CHAPTER – 2

Review of Literature

The purpose of this review is to provide a perspective on the present state of manufacturing of fruit jam using sucrose and alternative sweeteners, areas of improvement, and problems yet to be resolved. Literature on basic aspects of role of various ingredients for manufacture of jam and the effect of these ingredients on product quality (color, texture, rheology, and sensory properties) has been reviewed in the following sub-sections. Literature on the role of Fourier Transform Infra Red (FTIR) spectroscopy to understand molecular phenomenon and scanning electron microscopy (SEM) to elucidate microscopic structure of jam has also been reviewed.

2.1. Jam Ingredients

Fruit content of jam is approximately 35 g of edible fruit per 100 g of product, and the jam can be made from fruit, fruit pulp, clarified fruit juice, or a mixture of these (Broomfield, 1996). Other ingredients required to manufacture jam include sugar, pectin, acid, preservatives, and alternative sweeteners.

2.1.1. Mango Pulp

Mango (Mangifera indica L.) is grown commercially in more than 90 countries and the world production of mangoes is 28.51 MT per annum (Evans, 2008). India ranks first among world’s mango producing countries, accounting for 37.9% of the total mango produced worldwide in 2005 (FAOSTAT, 2007). The other prominent mango producing countries are China, Indonesia, Mexico, Pakistan, Philippines, and Thailand (Mukherjee, 1997; Evans, 2008). Mango is the most important commercial fruit crop of India and the prominent varieties cultivated are Alphonso (Badami), Banganapalli (Baneshan), Bangalora (Totapuri), Bathua, Bombay Green (Bhojpuri), Chousa (Khajari), Dashehari (Dasheri), Fajri, Gulabkhas, Himsagar, Kesar, Krishnabhog, Langra, Jamadar, Mallika, Mankurad, Mundappa, Mulgoa (Mulgoba), Neelam, Pairi (Paheri), Rajapuri, Suvarnarekha (Swarnarekha), and Vanraj (Salunkhe and Desai, 1984; Knight, 1997). Mango is known for its intense peel coloration, strong aroma, delicious taste, and high nutritive value.
The chemical composition of mango pulp varies with the variety, location of cultivation, and stage of maturity (Tharanathan et al., 2006). The major constituents of the pulp are water, carbohydrates, organic acids, fats, minerals, pigments, tannins, vitamins, and flavor compounds (Table 2.1). Mango pulp is widely used to manufacture canned pulp, jam, squash, juice, nectar, ready-to-serve (RTS) beverages, mango-cereal flakes, mango fruit bars (Aam papad), mango powder, and mango toffee (Tharanathan et al., 2006).

**Table 2.1. Food value of ripe mango pulp (per 100 g)**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories</td>
<td>62.1–63.7 Cal</td>
</tr>
<tr>
<td>Moisture</td>
<td>78.9–82.8 g</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>16.20–17.18 g</td>
</tr>
<tr>
<td>Fiber</td>
<td>0.85–1.06 g</td>
</tr>
<tr>
<td>Fat</td>
<td>0.30–0.53 g</td>
</tr>
<tr>
<td>Protein</td>
<td>0.36–0.40 g</td>
</tr>
<tr>
<td>Ash</td>
<td>0.34–0.52 g</td>
</tr>
<tr>
<td>Iron</td>
<td>0.20–0.63 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>5.5–17.9 mg</td>
</tr>
<tr>
<td>Calcium</td>
<td>6.1–12.8 mg</td>
</tr>
<tr>
<td>Vitamin A (carotene)</td>
<td>0.135–1.872 mg</td>
</tr>
<tr>
<td>Thiamine</td>
<td>0.020–0.073 mg</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>0.025–0.068 mg</td>
</tr>
<tr>
<td>Niacin</td>
<td>0.025–0.707 mg</td>
</tr>
<tr>
<td>Vitamin C (ascorbic acid)</td>
<td>7.8–172.0 mg</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>3–6 mg</td>
</tr>
<tr>
<td>Methionine</td>
<td>4 mg</td>
</tr>
<tr>
<td>Lysine</td>
<td>32–37 mg</td>
</tr>
</tbody>
</table>

Source: Adapted from Gopalan et al. (1977) and Tharanathan et al. (2006).
2.1.2. Sugar

Sugar is an essential constituent of jam imparting sweetness as well as body to the jam. Sugars in solution exert osmotic pressure and reduce water activity with increasing concentration (Lai et al., 1998). Water activity of jam should be less than 0.8 because the principal spoilage organisms are the yeasts and moulds. This implies that 40-65% sugar (sucrose, invert sugar) content is required in jam to prevent microbial spoilage (Salunkhe et al.; 1963; Nicol, 1980). Generally, more than 40% of total weight and 80% of total solids in jam is sugar (Lai et al., 1998). In addition to its sweetening effect, sugar contributes to soluble solids, that is essential for the physical, chemical, and microbiological stability; provides body and mouthfeel; improves appearance (color and shine), and makes gelation possible. The added sugar acts as a dehydrating agent for the pectin molecules, permitting closer contact between the chain molecules (Suutarinen, 2002).

The amount of sugar necessary to obtain a gel of optimum firmness depends on the type of pectin used and pH. More then 50% sugar (on pulp basis) is needed for gel formation of HM pectin. Higher sugar content reduces spoilage and increases stability of jam in transit. An excessive amount of sugar flocculates the pectin from solution (Molyneux, 1971).

Acidity of the pectin-pulp-sugar mix and duration during which the mix is at high temperature are the two main factors controlling the amount of invert sugar produced by boiling. It is more convenient to control the formation of invert sugar by decreasing the acidity with sodium citrate/sodium bicarbonate or increasing it with citric acid (Molyneux, 1971).

Tarr (1924) demonstrated that pectin breaks down and loses its jelly-forming strength if pectin solution is concentrated by boiling before the sugar is added. Sugar added, after first concentrating the extract, does not dissolve completely in the short period of subsequent boiling and also does not get sufficient time for inversion to the desired extent. The result is that on cooling the sugar crystals appear in the product. While sugar and acid are added to the pectin extract prior to boiling, strength of the pectin in the extract does not decrease even when the jelly is boiled for an appreciable time. The boiling should not be excessive, because it may result in a much greater inversion of sugar than desired, and the jam will be syrupy. Prolonged boiling also darkens the
color of jam due to Maillard reaction and degrade different phenolics and pigments present in the fruit pulp.

Substituting sucrose with other sugars or polyols has an influence on the gelling characteristics of pectin and the texture of gels (Mulinari-Campos and Bileski-Candido, 1995). This is due to the different water activities of the other sweeteners at similar soluble solids contents, or to substance specific differences in the stabilizing effect generated by the hydrophobic interaction (Oakenfull and Scott, 1984).

2.1.3. Pectin

Pectin is a polysaccharide and its ability to act as a thickener and gelling agent in an aqueous environment has made it a useful additive in food, pharmaceutical, and cosmetics industry (May, 1990; May, 1997). About 1% pectin is required for jam preparation. Commercial pectins are normally produced either from citrus peels (containing 25% pectin) or from apple pomaces (containing 15-18% pectin) (Pilgrim et al., 1991). In both cases the residue obtained after juice pressing is utilized as the raw material for pectin production.

Pectins are a class of complex polysaccharides. Pectin consists of chains of 300 to 1000 galacturonic acid units, joined with $\alpha-1\rightarrow4$ linkages partially esterified with methanol, and interrupted by (1$\rightarrow2$) linked $\alpha$-D- rhamnopyranosyl residues (Thakur et al., 1997). Pectin molecules in solution adopt a helical configuration with three monosaccharide units per turn and a pitch of 1.33 nm. The structure is stabilized by steric factors with a possible contribution from intra-molecular hydrogen bonding (Oakenfull, 1991). Some of the galacturonic acid units in the pectin molecule are esterified and are present as the galacturonic acid methyl ester (Figure 2.1).

Figure 2.1. Representation of different substituents potentially present in commercial pectins (respectively, methyl-ester, amide group, and acetyl group).
Pectin is characterized on the basis of jellying power, degree of methoxylation/esterification, and rate of solidification of the jellies. Based on the degree of methoxylation/esterification, it is classified as low methoxyl (LM) pectin and high methoxyl (HM) pectin. Degree of esterification (DE) of the pectin molecule is defined as the ratio of esterified galacturonic acid units to total galacturonic acid units in the molecule. The DE of HM- and LM- pectins are 50% and above, and below 50% respectively. Depending on the pectin type, coordinate bonding with Ca$^{2+}$ ions or hydrogen bonding and hydrophobic interactions are varied in gel formation (Figures 2.2 and 2.3).

In LM pectin, gelation results from ionic linkages via calcium bridges between two carboxyl groups belonging to two different chains in close contact with each other (Oakenfull and Scott, 1984; Cardoso et al., 2003). The affinity of pectin chains towards calcium increases with decreasing DE or ionic strength, and with increasing polymer concentration (Kohn, 1987; Garnier et al., 1994). Besides the influence of the charge density of the polygalacturonate chain, the distribution pattern of free and esterified carboxyl groups has also an important effect on the strength of calcium binding (Powell et al., 1982).

In HM pectin, the cross linking of pectin molecules involves a combination of hydrogen bonds and hydrophobic interactions between the molecules (Morris, 1986; Lopes da Silva et al., 1992). HM pectin can gel at pH value less than 3.5, partially suppressing ionization of the carboxylic acid groups. It can also gel with a cosolute such as sucrose at a concentration higher than 55% by weight (Norziah et al., 2001). HM pectin-sucrose gels are formed by combination of hydrogen and hydrophobic interactions (Oakenfull, 1991, Guillotin, 2005).

Gelation of HM pectin occurs spontaneously during cooling from the solution state at high temperature and the resulting gels do not remelt on heating (Christensen, 1986; Rolin, 1993).

Commercial LM pectins are generally produced from plant material containing HM pectin. The transformation (de-esterification) of HM pectin to LM pectin takes place under controlled conditions by treatment in either mildly acidic or alkaline conditions. Amidated low ester pectin is produced when ammonia is used in an alkaline de-esterification process.
Figure 2.2. Low methoxyl pectin gelation mechanism in the presence of calcium ions (Hoefler, 2003).

Figure 2.3. High methoxyl pectin gelation mechanism (Hoefler, 2003).
Presence of calcium ions is crucial to obtain gel formation in a system containing LM pectin. LM pectins may form gel at much lower solids concentrations than HM pectin and can tolerate greater variations in pH without any adverse effect on gel formation. Amidated low methoxyl ester pectin is capable of jellifying jams at the natural calcium level, i.e. with calcium ions originating from fruit. The degree of esterification and the degree of amidation largely determine the 'calcium-reactivity' of a specific LM pectin. Whereas, HM pectin can form gel with a good amount of cosolute (sucrose) present in the system.

Firmness of gel increases with the molecular weight of pectin (Lal et al., 1998). Physical characteristics of the gel are the consequence of the formation of a continuous three-dimensional network of cross-linked polymer molecules. Based on the solubility, two different types of pectins exist: water soluble or free pectin, and the water insoluble pectin. Solubility of pectin in water is related to its degree of polymerization and number and distribution of methoxyl groups. Generally, solubility increases with decreasing molecular weight and increase in the esterified carboxyl groups, although solution pH, temperature, and the nature and concentration of the solute present have an effect on solubility. In acidic solutions, at low temperature, deesterification of the pectin molecule is a dominant change, while at high temperature, depolymerization occurs more rapidly. Pectin grades are based on the number of parts of sugar that one part of pectin will gel to an acceptable firmness under standard conditions of pH 3.2 to 3.5, sugar 65 to 70 % and pectin 0.2 to 1.5% (Deman, 1999). Selection of pectin for a particular food depends on several factors, including the texture required, pH, processing temperature, concentration of cosolutes, presence of ions, proteins, and expected shelf life of the product.

2.1.4. Acids and Preservatives

Acids are added as a solution in water, usually as 10% w/v citric acid during jam manufacturing. The added acid suppresses dissociation of the free carboxyl groups and consequently the presence of negatively charged pectin molecules and thus facilitate closer contact between the pectin molecules and permits the formation of hydrogen bond bridges between undissociated carboxyl groups (Molyneux, 1971). There are two reasons for adding acid during jam manufacturing: (i) reduction of pH
to a value giving satisfactory gel formation; and, (ii) enhancement of total acidity in order to enhance the fruit flavor.

Tarr (1923) established that the best jam can be made when the pH of the pectin solution is between 3.1 and 3.3. The pH of the jam can be controlled in two ways: (i) by adjusting pH of the pectin extract; and, (ii) by adding suitable buffers. Huelin (1945) studied the effect of pH on jam strength by employing both the methods and obtained same results as that of Tarr (1923). According to Spencer (1929), although acid is not essential for pectin-gel formation, yet the presence of acid in fruit extracts for making jam is extremely important, because without it fruit jam of good taste cannot be made. Jam strength increases with the increase in hydrogen ion concentration until an optimum concentration level is achieved. The jellying point depends upon the amount of acid and pectin present in the original fruit juice/pulp used. The final jam should contain at least 0.5 % (preferably 0.75 %) total acidity (Lai et al., 1998).

Benzoic acid and sorbic acid (0.05-0.10 wt%) are used as preservative agents in jam. These preservatives are active only in their undissociated form (acid form). The undissociated acid is capable of permeating in the cell membrane of the microorganisms and interfering with enzyme systems in the cell to prevent further growth. As both acids are sparingly soluble in water, they are added as solutions (e.g. 10-20% w/v) of their neutral sodium or potassium salts.

2.1.5. Alternative Sweeteners

The dietary awareness of consumers has resulted in reduction of the sugar content of commercially prepared foods and its replacement by alternative sweeteners. The discovery of a large number of new sweeteners over the past three decades has also led to the development of various new sugar free products, particularly for diabetics and people using a special diet or prone to obesity (Sandrou and Arvanitoyannis, 2000; Nabors, 2001).

Sucrose is the most important carbohydrate sweetener used to manufacture jam. By partial or full replacement of sucrose with other carbohydrate or non-carbohydrate sweeteners (fructose, high fructose syrup, xylitol, sorbitol, aspartame, acesulfame-K, cyclamate, stevioside, sucralose, or, combinations of these) it is technologically possible to prepare jams with lower amounts of sucrose (Hyvönen and Törmä, 1983).
The functional and health benefits of alternative sweeteners are: (i) in providing and expanding food and beverage choices to control caloric, carbohydrate, or specific sugar intake; (ii) in assisting weight maintenance and reduction; and, (iii) aid in the management of diabetes.

The alternative sweeteners should be colorless, odorless, and non-carcinogenic. Consumer acceptability of the sweetener increases as its taste and functions approaches to that of sucrose. The alternative sweeteners should be water soluble and stable in both acidic and basic conditions and over a wide range of temperature. Length of stability of the sweetener and shelf-life of the final product prepared with the alternative sweeteners are also important. A sweetener must be compatible with wide range of food ingredients because sweetness is only one component of complex flavor systems (Nabors, 2002). Approximate relative sweetness of selected alternative sweeteners is given in Table 2.2.

Table 2.2. Relative sweetness of alternative sweeteners (Nabors, 2001).

<table>
<thead>
<tr>
<th>Sweeteners</th>
<th>Approximate Sweetness (Sucrose=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactitol</td>
<td>0.4</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>0.7</td>
</tr>
<tr>
<td>Mannitol</td>
<td>0.7</td>
</tr>
<tr>
<td>Xylitol</td>
<td>0.9</td>
</tr>
<tr>
<td>Cyclamate</td>
<td>30</td>
</tr>
<tr>
<td>Acesulfame potassium</td>
<td>200</td>
</tr>
<tr>
<td>Aspartame</td>
<td>180</td>
</tr>
<tr>
<td>Saccharin</td>
<td>300</td>
</tr>
<tr>
<td>Stevioside</td>
<td>300-500</td>
</tr>
<tr>
<td>Sucralose</td>
<td>600</td>
</tr>
<tr>
<td>Alitame</td>
<td>2000</td>
</tr>
<tr>
<td>Neotame</td>
<td>8000</td>
</tr>
</tbody>
</table>
One group of alternative sweeteners consists of substances of very intense sweet taste and are used in small amounts to replace the sweetness of a much larger amount of sugar. The five sweeteners of this group currently approved for use in the U.S.A. are acesulfame-K, aspartame, neotame, saccharin, and sucralose. Several other sweeteners of this type (alitame, cyclamate, and stevia/steviosides) are not currently approved for use as food ingredients in the U.S.A., but are being used in several countries.

A second group of alternative sweeteners consists of substances that can substitute both the physical bulk and sweetness of sucrose. Products of this type, sometimes called “sugar replacers” or “bulk sweeteners,” include the sugar alcohols (also called “polyols”) (sorbitol, mannitol, xylitol, isomalt, erythritol, lactitol, maltitol), hydrogenated starch hydrolysates, and hydrogenated glucose syrups. Two new sweeteners, trehalose and tagatose, are similar in function to the polyols although they are actually carbohydrate sugars rather than sugar alcohols.

There are ambiguities related to different terms used for sugar substitutes. The terms “artificial sweetener”, “alternative sweetener” or “sugar substitute” are sometimes used, but they can be confusing because they also refer to other types of sweeteners. The American Dietetic Association (ADA) uses the term “non-nutritive sweetener” (ADA, 2004), but the applicability of this term to aspartame can be questioned because aspartame is metabolized and provides dietary energy although the quantity is negligible. Therefore there is no unequivocal terminology for sugar substitutes. Sorbitol (nutritive sweetener), stevioside, and sucralose (non-nutritive) were used in the present work to replace/substitute sucrose. Therefore, a more general term “alternative sweeteners” is used instead of sugar substitute or non-nutritive sweeteners in the present work.

2.1.5.1. Sorbitol

Sorbitol is referred to as a nutritive sweetener because it provides energy (2.6 kcal/g) to the diet. Sorbitol can provide the desired bulk and sucrose texture, but with considerably less energy than sucrose. Sorbitol was discovered by a French chemist Joseph Boussingault in 1872. Sorbitol is widely accepted in food and pharma industries as nutritive ingredient because of its ability to improve the taste and shelf-life of foods and dietary products. Sorbitol is a hexose alcohol produced by
hydrogenation of glucose in presence of nickel catalyst (Figure 2.4) (Sandrou and Arvanitoyannis, 2000). Sorbitol is hygroscopic in nature and therefore used as a humectant (Le and Mulderrig, 2001). It is appropriate for the diet of diabetics because it is slowly absorbed in the intestine, converted to fructose in the liver, and metabolized independently of insulin. Sorbitol is considered as GRAS (Generally Regarded As Safe) and should be used at levels that do not exceed GMPs (Good Manufacturing Practice), because excessive consumption can have laxative, diuretic, and gastrointestinal side effects (Newsome, 1993). It is used in food products such as candies, chewing gums, jams, baked products, and frozen dairy desserts.

![Figure 2.4. Chemical structure of sorbitol.](image)

2.1.5.2. Stevioside

*Stevia rebaudiana*, a plant of South American origin, is the source of highly sweet ent-kaurenoid diterpene glycosides, stevioside, rebaudioside A, and several other sweet tasting analogues (Kinghorn et al., 2001). Although stevioside, the major sugar constituent was first isolated in the initial years of 20th century, it was not used commercially as a sweetener till 1970s (Rayaguru and Khan, 2008). Japan was the first country to use stevioside as a commercial alternative sweetener.

Stevioside is a non nutritive high intensity sweetener, which is acid stable and heat stable upto 200°C and has longer shelf-life. In pure form, stevioside (C_{38}H_{60}O_{18}) is white crystalline powder with a molecular weight and melting point of 808.88 and 196-198°C respectively. Stevioside is a stable molecule at 100°C when maintained in
pH range 3-9, but it decomposes quite readily at alkaline pH levels of greater than 10. One sugar unit of stevioside occurs as a D-glucopyranosyl functionality attached $\beta$ to a carboxyl group, whereas the second is a sophorose $[2-O-(\beta-D$-glucopyranosyl)$-D$-glucose] unit attached $\beta$ to a aglycone (Figure 2.5, Kinghorn et al., 2001).

Stevioside is approved as food additive in Japan, South Korea, Brazil, Argentina, Paraguay, and China. The use of stevioside as food additive is under review by CODEX Commission (Kinghorn et al., 2001).

![Figure 2.5. Chemical structure of stevioside (R$1^{-}\beta$ -glc, R$2^{-}\beta$ -glc$^{2}\beta$ -glc, glc= D-glucopyranosyl).](image)

2.1.5.3. Sucralose

Sucralose (Brand name: Splenda) was discovered in 1970s at Queen Elizabeth College, University of London with support from Tate and Lyle Company. Sucralose (1,6-dichloro-1,6-dideoxy- $\beta$ -D-fructofuranosyl-4-chloro-4-deoxy- $\alpha$ -D-galactopyranoside), one of the most promising candidate as an ideal non-nutritive sweetener is obtained by selective chlorination of sucrose. The selective chlorination produces profound changes in sweetness intensity and stability of sucrose, without compromising taste quality (Figure 2.6). Sucralose is white, crystalline, non-hygroscopic, and free flowing powder. It is highly soluble in water, ethanol, and has negligible effect on the pH of the solutions. Sucralose is heat stable and the physicochemical properties allow its use in wide range of food products (baked goods, beverages, coffee, tea, salad dressings, jams, dairy products, frostings, syrups,
fillings, processed fruits, and fruit juices) (Sandrou and Arvanitoyannis, 2000; Goldsmith and Merkel, 2001).

Regulatory agencies around the world have concluded that sucralose is safe. At present, more than 40 countries including India have endorsed the safety of sucralose as non-nutritive sweetener. U.S. Food and Drug Administration (FDA) approved sucralose as a general purpose sweetener in 1999.

![Chemical structure of sucrose and sucralose](image)

Figure 2.6. Chemical structure of (a) sucrose and (b) sucralose.

2.1.5.4. Alternative Sweeteners in Jam

There are few systematic studies undertaken on development of fruit jam using alternative sweeteners (Abdullah and Cheng, 2001; Gajar and Badrie, 2001; Khouriye et al., 2005; Acosta et al., 2008).

Abdullah and Cheng (2001) optimized the ratio of pineapple, papaya, and carambola to develop low calorie mixed fruit jam using acesulfame-K and sorbitol. The most acceptable single fruit was pineapple followed by papaya, while papaya had the best color among all these jams. Contour plot of sensory attributes revealed that formulations containing 3.5-37.7% papaya, 0-15% carambola, and 61.5-96.5% pineapple produced mixed jam of optimum acceptance.

Gajar and Badrie (2001) studied the effects of HM- and LM- pectins and carrageenan on gel set and texture in a low-calorie christophene jam using combination of aspartame, saccharin, and sucralose. The christophene jam with overall acceptance of ‘liked moderately’ to ‘liked very much’, and acceptable gel...
set and texture was developed using 2% HM pectin, 0.03% carrageenan, and 1.9% sucralose. Texture of jam improved during storage and the product had a shelf-life of at least 35 days at 7°C.

Khouriyeh et al. (2005) prepared jelly formulation using sucralose, maltodextrin, and LM pectin with either xanthan gum or locust bean gum singly or in combination. The overall acceptability, aroma, taste, texture, spreadability, and sensory attributes of sugar free jelly ranged between 5.8 and 6.4 on 9-point hedonic scale.

Acosta et al. (2008) used response surface methodology to evaluate and model effects of selected sweeteners, LM pectin, and calcium content on the overall acceptability of a tropical mixed fruit (pineapple, banana, and passion fruit) jelly. A mix of aspartame, acesulfame-K, and sorbitol was used as sweetener. Calcium level had a significant effect on the overall acceptability. The statistical model was further used to optimize the factors to produce ‘low calorie’ jelly, providing less than 12 calories per serving.

2.2. Product Quality

Quality is an increasingly important criterion for determining food choice. Food product quality is judged by several sensory (appearance, color, taste/flavor, textural) characteristics and nutritional value. It is highly desirable for the manufacturers to understand the relation between perceived quality and product characteristics to optimize the quality during product development, and to maintain quality of the food product during distribution and storage. Food product quality is a composite of attributes that are important for commercial success of the product (Singhal et al., 1997).

2.2.1. Color

Color plays an important role in selection of a food item by consumers as it is linked to quality of the product (Hutchings, 1994). Different types of fat soluble and water-soluble pigments (anthocyanin, beta carotene, myoglobin, chlorophyll, etc) are mainly responsible for different colors of fruits, vegetables, flowers, plant, and animal tissues. Color of plant and animal based products changes during processing due to chemical or physical changes in the pigments.

Color is primarily an appearance property attributed to the spectral distribution of light. The Commission Internationale de l'Eclairage (CIE) defined a system of
describing the color of an object based on three primary stimuli: red (700 nm), green (546.1 nm), and blue (435.8 nm). Because of the structure of the human eye, all other colors appear as different combination of these. CIE tristimulus values X, Y, and Z are the coordinates of color sensation based on three component theory of color perception and form the foundation of color space or metrics. There are number of color metrics based on the CIE system, like CIE Lightness, CIELUV, CIELAB, etc. CIELAB is popular in the food industry for color measurements of the food products. Objective measurements of color of food items are carried out using colorimeter and color parameters such as L* (lightness), a* (redness/greenness), b* (blueness/yellowness) and hue angle are used to evaluate product quality. The vertical axis L* is a measure of lightness from totally opaque (0) to totally transparent (100). On the hue-circle, a* is a measure of redness (-a* of greenness), and b* of yellowness (-b* of blueness). C* is chroma, $C^* = \sqrt{(a')^2 + (b')^2}$, and is 0 at the center of a color sphere and increases according to the distance from the center. Finally, $h_{ab}$ is the hue angle [$h_{ab} = \tan^{-1}(b*/a*)$], which is defined as starting at the $+a*$ axis and is expressed in degrees; $0^\circ$ would be $+a*$ (red), $90^\circ$ would be $+b*$ (yellow), $180^\circ$ would be $-a*$ (green), and $270^\circ$ would be $-b*$ (blue) (Hutchings, 1994).

Color of jam has been studied by several researchers (Garcia-Viguera et al., 1998; Garcia-Viguera et al., 1999; Zafrilla et al., 1998; Gajar and Badrie, 2001; Mckee et al., 2002; Suutarinen et al., 2002; Wicklund et al., 2005; Kirca et al., 2007). Change in color (L*, a*, b* values) with increasing TSS during jam manufacturing has, however, not been studied.

Zafrilla et al. (1998) investigated loss of color in fruit preserves during storage. They suggested that color of such products may be fortified by adding natural colorants. Elderberry extract, a commonly used colorant, was compared with a newly proposed alternative, pomegranate juice, for the stabilization of strawberry jam color. The results demonstrated that adding a colorant to jam helped to maintain the color, and that the pomegranate-derived colorant could possibly be used as an alternative to elderberry pigments for this purpose.

Garcia-Viguera et al. (1999) evaluated the stability of three strawberry cultivars for change in jam color during processing and storage at 20, 30, and 37°C for 200 days. Anthocyanin content of jam was determined using HPLC. The effects of cultivar,
processing, and storage on jam pigments, instrumental color (L*, a*, b*), and consumer preference were also determined. ‘Oso grande’ jam had the lowest anthocyanin concentration (110 mg/g fresh weight), higher monomeric pigment degradation during processing, and storage, highest pH, least desirable color score from the sensory panel, and shortest shelf-life.

Wicklund et al. (2005) examined color of jam from five strawberry cultivars; ‘Senga Sengana’, ‘Korona’, ‘Polka’, ‘Honeoye’, and ‘Inga’. The jam was stored at 4 and 20°C in darkness and under fluorescent light (950 lux). The quality parameters assessed were color reflectance at 650 nm, Hunter L*, a*, b*, anthocyanin pigments, and total antioxidant capacity assessed by ferric reducing antioxidant power (FRAP) assay. Jam produced from all cultivars and stored at 4 °C had significantly better color qualities and FRAP values than that stored at 20°C.

Kirca et al. (2007) used black carrot juice concentrate as an additive to enhance the color of strawberry jams prepared from two locally grown cultivars, Osmanli and Kara. Compared to other cultivars processed to jams, these two cultivars were lightly colored but very aromatic. Color and pigment stability of colored and non-colored (control) strawberry jams were studied during storage. The use of black carrot concentrate as a source of natural colorant stabilized the color of strawberry jam. The stabilization was more noticeable for jams prepared from Osmanli cultivar. Monomeric anthocyanin degradation was described by a first-order reaction model. Storage temperature had a strong influence on anthocyanin degradation. Stability of anthocyanins decreased significantly in both colored and non-colored jams with increased temperature during storage. Parallel to decrease in monomeric anthocyanins, hue values of all jam samples increased throughout the storage. Increase in hue values was however much smaller in colored samples than in non-colored samples.

2.2.2. Texture

Textural properties of foods are important component of food quality perception and acceptability (Bourne, 1978). The International Organization for Standardization has defined texture as “all the mechanical, geometrical, and surface attributes of a product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors” (ISO, 1992). Texture evaluation of food products is a complex and dynamic
process because physical properties of foods change continuously throughout the sensory experience. Texture assessment begins from the initial sight of a food product, and continues through touch, initial ingestion, mastication, and swallowing.

The food structure along with masticatory action produces stimuli, which are converted by neural factors into a texture response from the brain. These responses are converted into intensity ratings of certain textural attributes of a food product, which are usually rated by trained sensory panels. Further, texture responses can be converted into preference evaluations typically rated by consumers (Hutchings and Lillford, 1988). In addition to texture perceptions that occur in the mouth, vision, touch, and audition also play important roles in texture perceptions (Heath and Prinz, 1999; Kilcast, 1999). Taste and flavor perception of the product also affects texture perception by the consumer (Bourne, 2002). Food product manufacturers are therefore challenged to formulate specific textures and mouthfeels for better and consistent product development. Because of the importance of texture on quality and choice, understanding the microstructure of the food during product development process is important. Designed microstructure of food can be achieved by manipulating the ingredients functionality and concentration, and processing conditions. In order to have a complete understanding of food texture and microstructure, a multi-disciplinary approach must be taken, combining research from sensory studies, physiological studies, and physical and chemical properties of foods (Wilkinson et al., 2000).

Instrumental texture measurements of food materials are done by Instron or texture analyzer. In comparison to the sensing organs of human body, instrumental testing devices depend on transducers to convert physical characteristics of the material in terms of force-deformation behavior with time (Rosenthal, 1999). Instrumental texture analysis of solid or semisolid food products are done in different modes: shear, compression, torsion, or tension. Sensory perception of textural properties of food products however is a dynamic process which is difficult to mimic by instrumental means. Instrumental measures of texture cannot completely imitate oral motion, rates of force application, or the effects of temperature and saliva. However, accurate measurement of physical properties of foods and determination of their relationships with the dynamic perception of texture can lead to a better understanding of structure-function relationships (Jack et al., 1993).
Jam is a viscoelastic food material that exhibits both solid like and fluid like behavior. Texture of jam has to provide a balance between desired mechanical stability (for storage and handling) and desired instability (to elicit a specific texture attribute during spreading over a piece of bread or during mastication). The subjective textural property associated with jam is ‘spreadability’. The term ‘spreadability’ has been used by consumers for many years to represent the ease with which a food may be spread on bread. Spreadability is a desired characteristic of margarines, butter, jam, chocolate spreads, etc (Bourne, 2002). Hardness, stickiness, work of shear, and work of adhesion are considered as spreadability properties in food systems and can be determined by instrumental textural measurement.

Considerable work has been carried out on textural properties of jam or fruit gel (Gross et al., 1980; Hyvönen and Törmä, 1983; Raphaelides et al., 1996; Hernandez et al., 1999; Grigelmo-Miguel and Martin-Belloso, 2000; Suutarinen et al., 2000; Dervisi et al., 2001). Systematic studies on the texture of jam with variation in ingredients are however lacking. Information on textural attributes of jam prepared with alternative sweeteners is also limited (Hyvönen and Törmä, 1983).

Gross et al. (1980) used fourteen LM pectins to prepare a 30% sucrose gel with a final pectin concentration of 0.8% and an added calcium content of 25 mg Ca²⁺/g pectin. The texture of each gel was evaluated using three descriptors: firmness, coarseness, and graininess. The relaxation behavior of the gels under a constant strain was monitored using an Instron universal testing machine. The data were best defined by an equation that is represented by two Maxwell bodies in parallel. The normal creep behavior of the gels was best defined by the Burger's model.

Hyvönen and Törmä (1983) studied preparation of acceptable low sugar jams and replacement of sucrose by other sweeteners like fructose, high fructose syrup (HFS), sorbitol, xylitol, lactose, saccharin, cyclamate, and combinations of these. They established that it was technologically possible to prepare jams with lower amounts of sucrose than currently used and still attain an acceptable product. The attainment of suitable texture was difficult in xylitol and sorbitol jam than in jam with other sweeteners. Use of maltodextrin as a bulking agent in jam was found to be limited by the normal appearance and taste it imparts to the product.
Raphaelides et al. (1996) tested peach jam prepared using commercial glucose syrups of 39 DE and 44 DE (DE-dextrose equivalent), isoglucose, maltose syrup, and their mixtures with sucrose. Texture development of samples during ageing was studied using an Instron machine. Jam texture was markedly affected by composition of syrups. Consistency of jams ranged from very firm when 100% isoglucose syrup was used to very soft when 100% maltose syrup was used and three weeks ageing was needed for stabilization. The principal component analysis revealed that the jam could be classified according to their mechanical and textural attributes.

Hernandez et al. (1999) studied fruit gels that were prepared using different levels of strawberry pulp (20, 40, 60, and 80%), hydrocolloids (kappa-carrageenan and locust bean gum, 1:1) (0.5, 0.7, 0.9, and 1.1%), and sucrose (0, 10%). Mechanical properties were analyzed by compression (failure stress and failure strain) and by texture profile analysis (TPA) (hardness, cohesiveness, springiness, adhesiveness, and chewiness). Addition of hydrocolloids produced expected increase in both stress and strain at failure. Sucrose increased failure stress but did not alter strain values. Increasing the pulp content from 20 to 80% resulted in a slight increase in stress and lowered strain at failure. Fruit pulp addition increased hardness, chewiness, and adhesiveness values, and lowered cohesiveness and springiness. Statistical analysis of TPA data established that while gel hardness was mainly governed by hydrocolloid concentration, both cohesiveness and adhesiveness were clearly dependent on the proportion of fruit pulp.

Grigelmo-Miguel and Martin-Belloso (2000) studied the effects of reducing the sucrose content (from 55 to 30 °Brix in the final product) and of the use of gellan gum or a mixture of gellan, xanthan, and locust bean gums (3:1:1) on the mechanical characteristics (maximum rupture force and deformation at rupture) of orange gels prepared with 15% w/w fruit pulp, sucrose, and different amounts of hydrocolloids (0.25, 0.4, 0.55, and 0.7% w/w) by uniaxial compression. Use of the mixture of gums permitted attainment of low sugar gels exhibiting mechanical characteristics similar to those of the reference gel, though some differences in texture were perceived.

Suutarinen et al. (2000) investigated the structural changes in strawberry tissues and jam prepared after different pre-freezing treatments, freezing and thawing of raw strawberry tissues by means of instrumental textural measurements, bright field- and FTIR-microscopical studies, and, sensory evaluation. Jams made from strawberries

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Dervisi et al. (2001) evaluated high pressure treated strawberry jam with respect to its textural, and color properties, to establish the relationship between pectin concentrations, texture, and color. Samples were prepared with varying amounts of pectin (0.1, 0.5, 2.5, 5, 7.5, and 10% w/w) and were processed at 400 MPa for 5 min at 25°C. While comparing the experimental samples with commercially available samples of high pressure and traditional strawberry jams, it was found that the best texture was achieved when the pectin concentration was between 2.5 and 5% w/w. Storage and loss moduli were increased with pectin concentration.

2.2.3. Rheology

Rheology is the science of deformation and flow of matter. It is the study of the manner in which a material responds to applied stress or strain (Steffe, 1996). Rheological properties are considered to be important not only in design of food processing equipment and handling systems such as pumps, piping, heat exchangers, evaporators, sterilizes, and mixers, but also in product development and quality control of foods (Saravacos, 1970; Rao, 1977, 1987; Kokini and Plutchok, 1987). Thus the rheological measurements of a product in the manufacturing stage and during storage can be useful in quality control. The microstructure of a product can also be correlated with its rheological behavior allowing development of newer products. In particular, food rheologists have made unique contributions to the study of mouthfeel and its relation to basic rheological parameters (Rao, 1986).

The viscosity of a fluid is essentially its internal friction to flow, and rheology can provide information about the internal molecular structure of a system. In case of a Newtonian fluid, the viscosity is independent of shear rate, but for a non Newtonian fluid it is function of shear rate. According to a standard classification of non-Newtonian fluids, there are three main classes: (i) time independent; (ii) time dependent; and, (iii) viscoelastic fluids. Most materials exhibit a combination of two or more types of non-Newtonian behavior (Lapasin and Pricl, 1995; Steffe, 1996).
Time independent fluids are materials with flow properties that are independent of the duration of shearing. These fluids are further subdivided in three distinct types:

Shear-thinning or pseudoplastic fluids are characterized by an apparent viscosity which decreases with the increasing shear rate. The rate of decrease of viscosity is material specific.

Shear-thickening fluids, also known as dilatant materials, are characterized by an apparent viscosity that increases with shear rate. This trend is much less common in foods.

Viscoplastic fluids are those that exhibit yield stress ($\tau_0$) which is the unique feature of plastic behavior. Yield stress is a limiting shear stress at which the material begins to flow; below this yield value, the material behaves as an elastic solid.

Time dependent fluids are materials in which the shear flow properties depend on both the rate and the time of shearing. There are many food products that recover the original apparent viscosity after a sufficient period of rest; while others the change is irreversible. This type of fluid behavior may be further divided in two categories: thixotropy and rheopecty.

Thixotropic fluids are characterized by an apparent viscosity that decreases with time when sheared at a constant shear rate. This behavior may be caused by droplets or biopolymers that aggregate due to secondary forces (Lapasin and Pricl, 1995). During shearing, the apparent viscosity of the system decreases with time until a constant value is reached and this value typically correspond to the point where there is no further breakdown of structure.

Rheopectic (or anti-thixotropic) fluids are materials in which the apparent viscosity of fluid increases with time when subjected to a constant shear rate. This phenomenon is often an indication of aggregation or gelation that may result from increasing the frequency of collisions or a more favorable position of particles.

Viscoelastic fluids are materials that are simultaneously viscous and elastic. Most food materials exhibit some viscous and some elastic behavior simultaneously and are therefore referred to as viscoelastic (Gunasekaran and Ak, 2000). The viscoelastic properties of materials can be determined using dynamic or transient methods. The dynamic methods include frequency sweep and stress/strain sweep. The transient
methods include stress relaxation (application of constant and instantaneous strain and measuring decaying stress with respect to time) and creep (application of constant and instantaneous stress and measuring increasing strain with time).

2.2.3.1. Rheology of Mango Pulp

Numerous studies have been conducted on the rheological properties of fruit and vegetables products (Rao, 1977; Tanglerthaibul and Rao, 1987; Truong and Walter, 1994). Factors affecting the rheological behavior of the purees/pulps include total solids, total soluble solids, particle size, and temperature. It has been reported that fruit puree/pulp behave as non-Newtonian fluid (Holdsworth, 1971). Rheological properties of mango pulp have been studied by several researchers (Bhattacharya, 1999; Pelegrine et al., 2002; Kassama et al., 2003; Dak et al., 2006).

Bhattacharya (1999) tested time-independent and time-dependent flow properties of mango pulp using a coaxial cylinder rheometer. Mango pulp was found to be a pseudoplastic liquid with yield stress, and exhibited thixotropic properties. The yield stress calculated using the Casson or Bingham plastic models had markedly higher values than those determined by stress relaxation, controlled stress experiments, or from stress-strain plots. The yield stress of mango pulp decreased as temperature increased.

Singh and Eipeson (2000) studied the rheological behavior of clarified mango juice at different temperatures (15–85°C) and concentrations (15–66°Brix) using a rotoviscometer. Mango juice free of pectin and pulp behaved as a Newtonian fluid. The effect of temperature on viscosity was described by an Arrhenius-type equation. The activation energy for viscous flow was in the range of 1.64–8.44 kcal/g-mol. The effect of concentration on rheological behavior of juice was modeled by an exponential relationship.

Pelegrine et al. (2002) investigated rheological behavior of whole and centrifuged mango and pineapple pulps at 30°C in a rotational viscometer. The shear stress–shear rate data was described by Mizrahi–Berk model. It was observed that the pulps exhibited pseudoplastic behavior, and that the suspended solids had considerable influence on the consistency index.
Kassama et al. (2003) investigated the rheological and physical properties of mango puree using a controlled-stress and controlled-strain rheometer and a differential scanning calorimeter (DSC). The rheological behavior of mango puree was found to be thixotropic and that the yield stress was sensitive to temperature.

Dak et al. (2006) evaluated rheological parameters of ‘Totapuri’ mango juice using rotational viscometer at various temperatures (20, 30, 40, 50, 60, and 70°C) and concentrations (5.17, 8.51, 12.38, and 17% total solids). The power law model was fitted to the experimental results. The value of flow behavior index (n) was less than unity (0.24–0.41) at all temperatures and concentrations indicating the shear thinning (pseudoplasticity) nature of the juice. Arrhenius model was used to relate the consistency index with temperature. Consistency index was found to be related to solid concentration by a power equation.

2.2.3.2. Rheology of Jam/Gels

Flow behavior of fruit products containing high or moderate levels of sugars and/or very small amount of gelling agent have been widely studied by several researchers (Glicksman and Farkas, 1966; Saravacos, 1970; Collins and Dincer, 1973; Mizrahi and Firstenberg, 1975; Elfak et al., 1977; Gerdes et al., 1987; Carbonell et al., 1991a,b; Costell et al., 1993; Raphaelides et al., 1996). Considerable information is available on food gels made with different biopolymers (Lopes da Silva et al., 1992; Ndoni et al., 2000; Fu and Rao, 2001; Bulone et al., 2002; Lofgren et al., 2002; Cardoso et al., 2003; Kjoniksen et al., 2003; Sato et al., 2004; Ross-Murphy, 2005; Holst et al., 2006). Majority of the studies on jam investigated effects of formulation and temperature on steady state and time dependent rheological behavior. Therefore, studies on rheology of fruit jam are rather limited (Carbonell et al., 1991a, b; Costell et al., 1993; Grigelmo-Miguel and Martín-Belloso, 2000; Gabriele et al., 2001; Alvarez et al., 2006; Basu et al., 2007). These studies established that the rheological properties of the final product are affected by the amount and type of sugar added, proportion and kind of gelling agent used, fruit content, and process temperature. Systematic studies on rheological behavior during gelation and molecular level understanding of gelation mechanism in fruit jam are lacking.
Rheology of Jam

Carbonell et al. (1991a) studied rheological characteristics of apricot, peach, plum, and strawberry fruit jams and found that flow behavior was adequately described by the Herschel-Bulkley model. Flow behavior of sheared jam was time dependent, and could be quantified by the Weltman model.

Costell et al. (1993) studied the effect of formulation factors on Casson yield values measured at low ($\dot{\gamma}_{01}$) and medium ($\dot{\gamma}_{02}$) shear rates in previously sheared strawberry and peach jams. Twenty three samples of each fruit jam were prepared according to a second order composite rotatable design. Composition ranges were: fruit content 25-55%; soluble solids content 60-70°Brix; and, pectin 0.3-0.7% in strawberry jams and 0.1-0.5% in peach jams. Variation of $\dot{\gamma}_{01}$ in strawberry jams depended mainly on the interactions between fruit and soluble solids and between fruit and pectin, while in peach jams, it depended on fruit-soluble solids and soluble solids-pectin interactions. Variation of $\dot{\gamma}_{02}$ with composition was similar to that observed for $\dot{\gamma}_{01}$ in both strawberry and peach jams.

Alvarez et al. (2006) studied the rheological behavior of selected jams at 20 to 40°C in a rotational viscometer. The rheograms were fitted with power-law, Carreau, Carreau-Yasuda, Herschel-Bulkley, and Cross models and it was found that all the models explained rheological behavior of jam. It was observed that the jams exhibited pseudoplastic behavior and that the suspended solids influenced the consistency index.

Rheology of Gel

Flory (1953) defined gel as a soft, solid or solid-like material of two or more components, one of which is a liquid present in substantial quantity. It is composed of crosslinked polymeric molecules linked to form a tangled interconnected networks immersed in liquid medium. At the molecular level, gelation is the process which imparts stress resisting bulk character (solid properties) due to continuous framework of networks of polymer chains that extends throughout the gel phase. Flory (1974) later proposed a classification of gels based on structural criteria:

(i) well-ordered lamellar structures, including gel mesophases;
(ii) covalent polymeric networks; completely disordered;

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(iii) polymer networks formed through physical aggregation; predominantly disordered, but with regions of local order; and,
(iv) particulate, disordered structures.

Most food biopolymers form physical gels, structured by weak hydrogen, hydrophobic and electrostatic interaction (Clark and Ross Murphy, 1987; Ross-Murphy, 1995 a,b; Rao, 2003). Gelling of food biopolymers is divided into ‘cold setting’ and ‘heat setting’, based on the gelation mechanism. In the former, gelation is induced by cooling (agarose, carrageenans, pectin, whey protein, etc.) while in the latter, gelation occurs due to heating (bovine serum albumin, myosin, etc.).

Almdal et al. (1993) further refined definition of the solid-like characteristics of gels in terms of the dynamic mechanical properties, viz. a storage modulus, $G'(\omega)$, exhibiting a pronounced plateau extending to times at least of the order of seconds, and a loss modulus, $G''(\omega)$, which is considerably smaller than the storage modulus in the plateau region. Food gels in terms of mechanical viscoelastic characteristics can again be classified into two types: strong and weak gels. Both strong and weak gels behave as solids at small deformations. However, strong gels behave as solids, while the weak gels are structured fluids at large deformations.

Ross Murphy (2005) reviewed the structure/property relationships for biopolymer (including food biopolymer) solutions and gels. He described how small deformation oscillatory measurements enable distinction between “strong” and “weak” gels, as food thickeners, gels, and stabilizers. At small strains, both strong and weak gel systems exhibit essentially the same mechanical spectrum, with $G' > G''$, and with both moduli largely independent of frequency. However, the deformation dependence of these two classes of materials was different. At large deformations, strong gels rupture and fail, while weak gels flow without fracture and show recovery of solid (gel-like) character (Clark and Ross-Murphy, 1987). In a weak gel, the dynamic modulus was frequency dependent, suggesting the occurrence of relaxation process even at small time scales and lower difference in values between $G'$ and $G''$. Several researchers have identified weak gel like behavior of food biopolymer gels and solutions (Doublier et al., 1992; Ross Murphy, 1995 a,b; Mleko and Foegeding, 2000; Ikeda and Nishinari, 2001; Lofgren et al., 2002). A promising and new approach of
describing foods as a weak gel is found in recent studies (Rao and Cooley, 1992; Tunick, 2000; Gabriele et al., 2001; Ng and McKinley, 2008).

Gabriele et al. (2001) suggested that many systems can be treated as gels, characterized by three dimensional networks, in which weak interactions (like van der walls interaction or hydrogen bonding) ensure the stability of the structure. This kind of approach, called weak gel model, was found suitable for different gel systems (jam, dough, and yoghurt).

**Rheology of Pectin/Pectin-Sucrose Gel**

Jam is a type of food gel system comprising fruit pulp, pectin, sugar, and acid. The gelation process largely depends on the pectin and cosolute sucrose. Many studies are available on both HM- and LM- pectin gelation (Lopes da Silva et al., 1992, 1994, 1995; Grosso and Rao, 1998; Evageliou et al., 2000 a,b; Ndoni et al., 2000; Fu and Rao, 2001; Bulone et al., 2002; Cardoso et al., 2003; Lubbers and Decourcelle, 2004; Sato et al., 2004; Tsoga et al., 2004 a,b).

Lopes da Silva et al. (1992) investigated rheological properties of HM pectin and locust bean gum solutions in steady shear. Cross and Carreau flow models described well the shear rate and apparent viscosity data.

Lopes da Silva et al. (1995) investigated concentration and temperature dependence of the gelation kinetics of HM pectin (60% sucrose, pH 3) using small-amplitude oscillatory shear measurements. Rate of gelation close to the gel point was described as a second-order rate process. The gelation rate of HM pectin/sucrose systems was strongly dependent on temperature and the Arrhenius relationship was applied to describe the dependence.

Evageliou et al. (2000a) studied the effect of cosolutes on the formation and properties of HM pectin gels (pectin concentration 0.5 wt%; DE 70.3) by compression testing at 5°C using small-deformation oscillatory measurements of storage and loss moduli. They found that replacement of sucrose by glucose or fructose affected large changes in gelation temperature, in the order: fructose<sucrose<glucose: The departure from the normal order of effectiveness (fructose<glucose<sucrose) was anticipated from compatibility of cosolutes with water structure. This behavior was observed experimentally for the same sugars in combination with other biopolymers.
and was attributed to inhibition of intermolecular association by strong hydrogen-bonding of primary alcohol groups on the sugars (2 per residue in fructofuranose, 1.5 per residue in sucrose, and 1 per residue in glucopyranose) to the carboxylic acid and methyl ester groups of pectin.

Ndoni et al. (2000) studied the viscoelastic behavior of carrageenan and pectin gels measured in three ways: (i) texture analysis consisting of stress-strain measurements; (ii) parallel plates compression stress-relaxation; and, (iii) parallel plates oscillatory torsion shear deformation. They developed a correlation between the routine textural properties and the material properties, i.e. complex moduli.

Fu and Rao (2001) studied the gelation of LM pectin in presence of sugar and found that a non-isothermal kinetic model described temporal variation of $G'$ during gelation induced by cooling. Two different gelation regimes, corresponding to two different temperature ranges, were observed. During the ageing process, increasing the pectin and sucrose concentration resulted in a significant increase in $G'$. Using the plateau values of $G'$ and the rubber elasticity theory, the number average molecular weight of chains between cross-links ($M_c$) was estimated. At the same pectin concentration, $M_c$ of 0% sucrose gels was greater than those of 10 and 30% sucrose gels. These results reflected the important role of the hydroxyl groups of sucrose in gel formation and that sucrose stabilized the structure of junction zones.

Bulone et al. (2002) studied static and dynamic light scattering of semi-dilute solutions of HM pectin in the presence of different amounts of sucrose, ranging from few % (w/w) to a value just below the threshold required for gel formation. The dynamic behavior on approaching the condition required for gelation exhibited typical of a glass transition, thus providing new insight into the role of sucrose in promoting the gelation of pectin. The divergence of viscosity and associated structural relaxation time, a typical of a glass transition, was found to occur at a critical value of sucrose concentration, where gelation was in fact observed.

Cardoso et al. (2003) studied temperature dependence of formation and melting of pectin-Ca$^{2+}$ networks. Small deformation rheometry was used to characterize the calcium-induced gelation of LM pectins at different pH. The gelation kinetics was interpreted with the change of the storage modulus with time, taken as a measure of
changes in cross-linking density with pectin–calcium network. The structural diversity of the two pectin samples had substantial influence on the gelation kinetics and the thermal behavior of the pectin-calcium networks, due to differences in the steric arrangement or environment and availability of the chelating groups. An association mechanism different from the classical “egg-box” model was suggested to predominate under conditions of low availability of dissociated carboxylic groups due to low pH, higher degree of methylation, or steric constraints introduced by acetylation or neutral side chains.

Lubbers and Decourcelle (2004) studied the rheological behavior of pectin gels in the presence of aroma compounds during food concentration. Two techniques were used to investigate the effect of aroma substances on rheological properties of HM pectin based systems. Macroscopic fracture ($\sigma F$) was compared between flavored and unflavored gels on stress displacement curve, which was obtained with uniaxial compression until fracture. An oscillatory rheometer was used to determine the gelation time ($T_{gel}$). Results indicated that all the aroma compounds increased $\sigma F$ significantly. It is generally acknowledged that hydrophobic interactions are the main interactions leading to HM pectin gelation, and hydrophobic interactions increase $\sigma F$. It was assumed that esters might increase $\sigma F$ through increased hydrophobic interactions in HM pectin network.

Sato et al. (2004) investigated the inter-macromolecular interaction of HM pectins from citrus fruits and apple in various sugar solutions (ribose, mannose, glucose, sucrose, trehalose, and maltose) through the analysis of the specific viscosity ($\eta_p$) excluding the background effect of sugar solutions. Water activity ($a_w$) decreased with increase in sugar concentration while $\eta_p$ increased linearly with decrease in $a_w$ for all the sugars tested, showing a change in the hydrogen-bonding among pectin molecules. The effect of $a_w$ on $\eta_p$ was also dependent on the type of the sugar coexisting. Effect of sugars on the inter-macromolecular interaction was evaluated by $(-d\eta_p/da_w)$; which revealed a good correlation with aqueous solvent-ordering parameters for sugar solutions in the literature. Variation in effect of sugars on the inter-macromolecular interaction was explained on the basis of the hydrophobic interactions among pectin molecules through the change in the solvent-ordering.

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2.2.3.3. Cox-Merz Rule

A well-known empirical relationship in the rheology of polymer melts is the Cox-Merz rule, which relates the linear dynamic moduli as function of frequency to the steady shear flow viscosity as a function of shear rate (Cox and Merz, 1958). The Cox-Merz correlation is generally applicable to flexible molecules and has been tested for a wide variety of polymers, solutions, and complex food systems. Many deviations from the Cox-Merz rule have been found for biopolymer systems, weak- and concentrate-suspensions, and foods. In case, the Cox-Merz rule is not directly applicable and the data sets of the dynamic and steady viscosities are parallel, the deviation can be adjusted using the extended Cox-Merz rules (Bistany and Kokini, 1983; Doraiswamy et al., 1991; Rao and Cooley, 1992; Yu and Gunasekaran, 2001).

2.2.3.4. Thixotropic / Time Dependent Behavior

Many food products are thixotropic in nature and are characterized by decreasing shear stress/viscosity with shearing time (Holdsworth, 1993; Barnes, 1997). Recovery of stress occurs for some food products under rest. Thixotropy results due to structural reorganization with time of shearing and coupled with reduced resistance to flow. Commonly used method to characterize thixotropy is to apply a constant shear rate at a particular temperature and study the variation of shear stress/viscosity with time. Time dependent rheological models for food materials have been developed by several researchers (Weltman, 1943; Hahn et al., 1959; Tiu and Boger, 1974; Figoni and Shoemaker, 1981; De Kee et al., 1983; Baravian et al., 1996).

Many researchers have characterized the thixotropic behavior of food materials (Tiu and Boger, 1974; Figoni and Shoemaker, 1983; Ford and Steffe, 1986; Carbonell et al., 1991 a,b; Benezech and Maingonnat, 1993; Baravian et al., 1996; Ramos and Ibarz, 1998; Bhattacharya, 1999; Abu-Jdayil, 2002; Anderson et al., 2006; Basu et al., 2007). Time dependent rheology of fruit pulps have been investigated by several researchers (Mizrahi, 1979; Lozano and Ibarz, 1994; Ramos and Ibarz, 1998; Krokida et al., 2001). Thixotropic characteristics of mango pulp has been studied by Bhattacharya (1999). However few researchers have studied the thixotropic characteristics of fruit jam (Carbonell et al., 1991 a,b; Basu et al., 2007) and systematic study on time dependent rheological characteristics of mango jam has not been reported.
Bhattacharya (1999) tested time-independent and time-dependent flow properties of mango pulp using a coaxial cylinder rheometer and found that the mango pulp behaved as a pseudoplastic liquid with yield stress, and exhibited thixotropic properties. Weltman model described well the variation of shear stress with time.

Ramos and Ibarz (1998) investigated thixotropic behavior of orange juice and quince puree at selected temperatures and shear rates. The thixotropic behavior of orange juice and quince puree increased with TSS but decreased with increasing temperature. Figoni and Shoemaker (1983) model described the thixotropic behavior. Quince puree showed a greater thixotropic character than orange juice because it had a higher content of pulp and pectin and microscopic structure consisting of long particles and heterogeneous fibers.

Carbonell et al. (1991b) investigated the influence of three variables i.e. fruit content (25-55%), soluble solids content (40-70° Brix), and added pectin (0.3-0.7% in strawberry jams and 0.1-0.5% in peach jams) on time dependent parameters in previously sheared jams. Twenty three samples of each fruit jam were prepared according to a second order composite rotatable design. Weltman A values depended mainly on fruit content and on its interaction with soluble solids and added pectin for both fruit jams. Weltman B values depended on the three variables and on fruit-pectin interaction for strawberry jam, while for peach jam samples B values depended also on fruit-soluble solids interaction. Predictive power of time dependent parameters for estimation of fruit content was low, but considering them in conjunction with soluble solids content and total pectin values explained 91.7% of the variability of fruit content in strawberry jam samples and 83.7% of same in peach jam samples.

Basu et al. (2007) studied the effect of sugar and pectin concentration, pH, shear rate, and temperature on time dependent rheological properties of pineapple jam. Thixotropic behavior of pineapple jam was influenced by the shear rate employed, temperature, and composition. Hahn model described adequately the time dependent flow properties of pineapple jam.

2.2.4. Sensory Evaluation

Sensory evaluation is defined as a method that scientifically measures, evokes, analyzes, and interprets responses to products through smell, sight, taste, touch, and
hearing (Stone and Sidel, 1993). Sensory evaluation is aimed at profiling a product based on all of its perceived sensory characteristics. Sensory techniques can be used to optimize product development as well as quality of the final product (Lawless and Heymann, 1998).

There are different subjective and objective methods of sensory evaluation that are used to obtain sensory data. The main categories are: (i) discriminative sensory analysis; (ii) descriptive sensory analysis; and, (iii) consumer affective tests. The use of consumer affective or acceptance sensory evaluation is beneficial in determining the probable success of a product. In the food industry, consumer sensory testing has two main methods: the measurement of preference and the measurement of acceptance (Jellinek, 1964). Consumer acceptance scores may be used to infer preferences indirectly (Lawless and Heyman, 1998). Acceptance testing is typically measured using a hedonic scale with 5, 7, or 9 points. The 9 point or degree of liking scale is the most common hedonic scale and was invented in the 1940s at the Food Research Division of the Quartermaster Food and Container Institute, Chicago, U.S.A. The hedonic scale has preferences associated with the numerical values ranging from 1 (dislike extremely) to 9 (like extremely) and these preferences are chosen on the basis of equal interval spacing, thus giving the scale ruler like properties (Lawless and Heymann, 1998).

Sensory properties are important for ranking of the products during product development stage to understand the consumer’s perceptions of acceptability based on color, flavor, taste, texture, and overall acceptability scores. Sensory evaluation of jam has been studied by several researchers (Rosenfeld and Nes, 2000; Abdullah and Cheng, 2001; Khouryieh et al., 2005; Acosta et al., 2008).

Rosenfeld and Nes (2000) investigated sensory properties of fresh fruits, frozen non-cooked jam, and traditionally cooked jam of 14 strawberry cultivars. The purpose was to characterize and compare the sensory quality of different strawberry cultivars and different types of jam. The results were presented by means of multivariate modeling methods such as principal component analysis (PCA) and partial least squares regression (PLS). The sensory profile of cooked jam differed from that of fresh fruits and frozen jam, explaining 75% of the total
variation in the first component. Cooked jam scored high for sweet taste, stickiness, bitter taste, earthy flavor, off-flavor, and total intensity of taste. Frozen jam had many of the same sensory characteristics as that of fresh fruits and scored high for strawberry flavor, fruity flavor, and whiteness, while fresh fruits scored highest for color strength, hue, and sour taste. PLS analysis revealed that sensory color and flavor of fresh fruits predicted 35% of sensory cooked jam variables. Analyzing early cultivars alone, sensory fresh fruit variables were able to predict 69% of sensory cooked jam variables.

Abdullah and Cheng (2001) used response surface methodology to optimize ratio of papaya, pineapple, and carambola in the formulation of reduced calorie tropical mixed fruit jam. Ten formulations covering the entire range of a triangular simplex were subjected to sensory evaluation. Contour plot of sensory attributes revealed that mixed jam formulation containing 3.5-37.7% papaya, 61.5-96.5% pineapple, and 0-15% carambola had optimum acceptance.

Khouryieh et al. (2005) studied the formulation of sugar-free jellies. Three jelly formulations were prepared using sucralose, LM pectin, and maltodextrin with either xanthan gum or locust bean gum (LBG) used alone or in combination. Jelly formulations were evaluated with respect to chemical, physical, and sensory properties. The combination of xanthan gum and LBG significantly reduced syneresis compared to either gum used alone. The overall acceptability, aroma, taste, texture, spreadability, and sensory attributes for sugar-free grape jelly averaged 5.8–6.4 on a 9-point hedonic scale.

Acosta et al. (2008) evaluated effects of sweetener, LM pectin, and calcium content on the overall acceptability of a tropical mixed fruit (pineapple, banana, and passion fruit) jelly. Results indicated that calcium level had a significant effect, while LM pectin and sweetener levels did not have substantial effect on overall acceptability.
2.3. FTIR Spectroscopy

Fourier transform infrared (FTIR) spectroscopy is an analytical technique for fast and nondestructive analysis of foods compared to conventional methods (Wehling, 1998; Tewari and Irudayaraj, 2004). FTIR spectroscopy can be thought of as a molecular ‘finger printing’ method. Detection of individual constituents as well as subtle compositional differences between and among multi-constituent specimens is possible due to advanced optics and design, high spectral signal-to-noise ratio, and highly resolved spectra from modern FTIR spectrophotometers (Wilson and Goodfellow, 1994). An infrared (IR) spectrum contains features arising from vibrations of molecular bonds, and the mid infrared region (400–4000 cm⁻¹) in particular is highly sensitive to the precise chemical composition of the sample. IR radiation is divided into three regions: near infrared, from 4000 to 14000 cm⁻¹; mid infrared, from 400 to 4000 cm⁻¹; and far infrared, from 4 to 400 cm⁻¹. For food analysis, the near and mid infrared regions are more useful (Wehling, 1998; Kacuráková and Wilson, 2001).

Infrared spectroscopy is based on the discrete vibrational transitions that take place in the ground electronic state of molecules. Infrared absorption spectroscopy typically involves absorption of an IR photon of light by a molecule from a lower to a higher vibrational energy level. These vibrational transitions correspond to different stretching, bending, wagging, deformation, and other types of vibrational motions of the molecules (Ma and Phillips, 2002). Organic compounds have chemical bonds which vibrate or rotate when exposed to characteristic wavelengths of IR radiation. These vibrations are outcome of energy absorption at specific wavelengths in IR region. The absorbent wavelengths and natural vibration are unique for different chemical groups and depend on the bond (C-C, C-O, C-N, O-H, etc) and on the molecular matrix. The amplitude of vibrational frequencies increases during absorption of IR radiation and is directly proportional to the concentration of the molecules. The basic information obtained in FTIR spectroscopy is IR spectrum, which is a plot of absorbance (transmittance) against wavenumber calculated from the intensities of measured frequencies of vibration. The IR spectrum of an organic matrix therefore contains valuable information on the structure and concentration of chemical functional groups within the material (Smith, 1999).
FTIR spectroscopy is widely used in food processing industry and research for both qualitative and quantitative analysis of the product composition, quality and authenticity, detection of adulteration, etc. FTIR spectroscopy has been used for fruit juice composition and authentication (Duarte et al., 2002; Irudayaraj and Tewari, 2003); pectin characterization (Kamnev et al., 1998; Wellner et al., 1998; Monsoor et al., 2001 a,b; Barros et al., 2002; Pappas et al., 2004; Singthong et al., 2004); biopolymer gelation (Belton et al., 1989; Nagano et al., 1994; Matsumoto et al., 2006); and fruit jam composition (Wilson et al., 1993; Defemez and Wilson, 1995; Čopikova et al., 2001).

Duarte et al. (2002) used FTIR-attenuated total reflectance (ATR) spectroscopy and multivariate analysis for quantification of sugars in mango juices as a function of ripening. Calibration was based on sucrose/glucose/fructose mixtures, with six concentration levels and following a triangular experimental design. Partial least square regression of the spectra first derivatives gave the best results, enabling quantification of fructose, sucrose, and glucose with 1.4, 1.4, and 4.9% prediction errors respectively. Multivariate analysis of FTIR spectral data was useful to detect over-ripening in fresh fruits, a period when other indicators (pH and soluble solids) did not change significantly and found its usefulness in predicting fruit stability during transport and storage.

Wellner et al. (1998) studied the interaction of divalent cations with potassium pectate and three potassium pectinate samples with DE of 23.8, 59.1, and 93.4% respectively using FTIR spectroscopy. Characteristic shifts occurred in C–O and ring vibrations in the 1200–900 cm⁻¹ region as well as in the asymmetric and symmetric stretching (νas and νs) of the carboxylate bands at about 1617 and 1420 cm⁻¹, indicating a metal coordination by the pectate chains in accordance with the ‘egg-box’ hypothesis. The FTIR spectra revealed some interaction between pectate and K⁺ and Mg²⁺ even when no gels were formed. Ca²⁺ and Sr²⁺ interacted strongly with pectate and LM pectinates. Ni²⁺, Cu²⁺, Zn²⁺, Cd²⁺, and Pb²⁺ also showed complex formation with the pectinates at DE=59.1%, and Pb²⁺ and Cu²⁺ to some extent even with highly esterified pectinate (DE=93.4%).
Barros et al. (2002) used the combination of the absorbance spectra in two IR regions (1800–1500 and 1200–850 cm\(^{-1}\)) to construct a calibration model to determine the degree of methylesterification (DM) of pectic polysaccharides. The wavenumbers in the region 1800–1500 cm\(^{-1}\) were related to the carbonyl esters and carboxylates and those in the region 1200–850 cm\(^{-1}\) were related to the sugars composition. The model was developed by means of a matrix of the outer product of the two regions and PLS regression, using cell wall pectic polysaccharide extracts from olive and pear pulps.

Pappas et al. (2004) studied the spectroscopic properties of pectins isolated from bark, wood, and pith of four kenaf (Hibiscus cannabinus L.) varieties. The DE values ranged between 57 and 90% and there were no significant differences between kenaf varieties. The higher DE value was found in wood pectins (86–90%), intermediate in pith (75–83%), and lower in bark (57–64%).

Singthong et al. (2004) extracted pectins from Krueo Ma Noy (Cissampelos pareira) leaves. The dominant structure of Krueo Ma Noy pectin was established as 1,4-linked α-D-galacturonan by a combination of carboxyl reduction and methylation analysis, and confirmed by FTIR spectroscopy.

Belton et al. (1989) studied effect of different temperatures on gelation of i- and k-carragennan with specific ions using FTIR spectroscopy. They concluded that although the assignment of the sulfate symmetric stretch was probably correct, it was not sensitive to ion binding.

Matsumoto et al. (2006) studied silk fibroin sol-gel transitions under various physicochemical conditions with optical spectroscopy at 550 nm. The secondary structural change of the fibroin from a disordered state in solution to a \(\beta\)-sheet-rich conformation in the gel state was assessed by FTIR and circular dichroism over a range of fibroin concentrations, temperatures, and pH. The structural changes were correlated to the degree of gelation based on changes in optical density.

Wilson et al. (1993) investigated the potential of FTIR spectroscopy to determine fruit content of jam. A quantitative method was developed using dried jam and the
potassium bromide pellet technique in combination with simple linear regression and PLS analysis. Results demonstrated that FTIR spectroscopy can be used to determine fruit content of strawberry jam. Defernez and Wilson (1995) attempted to differentiate between ‘strawberry’ and ‘non-strawberry’ jams using FTIR spectra analyzed by chemometric methods. Diffuse reflectance infrared (DRIFT) spectra of the insoluble materials of the jams led to almost 100% success in classification. Using DRIFT combined with discriminant analysis, almost 100% success in reclassification of the jams into two groups ‘strawberry’ and ‘non-strawberry’ was achieved, indicating the feasibility of this method. However they suggested that the method of sample preparation was lengthy and needs some refinement to allow the data set to be increased in size and therefore the statistical method used to be more robust.

Čopikova et al. (2001) used FTIR spectra of isolated high molecule fraction for identification of hydrocolloids in confectionary jellies and food supplements. The simple comparison of spectra of standards and test samples was useful to understand hydrocolloid functionality in food products.

2.4. Food Microstructure and Scanning Electron Microscopy

Microscopy and imaging techniques are the most appropriate analytical techniques to evaluate food structure because they produce results in the form of images. Scanning electron microscopy (SEM) is one of the microscopy techniques to examine food microstructure. Food microstructure is the organization of biomolecules (fat, protein, carbohydrate, water, etc.) within food and their interaction. In fact, it is the microstructure which actually determines the sensory and mechanical characteristics of a food (Aguilera and Stanley, 1999). Foods having similar microstructures can be loosely grouped together as foods that have similar textures (Kalab et al., 1995). Observing microstructure of food and its variation with composition or processing condition can provide information on parameters directly related to texture. Knowledge of microstructure is important for controlling food properties since there is a relation between food microstructure and macroscopic functionality. Several scientists have demonstrated the importance of using microscopy for elucidating
the food microstructure (Kalab et al., 1995; Aguilera and Stanley, 1999; Aguilera et al., 2000).

Invasive techniques typically employ a microscope to observe the structure of foods from a few hundred microns to a few nanometers. SEM use electron beams emitted from a high voltage tungsten filament that fall onto a specimen. For secondary electrons to be emitted from the excited specimen, it must first be sputter coated with a thin layer of an electron-rich metal (typically gold and/or palladium). When such specimen is struck by a high-energy electron beam it will emit a lower energy secondary electron (Bozzola and Russell, 1999). These reflected electrons are captured by a detector and projected onto a screen as an image. The advantages of SEM are the ease of sample preparation and the capability to analyze more detail and contour in structures. The SEM is optimally utilized for examining structures from 30 nm to 60 μm (Aguilera and Stanley, 1999). Several researchers have examined the use of SEM technique to understand the microstructure of biopolymer gels. Pectin gels in presence of sugar have been studied by Fishman et al. (1992); Lofgren et al. (2002, 2005, 2006); and, Fishman et al. (2004). However, literature on microstructure of jam prepared with sugar and alternative sweeteners is lacking.

Lofgren et al. (2002) investigated the microstructure and rheological properties of pure HM- and LM- pectin gels, and mixed (HM+LM) pectin gels. Gel formation of either HM- or LM- pectin, or both, was initiated in the mixed gels by varying the sucrose and Ca²⁺ content. The microstructure was characterized by transmission electron microscopy, light microscopy, and confocal laser scanning microscopy. HM- and LM- pectin gels showed aggregated networks with large pores of about 500 nm and network strands of similar character. Small differences could be found, such as a more inhomogeneous LM pectin network with shorter and more branched strands of flexible appearance. LM pectin also formed a weak gel in 60% sucrose in the absence of calcium. A highly inhomogeneous mixed gel structure was formed in the presence of 60% sucrose and Ca²⁺ ions, which showed large synergistic effects in rheological properties. Its formation was explained by the behavior of the corresponding pure gels. In presence of 60% sucrose alone, a homogenous, fine-stranded mixed network was formed, which showed weak
synergistic effects. It was suggested that LM pectin interacts with HM pectin during gel formation, thereby hindering secondary aggregation leading to the aggregated networks observed for the pure gels.

Fishman et al. (2004) studied atomic force microscopy in the tapping mode for height and phase shift images of high methoxyl-sugar-acid gels (HMSAG) of pectin. Images revealed that pores in these gels were fluid and flattened out when measured as a function of time. These images revealed the structure of adsorbed sugar on pectin in the hydrated native gels and how the pectin framework is organized within these gels. Segmentation of images revealed that the underlying pectin framework contained combinations of rods, segmented rods, and kinked rods connected end to end and laterally. The open network of strands was similar to pectin aggregates from 5 mM NaCl solution imaged earlier by electron microscopy (Fishman et al., 1992). Area measurements revealed that the ratio of bound sugar to pectin was in excess of 100 to 1 (w/w). Furthermore, images indicated relatively small differences in the organization of native commercial citrus pectin, orange albedo pectin, and lime albedo pectin gels at optimal pH. The study demonstrated the advantage of simultaneous visualization of height and phase shift images for observing and quantification the nanostructure of relatively soft gels which are fully hydrated with a buffer.

2.5. Principal Component Analysis

Principal Component Analysis (PCA) is a widely used multivariate analytical statistical technique that provides a method of extracting structure from a variance-covariance or correlation matrix (Chapman et al., 2001). PCA is a mathematical transform which is used to explain variance in a data matrix (Wold et al., 1983). The data matrix consists of a number of observations (experiments) and each observation consists of a number of variables. A vector is calculated which describes the direction of the largest variance, that is the direction that describes the largest differences among observations. This vector is called the first principal component (PC). The second principal component is orthogonal to and thus independent of the first PC. Further PCs can be calculated in a similar way, until most of the observations are explained. A new matrix, as defined by the PCs
is then formed, and the data set is considerably reduced, depending on the significance for the different PCs, but in many cases to two dimensions. The PCs define a hyper plane which maximizes the variation in the original observations. The objective is to explicate as much of the total variation of the data with as few PCs as possible (Munoj, 1997). Furthermore, PCs are defined by loading vectors, which describes the direction of the PC in relation to the original variables, and score vectors, which describe the direction of the PC in relation to the observations. Thus, a loading plot can be made corresponding to the loading vectors, showing the relationships between the original variables and how much they influence the system. A corresponding score plot reveals the relation between the observations or experiments, and groupings of observations in the score plot can be used for classifications. In a bi-plot, scores and loading values are represented in the same plot, indicating their relation.

PCA has been used by researchers for various food processing applications like product quality classification, processing optimization, sensory evaluation, flavor profile, and chemometric data analysis (Chapman et al., 2001; Oomah and Mazza, 2001; Nakai et al., 2002; Cocchi et al., 2004; Bertram et al., 2006). PCA is a frequently applied method for multivariate overview analysis of sensory data (Jackson, 1991; Hough et al., 1992; Greenhoff and McFie, 1994; Chapman et al., 2001; Kallithraka et al., 2001).

Chapman et al. (2001) used PCA for identification of four significant PCs that accounted for 87.6% of the variance in the sensory attribute data of ultrapasteurized milk. Overall product quality was modeled as a function of PCs using multiple least squares regression.

Kallithraka et al. (2001) used PCA for classification of 33 greek wines from various regions by employing both instrumental and sensory analysis. Application of PCA to the experimental data resulted in satisfactory classifications of only Greek red wines in terms of their geographical origin.

For the present work, variations in the multivariate data sets originating from color, textural, and rheological parameters, sensory scores, and jam composition were used for PCA.
2.6. Summary of the Literature Review

It is now well established that alternative sweeteners can be effectively used to replace sucrose to manufacture fruit jams. However, systematic studies of the combined effects of sucrose and alternative sweeteners on color, rheological, textural, sensorial and structural properties of fruit jam are lacking. One of the ultimate goals in food product development is to be able to design food products with desired textures and sensory attributes. In order to accomplish this goal, molecular understanding of food structure and texture is essential. Fundamental rheological methods are valuable to study structural mechanisms because they are based on physical and chemical principles, when combined with sensory analysis, structure-function relationships can be established.