CHAPTER 2

REVIEW OF LITERATURE

A detailed review of the work done by different researchers related to the present study such as foaming, foaming and stabilizing agents, foam characteristics, foam mat drying of different fruit pulps and quality analysis are presented in this chapter.

2.1 FOAMING AND FOAM CHARACTERISTICS

Foam is a macroscopic colloidal dispersion of gas in which, gas is dispersed in a continuous liquid phase. The dispersed phase is referred as the internal phase and continuous phase is referred as the external phase. The dispersed phase is larger than the continuous phase (Baniel et al 1997). In polyhedral foams, the ratio of dispersed phase to continuous phase is large and small in case of dilute bubbly foam. The bubbles press each other to form honeycomb structure, as the number of bubble increases. Egg white foam is a good example of polyhedral foam. Foams have a thin liquid films or lamellae between bubbles. The lamellae meet each other at a point called a plateau border (Figure 2.1). The stability of the foam along with their air/water interface properties are determined by its mechanical strength. Viscous liquids usually produce more stable foams due to the increased elasticity of the lamella. Due to the curvature of the interface, the pressure in the plateau border is lower than that in the bubble (Dickinson 1992). The properties of
foams are controlled by surface forces, colloidal forces and interactions between the individual films (Indrawati & Narismhan 2008; Narchi et al 2009).

![Diagram of foam structure]

**Figure 2.1  Schematic representation of structure of foam**

A foaming agent is a surfactant material able to reduce interfacial tension, adsorb at the interface and form a stable film at the interface that resists collapse. Proteins are considered to be the best foaming agents to use in foods. Proteins have better foamability and greater foam stability due to their hydrophobicity and conformational rearrangements, which allow rapid adsorption at the air-water interface leading to the formation of a coherent elastic adsorbed layer (Dickinson 1998). During the formation of foams, destabilization of foams occurs. Therefore, a good foaming agent should have a foaming capacity and should be able to counter this destabilization. Egg white, gelatine, milk products are few of the protein based foaming agents commonly used in food preparations.

Egg albumen (EA) or egg white, on whipping get denatures at the interface and interact with one another to form stable, viscoelastic interfacial
film. The properties of albumen foams have been investigated with emphasis on their volume increase and stability (Elizalde et al 1991; Lomakina & Mikova 2006). The foaming capacity and stability of egg white foam were influenced by hen age, egg age, storage conditions, speed and time of whipping, temperature, pasteurization, pH, dry matter, presence of egg yolk, salt, sugar, stabilizers and surface active compounds, metal ions and proteolytic enzymes (Hammershoj & Qvist 2001). It was reported that the foam formation was higher with less whipping time in egg white protein than whey protein isolate (Pernell et al 2002). Greater foam volume was obtained from egg white at room temperature than those beaten at refrigerated temperature. Foam collapse in egg albumen was observed after 20 minutes of whipping, which resulted in unstable foam structure (Falade et al 2003). In such cases, addition of foam stabilizers was recommended which enhanced the stability of foam over time. The bubble size of the egg albumen foams were in the average range of 30-40 μm when foamed with 0.125% xanthan gum (Muthukumaran 2007).

Soy protein isolate (SPI) is a highly refined form of soy protein. The functional characteristics associated with soy protein isolate were gelation, emulsification, viscosity, water binding, dispersability and foaming or whipping properties (Daniel 2004). A minimum foam density of 0.8 g/cm³ only was obtained at soy protein isolate concentration of 5 g/100 g. However, the increase in concentration to 10 g/100 g reduced the foam density to about 0.5 g/cm³. Instability of soy protein isolate foams over time was noted. This was due to the compact tertiary structure of the soy protein, which provided poor foaming properties such as foam formation and foam drainage (Martinez et al 2009). The foam formed with soy protein isolate collapse faster than the foams made with Whey Protein Concentrate (WPC). Soy protein isolate foams were found to have less resistant interfacial films than whey protein.
concentrate and also the gravitational drainage in case of soy protein isolate foams was found to be faster (Abirached et al 2012).

Whey protein is derived from dairy and is a by-product of the cheese-making process. Whey Protein Concentrate (WPC) was classified based on its protein content as low protein WPC (25%–45%), medium protein WPC (45–60%) and high protein WPC (60–80%). Further purified and refined form of WPC is called as Whey Protein Isolate (WPI). Mott et al. (1999) found that the addition to suitable polysaccharide to whey protein increased the foam stability due to its increased viscosity. It was also found that the addition of xanthan gum to whey protein increased the foam stability due to the forces exerted by the liquid thereby forming a better solution. Whey protein was reported to have more solubility and hydrophobicity than soy protein isolate. Higher foamability of whey protein represents that it had faster rate of incorporation of the liquid into foam and was capable to retain more liquid than soy protein isolate. The foams made with WPI produced smaller bubbles than foams with soy protein isolate. It was reported that the volume of liquid retained by WPI was double the time retained by soy protein isolate. This was due to the higher resistance of the interfacial film formed by the WPI (Abirached et al 2012).

Stabilizing agents are substances that increase the stability of foams. Generally, polysaccharides are employed as stabilizers. Many polysaccharides being hydrophilic, they do not adsorb at the interface but they can enhance the stability of foam proteins by a thickening or a gelling effect of the aqueous solution (Klitzing & Muller 2002). Carboxymethyl cellulose or cellulose gum, xanthan gum, Arabic gum, starches, pectins and gelatin are the most common foam stabilizer used in food.
Carboxymethyl cellulose was used as stabilizer to stabilize emulsions and as thickener or viscosity modifier. The ability of stabilizing agent to adsorb at the oil/water interface by lowering the surface tension and by reducing the size of droplet was responsible for producing stable foam. They also formed crystalline lamellae in the continuous water phase and stabilized the emulsion by physically trapping the emulsion droplets in the micro gel matrix (Hennock et al 1984). Proteins was also used as stabilizers in retaining the foam structure. German & Phillips (1994) stated that for protein to be good stabilizing agent, it should be able to reduce the surface energy levels between the bubbles as they are continuously created during foaming. The combined presence of proteins and polysaccharides provide a net attraction between the two kinds of macro molecules (Carp et al 2004). It was found to be a good choice to produce mechanically and thermodynamically stable foam. Rajkumar et al. (2007c) foamed mango pulp using egg albumen and methyl cellulose. They reported that the foam expansion and foam stability of mango pulp increased with increase of the whipping speed of 400 to 1400 rpm and time (5 to 25 min). The stabilizers act by either increasing the viscosity of the continuous phase or by forming a three dimensional network that retards the movement of components within the foam (Walsh et al 2008).

In order to have good control over the foam, it is important to have a proper understanding of nature of the foam and its physical properties. Generally foam can be formed by the following three methods such as sparging or bubbling, whipping or beating and shaking. In sparging or bubbling, the liquid was forced through the orifice to form foam whereas foam was obtained by vigorous agitation of liquid in shaking. These methods were slower in producing the foam, hence not used in large scale foam production (Hailing & Walstra 1981). The incorporation of unlimited amount of air into known quantity of liquid to produce foam is called whipping or beating. When
a large amount of air is trapped inside the liquid caused by the action of an agitator, the size of the air bubble will increase and subsequently break into small bubbles because of the mechanical agitation. Whipping resulted in severe mechanical stress and more uniform dispersion of the gas/air when compared with sparging and shaking. The severe mechanical stress affected both the coalescence and formation of bubbles. The final size of the bubble depends on the speed of the agitator, the geometry of the apparatus and the rheological properties of the liquid. With increasing intensity of beating, the amount of air included usually drives to a maximum volume. Satyanarayana Rao et al. (1987) obtained maximum foam expansion of egg mélange when whipping speed of 1000 - 1500 rpm for a period of 5 - 10 min was used. Similarly, the foam expansion and foam stability of sunflower seed protein and soy protein isolate increased with the increase in the whipping speed from 5000 to 15000 rpm for a time period of 0.5 to 2.5 min (Kabirullah & Wills 1988). The paddle diameter and rotation speed of the agitator had an influence on the foam density and mean bubble diameter of the foamed product. The high viscous raw material and an apparatus with narrow gap favour foaming in continuous processes (Djelveh et al 1994). Thakur et al. (2003) studied that the average bubble size in foams depends only on the intensity of viscous forces generated by the impeller. It was suggested to prefer impellers with a small internal volume for foaming because they improve bubble dispersion and mixing of surface-active agents. These allow the manufacture of foams with a lower density, which has been shown to improve their texture and increase their mechanical strength. Kampf et al. (2003) found that longer whipping times narrowed the bubble size distribution. Commercially available electric hand blender was used for about 3–5 min to obtain consistent foam (Valenzuela & Aguilera 2013).
The drying rate of foamed product greatly depends on the foam characteristics such as foam density, foam expansion, foam stability or foam drainage volume. The influence of foaming parameters such as type of foaming agents, concentration of foaming agents, type of foam stabilizers, concentration of foam stabilizers and whipping time on the foam characteristics such as foam density, foam expansion and foam stability were investigated by various researchers were discussed. Addition of soy protein isolate at the rate of 10 g/100 g was found to be effective in producing low density foams in banana puree. The density of fresh banana puree was 0.904 g/ml before whipping. On addition of foaming agent and whipping for about 12 minutes produced foam of density 0.55 g/ml (Sankat & Castaigne 2004). It was also observed that the addition of gelatin as foaming agent in banana puree produced thermally stable foam, but produced a leathery and tough product due to case hardening. Hence, suggested that gelatin was not suitable to use in foam mat drying of fruit pulps. Bag et al. (2011) investigated that the low density foam can be produced on incorporation of more air. The higher the air in the foam, the higher is the whippability of pulp. Thuwapanichayanan et al. (2012) stated the influence of whipping time on foam density. The foam density reduced slowly with increase in whipping time. During whipping process, air is brought into contact with the pulp and encapsulated into bubbles by the liquid. This is responsible for the decrease in foam density as the whipping time increased. Ambekar et al. (2013) noticed a decrease in density from 1.2 g/cm$^3$ to 0.59 g/cm$^3$ during foam mat drying of potato puree after the addition of methyl cellulose as foaming agent. The drying of low density foam facilitated faster drying by rapid movement of moisture from inner core to the surface of foam which consecutively reduced the drying time. The addition of foaming agents to the Brazilian cherry pulp had a significant effect on the foamability of the product. It was observed that the bulk density decreased irrespective of concentration of foaming agent and a gentle decrease in density
was noted when albumen alone was used as foaming agent (Chaves et al 2013).

Foam expansion was described as the ability of foam to incorporate air into the structure of foam. The initial volume of fruit pulp and the final volume of foam were used to calculate the foam expansion. The lower density of foam also represents the higher foam expansion. It was observed that at lower concentration of foaming agent, the air bubbles were not stable, because the critical thickness required for interfacial film could not be formed (Karim & Wai 1999a). The whipping time was also found to have a direct influence on the foam expansion. The percentage of foam volume increased with whipping time up to a maximum and decreased due to excessive whipping which could cause bubbles to collapse (Raharitsifa et al 2006). Rajkumar et al. (2007c) observed that the percentage of foam expansion increased with increase in the concentration of foaming agents. The foam expands up to 20 min of whipping and after than it was found to remain constant. Widyastuti & Srianta (2011) observed an increase in foam expansion when the concentration of egg albumen was increased from 10% to 20%. This produced papaya pulp with highest foam expansion. The author also correlated the porosity of final product with the increased foam expansion, which caused lower surface area of the foamed pulp. At the same time, the foam volume decreased with higher pulp concentration. This was due to the increase in viscosity and consistency of the pulp. It was noted that the foam expansion increased with a decrease in total soluble solids content of papaya pulp from 11 to 9°Brix (Kandasamy et al 2012). Higher foam expansion indicated that more air was trapped in the foam. The addition of foaming agent reduced the surface tension and interfacial tension to form the interfacial film that exceeds the critical thickness.
Foam stability represents the foam syneresis or foam collapse as a function of time. The syneresis rate indicates the water holding capacity of foam. The foam without stabilizer exhibited the highest degree of syneresis. The rate of syneresis decreased with increase in the concentration of stabilizing agent. The open foam structure was found to have a direct influence on the rate of drying and ease of dried product removal from the tray. Foams with high drainage volume increased the drying time and reduced product quality (Karim & Wai 1999b). The incorporation high degree of aeration by excessive whipping could result in foam collapse by rupturing the bubble wall structure. This was due to the thinning of the liquid film between the foam bubbles. Figure 2.2 represents the liquid drainage from the foam cells. It was studied that whipping of bael pulp for 2 minutes along with GMS-MC resulted in stabilized foams. Also the foams with higher concentration of methyl cellulose exhibited less drainage as compared to lower concentration of methyl cellulose. It was reported that the foam stability was enhanced by increased total solid content of the food material. The drainage volume of foam was highly influenced by the thickness of the interface, foam size distribution, interface permeability and surface tension (Falade et al 2003). Foams are highly liable to film drainage, where the liquid flows between the dispersed cells, leaving the cells to be forced closer together, eventually forming a thin film (Damodaran 2005).
Widyastuti & Srianta (2011) described that the protein molecules in the pulp mixture formed a cohesive viscoelastic film by rapidly adsorbing on the air-liquid interface during whipping. They also stated that the hydrophilic groups of amino acids lowered the surface tension at interface of liquid and gas. This was observed when higher concentration of egg albumen was added as foaming agent to papaya pulp. It was seen that there was a direct relationship between foam density and the extent of syneresis. In other words, low density foams exhibited less syneresis as compared to high density foams. The film in air bubble gets steadily thinner until it breaks and the two adjacent cells coalesce into one larger cell, leads to instability of foams (Green et al 2013). Mechanical and thermal stability of foam is necessary for foam mat drying. The stable foams were produced using suitable foaming and stabilizing agents. When placed in the perforated tray the foam should be stiff enough to not flow through the orifices of the supporting grid.
2.2 FOAM MAT DRYING

Drying is an essential part of many food processing operations. Among various drying methods, foam mat drying is one of the unique methods developed for the drying juices or pulps. In foam mat drying, a liquid material is converted into stable foam by whipping; the foam is then spread as a thin sheet or mat and dried by means of hot air at atmospheric pressure. The drying is carried out to form a thin porous honey comb structure which is disintegrated to yield a free flowing powder. The large surface area of the tiny bubbles in the foam are exposed to the drying medium is the main cause of moisture removal. The rapid drying is due to the moisture movement by capillarity in the liquid films separating foam bubbles. The foaming renders the product extremely porous and more amenable to drying to its inner most layers (Sankat & Castaigne 2004).

Any fluid material could be dried by the foam mat drying method, provided it is capable of forming stable foam. The stable foam can be produced with the aid of foaming and stabilizing agents. The success of foam mat drying depends upon the production of stable and uniform foam. The foamed product can be dried and pulverized to get good quality powder. The dried product obtained from foam mat drying is of better quality, porous and can be easily reconstituted. The foam mat drying process was reported to be considerably cheaper than vacuum, freeze and spray drying methods. The foam mat drying uses lower temperature and shorter residence time due to increased surface area of foam and enormous increase in liquid gas interface. This resulted in rapid drying of foam than the liquid. Also the heat transfer is impeded by a large volume of gas present in the foamed mass. Heated air is normally employed in foam mat drying process, whereas Muthukumaran (2007) utilized the advantages of both freeze drying and foam-mat drying to
produce better quality egg white powder. Raharitsifa & Ratti (2010a) also observed that the process time got reduced when foamed apple juice was dried by freeze drying. The lower density of foamed materials decreased weight load to the dryer.

Foam mat drying was undertaken for conversion of fruit pulp into foam and dried further to make ready to serve fruit bars. The authors also recommended for commercialization of this process in the food industry as the process is uncomplicated and easily accessible. Foam mat drying was employed for various fruit pulps like Apple (Raharitsifa et al 2006), Bael (Bag et al 2011), Blackcurrant (Zheng et al 2011), Papaya (Kandasamy et al 2012), Banana (Falade & Okocha 2012), Pineapple (Kadam et al 2012), Tomato (Balasubramanian et al 2012), Sea buckthorn (Kaushal et al 2013), Cherry (Chaves et al 2013), Mango (Wilson et al 2014). In addition to fruit pulps, foam mat drying was also utilized for drying of other products such as Soy milk (Akintoye & Oguntunde 1991), Cowpea (Falade et al 2003), Carrageenan (Djaeni et al 2013), Shrimp paste (Azizpour et al 2013). It was suggested that the application of foam drying technology has great potential in an industrial scale. Hence this process is described as an alternative to drum or spray drying and more applicable in smaller scale, less capital intensive food industries.

Foam mat drying was also employed for the production of egg powder from egg albumen. One kg of egg white was made into foam with a stirrer rotating at a speed of 1000-1300 rpm and the foam was dried in a cross flow dryer at 50-60°C for 10 to 15 min. The total solids content of the egg albumin ranged from 24 to 26 per cent. Proximate composition, solubility and organoleptic scores of egg powder prepared by foam-mat drying were comparable to the commercially available spray dried sample (Satyanarayana Rao et al 1987). During the studies on foam-mat drying of cowpea, various
concentrations of glycerol monostearate (GMS) and egg albumin were incorporated into cowpea paste of different solid concentration. The paste was whipped for different times such as 3, 6, 9, 12, 15, 18 and 21 min. Cowpea foams were dried at 60°C for 48 min. Foam density decreased with decrease in total solids of cowpea paste. Minimum foam densities were obtained in cowpea foams with glycerol monostearate and egg albumin after 9 and 21 min of whipping, respectively (Falade et al 2003). Krasaekoopt & Bhatia (2012) studied the foam mat drying of yogurt. The mixture of plain yogurt and foaming agent were blended by using high speed mixer for 5, 7, 9 and 12 min. The yogurt foam had a very high foam stability, low foam density and high foam expansion. Egg albumen of 3 percent with the mixing time of 12 min provided better foam characteristics. The highest viscosity product was obtained when 60°C yogurt powders was used. Sensory evaluation showed no significant difference in the quality attributes of akara produced from fresh and reconstituted GMS-stabilized cowpea powders. During the study on foam mat drying of shrimp, the incorporation of 0.2% w/w xanthan gum with 3.5:1 w/w water: shrimp ratio was found to produce foam of better characteristics. The authors concluded that foam density and stability increased with increasing concentration of xanthan gum. However, increasing water to shrimp ratio caused a decrease in foam density and stability (Azizpour et al 2013).

2.3 RESPONSE SURFACE METHODOLOGY

Design of Experiment is systematic method to determine the relationship between independent and dependent parameters. In other words, it is used to find cause-and-effect relationships. The individual and interaction effects are needed to manage process inputs in order to optimize the output. The optimization of process parameters can be done by various techniques. Response Surface Methodology was considered as one of the effective and
commonly used techniques for purpose of optimization. Response surface methodology is a collection of statistical and mathematical technique useful for developing, improving and optimizing processes. A number of factors are responsible for the production of stable foam. A central composite rotatable design (CCRD) was used to find the interaction effect of foaming agent (glycerol mono stearate), foam stabilizer (methyl cellulose), pulp concentration, and whipping time on the quality of bael foam (Bag et al 2011). Similarly, central composite design (CCD) was used to find the effect of independent variables such as concentration of Arabic gum, puree to water ratio and whipping time on the foam density and foam drainage volume. During the microwave foam mat drying of honeysuckle pulp, the independent variables such as microwave power, load mass and thickness of pulp were considered and its effect on biochemical properties of was investigated using central composite design (Sun et al 2012). Box-Behnken Design (BBD) was used as the common tool for optimization of three independent variables. The processing parameters of foam mat drying of tomato pulp were optimized by using Box–Behnken design with a second order polynomial built by response surface methodology. The fitted equations were expressed as contour plots which were generated using Design expert® software (Balasubramanian et al 2012).

2.4 DRYING CHARACTERISTICs

The following literature shows the effect of foaming, foam thickness and drying temperature on drying characteristics of various foamed fruit pulps. Chandak & Chivate (1972) investigated the drying characteristics of foam mat drying of coffee extract with varying thickness of 2, 3, 5, 7, 10 and 15 mm. They reported that the minimum foam thickness required minimal air flow rate and lower temperature for drying. Whereas, higher foam
thickness such as 7, 10 and 15 mm needed higher drying temperature and also took longer time to reach the final moisture content. The foam thickness of 5 mm dried at 80°C with an airflow rate of 1045 kg/h m² was suggested for the production of foam dried coffee powder. Drying time was found to vary approximately with square of foam thickness within limits and square root of the bubble size. Hence, it is recommended to control the foam mat thickness while drying. The foamed apple pulp exposed to three levels of drying air temperatures (50, 65 and 80°C) and air velocities (1.0, 1.5 and 2.0 m/s) in a cabinet dryer. It was found that drying air temperature, air velocity and foam thickness had significant effect on drying characteristics of the foamed and dried apple powder (Mishra et al 2002).

Rajkumar et al. (2007a) experimented drying of foamed mango pulp in a continuous type foam mat dryer. It took 35 min to dry the foamed pulps from the initial moisture content of 79.75 % (w.b) to a final moisture content of 5.56 (w.b). However, the fresh non-aerated mango pulp took 75 min to reach a final moisture content of 6.22 % (w.b). The results indicated that fresh non-aerated pulp took double the time of foamed mango pulp due to dense physical structure leading to slow moisture reduction and also concluded that the porous nature of the foamed structure was responsible for the reduced drying time. Foam mat drying of foamed mango pulps was carried out using the optimized level such as egg albumen (10%) with methyl cellulose (0.5%) at three foam thicknesses such as 1, 2 and 3 mm and three drying temperatures of 60, 65 and 70°C in a batch type convection hot air dryer. It was observed that the biochemical changes were comparatively higher in 2 and 3 mm thick foam dried at 65 and 70°C than in 1mm thick foam dried at 60°C. The results indicated that the mango pulps dried with lower foam thickness dried at a faster rate as compared to the foamed mango pulps dried with higher foam thickness. The reason behind the rapid drying was due
to the complete exposure of mango pulps at lower foam thickness to the drying air (Rajkumar et al 2007c).

Similarly during the study of foam mat drying banana, it was stated that the drying time required for reducing the final moisture content to about 0.03 kg/kg db was 120 and 300 min for the initial foam densities of 0.3 and 0.5 g/cm$^3$. The required drying time was much longer than 540 min for initial foam density of above 0.5 g/cm$^3$ (Thuwapanichayanan et al 2008). Foamed and non-foamed apple juice samples having different thickness and different initial weight were frozen at -40°C and then freeze dried at 20°C during 48 h under vacuum. Foaming reduced process time when done at equal sample thickness. However, lower density of foamed materials decreases weight load to the dryer. Foamed juice not only showed higher drying rate and higher dryer throughput than non-foamed during freeze-drying (Raharitsifa & Ratti 2010a). During drying of foamed tomato juice at 60, 65 and 70°C in a hot air dryer, almost 30 min reduction in drying time for every 5°C increase in drying temperature was observed. It was evident that the air temperature had an important effect on foam mat drying. A decrease in moisture content was noticed with increase in foaming agent upto 15% (w/w) during foam mat drying of tomato juice. The author used 5 thin layer drying models to predict the drying constants and concluded that the logarithmic model had the highest $R^2$ value of 0.985 indicating good fit (Kadam & Balasubramanian 2011).

Foam mat drying of papaya pulp was dried at different temperatures with foam thickness of 2, 4, 6 and 8 mm. The drying time for papaya foams of different thickness were 1, 2, 4 and 5 h respectively to reach the final moisture content 4.5 % dry basis. The drying time increased with the foam thickness and decreased with temperature. This was correlated to the fact that moisture migration was higher in foam of less thickness than high
thickness foams. It was also observed that the rate of moisture removal in the non-foamed papaya pulp was less than the foamed papaya pulp due to the fact that the water in the foamed pulp was present in thin films making it easily vaporizable (Kandasamy et al. 2012).

Plantain and banana foams incorporated with 0.015% GMS were dried at 60°C, 70°C and 80°C. The drying of plantain foam took 3.5, 3.1 and 2.5 hours whereas drying of banana foam took 3, 2.5 and 2.1 hours at 60°C, 70°C and 80°C, respectively. The dried samples obtained at all the drying temperatures were acceptable with minimal loss of colour (Falade & Okocha 2012). Drying of apple foam was carried out in a cabinet dryer using hot air at a temperature of 60°C. The moisture content of apple foam decreased from an initial moisture of 3.65 kg water / kg dry matter to a final moisture content of 0.13 kg water / kg dry matter. The apple juice without aeration and gelatine took more time (5.67 h) to reach the same final moisture content. The shortest drying time of 2.83 h was reached with 1.5% gelatine and 7 min of whipping. These results implied that diffusion of water through foams was much easier and became faster with low density foams, resulting in lower drying times. The decrease in drying rate during the second falling stage could be associated with the moment when gelification takes place, and sugar and pectin molecules concentrate and compete for water (Valenzuela & Aguilera 2013).

Djaeni et al. (2013) proved that the addition of foaming agent and stabilizer enhanced the drying rate. Egg albumin as foaming agent to carrageenan generated the porous structure of foam and opened up the gel structure in carrageenan. Similarly, the addition of methyl cellulose stabilized the foam structure which facilitated higher moisture diffusion to the surface during drying. For drying of carrageenan of same thickness, foaming was found to have more significant effect compared to carrageenan drying without
foam. It was noticed that the moisture content decreases exponentially throughout the drying period of carrageenan and higher drying temperature resulted in higher rate of moisture diffusion and surface evaporation. For instance, at air temperature of 80 °C with drying time of 120 min, more than 95% of moisture content was removed. Azizpour et al. (2013) studied the influence of drying temperature on the drying characteristics of shrimp foams. The moisture ratio of foamed shrimp reduced with increased drying time. The time required for drying of shrimp foam was 135, 105 and 80 min at 50, 60 and 70°C respectively to reduce from the initial moisture content of 2335 % (dry basis) to the final moisture content of 7.25 % (dry basis). The statistical results of the different models showed that Midilli–Kucuk model was the best fitting model with highest value of $R^2$ and the lowest value of $\chi^2$ and RMSE at all drying temperatures.

Ambekar et al. (2013) performed foam mat drying of passion fruit pulp under isothermal conditions at different inlet air temperatures of 50–80°C in convective hot air dryer. It was observed that at higher moisture content and increased temperature, drying rate was increased considerably compared to lower moisture content, which was almost negligible towards the end. The authors examined 9 semi-theoretical drying models to describe the drying curves of passion fruit pulp at different temperatures. Moisture ratio was found to decrease exponentially with time and 60°C was found to be the optimum temperature. Henderson and Pabis model gave good fit for the experimental data ($R^2= 0.99$) and also gave good correlation for modeling constants and temperature. Similarly during the foam mat drying of carrageenan with egg albumen, higher moisture diffusivity was observed for foamed products compared to the non-foamed products. The drying time reduced with increase in moisture diffusivity (Djanei et al 2014).
2.5 EFFECTIVE MOISTURE DIFFUSIVITY

The moisture diffusivity of any food material symbolizes the intrinsic mass transport property of moisture which comprises molecular diffusion, liquid diffusion, vapour diffusion, hydrodynamic flow and other possible mass transfer mechanics (Karanthanos & Villalobos G 1990). The following literature shows the effect of foaming and drying temperature on effective moisture diffusivity. For food materials, the suggested values of $D_{\text{eff}}$ lie between the ranges of $10^{-11}$ to $10^{-9} \text{ m}^2/\text{s}$ (Babalis & Belessiotis 2004). Thuwapanichayanan et al. (2008) obtained a non-linear relationship between logarithms of moisture ratio versus drying time of banana foam mats. The non-linearity of the plots indicated the variation in effective diffusivity with moisture content. The effective diffusivity increased with decreasing moisture content at the initial stage of drying, due to rapid increase in product temperature. As drying progressed, the effective diffusivity decreased with decreasing moisture content. The effective diffusivity was also found to decrease from $2.34 \times 10^{-9}$ to $1.02 \times 10^{-9} \text{ m}^2/\text{s}$ for an increase in foam density from 0.3 to 0.7 g/cm$^3$. The values of effective moisture diffusivity were related with the density of banana foams. It was found that $D_{\text{eff}}$ values were relatively lower for the high density banana foam than for the low density foam. The porous structure of foam provided less diffusional flux resistance and thus greatly facilitated the moisture transport which resulted in high value of $D_{\text{eff}}$.

A new initiative on osmo-foam drying of mango pulp was executed. The mango slices was given osmotic treatment by immersing the mango samples into sugar syrup solution. The osmosed mango samples were blended along with foam stabilizer and dried. The moisture diffusivities of non-osmosed sample were found to be higher than the osmosed sample. This was due to the fact that the solute uptake would have reduced the porosity and
in turn moisture adsorption. Similarly, the mango pulp incorporated with foam stabilizers showed higher moisture diffusivities than sample without foam stabilizers. The author concluded that more the porous material, the higher was the diffusion coefficient. The moisture diffusivity of the powders ranged from $2.68 \times 10^{-7}$ to $2.58 \times 10^{-6}$ m$^2$/s (Alakali et al. 2009). No significant effect was observed on $D_{\text{eff}}$ values of foam mat dried tomato powder with respect to varying concentrations of egg albumen. However, the maximum $R^2$ value of 0.985 was observed in 15% egg albumen incorporated tomato powder dried at 65°C and minimum $R^2$ value of 0.891 was observed at 60°C. The effective moisture diffusivity ($D_{\text{eff}}$) was determined using the method of slopes. Effective moisture diffusivity of foam mat tomato juice ranged from $2.026 \times 10^{-8}$ to $3.039 \times 10^{-8}$ m$^2$/s. It was also stated that the moisture diffusivity of tomato juice increased with increase in drying air temperature from 60-70°C (Kadam & Balasubramanian 2011).

In case of foam mat drying of shrimp, it was observed that the $D_{\text{eff}}$ increased with the increase of drying temperature from 50-70°C. The average values of effective diffusivity of dried shrimp samples varied in the range of 3.24–6.49×10$^{-9}$ m$^2$/s (Azizpour et al. 2013). It was evident that the drying air temperature has prominent effect on the drying rate which subsequently affected the effective diffusion coefficient. The effective diffusivity increased with increase in drying temperature due to the increase in the vapour pressure inside the grape sample. The $D_{\text{eff}}$ values of foamed grape concentrate with non-foamed grape concentrate were compared and recorded a higher value of $D_{\text{eff}}$ for foamed grape concentrate. The higher values of $D_{\text{eff}}$ were due to increase in air bubble formation resulting in increase in moisture removal in foamed samples (Gupta & Alam 2014).
2.6 THIN LAYER DRYING MODELS

The empirical and semi-theoretical models were used to describe the drying kinetics. The experimental moisture ratio values were fitted to the drying equations and the best fit was analysed. Drying curves obtained during thin layer drying of apples were fitted with 14 different drying models to find the best fit. Midilli model was found to be the most suitable model to predict the moisture content of the product at any time of drying between drying air temperatures of 60 and 80 °C and velocities of 1.0 and 3.0 m/s (Menges & Ertekin 2006). The drying kinetics was investigated for foamed and non foamed grape concentrate. For the selection of best fitting models, the authors selected six drying models and the best model describing the drying characteristics of the product was chosen as the model with highest degree of determination and reduced error. The model coefficients for each model was determined using non-linear regression techniques using SPSS 7.5. For the foamed sample, two term exponential and logarithmic model was found to be the best fitting model describing the drying kinetics of the foamed grape concentrate (Gupta & Alam 2014). Similarly thin layer infrared drying of green bean was performed and the experimental results of moisture ratio variation with drying time were fitted to five thin layer drying models. Among the thin-layer drying models, the Midilli and Aghbashlo models were found to represent the drying kinetics of green bean slices with high R² values. The model fitting and statistical analysis were carried out using Using Statistica 8.0.550 (StatSoft Inc., Tulsa, USA) software (Doymaz et al 2015).

2.7 ANALYSIS OF FOOD POWDERS

Processing and successive storage causes change in characteristics of food. Experimental conditions can trigger reaction
mechanisms that lead to the degradation of quality aspects of the food (Kadam et al 2005). The studies of food properties are required for quality assessment. The following literature shows the physical, chemical and structural properties of various food powders obtained different drying methods.

The various properties of foam freeze dried apple powder were compared with non-foamed freeze dried powder. Freeze dried juice powder dissolved instantaneously as compared with foamed freeze-dried products. Also non-foamed freeze-dried juice powder retained more ascorbic acid possibly due to the addition of macromolecules such as egg albumen or methyl cellulose to the juice. However, foam-mat juice powders exhibited higher stability during storage at 20°C whereas, freeze-dried juice powder stored at this temperature collapsed showing a decrease in solubility and a marked colour change. Freeze-dried juice stored at this temperature collapsed showing a decrease in solubility and a noticeable colour change (Raharitsifa & Ratti 2010b).

The average values of bulk and tapped bulk densities of sun-dried, solar-dried and foam-mat-dried okra were estimated by Falade & Omojola (2010). The bulk and tapped densities of sun-dried, solar-dried and foam-mat-dried okra were found to be 800 and 950, 715 and 765, 355 and 367 kg/m³, respectively. The mass load of foam mat dryer was usually lesser because density of foamed material was lower than of non-foamed ones. The redness value in foam dried tomato powder varied with the concentration of foaming agent.

Kadam & Balasubramanian (2011) observed that the redness value reduced with the sample having higher concentration of foaming agent (20% egg albumen) compared with lower level of foaming agent. Also noted
that the L*, a*, b* values were highly significant with drying temperatures. The tomato powder were completely dissolved within 10 min and obtained tomato juice which was at par with fresh tomato. The rehydration ratio was found to 1:12. Kadam et al. (2011) also performed the quality analysis of foam dried mandarin powder stored for a period of 6 months. From the study it was clearly concluded that the foam mat drying of mandarin was the best option to preserve the product without much quality degradation.

Flowability and cohesiveness of powders were estimated using Carr index (CI) and Hausner ratio (HR). The Hausner ratio and Carr Index of apple powders varied from 1.32 to 1.43 and 24.0-30.0, respectively. The flowability of apple puree powder was classified as intermediate flowability and fair flowability, based on the classification of powders. The foam freeze-dried apple puree without maltodextrin was found to have high cohesiveness with Hausner ratio of above 1.4. The other powder properties such as hygroscopicity, solubility were also studied. Foaming before drying produced less hygroscopic powders with low moisture content and water activity. The solubility of non-foamed freeze-dried apple puree was two times lower than observed for other powders (Jakubczyka et al 2011).

During the quality evaluation of banana foam mat, it was found to be highly hygroscopic and the texture was very sensitive to moisture migration. The increase in moisture content of banana foam mat during adsorption decreased the number of peaks and initial slopes, implying less crispiness, but the maximum force increased, indicating a tough texture. The banana foam mats for all densities lost definitely their crispy texture at moisture content of 0.078 kg/kg db (Thuwapanichayananan et al 2012).
Moisture absorption capacity of plantains and cooking banana powders were studied by Falade & Okocha (2012). The water absorption capacity indicated the level of water required for rehydration. The values ranged from 56.75 to 63.22% and 58.66 to 64.02%. The fruit powders dried at higher temperature (80°C) showed more water absorption than those dried at lower temperature (60°C). The authors concluded that the higher drying air temperatures exhibited lower moisture contents which would absorb more water. It was also found that powders with lower quantity of foaming agent absorbed more water compared to those with higher levels of foaming agent.

The biochemical and microbiological properties of foam dried pineapple powder was dealt by Kadam et al. (2012). Moisture content of pineapple powder were reduced from initial value of 822 g/g dry mass to final moisture content of 3–3.5% d.b. An increase in the total sugar content and reducing sugar was observed with the addition of foaming agents, where ascorbic acid content was reduced in the pineapple powder. When compared with the fresh pineapple pulp, the foam dried powder did not show any fungal or bacterial growth. It was reported that the reduction of microbial load in dried powder was due to the effectiveness of the drying process.

Sharma et al. (2013) noticed an increase in bulk density and decrease in water solubility and water absorption index, with a decrease in particle size of mango powder. It was also concluded that the particle size of fruit powder had highly significant effect on sensory parameters.

The colour components of foam dried Brazilian cherry powder were investigated. The lightness (L*) value of rehydrated sample showed decreased trend. The author also stated that the reduction in lightness was due to the higher solid contents in the reconstituted samples from the foaming
agents. The red colour (a*) of fresh juice was not significantly affected by the addition of foaming agent whereas the yellowness (b*) increased with higher concentrations of foaming agents. The physical properties of foam dried mango powder was analysed at 0, 2, 4 and 6 month period at ambient storage conditions. The water solubility of foam dried powder ranged between 51.83 and 66.65 %. Water absorption index was ranged from 244.82 to 390.94 %. The solubility increased with increase in temperature whereas, water absorption index decreased with decrease in temperature. Concentration of egg albumen had significant effect on the absorption index and found to decrease with increasing concentration. The author also studied the physicochemical and sensorial properties of foam dried Brazilian cherry powder. The soluble solids content and pH was found an increasing trend with increasing concentrations of foaming agents. The titratable acidity reduced with the increased concentrations of foaming agents. The authors examined that the titratable acidity of albumin and albumin + Superliga® had titratable acidity of 1.49 and 1.51 at 4% concentration and 1.38 and 1.39 % at 10 % concentration respectively. It indicated that the reduction in titratable acidity ranged from 6.5 to 15 % on addition of foaming agents. Therefore, the reduction was found useful for adjusting juice taste. During the sensory evaluation of foam dried Brazilian cherry powder, the sample with albumin + Superliga® had increased flavour and consistency of the juice and was preferred by the consumers. This was due to the beneficial effect of the stabilizing agent Superliga® on the flavour of the juice made from Brazilian cherry powder (Chaves et al 2013).

Kaushal et al. (2013) added sulphur dioxide to sea buckthorn foam and produced fruit leather. It was noticed that the addition of sulphur dioxide to the sea buckthorn foam did not cause any undesirable effect to the final product. From the results of sensory evaluation, it was inferred that for product treated with and without sulphur dioxide were at par with each other.
The fruit leather prepared from sulphur treated sample exhibited better retention of vitamin C and carotene up to six months of storage period.

Ambekar et al. (2013) assessed the quality of foam dried passion fruit powder and found a direct relationship between non-enzymatic browning index and drying temperature. Use of higher drying temperature induced browning of product due to non-enzymatic browning or Maillard reaction, with decrease in moisture content. The formation of compounds related to non-enzymatic browning index was found to be higher at 80°C and also found significant difference among the samples at all drying temperature. However, the antioxidant capacity and total phenolic content of dried sample in comparison with untreated pulp sample showed increase with increase in air-drying temperature.

In case of foamed grape concentrate, the lightness value was higher than non-foamed grape concentrate. The lightness of non-foamed grape concentrate reduced linearly and also darkened with drying temperature and time. Increase in redness value was observed for both samples which were due to non-enzymatic browning of product. Total colour difference (ΔE) was also increased with drying time and temp. But it was observed that ΔE reached a minimum for foamed grape powder when compared to non-foamed grape powder. Chroma value decreased for non-foamed grape sample whereas increased for foamed grape powder (Gupta & Alam 2014).

The biochemical properties of foam dried mango powder were analysed at 0, 2, 4 and 6 months period shelf life at ambient storage conditions. It was found that the water soluble index and water absorption index of mango powder decreased with storage period. It was also observed that the moisture content, total acid, non-enzymatic browning and calcium
content increased with storage period whereas total sugars, reducing sugars, ascorbic acid, pH, total carotenes, iron and phosphorus of mango powder decreased with storage period. 5-hydroxymethylfurfural (HMF) was formed during Maillard reaction. HMF of the mango powder ranged between 11.98 and 86.01 µg/100g. It was found that the samples dried at 85°C had the highest HMF content followed by 75 and 65°C. It was due to the fact that at high temperatures, degradation of sucrose occurred and resulted in an increase in the reducing sugar which underwent HMF formation. Throughout the storage period and even after 6 months, no bacterial or fungal contamination was observed which made the product suitable for domestic and commercial use (Wilson et al 2014).

2.8 POWDER CHARACTERISATION

The microstructure of dried foam was studied by different researchers. The porous foam characteristics of dried banana foam such as pore diameter and pore area were studied using image analysis software (ImagePro+ 5.0, USA). The pore diameters of samples with initial foam density of 0.3 g/cm³ were larger ranged between 240 and 480 µm. At the same time, the samples with 0.5 g/cm³ foam density did not had pores larger than 400 µm. The void area fraction of the samples were found to be 22% and 18% for initial foam densities of 0.3 g/cm³ and 0.5 g/cm³ when dried at a temperature of 60°C (Thuwapanichayanan et al 2008).

The Fourier Transform Infrared analysis of dried guava powders revealed the characteristic signals of polygalacturonic acid. They observed a higher ratio of peak areas for lyophilized powder than that of hot air dried guava powder, indicated a larger fraction of esterified groups in pectin contained into the freeze dried guava powder. Also it was revealed that hot air
drying caused de-esterification and a partial depolymerisation of pectin which indicated that hot air drying was more aggressive on the structural components of guava (Osorio et al 2011).

Thuwapanichayanan et al. (2012) studied the microstructure and distribution of pore size in dried banana foams using Scanning Electron Microscope (SEM). The micrographs were taken at an accelerating voltage of 10 kV and a magnification of 35 times. It was observed that the microstructure of dried banana foam with soy protein isolate (SPI) was more compact and the void fraction was also much lower than that of sample treated with egg albumen (EA) and whey protein (WPC). This compact structure and lower void fraction resulted in a greater difficulty for the moisture to travel from an inner space to the surface. Also the pores were more elongated in pulp treated with Egg Albumen and soy protein isolate than those of treated with whey protein concentrate. The elongated structure was due to foam collapse and excessive shrinkage in the foams.

Also the IR spectra were determined for freeze dried guava, sapota and papaya powder. The IR spectra of dehydrated fruit powders uncovered the presence of different functional groups. The observed peak at 1054 cm\(^{-1}\) in papaya and guava powder indicated the presence of esters. The high absorbance band between 250 and 950 cm\(^{-1}\) wavenumber values reported the presence of carbohydrates. The presence of carboxylic acid may be related to polygalacturonic acid and other acids (Athmaselvi et al 2014).

Djanei et al. (2014) studied the physical structure of the carrageenan powder using Transmission Electron Microscope (TEM). The images of carrageenan-egg foam dried powder and non-foamed powder were compared and the former sample showed porous structure which was clearly
identified by TEM analysis. The highly porous structure improved the surface area for drying as well as water evaporation. The pore diameter of dry banana foam was assessed from a binary image of the SEM micrograph. Foam dried banana with initial density of 0.31 g/cm³ had small and large pores in the range of 7–120 µm and greater than 120 µm, which accounted for 63 and 37% of the total pores, respectively. For the densities of 0.26 and 0.21 g/cm³, the relative amount of small pores accounted for 57 and 43%, respectively. The void area fractions for banana foam densities of 0.21, 0.26, and 0.31 g/cm³ obtained by counting the pore area of the binary images were 31, 26, and 22 %, respectively. The shape of the pores for the dried banana foam at densities of 0.21 and 0.26 g/cm³ was rather elongated. However, at a banana foam density of 0.31 g/cm³, the pore shape was rather circular. The author summarized that the different arrangements of the solid matrix in the porous material and provided different length scales for the travel path of the fluid (Prakotmak et al 2014).

The morphological and structural characteristics foam dried yacon juice and concentrated yacon juice was examined. It was reported that the juice concentration or the drying conditions does not have influence on the powder morphology, however, the micrographs indicated that all samples had cavities in their structure which might probably from the pore space left by the air bubbles (Franco et al 2016).

### 2.9 MODEL FOOD SYSTEMS

The spray dried apple fiber powder was incorporated into bread, cookies and muffins by Chen et al. (1988). The study revealed the apple fiber powder (4%) incorporated bread showed reduction in loaf volume by 14%. However, the addition of apple fiber powder (4%) to cookie and muffins does
not had any adverse effect on its quality. Ganjyal et al. (2005) incorporated 20% by weight sapodilla powder into coconut burfi, milk shake, ice cream, rava laddu and banana milk shake and also evaluated the sensory analysis. Colour, texture, flavour, taste and overall acceptability of the food products were studied. Dried apple skin powder was incorporated into model food system of muffins. The total dietary fibre, total phenolic content, and total antioxidant capacity of muffins were evaluated and a positive correlation to the amount of apple skin powder was observed. Hence, it was suggested that apple skin powder could be an alternative dietary fibre source for bakery products (Rupasinghe et al 2008).

A study was conducted by Cam et al. (2013) to improve the functional properties of ice cream by incorporating pomegranate peel phenolics and pomegranate seed oil. Similarly, vacuum dried apple pomace powder was incorporated in extruded oat-based cereal product and no significant difference was found in overall acceptability from sensory evaluation. Physicochemical and sensory properties were evaluated for the model food product and also inferred that increased apple pomace powder in extruded product does not affect textural properties. Higher quantity of apple pomace powder resulted in darker product (Liu 2014).

Investigation was carried out on physico-chemical, nutritional quality and sensory evaluation of ice cream made with different types of milk which was fortified with guava pulp. From the sensory analysis it was found that ice cream made from mixture of cow milk and guava pulp scored higher sensory ratings (Patel & Amin 2015). The effect partial replacement of wheat flour with pumpkin seed flour in muffins was investigated by Białek et al. (2015). The sensory analysis was carried out to study the consumer acceptance from children aged 7–12 years. The study showed that muffins incorporated
with 33% of pumpkin seed flour was accepted by more 71 % of the children as ‘tasty’ and ‘very tasty’. The author also concluded that the experimental muffin formulation resulted in a novel product suitable for children’s nutrition. Muffins were also prepared by incorporating date seed flour hydrolysate or date seed flour into the formulation. Sensory evaluation was performed by an untrained panel of 15 adults. Five point scaling system (Like very much [5]; Like [4]; Neither like nor dislike [3]; Dislike [2]; Dislike very much [1]) was used to evaluate colour, texture and flavour. Muffins prepared using date seed flour hydrolysate was found to be highly acceptable in terms of texture and flavour, whereas date seed flour enriched muffins were dark brown in colour and had a lower sensory acceptance (Ambigaipalan & Shahidi 2015).

2.10 STATISTICAL ANALYSIS

Different statistical soft wares were used by researchers to determine the level of significance of the mean values. Raharitsifa & Ratti (2010a) employed SAS (SAS Institute Inc., Cary, NC) for conducting the statistical analysis. The foam mat freeze drying experimental data were subjected to statistical analysis using general linear model procedure of and a least significant difference test with a confidence interval of 95% was used to compare the means.

Kadam et al. (2012) used AgRes Statistical Software, Version 7.01 (Pascal InternationalSoftware Solution, Boston, MA, USA) for the statistical analysis. The effect of different foaming agents, concentrations of foaming agent and different temperatures were studied using three-way ANOVA, and the means were compared using least significant difference.
Zheng et al. (2013) utilized SAS statistical software (SAS, version 9.0, SAS Institute Inc., Cary, NC) to analyse the variance in the data using analysis of variance. During the evaluation of physico chemical properties of foam dried sour cherry, the experimental data were subjected to statistical analysis using the SPSS software (version 16.0.0 software, SPSS Inc., Chicago, IL). ANOVA and Duncan’s Multiple Range Test was used to determine the significant differences of the mean values at 95% significance level (Abbasi & Azizpour 2016).

2.11 SUMMARY OF LITERATURE REVIEW

The content of this chapter is condensed below based on the gaps and scopes in the literature: Many types of foaming agents were utilized during the process of foam mat drying. Proteins are considered to possess better foamability and higher foam stability, which allow rapid adsorption at the air-water interface leading to the formation of a coherent elastic adsorbed layer (Dickinson 1998). Similarly, polysaccharides were preferred as the stabilizing agent. Being hydrophilic in nature, the polysaccharides do not adsorb at the interface but enhances the stability of foam by a thickening or a gelling effect of the aqueous solution (Klitzing & Muller 2002). Any fluid material could be dried to form porous powder using foam mat drying method, provided the fluid is capable of forming stable foam. Stable foam can be achieved with the aid of foaming and stabilizing agents (Kadam et al 2010). Whipping, sparging and shaking are the three methods of foam generation, in which whipping resulted in uniform dispersion of the gas/air when compared with sparging and shaking. Electric hand blender was used for about 3–5 min to obtain consistent foam. The researchers investigated the foam characteristics, as the success of foam mat drying depends upon the stable and uniform foam. The foam characteristics such as foam density, foam expansion,
foam stability were analysed under different conditions. For the drying of foam, hot air drying was widely used and also combination of foam mat freeze drying was performed. The drying characteristics and moisture diffusivity under different temperatures for different drying methods was investigated. Thin layer drying models and best suitable models for the drying process were studied. Also the variety of dried products was incorporated into the model food systems and studies on consumer acceptability were also done. Foam mat drying was employed for various fruit pulps like Soy milk (Akintoye & Oguntunde 1991), Cowpea (Falade et al 2003), Bael (Bag et al 2011), Papaya (Kandasamy et al 2012), Banana (Falade & Okocha 2012), Pineapple (Kadam et al 2012), Sea buckthorn (Kaushal et al 2013), Carrageenan (Djaeni et al 2013), Mango (Wilson et al 2014). Though many methods were available for the production of fruit powder, from the above literature survey, it was concluded that foam mat drying could be very well practiced for drying of muskmelon pulp for the production of muskmelon powder.

2.12 PROBLEM IDENTIFICATION

For the past years, different preservation methods have been carried out to improve the shelf life of muskmelon either in their fresh form or processed form. Being a climacteric fruit, respiration starts immediately after harvest and also during the seasonal period, the surplus quantity of muskmelon goes a waste due to improper storage and processing conditions. Also whole muskmelon can be stored for up to only 5-15 days at 5°C. Minimal processing of muskmelon into fresh cut product also found to show lesser shelf life. Drying of muskmelon has been carried in the form of osmotic dehydration. Though it partially removes the moisture content from the product during osmotic dehydration, it is not suitable for a fully ripened muskmelon and also recycling of huge quantity of osmotic solution is a challenging issue during
osmotic dehydration. Hence there is a need for a drying method which is cheap, simple and effective. Similarly, foam mat drying has been used for variety of fruit pulps and also other products such as soy milk, cowpea, and shrimp. Researchers have experimented foam mat drying of various products and reported the quality characteristics of foam dried powders. However, a comprehensive research on optimization of foaming properties, drying and characterization of foam dried powders was lagged in previous research. Also very limited researches on the production of muskmelon powder and foam mat drying of muskmelon have been reported.

Hence, in this current study an attempt has been made to perform the foam mat drying of muskmelon. In this present research, foamed muskmelon was produced using different foaming agents. The foam characteristics depend on the foaming parameters such as type and concentration of foaming agents, concentration of stabilizing agents, and whipping time. The foaming agents and stabilizing agents were selected after complete review of literatures. The effect of foaming parameters on foam density, foam expansion and foam drainage volume were investigated and foaming parameters are optimized using response surface methodology. The optimized foam parameters are used to produce the foam which is further dried using hot air under three different temperatures and foam dried muskmelon powder was obtained. Also the unfoamed muskmelon pulp was also dried under the same conditions to compare the results with the foamed muskmelon pulp. The drying characteristics, moisture diffusivity were determined and also the best fitting thin layer drying models were also investigated. Study on the quality parameter and morphology of both unfoamed and foamed muskmelon powder were carried out. Finally, the foam dried muskmelon powder of better quality was incorporated in ice cream and cake. The sensory evaluation of the two products was carried out.
2.13 OBJECTIVES

The following are the objectives of this research

1. To optimize and study the effect of foaming parameters such as concentration of foaming agents, concentration of foam stabilizer and whipping time based on foaming properties such as foam density, foam expansion and foam drainage volume of muskmelon pulp using response surface methodology

2. To study the drying characteristics of the unfoamed and foamed muskmelon pulp during different drying temperatures and to obtain the muskmelon powder

3. To select the suitable models from the selected 8 thin layer drying models and also to determine the effective moisture diffusivity and activation energy of the unfoamed and foamed muskmelon pulp

4. To analyse and compare the physico-chemical properties of foam dried muskmelon powder with un-foamed muskmelon powder and to study the morphology of foam dried muskmelon powder

5. To incorporate the foam dried muskmelon powder in model food systems such as ice cream and muffins and to evaluate the consumer acceptance of the two model food products