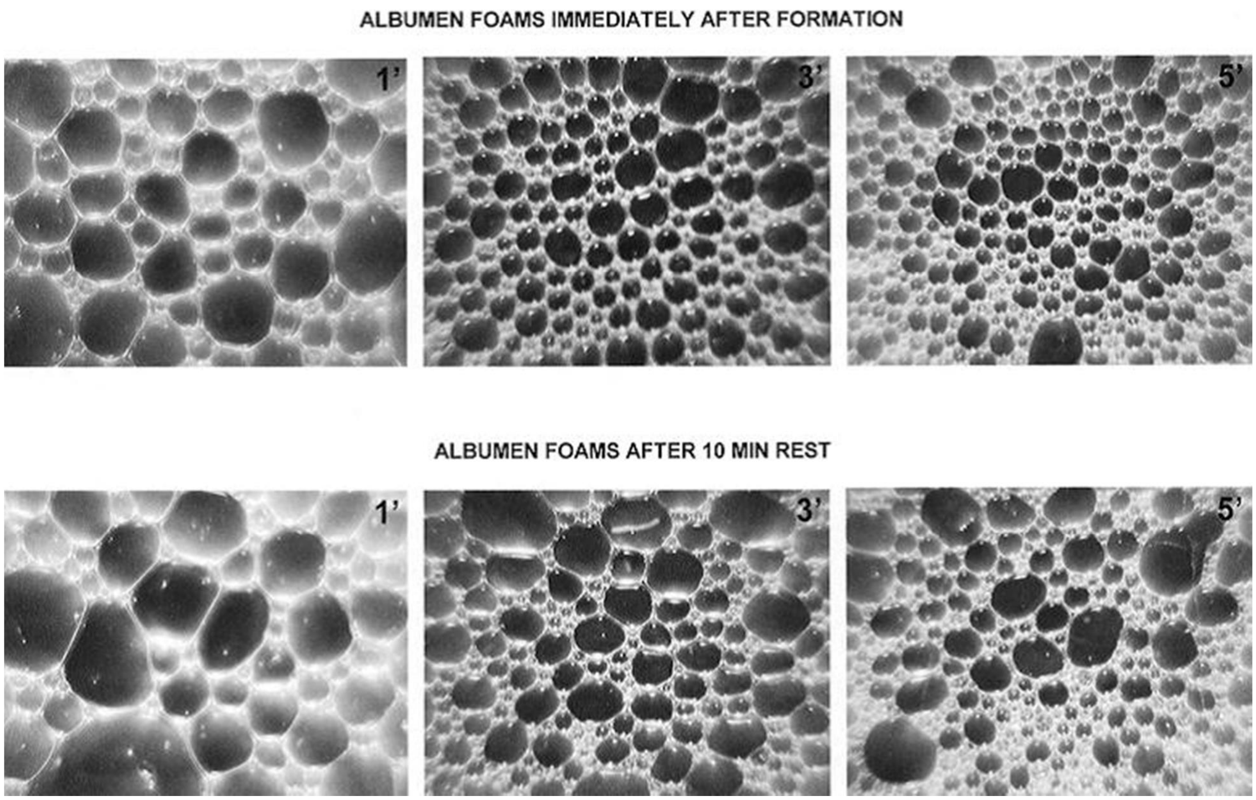

Figure 3 Structure of egg albumen foams after 1, 3 and 5 minutes whipping and after 10 minutes standing (Kampf *et al*., 2003)

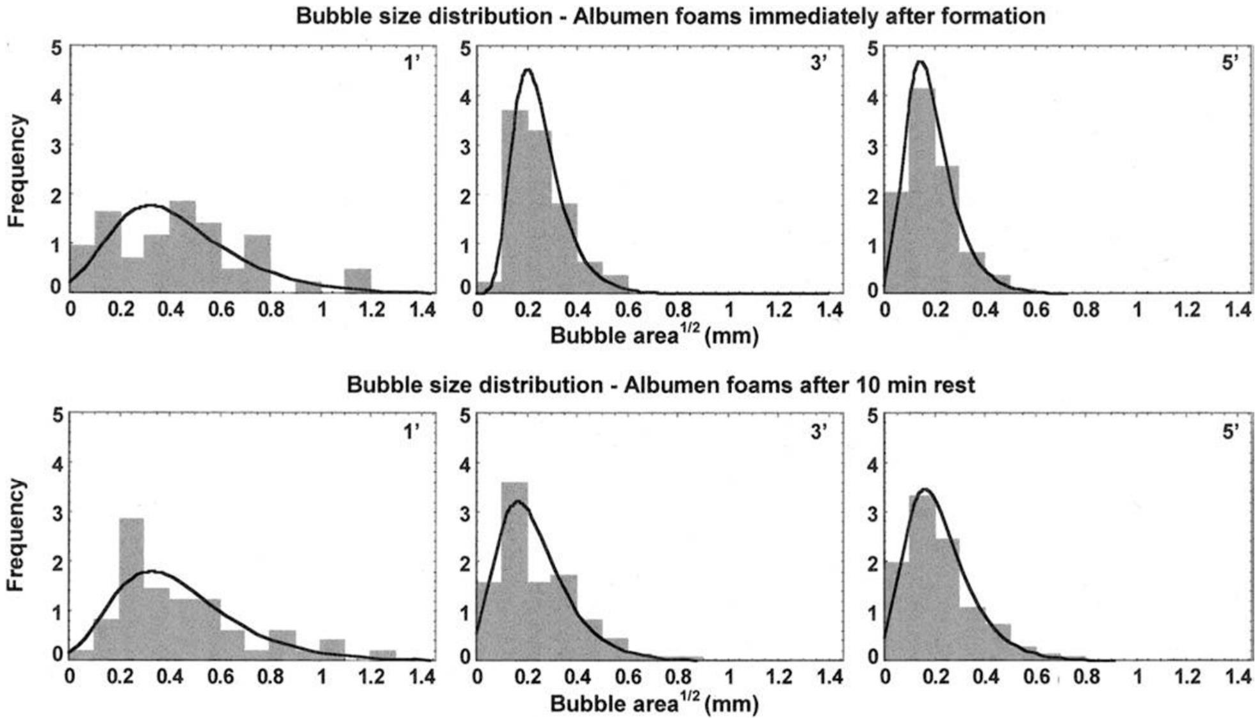

Figure 4 Size distribution of egg albumen foam bubbles in 8% egg albumen concentration, with 1, 3 and 5 minutes whipping immediate formation and after 10 minutes standing (Kampf *et al.*, 2003)