CHAPTER-II

REVIEW OF LITERATURE

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2.1 Nutritional properties of pineapple

Pineapple (*Ananas comosus)* is a tropical fruit popularly known for its taste and nutritional benefits. Pineapple is becoming increasingly popular because of its many health benefits and nutritional composition. Pineapple comprises reasonable amounts of minerals (calcium and potassium), ascorbic acid (Vit. C), carbohydrates, and dietary fiber that are helpful for human health, support a healthy weight, and promote balanced nutrition. Pineapple is mainly grown in tropical and subtropical climates. After citrus fruits and bananas, it is the third most popular fruit worldwide, and demand continuously increases. Particularly in waste management and food-based product development, the pineapple sector has experienced tremendous growth. The fruit contains vital nutrients, dietary fiber, and bioactive substances. According to research, pineapple provides several health benefits, including antioxidant and anti-inflammatory effects, neurological system support, and digestive health (Ali et al., 2020).

2.2 Enzymatic activity of pineapple

Fresh pineapples are a good source of the enzyme Bromelain, a protein-tenderizing enzyme that helps in digestion and has many cosmetic applications (Hossain et al., 2015). Pineapple also naturally contains oxidative enzymes such as polyphenoloxidase (PPO) and peroxidase (POD). These enzymes cause enzymatic browning in the fruits and vegetables due to their reactions with atmospheric air. Enzymatic reactions cause several losses, such as color loss, flavor loss, and nutritional losses in fruits and vegetables, which may affect the overall quality of the food products. PPO and POD can catalyze different hydroxylation and oxidation reactions in fruits and vegetables, which can cause spoilage (Panigrahi et al., 2021). The conversion of this phenomenon ultimately causes the formation of melanins, which are responsible for undesirable changes in fresh produce. When phenolic chemicals are finally oxidized, they produce melanin compounds that are black, brown, or red, which causes color and nutrient loss.

Conventional thermal treatments are frequently used techniques to inactivate the enzymes and pathogens in juice processing. Thermal treatments may degrade fruit juices rich in heat-sensitive nutrients such as vitamin C, aroma, and flavor compounds (Chakraborty et al., 2014). In order to overcome the problems and reduce the nutritional losses, non-thermal electric field treatments are gaining attention in fresh juice or pulp processing units. In recent years, research on food technology has mainly focused on developing novel technologies as alternatives to conventional thermal treatments for processing fruit juices/pulp. Non-thermal plasma technologies are a preferable replacement for decontaminating and inactivating various enzymes in foods. A variety of technologies are widely applied in the processing and preservation of food. However, DBD plasma showed its effective approach for food processing because of its low operating costs, environmental friendliness, low temperature, and ease of fabrication.

2.3 Cold plasma treatments

Cold atmospheric plasma, a non-thermal plasma technology, is suggested as a possible substitute for conventional techniques in food decontamination. It is the fourth state of matter. High atmospheric cold plasma generates photons, ions, and reactive species. This technology provides excellent opportunities for the inactivation of pathogens, enzymes, spores, and viruses and enhances food product preservation. The inactivation of the enzymes might be due to the damage of the cell membrane through permeabilization, denaturation of the protein, and nucleic acids. It can be considered a safe, quick, economical, and nonhazardous technique for disinfection. The microbes on the surface of fresh and processed foods could be rendered inactive using Cold plasma. The cell membrane may rupture due to the buildup of charged particles. Upon exposure to cold plasma, microbial death results from the reaction between the plasma-generated reactive species and the lipids, amino acids, and nucleic acids.

In contrast to light (such as UV light decontamination), plasma moves around objects, removing shadow effects and ensuring that every product part is cleansed. Cold plasma may be used to clean surfaces before or during packing. The electronics and longevity of plasma technologies are comparable to those of UV-C systems in terms of energy consumption and food treatment profitability, notwithstanding the additional need for carrier gas. Strong antibacterial cold plasma could shorten treatment times and take advantage of low operating temperatures (30–50 ^{o}C) to preserve food's nutritional value and sensory appeal (Misra et al., 2016). This technology is successfully used in foods to enhance nutritional value and lower microbial load (Xiang et al., 2018). Nevertheless, it has demonstrated encouraging potential to improve the release of phenolic substances. Enhancing the extraction and bioavailability of these active compounds makes it easier for the body to absorb them, which benefits health. Furthermore, the reactive gas species generated by the plasma have enough energy to trigger chemical processes that can break covalent bonds, allowing the phenolics affixed to the food's plant structure to be liberated (Belgacem et al., 2017). Several studies have explored the potential of cold atmospheric plasma for enzyme inactivation and quality enhancement in different fruits and juices. Table 2.1 summarizes representative research findings on PPO and POD inactivation and related quality outcomes using thermal and non-thermal plasma-based methods.

2.4 Processing of pineapple

India is the country that produces the most fruits and vegetables, but it also has the highest rate of post-harvest losses and waste. In recent years, pineapple production has increased in the country. In northeastern India, it is primarily grown in the plains and hills (Abraham et al., 2023). The quality of pineapples rapidly deteriorates throughout the post-harvest period, resulting in excessive softness, flavor degradation, and a higher rate of sensitivity to microorganisms. Additionally, pineapples have a high water content, which increases their vulnerability to microbial infection and shortens their shelf life (Hajare et al., 2006). Pineapples can be turned into a wide range of processed products, including juices, ready-to-serve (RTS) beverages, jam, jellies, squash, powder, etc., to prolong their shelf life and minimize losses. Processing pulp into dried powder makes packaging and storage more convenient and reduces transportation costs (Kadam et al., 2008). Fruit pulp powder can have various applications, such as being used as a food color, flavour, and nutritional supplement.

However, the dried powder forms also make it available throughout the year. Pulp can be converted into powder using various drying techniques, including vacuum, tray, spray, and foam-mat drying (Shaari et al., 2018).

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Table 2.1 PPO and POD inactivation in fruits using thermal and non-thermal methods

SN	Product / Matrix	Target parameters	Representative Parameters	Findings	Reference
1.	Star Fruit Juice	Physicochemical Stability and Antioxidant Properties	Thermal treatment Temperature:70 °C, 80 °C and 90 °C Treatment time: 10, 20, 30, and 40 min	Treatment temperature and time decrease the bioactive compounds. Maximum color changes were observed when the sample was treated at 90 ºC for 40 min.	Shourove et al. (2020)
2.	Fresh-cut apples	Polyphenol oxidase	DBD cold plasma Voltage:15 kV (peak to peak) Frequency: 12.7 kHz; Treatment Time: 10- 30 min (3 levels); Gas: Air	Residual activity of the enzymes linearly decreased with time, as 88, 68, and 42% after 10, 20, and 30 min of treatment, respectively.	Tappi, et al. (2014)
3.	Apples	PPO	DBD cold plasma 150 W Air speed: 0.5 m/s	Residual activity of 50 and 10% after exposure to 15+15 (both sides) and 30+30 min of treatment time, respectively	Tappi et al. (2019)
4.	Fresh-cut melon	POD	DBD cold plasma Voltage: 15 kV (peak to peak) Frequency: 12.5 kHz	Residual activity of the melon showed a significant reduction of 91 % and 82% after 15+15 and 30+30 min of exposure time, respectively.	Tappi et al. (2016)
5.	Tomato	POD	DBD cold plasma Voltage: 30,40, and 50 kV Distance between electrodes: 26 mm	Enzyme activity significantly decreased with the voltage and treatment time.	Pankaj, et al., (2013)
6.	Cloudy apple juice	PPO and quality parameters	Cold plasma Voltage: 7.9375 to 10.875 kV Treatment time: 1 to 5 min	Spark discharge to liquid was an effective alternative for the treatment and quality preservation of cloudy apple juice	Illera, et al. (2019)

				at 10.5 kV and 5 min of treatment.	
7.	Blueberry juice	quality parameters	Cold plasma Voltage: 11 kV Frequency: 1000 Hz, Oxygen concentration: 0, 0.5% and 1%) Treatment time: 2, 4, 6 min Distance: 2.0 cm	Cold plasma treatment significantly increased the phenolic content, DPPH, and retained the original color of the juice.	Hou, et al., (2019)
8.	Pomegranate juice	anthocyanins and color	Cold plasma Treatment time: 3, 5, 7 min, Juice volume: 3, 4, 5 cm^3 Gas flow: 0.75, 1, 1.25 dm^3 /min	Cold plasma-treated pomegranate juice yields higher anthocyanin content. It also showed a positive influence on the color value of the juice.	Kovacevic, et al. (2016)
9.	Fresh-cut kiwifruit	Physico-chemical parameters	Atmospheric double barrier discharge (DBD) plasma Voltage: 2 to 19 V Electrodes distance:70 mm Treatment times: 20 min (10 + 10 min for each side) and 40 min (20 + 20 min for each side).	DBD plasma showed insignificant changes in antioxidant activity	Ramazzina et al., (2015)
10.	Pineapple juice	Polyphenol oxidase and peroxidase	Dielectric barrier discharge plasma Voltages: 25, 35, and 45 kV Treatment time: 10 min	Voltage and treatment time significantly reduced the enzyme activity of PPO and POD, with the former parameter having a more pronounced influence on enzyme inactivity. POD showed more resistance to inactivation. The Weibull model was best fitted for the enzyme inactivation kinetics.	Pipliya et al., (2022)

2.5 Foam mat-drying

It is an alternative method for drying sugar-rich and acid-rich liquid foods that are difficult to dry. Fruit and vegetable extracts that are sticky, thick, and difficult to dry, as well as those that are extremely sensitive to heat, can be dried by using the foam-mat drying technique. This technique allows for drying an extensive range of foodstuffs (including milk, pureed vegetables, fruit liquids, soluble coffee, etc.) without compromising quality. In order to lower the food's moisture content and produce a stable, porous sheet that resembles a honeycomb and can be crushed into powders, the watery food is treated to concentrations and air-dried at a lower temperature using the foam-mat drying technique. The increase in surface area of the bubbles enhances the moisture removal in this technique, and hence, the amount of time needed to dry the foamed product is less than that of non-foam-dried products. The application of low temperature could be the reason for retaining the nutritional value and reducing the browning reactions in the final dried product (Muthukumaran et al., 2008). The foam-mat drying technique produces a higher-quality, porous final product that, when reconstitution occurs, maintains its original properties. They take less drying time, retain excellent product quality, and ease of reconstitution, making this drying technology highly efficient for food components sensitive to heat (Javed et al., 2018). Foam-mat drying can dry various sugar-rich, acid-rich fruits while maintaining the final product's original color, flavor, and nutritional constituents (Kadam & Balasubramanian, 2011; Fernandes et al., 2013). This technique has many applications in the food industry; it can be used as a rehydrated water mix and a flavoring agent to make various food products. It added nutritional value as its uses increase biological value and improve texture and taste.

2.6 Foaming process

The foaming process involves adding foaming agents with other additives while whipping air into the mixture (Figure 2.1) (Rajkumar et al., 2007). In the foaming process, liquid foods are mixed with the foaming agents (Egg albumin, whey protein, soy protein isolate, CMC, etc.) and other additives. The mixed solutions and the other additives are whipped in a whipping mixer with a maximum speed for a varying time to obtain the maximum incorporation of air. The protein used for whipping gets denatured at the air-water interface and develops a stable emulsion. The air and holding capacity of the air-water interface depend on the foaming agents used for the foam formation (Lomakina & Mikova, 2006).

2.7 Principles of foam mat drying

This technology involves converting the liquid food into stable whipped foam (incorporating air) using foaming agents and then allowing them to dry by air (Rajkumar et al., 2007). The main requirement for a successful foam-mat drying process is that the foam must be mechanically and thermodynamically stable to form a gas-liquid emulsion. Foaming agents include proteins, gums, and different emulsifiers (such as trichlorophosphate, carboxymethyl cellulose [CMC], propylene glycerol monostearate, and glycerol monostearate). Liquid food is followed by adding a foaming agent, and then subjected to whipping using the whipping device to produce stable foam. The prepared foam is spread into a thin mat or sheet, and hot air is used to dry it until the desired moisture content is achieved. The moisture removal rate was due to the increased surface area in the foamed samples during whipping. A thin, porous honeycomb sheet or mat is produced by drying at relatively low temperatures, and this is subsequently broken down to create a freely flowing powder. The primary element accelerating moisture removal was the foam bubbles' greater surface area. However, throughout the process, moisture movement within the sample might be due to capillary diffusion (Sangamithra et al., 2015). Much literature has also revealed the same findings for the foam (Kadam et al., 2012). The mass transfer rate in this technique is attributed to the foam's increased bubble area and porosity, which can dry the product at a lower temperature for a short period. Hence, it can maintain the original quality of the product. Although foam's high air content was a barrier against heat transmission, its porous structure permits moisture removal faster from the interior foam layers (Thuwapanichayanan et al., 2011). Powder from foam mat drying technology retains the original color, flavor, and nutrients. Fruit juices exposed to prolonged temperatures could result in losses of volatile compounds (Thuwapanichayanan et al., 2012).

A practical method to reduce these losses is to reduce drying temperature and time. Banana foaming before drying may help minimize the volatile losses because the resulting porous structure promotes internal moisture movement and speeds up drying. (Thuwapanichayanan, et al., 2011). A common problem in this technology is the lack of foam air-water holding capacity during foaming and drying operations. The instability may cause foam collapse, resulting in deteriorated quality products (Ratti & Kudra, 2006).

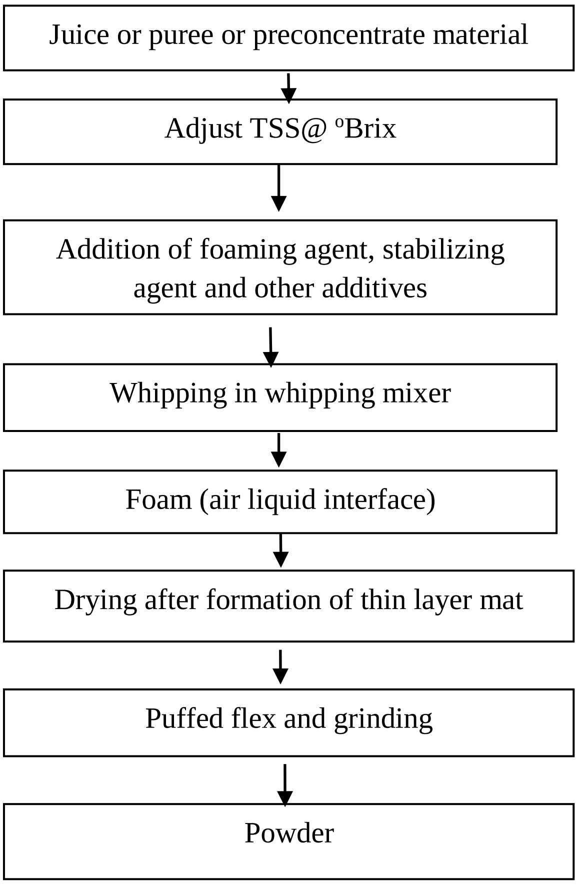

Figure 2.1 Flowchart of the foaming process

2.8 Basic concepts of foam

2.8.1 Theory of foam

The lamellar phase is a thin film liquid wall of the bubbles, separating the fluid's dispersed and continuous phases in a food foam system. According to Eisner et al. (2007), foam in food and beverages is a mixture of solids, liquids, and gases. A plateau border encircles gas bubbles in foams. Since the development of foam is a crucial step, it is essential to comprehend the elements that lead to its appearance or absence. The texture of the foam is determined by the quantity, size, and distribution of these bubbles; evenly dispersed microscopic bubbles further produce softer foams. Whipping air dispersed into the liquid produces an air-liquid interface in the foam. The surface tension develops between the interfaces, making the foam unstable, which causes foam drainage. Proteins and surfactants are additional components that influence foam's texture and aid in its stability or retention. Proteins will attach to the interface and further interact with the lamella through covalent bonds, hydrogen bonds, or electrostatic or hydrophobic forces. Surfactants will migrate quickly against a gradient towards thinner portions of the bubble walls (lamella). As a result of these interactions, viscoelastic films are produced on the surface of the air-liquid interface that can reduce the tension and withstand their own thickness. Proteins interact with one another until there are no free molecules, forming foam (Hardy & Jideani et al., 2017).

2.9 Method of foaming

Agitation is the mechanical procedure for the foam formation. It is the most common method of foam formation, which includes whipping, stirring, and shaking (the influence of energy density on foam ability). Whipping is the beating operation that involves adding an infinite amount of air into liquid foods (Sangamithra et al., 2015). The incorporation of air is due to the mechanical action of the agitator. The size of the bubbles increases as the amount of air incorporated into the liquid gets dispersed. However, the larger bubbles break into smaller sizes due to agitation and mechanical stress that occurs on the surface of the bubbles during whipping or beating. The bubble size of the foam was greatly influenced by the agitator's speed, the apparatus's shape, and the fluid's rheological properties.

2.10 Foam-forming agents

A foam-forming agent is a substance that aids in creating and stabilizing foam by incorporating gas or air into a liquid and preserving the bubble structure over time. The properties of an effective foaming agent should have the ability to interact with the proteins that unfold their structure to produce a cohesive, viscoelastic film around the created bubbles that can be resistant to the agitation that occurs due to mechanical and thermal disturbance. Proteins are hydrophobic and show excellent foam stability and good foam ability due to their potential structural rearrangements, which can reduce the interfacial tension around the foam bubbles. Egg albumin, whey protein, skimmed milk protein, soy protein, soy protein isolate, etc, are the most commonly utilized agents in food foaming. Some other proteins, along with the stabilizing agents used for food foam mat drying by many researchers, are reported in Table 2.2.

2.11 Protein-containing foaming agent

The primary protein of the egg is egg albumin or egg white. The protein in egg albumin is complex and can have up to 40 different proteins. The three main proteins, ovomucoid, globulins, and ovalbumin, mainly contribute to the foaming behavior during the agitation of egg albumin. The protein monolayer is created by ovalbumin at the interface, while lysozyme forms films around the significantly thicker bubbles (Hardy & Jideani, 2017). A stable viscoelastic interfacial film around the bubbles is generated due to the structural breakdown of the protein during whipping. The quality of the egg albumin could be judged based on its increase in foam expansion and holding capacity (Lomakina & Mikova, 2006). Egg white protein (EWP) has long been utilized as a foaming agent due to its seemingly special properties (Yang & Foegeding, 2011). Egg albumin showed a good foaming capacity and finer bubble structure with increased foaming concentrations from 0.5 to 3% in foamed apple juice. Egg protein and CMC concentrations in the fruit juice produced foam with greater stability than egg white protein alone (Raharitsifa & Ratti, 2006). Egg albumin used at a concentration of 4.5% in tomato juice showed the most stable foam and dried the product at a lower time (Kadam & Balasubramanian, 2011). Egg albumin is used as a foaming agent for drying lime juice concentrations, and it develops the foam with lower foam density, higher expansion, and stability. These foam properties hold the foam interface, which could result in a higher drying rate and produce powder with good quality attributes. A milk protein mainly consists of casein protein (80%) and whey protein (20%). The casein in milk protein is a mixture of heterogeneous phosphoproteins such as α_{S1}-, α_{S2}-, β-, and κ-casein. These mixtures are highly hydrated and form casein micelles. Whey protein is derived from the watery part of milk called whey, which separates from the curds during the cheese-making process. It can yield a functional protein that might be utilized as an emulsifier, stabilizer, and whitening agent. Whey protein concentrate (WPC) is a milk protein produced when enough non-protein components are eliminated from pasteurized whey to produce a final dry product with more than 25% protein. There are three types of WPC: medium protein (45–60%), high protein (60–80%), and low protein (25–45%).

Whey protein isolate (WPI; 90%) is produced by further processing and purification of WPC. Protein derived from dehulled and defatted soybean meal is known as soy protein. A highly processed or purified type of protein with a minimum protein concentration of 90% is called soy protein isolate (SPI). The functional attributes of SPI include water binding, dispersibility, gelation, emulsification, viscosity, and foaming or whipping properties (Daniel, 2004).

Table 2.2 Comparative studies on foam-mat drying of fruit juices/pulps

SN	Product	Foaming agent	Whipping and drying conditions	Findings	References
1.	Banana puree	Egg albumin: (5 g/100 g) Soy Protein Isolate: (5gprotein/100g dry solids) Whey protein concentrate (5g protein/100g dry solids)	Whipping speed: 200 rpm Drying temperature: 80 ^{o}C Air velocity: 0.5 m/s	Foam prepared with WPC was more stable during whipping and hence showed higher effective moisture diffusivity during drying.	Thuwapanichayanan et al., (2012)
2.	Tomato juice	Egg albumin: (0-20 % w/w)	5 min	An increase in foaming agent enhanced the drying process of tomato juice, and it was optimum at 10% egg albumin.	Kadam and Balasubramanian (2011)
3.	Mango juice	Egg albumin: (5-15%) Methylcellulose: (0.5%)	5 min 1400 rpm Drying temperature: 60 ^{o}C Thickness: 1 mm	Foam-mat dried mango flakes take less time, and quality parameters showed fewer changes than non-foam dried flakes.	Rajkumar et al., (2007)
4.	Bael juice	Glycerol monostearate: (0-8g/100g) methyl cellulose (0-1g/100g)	5000 rpm	The more air incorporated with the whipping time, the lower the foam density. The foaming process was best optimized at a minimum density and drainage volume.	Bag et al., (2011)
5.	Pineapple pulp	Tricalcium phosphate: (0-1.0%) Egg albumin: (0-2.0%)	18000 rpm Drying: 60,75, and 85 ^{o}C	Pineapple powder developed by foam mat drying at 60 ^{o}C resulted	Kadam et al. (2012)

		Carboxymethyl cellulose: (0.25%)		in retention of maximum nutrients.	
6.	Mulberry juice	Maltodextrin: (2-10g/100mL) CMC: (1–5 g/100 mL) Glycerol monostearate: (1–5 g/100 mL)	5 min Drying: 60 °C	Mulberry juice powder produced with 5g/100 mL of CMC offers a shelf-stable product with high retention of bioactive compounds.	Khatri & Jaiswal., (2024)
7.	Mulberry puree	Egg albumin (4 - 8%) CMC (0.2-0.4%) Maltodextrin (1-2%)	5-15 min Drying: 60,65,70, and 75 °C	Mulberry powder produced at 60 °C offers less water activity, less color change, and maintains high anthocyanin content compared to the original puree.	Thuy et al. (2022)
8.	Raspberry puree	Potato protein isolate (2.5, 5, 10% w/w) maltodextrin (5, 15, 30% w/w)	10 min 200 rpm	Foam stability is enhanced by the addition of protein and hydrocolloid concentration.	Dachmann et al., (2018)
9.	Tomato juice	EA: 5% - 15% (w/w) CMC: 0.15% - 0.60% (w/w)	3– 7min 18000 rpm	Foam developed with optimized conditions of EA-11.45, CMC-0.33% and WT-5.21 min was a stable foam and helped quickly dry powder at a lower temperature with less nutrient loss.	Balasubramanian et. al. (2012)

2.12 Foam stabilizing agents

Foam stabilizers are used in foam preparation, which mainly help stabilize the foam and make it less unstable. Polysaccharides are often used as foam stabilizers in many food applications. The hydrophilic nature of many polysaccharides prevents them from adsorbing at the interface. Nevertheless, they have been shown to thicken or gel the aqueous solution, increasing foam protein stability (Klitzing & Müller, 2002). Many researchers have revealed that CMC is a commonly used foam stabilizer in many food products. It is frequently added to food in its sodium form to modify its viscosity and maintain the foam's stability and emulsion. It can produce more stable and less unstable foam, holding the air-liquid interface for effective foam-mat drying. According to the literature, thickening or gelling agents (starches, gums, gelatin, hydrocolloids such as pectin and maltodextrin) are also used as foam stabilizers. These compounds inhibit bubbles from coalescing by developing the viscoelastic layer around the bubbles or by generating steric hindrance (bulky molecular shapes) or electrostatic repulsion (charged molecules) (Sangamithra et al., 2015; Dachmann et al., 2018). These hydrocolloids and gelling agents interact with the food foam, increasing the bulk viscosity and reducing the foam's drainage due to gravity. Several kinds of literature have revealed that the hydrocolloids and the protein foaming agents used in food foam create electrostatic interaction, reducing the foam's instability during storage. The scientific work carried out by Sadahira et al. (2014) reported that the gel-like interaction between the protein-hydrocolloids develops consistency and thus helps increase the holding capacity of the air-liquid interface.

2.13 Foam stability

Foam stability is defined as the capability of the foam to maintain its air-liquid structure for a specific period during storage. Foam stability is one of the important criteria for achieving effective foam mat drying. Various factors can affect the stability of foam, such as the use of foaming agents, additives, hydrocolloids, etc. The ability of the interaction between the foaming agents and hydrocolloids can determine the quality and stability of the foam. The instability of the foam can also be due to the higher interfacial energy between the air-liquid interface and gravity. The high interfacial energy of foams makes them thermodynamically unstable. Two categories of instability exist: (1) transitory or unstable foams, lasting only a few seconds, and (2) metastable or "permanent" foams, lasting several hours to several days. The process by which smaller bubbles unite to create a single, bigger bubble is known as bubble coalescence, which can cause the foam to collapse. This process consists of three stages: film draining, bubble approach, thin film production, and film rupture. In pure water, it is challenging to create a stable film due to the high surface tension, which causes coalescence to occur quickly. However, adding surfactants allows the foam to remain longer by stabilizing against coalescence. The foam production is also evidently influenced by gravity, which causes the liquid between the air bubbles to drain. Systems such as these can produce very stable foam by decreasing the amount of liquid draining or increasing the bulk liquid's viscosity. The formation and stability of foam can be affected by solid particles, particle size, concentration, and surfactant types.

2.14 Rheology of puree/pulp

Rheology is important to know the food behavior for quality and sensory evaluation to handle processing, storage, and transportation. Rheological parameters are a crucial component of fluid heat transport and have been regarded as an analytical tool that can offer fundamental insights into the structural organization of food. Rheological characteristics provide information on the physical characteristics of the food and are a crucial quality control parameter in the food business during production (Mohamed & Hassan, 2016). Fruit purees are complex mixtures of various constituents and generally show non-Newtonian behaviors due to the interaction of the constituents in the purees. The characteristics of these fluids can be better explained by the curve fitting of empirical rheological models widely used to characterize the fruit puree (Lopes et al., 2013). Goula and Adamopoulos (2011) reported that the pseudoplastic behavior of the kiwi fruit puree was determined from the power law model coefficients. Ahmed et al. also reveal that the Herschel-Bulkley model can be applied to study the steady rheology of fluid foods. They have also reported that some fruit purees/pastes show yield stress, which denotes the minimum stress required to initiate the flow. The latest Rheometer has software for low shear measurement and data analysis that regularly computes rheological parameters and yield stress. The pseudoplastic nature of the fluid foods was well explained by the Power law, Casson, Bingham plastic, and Herschel-Bulkley models (Bhattacharya et al., 1992). Herschel-Bulkley model and Casson model coefficients provide the idea of the yield stress required to start their flow. The actual value of yield stress is an essential factor for optimizing the design for the thermal processing of foods. A study of the rheological behavior of fluid foods is vital for their storage and handling (Ahmed et al., 2007). The study from their investigations also reveals that the steady shear rheology of the honey sample showed Newtonian fluid behavior. The viscoelastic behavior of the fluid foods has been investigated by conducting dynamic flow measurements. This study provides the relationship between the dynamic moduli (G', G'') and frequency. These moduli exhibit non-linear frequency-dependent behaviour. However, viscous-like behaviour of the date syrup can be seen by the significantly greater G″ value than G' (Mohamed & Hassan, 2016). The phase angle (δ) is measured in terms of tan (δ) from the ratio of dynamic moduli (G''/G'). While a phase angle of 0° denotes ideal elastic behavior with all shearing energy stored, a phase angle of 90° denotes perfect viscous behavior with all shearing energy dissipated. A substance exhibiting a phase between 0 ° and 90 ° shows some viscoelastic characteristics in the food sample. G' exhibits over G'' obtained for the dynamic rheological study of kiwi fruit tissue, showing their elastic solid nature in the sample (Gerschenson et al., 2001). Rheological characteristics of the semisolid foods are generally studied by employing the small-amplitude oscillatory shear test. Dynamic frequency sweep tests are conducted in a viscoelastic region to determine the elastic and viscous behavior of frequency-dependent fluid foods. Small-amplitude oscillatory shear measurements are considered an efficient technique for evaluating the dynamic response of a fluid material over a specific period. In addition to analyzing the linear viscoelastic characteristics of complex fluid food material, Small-amplitude oscillatory produces data on material functions in terms of yield stress, complex viscosity, and elastic and viscous modulus (G' and G''). Small-amplitude oscillatory measurement can quantify how biomaterials' microstructure and entanglement changes when heated, cooled, or sheared in-situ without compromising the test specimens' structural integrity (Ahmed., 2018).In the non-linear domain, the material stress response deviates from the proportionality between the stress and deformation amplitude. The stress response does not follow a sinusoidal wave pattern in the non-linear area, and dynamic moduli (G', G") become functions of the strain amplitude. Ahmed et al. (2007) implied that the lower (G') < (G'') observed ($p<0.05$) for honey samples indicated their viscous behavior. Their work also reveals that the honey samples had no network formation and weak particle interactions due to the low elastic modulus. Gel properties of the caprine and bovine milk coagulation in terms of the dynamic moduli (G', G'') by Nassar et al. (2020). Some fruit purees/pastes show a time-dependent thixotropic nature. Thixotropy in the fruit sample is determined by decreasing the apparent viscosity with varying shearing times. Upon removal of the stress, the initial viscosity can be achieved. This test is employed in the Rheometer at a constant shear rate as a function of shear stress with varying shearing time. Various time-dependent rheological models, such as Weltman, Hahn, Figoni, and Shoemaker, can be studied to fit the thixotropy of fluid foods.

Although pineapple processing, enzyme inactivation, and drying methods have been studied previously, several critical gaps remain. Limited studies have examined the combined effect of cold plasma treatment and foam-mat drying on pineapple pulp, particularly with reference to enzyme inactivation (PPO, POD) and the retention of nutritional quality. Research on optimizing foaming and stabilizing agents during foam-mat drying is also scarce, as most existing studies focus on other fruits such as mango, banana, and tomato rather than pineapple (Table 2.1). Furthermore, there has been little effort to integrate the rheological properties of pineapple pulp with foam stability and drying kinetics, despite the importance of this relationship for designing efficient drying processes and improving powder quality. In addition, systematic comparative evaluations of cold plasma treatments for quality retention in pineapple pulp are lacking. To address these gaps, the present study investigates the effect of cold plasma on enzyme activity, nutritional attributes, and rheological behavior of pineapple pulp; optimizes foaming and stabilizing agents for foam-mat drying; and establishes relationships between foam stability, drying kinetics, and rheological parameters, thereby contributing novel insights into sustainable pineapple processing methods.

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