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DEVELOPMENT OF FRUIT PASTE FROM STANLEY PLUMS AND A STUDY OF PROCESSING AND STORAGE PARAMETERS ON PHYSICAL, CHEMICAL AND SENSORY CHARACTERISTICS

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WEN-MIN WANG

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# DEVELOPMENT OF FRUIT PASTE FROM STANLEY PLUMS AND A STUDY OF EFFECT OF PROCESSING AND STORAGE PARAMETERS ON PHYSICAL, CHEMICAL AND SENSORY CHARACTERISTICS

By

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# ABSTRACT


## DEVELOPMENT OF FRUIT PASTE FROM STANLEY PLUMS AND A STUDY OF EFFECT OF PROCESSING AND STORAGE PARAMETERS ON PHYSICAL, CHEMICAL AND SENSORY CHARACTERISTICS

By

Wen-Min Wang

Stanley plums are the leading plum variety in Michigan. In order to increase the economic significance of this commodity, there is a need for development of new product from Stanley plums. Standard and substandard plums were processed to pastes by heat concentration to 25 and 30°Brix, respectively. It was not feasible to concentrate plum paste beyond 40°Brix. Pastes made from standard plums had higher quality and yield. Heat concentration significantly increased total solids and apparent viscosity, but decreased water activity, titratable acidity, Hunter color values, pectin and anthocyanin content. Sugar addition darkened color.

24-week storage decreased titratable acidity, Hunter 'a' values, pectin and anthocyanin content. Samples stored at 4°C had higher color retention than at 22°C.

Sensory evaluation indicated that preference could be adequately predicted by flavor and color under suitable Brix/acid ratio. Storage effect was variable based on the results of sensory analysis.

This is dedicated to Yu-Chen Wang
and Hsiu-Chu Wang-Chou
to whom I stand in debt for my education and knowledge.

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# INTRODUCTION

Plums can be an important crop in Michigan, but in order to increase the economic significance of this commodity there is a need for development of new products from plums. Stanley plums are the most abundant plum variety in Michigan and its importance to the industry is derived from the fact that : 1) timing of harvest falls between two major fruit crops, cherries and apples, thus optimizing available labor and equipment; 2) cultivar of Stanley plums is especially suited to Michigan climate (Elliott, 1983). The development of a strong market for Michigan plums is particularly relevant for the state's fruit growers because it is one of their most important minor crops.

A Great deal of work has already been done in our group to develop plum juice from Stanley, as well as from several other cultivars of plums which may be grown in Michigan in the future. In addition to juice, the apparent success of several recently developed new products in the U.S. which use fruit pastes indicates that plum paste might find very good acceptance in the marketplace. Such a product could utilize fairly large quantities of fruit and give a "value added" product which would increase use of plums. Therefore, the objectives of this study were to 1) develop a processing procedure to produce pastes from Stanley plums and determine the effect of processing conditions on the chemical, physical and sensory characteristics of plum pastes, and 2) evaluate the effect of storage conditions on the chemical, physical and sensory characteristics of plum pastes.

# LITERATURE REVIEW

## I. Plum Description

Plums belong to Rosaceae family and *Prunus* genus and are native of the temperate parts of the Northern Hemisphere. This fruit consists of several species, such as *Prunus domestica, P. cerasifera, P. damascena, and P. salicina* (Timberlake and Bridle, 1982) . Stanley plum (*P. domestica* L.) is an Italian plum and characterized by oval shape, large size, mostly free stone, firm and greenish-yellowish flesh, and dark purple skin. The variety is harvested from August until early October in Michigan ( Anon., 1988).

### Nutrient Composition

The general nutrient composition of plum fruit is presented in Table 1. Plum, relatively high in dietary fiber and low in calories, is a healthy food for human beings. Due to the reported association of low fiber diets with diverticulitis, cancer of the bowel, cardiovascular diseases, diabetes, and other diseases of the gastrointestinal tract (Behall and Reiser, 1986), there has been an increased interest in high fiber foods during the past few years, especially in developed Western countries. Consumption of pectin has also been shown to have healthful benefits (Cara et al., 1992; Nishimune et al., 1991; and Schneeman, 1989).

Recommendations to include more fiber in the average U.S. diet could be achieved by adding commercial dietary fiber in meals, however, this is not economically efficient. Another alternative is

Table 1 Content of various compounds in the edible portion of ripe plum fruit

| Constituent | Content (% fresh wt) | Reference |
|---|---|---|
| Moisture | 78.70 | Gur, 1986 |
| Protein | 0.80 | Gur, 1986 |
| Fat | 0.20 | Gur, 1986 |
| Carbohydrates | 21.40 | Gur, 1986 |
| Starch | Trace | Wrolstad & Shallenberger,1981 |
| Sugars | 7.40-7.79 | Money & Christian , 1950 |
| Glucose | 1.70-5.20 | Wrolstad & Shallenberger,1981 |
| Fructose | 0.70-3.50 | Wrolstad & Shallenberger,1981 |
| Sucrose | 0.96 | Wrolstad & Shallenberger,1981 |
| Sorbitol | 0.60-2.00 | Wrolstad & Shallenberger,1981 |
| Dietary fiber | 1.06-1.56 | Vidal-Valverde et al., 1982 |
| Cellulose | 0.36-0.45 | Vidal-Valverde et al., 1982 |
| Hemicellulose | 0.08-0.25 | Vidal-Valverde et al., 1982 |
| Lignin | 0.07-0.47 | Vidal-Valverde et al., 1982 |
| Pectin | 0.38-0.58 | Vidal-Valverde et al., 1982 |
| Vitamin C | 4.00[1] | Watt & Merill, 1963 |

[1] mg/100g fresh weight

consuming native high-fiber foods or food products. Kay and Truswell (1977) also suggested that foods naturally having high pectin content are the best source for pectin. They observed that pectin appears to be better tolerated when it is included in the diet as a food product rather than as a powder mixed with water, juice or other foods. Plums are an excellent source of both dietary fiber and pectin. Plums also contain high amounts of vitamin C and sorbitol. The high fiber and pectin content of plums, if concentrated to a paste, might yield a product which could be used as a substitute for shortening in the bakery industry to develop low fat products. These characteristics may make plum paste, a concentrated form of plums, a high potential processed product.

**Stanley Plum Production and Utilization**

Stanley plum is the leading plum variety grown in Michigan, which was ranked in the top 4 plum and prune producers in the nation from 1986 to 1990. About 50% of the 10,000 tons of plums produced annually is consumed fresh, while the remaining goes for processing (Espie, 1992; 1991). The major processed plum products available in the market are prune juice and prunes. Other processed forms , such as plum juice, plum sauce, plum juice concentrate, prune bits, etc., are also being developed. However, plum processed products have not been developed and marketed on a scale similar to other fruits like apples, pears, apricots, etc. (Siddiq, 1993). The purpose of this work was to develop a plum paste which can utilize a large quantity of fruit, and study the factors which affect the processing quality and storage stability.

## II. Plum Paste Production

Paste is the product resulting from the concentration by evaporation of water from pulp, after the removal of skin and seeds (Goose et al., 1964). Several kinds of fruit paste have been developed and marketed. Among them, tomato paste is the most popular and has been studied intensively. Generally, plum paste production is conducted using the following procedure:

1) Select good quality fruit and wash; 2) inactivate undesirable enzyme reactions and soften fruits by preheating to a certain temperature and then holding for a short time at the temperature; 3) remove seeds and finish the pulp by passing through a mechanical finisher with an appropriate screen; 4) concentrate the puree by heat or a combination of heat and vacuum; 5) add other ingredients, if necessary, and heat for a short time; 6) fill into containers (Shol'ts et al., 1990; Exama and Lacroix, 1989a,b; Liu and Luh, 1979; Sherkat and Luh, 1977,1976).

According to the United States standards for grades of tomato paste (Anon., 1977), Fine paste is the clean, sound and whole product with high consistency, smooth texture, distinct flavor, typical red color, and no defects. This standard can be used as a guideline to make high quality plum paste.

### Selection and Cleaning

Plums are harvested mechanically at maturity. It is possible to have debris, leaves, and defective fruit with whole and sound fruit. Sorting is needed for proper assurance of freedom of imperfections. The fruit surface may also have contaminants, such as soil, chemicals, microorganisms, and insects. Washing, in addition to separating soil

and foreign materials, also reduces the load of spoilage microorganisms naturally present in foods. Washing also improves the quality and appearance (Lopez, 1987).

## Preheating

Preheating is an operation in which raw fruit is heated, usually with continuous stirring. If the fruit is firm like plums, crushing may take place during heating process. Once the product reaches the temperature which is proper for the particular fruit being used, the macerate should be held for a short time. Preheating is done for the following reasons: a) to release cell components, b) to facilitate preliminary operations, c) to inhibit undesirable enzymatic actions (Lopez, 1987). These processes will be discussed below.

### Release of Cell Components

Anthocyanins (ACYs) are the main color source in red-to-blue fruits and their food products, especially plums. Plum ACYs are located mainly in the skin (Weinert and Escher, 1989). They accumulate in the vacuoles of the epidermal and subepidermal tissue (Gross, 1987). Heat treatment breaks down cell integrity resulting in the release of ACY pigments and hence improving the color of paste.

Carbohydrate polymers are also important components contributing to the paste quality because they serve as thickening agents. According to Morris (1973), polysaccharides are highly hydrophilic giant molecules that can radically affect the physical properties of up to 100 times their own weight of water. They are, therefore, used widely in the food industry as thickeners and texture modifiers. Carbohydrate polymers, such as cellulose, hemicellulose,

pectin, and lignin, are components of plant cell walls and are liberated from cell walls when heat treatment destroys plant tissues. The positive relationship between pectin content in tomato paste and consistency have been proven by several authors (Liu and Luh, 1979; Sherkat and Luh, 1977; Luh and Daoud, 1971; Luh et al., 1954).

Facilitating Preliminary Operations

In order to have smooth and good colored plum paste, it is necessary to cook the plums to soften the tissue, extract pigments, extract pectins and facilitate the removal of pits. The cooked plums can be easily passed through certain types of finishers or through screens to remove pits.

Inhibition of Undesirable Enzymatic Actions

The major enzymes which affect plum paste qualities are polyphenoloxidase (PPO), which oxidizes phenolics and therefore causes browning and degradation of ACYs, and pectic enzymes (polygalacturonase, PG, and pectic esterase, PE) which break down pectic substances and decrease paste consistency. The most effective way to inactive these enzymes is high temperature treatment (Langdon, 1987). In plums, this amounts to heating the whole fruit to 95°C and holding at this temperature for 10 minutes. This allows for subsequent screening or finishing without browning. Once the puree is obtained the product is further heated to concentrate it.

**Preparation of Puree**

After preheating, the skins and seeds are removed and the pulp is passed through a finisher to break down fibers and cells so that the

refined pulp, or puree, is homogeneous, smooth and free from skins and seeds ( Goose et al., 1964). The particle size within the puree can be controlled by screen size. Usually, fine product without granules is suggested for high quality paste (Anon., 1977).

## Heat Concentration

Paste is usually processed via heat evaporation. Although it has the disadvantage of possibly developing off-flavor, it is the most common method of concentration (Troller and Christian, 1978). Longer the heating time, higher the solid content and consistency. However, increasing heating time is usually associated with undesirable properties, such as browning, and degradation of ACY, pectin, organic acid, flavor and vitamin content ( Wani et al., 1990; Exama and Lacroix, 1989a ). In order to produce high quality paste with minimal negative characteristics, heating processing under partial vacuum is often utilized to shorten heating time and lower heating temperature. In the current study, plum paste was processed by heating at atmospheric pressure because vacuum processing equipment was unavailable. This type of process gave a paste with good consistency, color and flavor. Siddiq (1993) indicated that plum juice ACYs were relatively stable to thermal processing with losses of only 16% observed when the juice was heated for 70 minutes at 65°C.

## Addition of Other Ingredients

Variation of paste can be accomplished by adding other ingredients. Based on the determination of the effect of sugar addition on the quality and usability of tomato paste at the time of manufacture, Bash et al. (1984) reported that sugar addition

increases color darkening and soluble solids, and has dilution effect on total acidity. They also concluded that it may be more efficient to add the required sugar at the time of paste production rather than waiting until final product formulation as there is no effect on quality when sugar is added during initial stage of paste production. Exama and Lacroix (1989a), while studying the development of high protein fruit pastes based on whey protein isolate, mango puree, and sugar, stated that sugar content had little effect on the texture. Both of the studies indicated that heating after the addition of ingredients is necessary due to the possibility of microbiological contamination that may be present in them, but heating time should not be too long as it may induce negative changes in the composition and texture.

Wrolstad et al. (1990) investigating the effect of sugar on the quality of frozen strawberries reported that sucrose addition had a significant protective effect on ACY pigment and also retarded browning and polymeric color formation. In this study, the addition of sugar was deemed necessary for improvement of flavor but it also seemed to have some positive affects on consistency and color.

## Filling

To prevent microbial contamination, well-mixed acidic products (like plum paste) can be preserved in two ways: 1) hot filling into pre-washed containers immediately followed by sealing and then inverting containers to sterilize the lids (i.e. pasteurization processing), or 2) filling into clean containers followed by heat processing. However, the heat processing may cause further composition degradation. Pasteurizing acidic products is usually the better choice if it is done properly. Shol'ts et al. (1990) suggested that filling temperature be

not lower than 90°C for grape paste. Plum pastes showed no microbial growth problems when pasteurized at 85°C and stored at ambient room temperature.

## III. Storage Stability

Factors affecting the shelf-life of a certain product include: intrinsic properties of foods, such as composition, moisture content, pH, etc., as well as extrinsic factors, such as time, temperature, light, etc. Texture, color, and microbial contamination are most frequently used as storage stability indicators (Canellas, et al., 1993; Pouget et al., 1990; ; Wrolstad, et al., 1990; Weinert et al., 1989).

Low temperature storage extends food quality retention by retarding chemical reactions of food composition and microbial growth. This is because the rate of chemical reaction is dependent on temperature. With a rise in temperature, there is an increase in reaction rate. This concept is associated with the temperature coefficient ($Q_{10}$) which is defined as follows:

$Q_{10}$ = (Velocity at a given temperature + 10°C)/Velocity at T

The $Q_{10}$ for most systems is 1.5 to 2.5, so that for each 10°C rise in temperature within the suitable range, there is a twofold increase in the rate of reaction. For every 10°C decrease in temperature, the reverse is true (Jay, 1992).

Comparing color, browning and water activity of raisins stored at different temperatures, Canellas, et al. (1993) indicated that the refrigerated samples were of higher quality in composition as compared with nonrefrigerated samples. Pouget et al. (1990), investigating the stability of ACYs under various storage conditions,

showed that the percentage of remaining color at 4°C was much higher than at 22°C. After 6 months storage, blackberry and red raspberry wines stored at 2°C had considerably higher total ACY concentration than that stored at 20°C (Rommel et al., 1992, 1990). Palamidis and Markakis (1975) investigated the degradation of a colorant extracted from grapes in a carbonated beverage. They reported that the half-life of the colorant ranged from 80 days at 38°C to 1,536 days at 3.5°C in the dark.

Kanujoso and Luh (1967) investigated the effect of storage temperature on peach texture and found that peach tissues softened more rapidly at 98°F than at 80°F and 68°F and softening during storage may be attributed to the transformation of protopectin to water-soluble pectin. In this study, plum paste was stored at both ambient room temperature (~ 22°C) and at refrigerated temperature (~4°C).

## IV. Quality Evaluation of Plum Paste

### Color

Color of foods is often the first quality attribute judged by consumers and is, therefore, extremely important in overall product acceptance. Factors affecting the color of plum paste include browning and the degree of ACY retention.

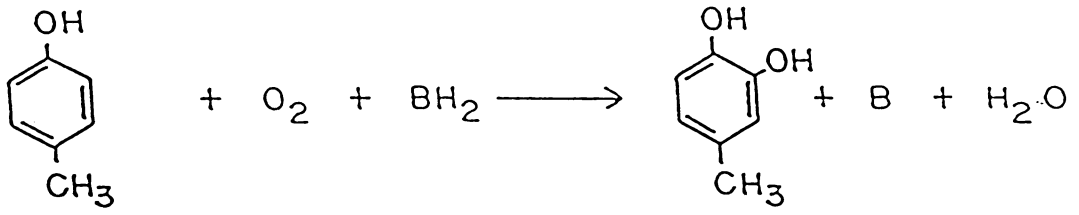
#### Browning

Browning reactions of foods may lead to undesirable color, flavor, and nutrient losses, which result in poor acceptability of food

products. In general, browning reactions in fruits and vegetables can be divided into 1) enzymatic browning which is the result of PPO activity on phenolic compounds, and 2) Maillard reaction, Non-enzymatic browning, which results from the heat-induced reaction between sugar and amino acids (O'Brien, 1989 ; Sapers et al., 1989).

Enzymatic browning has been a problem throughout the history of fruit and vegetable processing. The sequence mechanism of enzymatic reactions follows: 1) hydroxylation of monophenols to *o*-diphenols; 2) the further oxidation of *o*-diphenols to *o*-quinones (Whitaker, 1972). These reactions are shown in figure 1. The *o*-quinones formed, (a) polymerize to form brown melanins and then brown high molecular weight polymers, known as enzymatic browning, (b) react with amino acids or proteins to form macromolecular complex, and (c) oxidize compounds of lower oxidation-reduction potential, such as ACYs. Reaction (c) is especially undesirable as the quinones formed by PPO, in addition to oxidizing compounds of lower oxidation-reduction potential, are themselves also reduced to dihydroxyphenols providing "fresh" substrates to the enzyme (Vamos-Vigyazo, 1981). PPO and its substrates are separated in different compartments in plant cells. Once the plant cells are bruised or ruptured, which occurs in the process of thawing, cutting, heating, transportation etc., they come in contact and undergo the oxidation reactions (Bolin and Huxsoll, 1989).

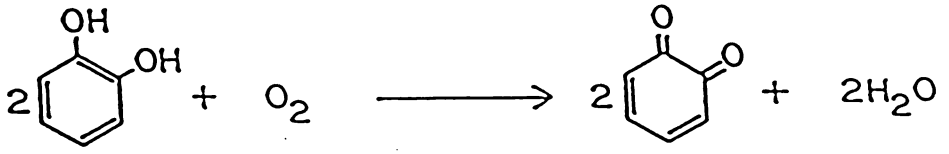
High temperature inactivation is the most effective method for preventing these enzymatic processes (Langdon, 1987). Vamos-Vigyazo (1981) reported that PPO did not belong to the extremely heat-stable enzymes, and short exposure to a temperature of 70 to 90°C was sufficient for the destruction of its catalytic function in most




*p*-cresol

4-Methylcatechol

**A. Hydroxylation of monophenols to *o*-diphenols**




**B. Oxidation of *o*-diphenols to *o*-benzoquinones**

Figure 1 Reactions catalyzed by polyphenolosidase (PPO)

cases. Grape PPO activity declined very rapidly with increases in temperature above 30°C (Cash et al., 1976). At pH 6.5 mushroom PPO was active at 45°C but not at 70°C (McCord and Kilara, 1983). Sweet potato PPO was markedly inactivated at 100°C for 3 minutes or 94°C for 5 minutes (Ma et al. 1992). Pigment loss in red frozen sour cherries could be minimized by blanching for 45 to 60 seconds prior to freezing (Siegel et al., 1971). DaDamio and Thompson (1992) stated that blanching mushrooms using microwave method eliminated PPO activity.

Arnold (1992) reported that pasteurization was the best way to inactivate PPO and preserve ACYs in plum juice. Palmasano (1972) indicated that the rate of enzymatic browning of Stanley plum processed products was not retarded at 82.2°C for 2 minutes. Investigating the properties of Stanley plum PPO, Siddiq (1993) indicated that heating at 65° and 75°C for 30 and 5 minutes, respectively, rendered PPO completely inactive.

Maillard reaction, or non-enzymatic browning, is a heat-induced reaction and occurs between sugars and amino acids, peptides, or proteins effecting changes in color, flavor, functional properties, and nutritional value of the food (O'Brien, 1989). It may happen during processing and storage of foods. The Maillard reaction consists of an interconnected network of processes and has not been completely understood. Hodge (1953) integrated the available information into a simplified scheme (Figure 2). According to O'Brien (1989), it is still the most appropriate description of the Maillard reaction. It is also supported and described in more detail by recent research (Yaylayan and Lachambre, 1990; Helak et al., 1989; Schussler and Ledl, 1989; Velisek et al., 1989; Handwerk and Coleman, 1988). According to the

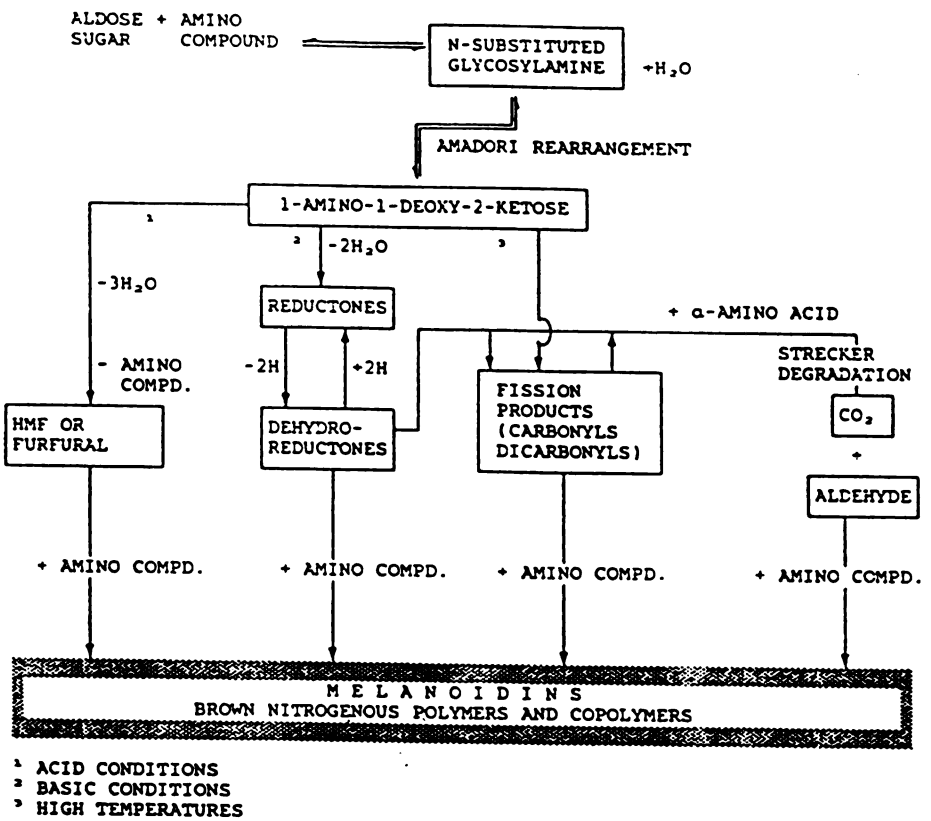



Figure 2 Maillard reactions

scheme, the first step is the condensation of the amino and carbonyl compounds. The subsequent rearrangement of N-substituted glycosylamine to form deoxyketose or deoxyaldose compounds, depends on whether the reacting sugar is an aldose or ketose. Under acidic conditions, the reaction results in loss of water with the subsequent deamination of Amadori compounds. Under basic conditions, the Amadori compounds may lose water and then hydrogen to form dehydro-reductones. A variety of fission products including reductones, other dicarbonyls and aldehydes may be produced under high temperature condition or following the oxidation reaction under basic conditions. Subsequent Strecker degradation involving dicarbonyls produced in the Maillard reaction may occur with the production of carbon dioxide and a variety of volatiles. The final stages are complex and involve the conversion of low weight precursors, such as furfurals, fission products, and reductones into the high molecular weight melanoidin pigments. Amines may be involved in such reactions. The production of melanoidins is believed to involve aldol condensations and aldehyde-amino polymerization.

Major factors affecting the rate of Maillard browning include: 1) nature of reactants, 2) water activity of foods, 3) pH value of the product , and 4) temperature (O'Brien, 1989).

Low molecular weight compounds tend to be more reactive than high molecular weight compounds as a result of greater stearic hindrance in the latter (O'Brien, 1989). Glucose is the main reactant in the Maillard reaction (Jiang and Ooraikul, 1989). Leszkowiat et al. (1990), investigating the contribution of sucrose to nonenzymatic browning, postulated that sucrose, a non-reducing sugar, enters the

browning reaction by thermal hydrolysis to yield glucose and fructose. Handwerk and Coleman (1988) mentioned that rhamnose and galacturonic acid, becoming constituents of citrus juices when enzymic degradation of pectin occurs during juice processing, may undergo browning degradation to produce 2-furaldehyde and reductic acid.

Water in food systems has an important influence on the Maillard reaction. It exerts its influence by controlling the liquid viscosity, concentration, or dilution of reactants (Pomeranz, 1991). Cuzzoni et al. (1989) showed that the browning rate of the ribose-lysine model system was increased with a decrease in the water activity in the range of 0.98 to 0.60. Eichner and Karel (1972) also observed the same results and postulated that it is likely the law of mass action leads to a decreased rate of reaction at high moisture levels.

Nursten (1980) reviewed the Maillard reaction and stated that both the initial pH of the product and the buffering capacity of the system influence the rate and direction of the reaction. The rate of browning is low at acidic pH values and increases with increasing pH to a maximum at a pH of about 10 (Ashoor and Zent, 1984). Friedman and Molnar-Perl (1990) confirmed the observation by measuring the browning extent of amino acid-glucose systems under the pH range of 4 to 10.

It is generally agreed that Maillard reaction is heat induced. Friedman and Molnar-Perl (1990) reported that browning increases progressively as a function of heating temperature and time. Cuzzoni et al. (1989) demonstrated that the extent of browning is significantly higher for model systems treated at 160°C than at 100°C. The

browning also increases as a function of storage temperature and time. Investigating the storage stability of dehydrated carrot at 50°C, Baloch et al. (1973) stated that browning showed a marked increase with storage time. Although the extent of browning increases with storage time and temperature, the heating temperature and time during processing has much larger influence on the formation of browning pigments (Cuzzoni et al., 1989).

Inhibition of nonenzymatic browning has been investigated in different ways. Sulfite, cysteine, urea, $NH_4Cl$, sulfur amino acid, and glucose oxidase have been studied to retard nonenzymatic browning in foods as well as model systems(Friedman and Molnar-Perl, 1990; Pham, 1990; Jiang and Ooraikul, 1989; Baloch et al., 1973). Maintaining the product at low temperature has been and still is the only means to retard color deterioration of processed citrus fruit juices, concentrates, and dehydrated products in long term storage (Handwerk and Coleman, 1988).

## Anthocyanins (ACYs)

ACYs are among the most important groups of plant pigments (Brouillard, 1982). They are widely present in fruits and flowers and are responsible for their attractive colors. ACYs are the main color source in red-to-blue fruits and their food products, including plums. Therefore, the stability of ACYs is an important factor related to product appearance and hence its acceptance.

### Chemical Structure

The ACYs are a part of the general flavonoid group of compounds which are characterized by the flavylium nucleus. The basic nucleus

and the numbering of its carbon atoms are shown in figure 3. An ACY pigment is composed of an anthocyanidin (flavonoid nucleus) esterified to sugars or acylated sugars. These sugars consist of 4 main monosides (glucose, galactose, rhamnose, and arabinose) and 4 main biosides (rutinose, sambubiose, lathyrose, and sophorose); others are comparatively rare. The triosides which occur can be linear or branched chain(Timberlake, 1980). The main acylating groups are the coumaric, caffeic, ferulic, p-hydroxy benzoic, synapic, malonic, acetic, succinic, oxalic, and malic acids , in the form of acylated sugars ( Francis, 1989, Timberlake, 1980).

ACYs in Plums

Plums contain 3 ACYs : cyanidin and peonidin 3-glycoside and 3-rutinoside (Timberlake, 1980). Ahn (1973) identified cyanidin 3-glucoside and 3-xyloglucoside from "Santa Rosa" plums and stated that cyanidin 3-glucoside was the most abundant pigment of the plums. Ishikura (1975) found cyanidin 3-rhamnoglucoside in the Japanese red-purple plums. On the basis of his investigation of 52 species, he concluded that in general, the plants belonging to a certain genus contained the same ACYs. It seems probable that similar pigments will be present in Stanley plums with Cyanidin and peonidin derivatives being the main ACYs.

Enzyme Effect

ACYs can be degraded by a number of enzymes found in plant tissue. These enzymes may be classified as glycosidases (Huang, 1956, 1955), peroxidase (Grommeck, and Markakis, 1964), and polyphenoloxidase (PPO) (Sakamura et al., 1965; Peng and Markakis,

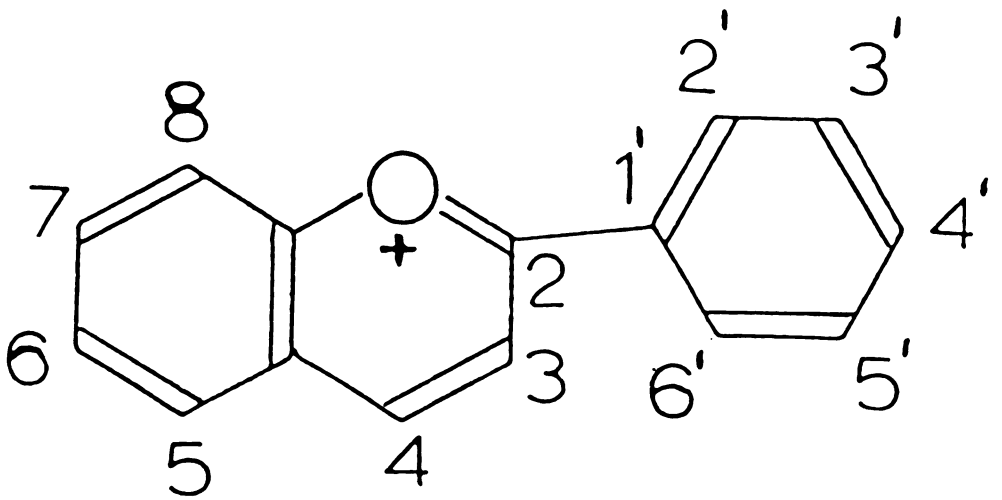



Figure 3 The flavylium nucleus of anthocyanins

1963). Most of these authors have demonstrated the involvement of polyphenoloxidase in ACY decolorization.

Peng and Markakis (1963) observed that ACYs were poor substrates for PPO and proposed a scheme of sequential reactions (Figure 4). According to the mechanism, PPO oxidizes pyrocatechol to o-benzoquinone which can reduce to pyrocatechol at the expense of ACYs. Pifferi and Cultrera (1974) supported the mechanism by showing that chlorogenic acid and catechin accelerated the destruction of ACYs by sweet cherry PPO. Wesche-Ebeling and Montgomery (1990) examined the mechanism using mixture systems, and also observed that the loss of ACYs caused by PPO and D-catechin was 2 times greater than that by PPO alone.

Temperature Effect

The effect of temperature on the stability of ACYs has been well studied because of their obvious importance to the quality of foods. The general consensus is that ACY's are readily destroyed by heat during the processing and storage of foods. Meschter (1954) reported that the half-life was only 1 hour for the ACY pigments in strawberries preserved at 100°C. Siddiq (1993) reported that the ACY loss of 16% was observed when plum juice was heated for 70 minutes at 65°C. After 6 month storage, blackberry wine and red raspberry wine stored at 2°C had considerably higher total ACY concentration than that stored at 20°C (Rommel et al., 1992, 1990). Adams (1973) described a logarithmic destruction of ACY's with time of heating at 100°C and the measurement of half-life of ACY breakdown.

The mechanism of ACY degradation by heat is not completely understood. Brouillard and Delaporte (1977) found that , on heating,

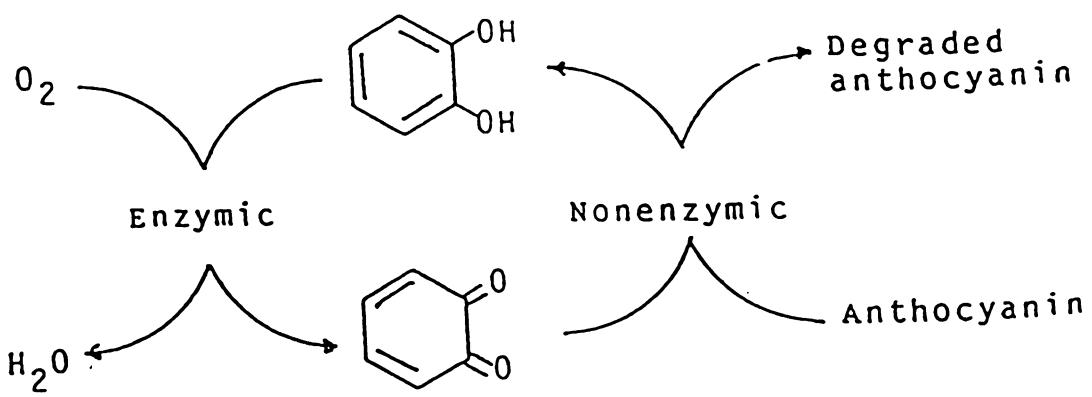



Figure 4 Mechanism of anthocyanin degradation by polyphenoloxidase (PPO)

the equilibrium was driven toward the chalcone form (C) with a resulting loss in color, suggesting that this was the path of thermal degradation. Adams (1973) studied the ACY degradation and suggested that sugar hydrolysis could be part of degradation scheme.

pH Effect

ACYs are water soluble and pH dependent. They appear to be red in acidic media, almost colorless at intermediate hydrogen ion concentration, and blue or purple in alkaline media. Brouillard (1982) and his co-workers (Brouillard and Delaporte, 1977; Brouillard and Dubois, 1977) demonstrated an equilibrium system based on kinetic, thermo-dynamic and spectroscopic techniques. Figure 5 shows the 4 ACY species and interconversion between them which subsequently results in a color change. Structural modifications of ACY's in water with pH are due to the high reactivity of the anthocyanidin moiety. Sugar, acylated sugars, and methoxyl groups have a marked effect on the reactions but, in general, do not react themselves (Brouillard, 1982). Protonation of the blue quinoidal base (A) of malvidin 3-glucoside gives the red flavylium cation ($AH^+$), which can hydrate to a colorless carbinol pseudo-base (B) which itself can exist in tautomeric equilibrium with its chalcone form (C), also colorless, formed by opening the heterocyclic ring (Brouillard and Delaporte, 1977).

Brouillard (1982) illustrated the color change of ACY's in acidic media with the distribution of structures with change in pH (Figure 6). In very acidic solution ($pH < 0.5$), the red $AH^+$ is the only species. With increasing pH, the $AH^+$ hydrates to the colorless B, resulting in color decrease. At the equilibrium pH, there is some formation of the

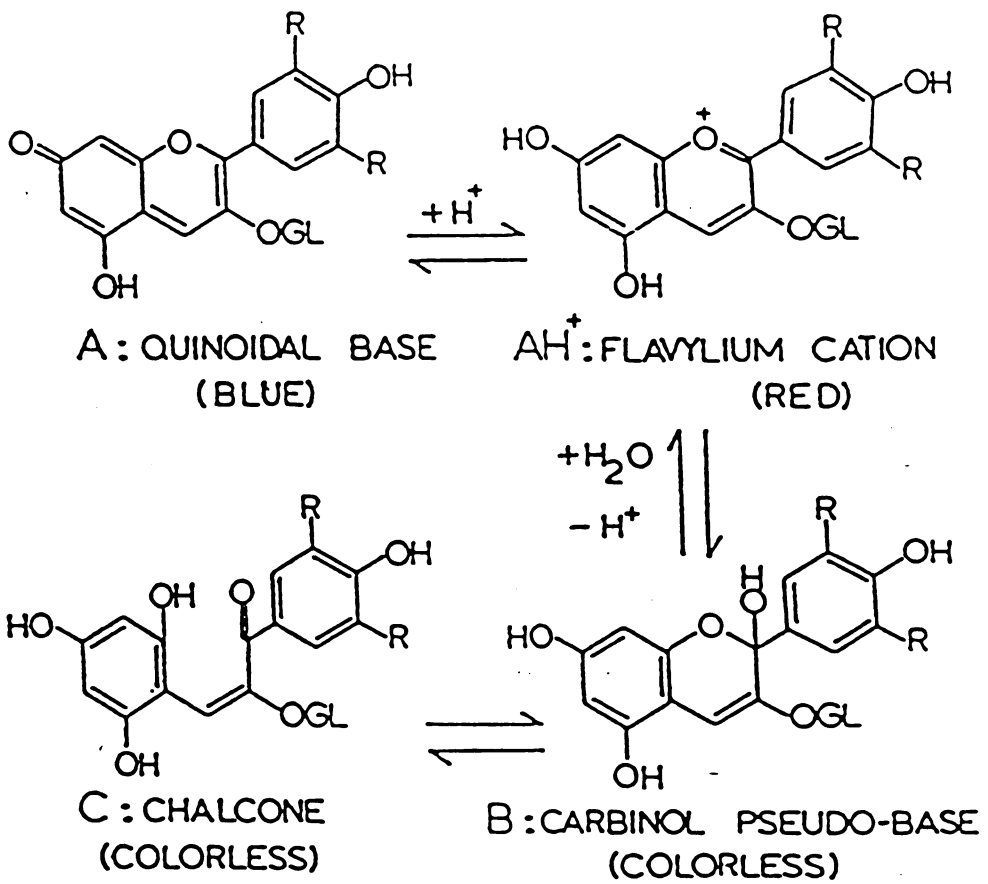



Figure 5 The four structures of anthocyanins which exist in equilibria in aqueous solutions

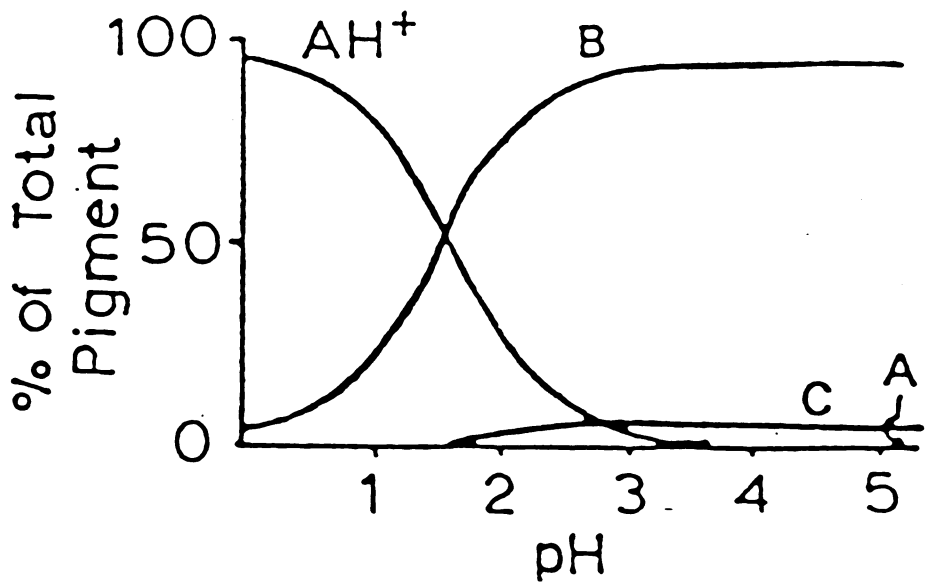



Figure 6 The equilibrium distribution of $AH^+$, A, B, and C for Malvidin 3,5-diglucoside at different pH values at 25°C

colorless C and of the blue A. The proportions of B, C and A continue increasing with increasing pH at the expense of the red $AH^{+}$.

In terms of visual color, the amount of the $AH^{+}$ form is the most important. Francis (1989) reported that among the four forms of ACYs, the $AH^{+}$ form is the most stable. Therefore, ACYs in acidic condition should be most stable.

Lukton and co-workers (1956) reported that the breakdown of ACYs in the presence of oxygen was dependent on pH and inversely proportional to the amount of $AH^{+}$ form. Adams (1973) found similar results when cyanidin-3-glucoside and cyanidin-3-rutinoside were heated in the pH range of 2 to 4. Meschter (1953) stated that the rate of ACY breakdown was dependent on pH and that lowering the pH resulted in greater degree of stabilization. Daravingas and Cain (1968) similarly observed that lowering the pH significantly slows down the breakdown of the major ACYs in raspberry.

Others

In addition to above factors, loss of ACYs could also result from reaction with light, oxygen, metal-ACY complex formation, and copigmentation with other compounds. Ascorbic acid has also been known to accelerate destruction of ACYs (Francis, 1989).

## Pectic Substances

Chemical Structure

Pectic substances are polyuronides composed mostly of anhydrogalacturonic acids. They are present in the growing tissues of many higher plants where they serve as the cementing agent of cells and regulate the water content by bonding to calcium, mainly in the

middle lamella, and to cellulose in the primary cell membrane (Pomeranz, 1991).

Pectin is composed primarily of essentially linear polymers of D-galactopyranosyluronic acid units joined in α-D(1,4) glycosidic linkages. The polymer chains are esterified to various degree with methanol (Richardson and Hyslop, 1985) (Figure 7). This regular structure is interrupted with rhamon units and with side chains containing other neutral sugars. The polymer chains may also be partially acetylated (Kertesz, 1951). In addition to being heterogeneous in structure, it is also heterogeneous with respect to molecular weight. From molecule to molecule, both the number and percentage of individual monomeric unit type will vary. The degree of polymerization and esterification can vary with the modification during ripening, processing, and storage. The alterations are highly responsible for texture change of foods (Fishman et al., 1989; Van Deventer-Schriemer and Pilnik, 1976).

According to the structures and properties, pectin can be divided into 1) pectic acids which are polygalacturonic acids without or with only a negligible content of methyl ester groups. Salts of pectic acids are called pectates, 2) pectinic acids which are galacturonic acids containing more than a negligible proportion of methyl ester groups. Salts of pectinic acids are called pectinates, and 3) protopectins which are water-insoluble parent pectic substances and yield the above two water-soluble compounds upon restricted hydrolysis. (BeMiller, 1986; Rouse and Atkins, 1955; Kertesz, 1951).

Pectin solutions exhibit the non-Newtonian, pseudoplastic behavior characteristic of most polysaccharides. The rheological behavior of a pectin solution is related to the molecular weight, degree

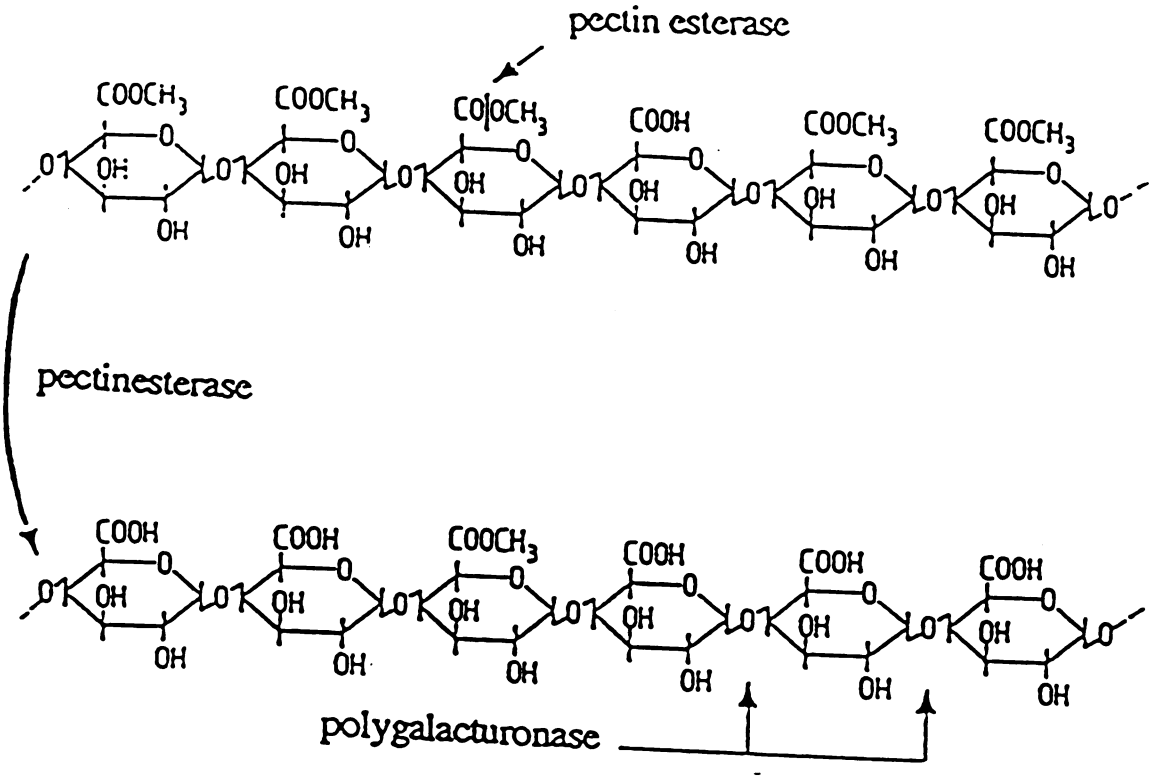



Figure 7 Fragment of a pectin molecule and points of attack by pectic enzymes

of esterification, pH, and presence of counter ions. Kaneko et al. (1989), investigating various parameters related to texture of processed plum, concluded that increase in acid content, resulting in low pH, gives rise to chelate binding of divalent cations combined with pectic substances. The release of these divalent cations, changing the pectic substances to some degree, consequently causes a decrease in firmness.

Pectic Enzymes

Enzymes showing specific actions on pectic substances in higher plant tissues are mainly pectinesterase (PE) and polygalacturonase (PG). PE cleaves methanol from esterified carboxyl groups yielding low-methoxyl pectin and polygalacturonic acids. PG depolymerizes de-esterified polygalacturonic acids by hydrolyzing at the $\alpha$-1,4 position (Pressey, 1986; Richardson and Hyslop, 1985), as shown in Figure 7.

The inactivation of pectic enzymes during processing and storage can be achieved by heat treatment. High temperature inactivation of pectic enzymes has been intensively studied and applied in the fruit and vegetable processing industry. Luh and Daoud (1971) reported that pectic enzymes in tomatoes may be inactivated by giving the macerated fruits a hot break temperature higher than 93.3°C. They also concluded that the effect of break temperature on consistency was much greater than that of the holding time. Sherkat and Luh (1977, 1976) studied the effect of break temperature on quality of tomato paste and reported that heat inactivation of pectic enzymes, at 100°C during maceration, stopped undesirable biochemical changes,

and hence yielded a product with higher pectin retention and consistency.

## Rheological Properties

The measurement of fundamental rheological properties of foods is critical in optimizing product development efforts, processing methodology and testing final product quality. Many fluid foods, such as applesauce, orange juice concentrate, tomato paste, and honey, exhibit non-Newtonian behavior (Steffe, 1992).

### Flow Model

Several flow models have been employed to describe the flow behavior of non-Newtonian foods. The Herschel-Bulkley model has been applied extensively to relate shear rate and shear stress of these foods (Steffe, 1992; Guariguata et al., 1979; Toledo et al., 1977; Odigboh and Mohsenin, 1975) :

$$\sigma = K(\dot{\gamma})^n + \sigma_0 \qquad (1)$$

where $\sigma$ is shear stress, K is the consistency index, $\gamma$ is shear rate, n is the flow behavior index, and $\sigma_0$ is yield stress. This model is a general model. Newtonian (n=1, $\sigma_0$=0), power law (shearing-thinning when $0<n<1$, or shearing-thickening when $1<n<\infty$, and $\sigma_0$=0), and Bingham plastic (n=1, $\sigma_0>0$) behavior may be considered as special cases (Steffe and Morgan, 1986).

### Apparent Viscosity

Apparent viscosity, another parameter to evaluate the rheological behavior of fluids, is defined as shear stress divided by shear rate:

$$\eta_a = \sigma/\dot{\gamma} \quad (2)$$

where $\eta_a$ is apparent viscosity.

For Herschel-Bulkley fluids, apparent viscosity is

$$\eta_a = \sigma/\dot{\gamma} = [K(\dot{\gamma})^n + \sigma_0]/\dot{\gamma} = K(\dot{\gamma})^{n-1} + \sigma_0 / \dot{\gamma} \quad (3)$$

Therefore, the apparent viscosity for power law food fluids is

$$\eta_a = K(\dot{\gamma})^{n-1} \quad (4)$$

Effect of Time on Flow Behavior

Some non-Newtonian fluids exhibit time-dependent flow behavior. In these cases, thixotropic materials exhibit decreasing shear stress over time at a fixed rate of shear, i.e. time-dependent thinning behavior. And rheopectic materials exhibit increasing shear stress over time at a fixed rate of shear, i.e. time-dependent thickening behavior (Rao and Anantheswaran, 1982). The response of substance to stress is instantaneous and the time-dependent behavior is due to changes in the structure of the material itself. In most cases, the time span over which this behavior encountered is relatively short. The measurement of flow behavior, to be conservative, can be done on the basis of magnitudes after the time-dependent span (Steffe, 1992; Rao and Anantheswaran, 1982).

Effect of Temperature on Flow Behavior

The effect of temperature on the viscosity of non-Newtonian fluids can be expressed in terms of an Arrhenius type equation:

$$\eta_a = A \exp (E_a/RT) \quad (5)$$

where $\eta_a$ is apparent viscosity, A is a constant determined from experimental data, $E_a$ is the energy of activation, R is universal gas constant, and T is absolute temperature. Rheological properties are

highly temperature dependent and, based on equation (5), the increase in temperature decreases apparent viscosity of food fluids (Steffe, 1992).

Using Mixing to Evaluate Rheological Properties

Mixers for rheological studies have been used by investigators for different food products, such as apricot puree (Castell-Perez, et al., 1987; Ford and Setffe, 1986), applesauce (Rao, 1975), and tomato sauce (Rao, 1975). The general principle of measurement used in mixer viscometry is based on the determination of the torque on the shaft of the impeller as a function of its rotational speed. Thus, a suitable value of the apparent viscosity for a non-Newtonian fluid can be obtained from the viscometric measurement if a representative value of shear rate in the given vessel can be predicted. Castell-Perez (1990) evaluated three system models for the approximation of the average shear stress in the mixing system and established a new model using the flag impeller. The procedure is simplified and has been tested to be suitable for power law fluids. Based on the model, the shear rate is given by

$$\dot{\gamma} = 4\pi N \qquad (6)$$

where, $\gamma$ = shear rate, 1/s

N = impeller rotational speed, rev/s

And the shear stress is approximated by

$$\sigma = 2M/(\pi d^2 b) \qquad (7)$$

where, $\sigma$ = shear stress, Pa

M= torque, Nm

d= diameter of flag impeller, m

b= flag impeller blade height, m

For the power law behavior within the rpm ranges :

$$\sigma = K(\dot{\gamma})^n \quad (8)$$

The power law parameters were determined from a linear regression analysis of shear stress versus shear rate as :

$$\ln(\sigma) = \ln(K) + n \ln(\dot{\gamma}) \quad (9)$$

The apparent viscosity is

$$\eta_a = \sigma/\dot{\gamma} = K(\dot{\gamma})^n/\dot{\gamma} = K(\dot{\gamma})^{n-1} \quad (10)$$

Since $\sigma=K(\dot{\gamma})^n$, Eq.(9) becomes

$$\eta_a = K(\dot{\gamma})^n/\dot{\gamma} = K(\dot{\gamma})^{n-1} \quad (11)$$

This procedure was used to evaluate the rheological properties of plum paste.

**Microbiological Content**

The contamination of microorganisms in foods has been considered critical for the reason of food safety, shelf life and food quality. The HACCP (Hazard Analysis Critical Control Point) system has been applied in industry for many foods to control organisms in ingredients at the point of production and preparation of foods (Jay, 1992).

The plants and animals that serve as food sources have all evolved mechanisms of defense against the invasion and proliferation of microorganisms. Fruits generally consist of high level of water, some carbohydrate, and trace amount of protein, fat and ash. On the basis of nutrient content, fruits would appear to be capable of supporting the growth of bacteria, yeasts, and molds. However, their pH is below the level that generally favors bacterial growth. Therefore, the major microorganisms that exist in fruit products are yeasts and molds (Jay, 1992).

The extent of microorganism contamination in processed food can be controlled in many ways: 1) by reducing the microbial load on raw materials, personnel as well as processing facility, 2) by reducing the microbial load by thermal process, 3) by controlling the growth of microorganisms by intrinsic and extrinsic parameters of foods, such as pH, water activity, temperature, and preservatives, 4) by preventing further contamination during processing and storage. Basic and traditional measurements used to monitor microbial content should be done for bacteria, yeasts, and molds for newly developed food products.

# MATERIALS AND METHODS

## I. Whole Plum Samples

Stanley plums grown in northern Michigan, harvested at maturity in September, 1992 were used for this study. The plum samples were frozen to -20°C immediately after harvest and kept at this temperature until further processing was required.

## II. Plum Puree Production

### Pilot plant Puree Made From Standard Plums

Stanley plums were removed from -20°C storage and allowed to thaw overnight at 4°C. The plums were washed with tap water and debris was removed. The plums were heated to 95°C and macerated for 10 minutes in double jacketed stainless steel kettles. The macerate was then cooled slightly down and the pits removed by passing through a particular screen. The pitted macerate was passed through a finisher (Dodge, Mishawaka, IN) equipped with 0.060 in. screen. The plum puree was stored at -20°C until further processing was required.

### Commercial Puree Made From Substandard Plums

Stanley plums grown in southern Michigan, harvested at maturity in September, 1992 were processed by Cherry Central Inc. (Traverse

City, MI) to puree using a somewhat similar procedure as described above and then stored at -20°C until further processing was required.

## III. Plum Paste Production

The procedure for making plum paste was carried out according to the method of Shol'ts et al. (1990). The two puree samples (i.e. commercially produced and produced in our pilot plant) were removed from -20°C storage and allowed to thaw overnight at 4°C. Upon thawing the samples were concentrated by heat in double jacketed, stainless steel kettles. A portion of each sample was removed when the soluble solids reached 25°Brix. The remainder of each sample was further concentrated to 30°Brix. One batch was filled hot into jars. The other batch had sucrose added to give a 15°Brix increase. The paste with added sugar was mixed well, heated, and hot filled into 12-oz glass jars (Ball Corporation, Muncie, IN). The jars were sealed immediately, inverted for 3-4 minutes, cooled to room temperature in air, and then stored at 4±2°C and 22±2°C in dark.

## IV. Quality Evaluation of Plum Paste

### Processing Effect

The puree and paste samples were used to determine the effect of heat treatment and sugar addition on yield, PPO activity, soluble solids, total solids, moisture content, water activity, pH, titratable acidity, color, total anthocyanins (T ACYs), pectin content, rheological properties, and microbial counts. Sensory evaluation for color,

sweetness, acidity, consistency, flavor, and overall acceptance were done on pastes from standard plums.

### Storage Effect

The plum paste samples stored at 4±2°C and 22±2°C in the dark were evaluated every 4 weeks for up to 24 weeks for soluble solids, total solids, moisture content, water activity, pH, titratable acidity, color, T ACYs, pectin content , rheological properties, and microbial counts. Sensory evaluation for color, sweetness, acidity, consistency, flavor, and overall acceptance were done on pastes from standard plums.

## V. Physical and chemical Analyses

### Soluble Solids

Percent soluble solids of samples was measured using an Abbe-3L (Bausch & Lomb Optical Co., Rochester, NY) refractometer (sensitivity 0.1%). The results were expressed as °Brix at 20°C. The refractometer was calibrated using distilled water.

### Total Solids

Six grams of samples were weighed into aluminum weighing dishes which had been dried in a vacuum oven (Hotpack, Phila., PA) for 1 hour at 100°C under a pressure of 27 in Hg. Drying of samples was done in the vacuum oven for 8 hours at 100°C under a pressure of 27 in. Hg. The dried samples were allowed to cool in a desiccator for 30

minutes and then weighed. The percent total solids were calculated using following formula:

% total solids = (dried sample weight/fresh sample weight)x 100

**Moisture Content**

The moisture content of samples was calculated from percent total solids using following formula:

% moisture content = 100 - % total solids

**Water Activity**

Approximately 2 grams of sample were measured using a water activity system (CX-1, Decagon Devices, Inc., Pullman, WA) at storage temperatures (4±2°C and 22±2°C).

**pH**

Five grams of sample were diluted with 45ml distilled water and then measured with a pH meter (Model 601A, Corning Glass Works, Medfield, MA.).

**Titratable Acidity**

Five grams of sample were mixed with 95ml distilled water and titrated to pH 8.1 with a 0.1N NaOH solution using a pH meter. Results are expressed as percent malic acid by weight using the following formula:

% malic acid = ml NaOH x 0.1N NaOH x 0.067 mEq x 100/5g sample

**PPO Activity**

Enzyme extraction

The method of Cash et al. (1976) modified by Siddiq (1993) was used. All extraction materials were maintained at low temperature (2-5°C) to reduce enzymatic activity during extraction. Twenty grams of sample was blended in Waring blender with 100 ml of 0.1M Tris hydroxymethyl aminomethane (Trizma) buffer (pH9.5) for 2 minutes. The slurry was filtered through 8 layers of cheese cloth and the filtrate was precipitated by slowly adding 200 ml of -20°C acetone with gentle stirring. When precipitation was complete, the precipitate was collected by straining through 45 micron mesh nylon cloth. The precipitate was suspended in 50 ml of 0.1M sodium acetate (pH 7.0). Pectic substances were precipitated by the addition of 8.0 ml of 0.05M calcium chloride. The solution was centrifuged in refrigerated centrifuge at 4400 x g for 10 minutes and the supernatant was used as crude enzyme extract.

Assay of enzyme activity

Enzyme activity for PPO was assayed according to method of Cash et al. (1976). The standard reaction mixture consisted of 3.4 ml of 0.1M sodium acetate buffer (pH 6.0); 0.4 ml of 0.3M catechol; and 0.2 ml of freshly prepared enzyme extract. A spectrophotometer (Milton Roy Spectronic-70, Rochester, NY) was used to monitor change in absorbance at 420 nm for 3 minutes for assay of PPO activity. The increase in absorbance was recorded every minute.

One unit of enzyme activity was calculated from the slope of the curve which determined ΔA420nm/min due to the oxidation of catechol (i.e. one unit = change in absorbance of 0.001/min).

## Color

Color of samples was measured by Hunter Color Difference Meter (D25 DP-9000 system, Hunter Associates Laboratory, Reston, VA). Approximately 200 grams of sample were placed in a standard optical cell for the measurement after standardization with a pink tile (L=73.49; a=17.34; b=10.28). This system is based on the Hunter 'L', 'a' and 'b' coordinates. The L represents lightness, going from white (L=100) to black (L=0), and the a and b indicate hue, measuring +a (redness), -a (greenness), +b (yellowness) and -b (blueness).

## Total Anthocyanins (T ACYs)

Extraction of T ACYs was carried out using a method of Cash et al. (1976) with minor modification based on the method of Lees and Francis (1971). Ten grams of sample were mixed with 20 ml of 0.1N HCl buffer. The mixture was blended in a Waring blender for 1 minute with 100 ml of acidified ethanol solution (95% ethanol:1.5N HCl = 85:15, v/v). The extraction solution was made up to 200 ml and was kept in the dark for 2 hours. The mixture was centrifuged under refrigeration at 9000 x g for 10 minutes and then the absorbance was measured using a spectrophotometer (Milton Roy Spectronic-70, Rochester, NY) at 535nm. Acidified ethanol was used as a blank.

The T ACYs was calculated using following formula:

T ACY, mg/100g = [(absorbance x dilution factor)/E] x (100g/10g)

The factor E is 98.2 for the acid-ethanol solvent (Francis, 1982; Fuleki and Francis, 1968a,b).

## Pectic Substances

### Versene-pectinase Extraction of Pectin

Total pectin The procedure for extraction of pectic substance was the method of McCready and McComb (1952). Ten grams of sample were blended in a Warning blender for 1 minute with 150 ml 95% ethanol. The mixture was filtered through Whatman #1 paper under suction and the pulp was washed with 400 ml 75% ethanol. The filtrate was discarded and the alcohol-insoluble residue was transferred to a 250 ml beaker. Cations were sequestered and the pectin de-esterified with 100 ml of a 0.5% Versene solution at pH 11.5 (adjusted with 1N NaOH) for 30 minutes. The mixture was acidified to pH 4 with glacial acetic acid, 0.1 ml of pectinase (EC 3.2.1.15, from *Aspergillus niger*) was added, stirred for 1 hour, diluted to 500 ml with distilled water and filtered through Whatman #1 paper. The first few drops of filtrate were discarded before collecting 2 ml for analysis.

Protopectin The procedure was modified from the method of Kanujoso and Luh (1967). The alcohol-insoluble residue was prepared as described above. Two hundred ml distilled water were added to the residue and stirred for 1 hour. The solution was filtered through Whatman #1 paper under suction and the residue was washed with 400 ml distilled water. The filtrate was discarded and the water-insoluble residue was transferred to a 250 ml beaker. Cations were sequestered and the pectin de-esterified with 100 ml of a 0.5% Versene solution at pH 11.5 (adjusted with 1N NaOH) for 30 minutes. The mixture was acidified to pH 4 with glacial acetic acid, 0.1 ml of

pectinase (EC 3.2.1.15, from *Aspergillus niger*) was added, stirred for 1 hour, diluted to 500 ml with distilled water and filtered through Whatman #1 paper. The first few drops of filtrate were discarded before collecting 2 ml for analysis.

Colorimetric Determination of Galacturonic Acid

The colorimetric measurement of galacturonic acid was done using the method of Kintner and Van Buren (1982). The pectin extract was diluted in order to obtain absorbance reading within the range of the standard ( 10-80 μg galacturonic acid). One ml sample containing pectin was pipetted into a 15x180 mm pyrex test tube and placed in ice-water bath for 5 minutes. Subsequently 6 ml of $H_2SO_4$/tetraborate solution (0.0125M solution of sodium tetraborate prepared in concentrated sulfuric acid) was added to each tube in the ice-water bath and the tube was shaken carefully using Vortex mixer. The mixture was heated in a 100°C water bath for 5 minutes and then immediately placed in an ice-water bath to cool. Duplicate samples were developed by adding 0.1 ml 0.15% *m*-hydroxydiphenyl solution (in 0.5% sodium hydroxide) , mixing and allowing to stand for at least 20 minutes at room temperature to allow bubbles to dissipate (absorption values were stable for up to 1 hour). A blank was prepared by replacing *m*-hydroxydiphenyl with 0.1 ml 0.5% NaOH, keeping all other additions and treatments similar. The blank absorbance was later subtracted from the total absorbance to obtain the absorbance due to *m*-hydroxydiphenyl. Absorbance measurements were taken at 520nm using a Milton Roy Spectronic-70 spectrophotometer. A reagent blank containing 1 ml distilled water, 6 ml sulfuric acid/tetraborate solution and 0.1 ml 0.5% NaOH was used

to zero all instruments. The concentration of pectin was calculated from the standard curve of galacturonic acid (Appendix 1).

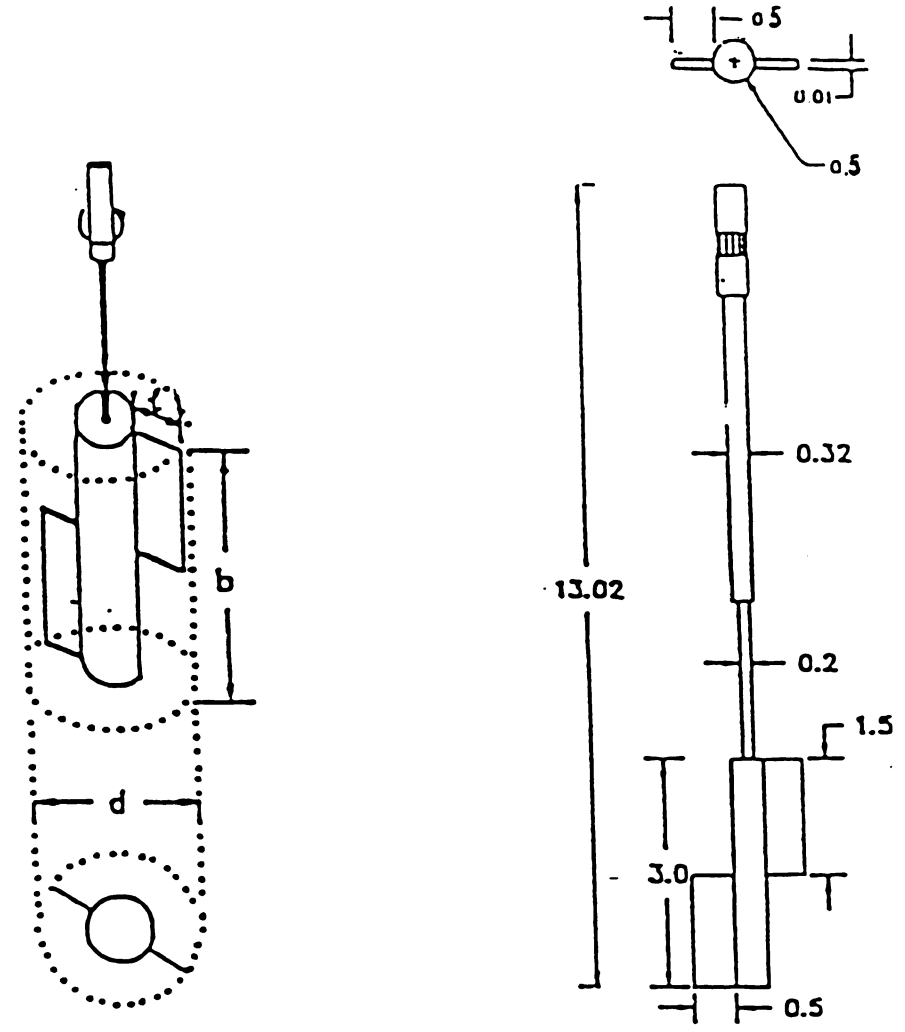
## Rheological Properties

### Procedure for Data Collection

The experimental procedure was based on the method of Castell-Perez (1990). A Brookfield HBTD viscometer (Brookfield Engineering Laboratories, Inc., Stoughton, MA) connected with a data acquisition system (Dianachart PC-Acquisition Model PCA-14, Dianachart Inc., Rockaway, NJ) was used to measure the rheological properties of plum pastes. The sample temperature was controlled at 30±0.2°C by Brookfield water circulator.

Samples were loaded into a cylindrical cup, with flat bottom, made of stainless steel with fluid jackets for temperature control. Inside diameter was 2.54 cm (d/D=0.59) and cup height was 4.0 cm. Fluid level was kept at 1.2D and impeller depth (distance from the bottom of the impeller to the bottom of the cup) set at 0.5d which allowed completed immersion of the flag impeller (Figure 8) under a significant volume of fluid. The effect of other geometric parameters was found to be negligible (Castell-Perez, 1990).

Once loaded into the cylindrical cup, the temperature of the sample was controlled with a water bath connected to the cup jacket. When the temperature reached 30°C, the flag impeller was immersed into the solution and readings (% torque) at a selected rotational speed were recorded after steady state was reached (constant readings). For any given run, the rotational speed varied (a stepwise increase) from 20 to 100 rpm.




Model system

Flag impeller

Figure 8 Model system and flag impeller used in the determination of rheological properties with a mixer

Data Calculations

The shear rate in the mixing system was calculated as:

$$\dot{\gamma} = 4\pi N \quad (12)$$

where, $\dot{\gamma}$ = shear rate, 1/s

N = impeller rotational speed, rev/s

And the shear stress is approximated by

$$\sigma = 2M/(\pi d^2 b) \quad (13)$$

where, $\sigma$ = shear stress, Pa

M = torque, Nm

d = diameter of flag impeller, m

b = flag impeller blade height, m

It was assumed that the rheological properties of plum paste follow the power law behavior within the rpm ranges :

$$\sigma = K(\dot{\gamma})^n \quad (14)$$

where, K = consistency index, Pa $s^n$

n = flow behavior index, dimensionless

The power law parameters were determined from a linear regression analysis of shear stress versus shear rate as :

$$\ln(\sigma) = \ln(K) + n \ln(\dot{\gamma}) \quad (15)$$

The apparent viscosity is

$$\eta_a = \sigma/\dot{\gamma} = K(\dot{\gamma})^n/\dot{\gamma} = K(\dot{\gamma})^{n-1} \quad (16)$$

where, = apparent viscosity, Pa s

Since $\sigma = K(\dot{\gamma})^n$, Eq.(15) becomes

$$\eta_a = K(\dot{\gamma})^n/\dot{\gamma} = K(\dot{\gamma})^{n-1} \quad (17)$$

**Microbial Content**

Samples were tested for total (standard) plate count (SPC), coliform counts, and yeast and mold counts using the methods of Pestka (1993).

Dilution buffer

A stock phosphate buffer was prepared by combining 34 g $KH_2PO_4$/liter distilled water and adjusting to pH 7.2 with sodium hydroxide. The dilution water was prepared by combining 1.25 ml stock phosphate buffer/liter distilled water, dispensed out in 90 ml aliquots, and autoclaved for 15 minutes.

Sample preparation

Ten grams of sample were aseptically weighed and put into a sterile stomacher bag, with 90 ml of sterile buffer, and homogenized for 1 minute using stomacher lab blender (Model 400, Tekmar Co., Cincinnatti, OH).

Standard plate count

SPC agar was prepared according to package directions, by heating to boil to dissolve completely, separated into 250 ml increments, sterilized in the autoclave for 15 minutes at 15 pounds pressure and 121°C, and cooled to 45°C. One ml of sample was pipetted into a petri dish and about 15 ml of hot, liquid agar was poured in the plate, incubated at 32°C for 48 hours in inverted position, and the colonies were counted using a Quebec colony counter.

Coliform count

Violet red bile (VRB) agar was prepared according to package directions, by heating to boil to dissolve completely, and cooled to 45°C. One ml of sample was pipetted into a petri dish and about 15 ml of hot, liquid agar was poured in the plate, incubated at 32°C for 24 hours in inverted position, and the colonies were counted using a Quebec colony counter.

Yeast and mold counts

Sabouraud dextrose agar (for culturing yeasts, molds, and aciduric microorganisms) was prepared according to package directions, by heating to boil to dissolve completely, separated into 250 ml increments, sterilized in the autoclave for 15 minutes at 15 pounds pressure and 121°C, and cooled to 45°C . One ml of sample was pipetted into a petri dish and about 15 ml of hot, liquid agar was poured in the plate, incubated at 22-25°C in the dark for 5-7 days in inverted position, and the colonies were counted using a Quebec colony counter.

Data calculations

After counting the colonies, the results were expressed by following formula:

Dilution factor = initial dilution x amount plated

Total count, CFU per gram = colonies counted / dilution factor

**Statistical analysis**

In this study, the experiment was designed as a three factor (source x concentration x sugar) (for processing condition effects) and

a five factor (source x concentration x sugar x time x temperature) (for storage condition effects) randomized model with balanced data. All determinations were made in duplicate, except for Hunter color values, which were determined in triplicate. Mean, standard deviation, standard errors, ANOVA tables, and correlations were done using the Super ANOVA software (Abacus Concepts, Inc., Berkeley, CA), Lotus software, and SAS software. Interactions between statistically significant factors may not be biologically significant. Therefore, those interactions important both statistically and biologically were focused. LSD test for multiple comparisons was applied to determine significantly different treatment effects.

## VI. Sensory Analysis

### Sensory Analysis Test Method

The sensory test of paste from whole plums was carried out to determine the effect of processing conditions and storage conditions at the beginning and end of storage using the descriptive test with unstructured scaling (Poste et al., 1991). Samples were tested by a panel of 60 people for color, acidity, sweetness, consistency, flavor, and overall acceptance. Panelists were asked to evaluate the first 5 descriptors by intensity only and the last one by personal preference. A 15-cm horizontal line with an anchor at mid-point was used. Each line was labeled with a descriptor expression at each end. A separate line was used for each sensory attribute to be evaluated. Panelists were asked to record each evaluation by marking the horizontal line at the point that best reflected their perception of the magnitude of

that property. Each panel consisted of 60 panelists from the faculty, staff, and students in the Food Science and Human Nutrition Department. Panelists ranged in age from 18-55 years old and included both males and females (see Appendix 2 for sample ballot).

### Environmental Conditions

All sensory tests were held in the sensory evaluation laboratory of the Department of Food Science and Human Nutrition at Michigan State University. This laboratory is equipped with fifteen isolated testing booths that have temperature regulated positive airflow, and constant illumination. Panelists evaluated the paste samples under white fluorescent lighting.

### Sample Preparation and Presentation

Approximately 15 grams of sample was put into 2-oz cups labeled with a three-digit random numbers for identification. The samples were allowed to come to room temperature prior to the sensory evaluations. All sample presentation orders were randomized and balanced. Subjects were instructed to drink ambient temperature distilled water, as well as eat unsalted crackers ad libitum prior to and between sample evaluations. Panelists were also allowed to swallow or expectorate the paste samples. The tests were held consecutively on one day lasting from mid-morning to mid-afternoon.

### Data Analysis

The points on horizontal lines were measured in cm and translated into numerical values for statistical analysis. Three-way ANOVA was used to test the significance of main effects and

interactions of processing conditions using Super ANOVA (Abacus Concepts, Inc., Berkeley, CA). The correlation coefficient of overall acceptance and other attributes were calculated .

To determine the effect of storage time, the difference of each value for each attribute and two-way ANOVA were used to test the significance of effect of concentrations and sugar addition on time effect. If it was not significant, the t-test was conducted to see if time affected storage ability significantly.

To determine the effect of storage temperature, the difference of each value for each attribute and two-way ANOVA were used to test the significance of effect of concentrations and sugar addition on temperature effect. If it was not significant, the t-test was conducted to see if temperature affected storage ability significantly.

# RESULTS AND DISCUSSION

## I. Processing Effect

### Puree Production

The yield of puree from standard plums (i.e. pilot plant product) was 71.25% by weight. The quality characteristics of the commercial and pilot plant purees are listed in Table 2. The processing conditions for both batches of purees were basically the same. Pilot plant puree had significantly ($P<0.01$) higher soluble solids, total solids, titratable acidity, Hunter 'a' value, chroma, T ACYs, total pectin, Protopectin, apparent viscosity ($\eta_a$), consistency index (K), and flow behavior index (n) than the commercial pure. The commercial puree was higher in water activity, moisture content, pH , Hunter 'L' value, Hunter 'b' value, and hue angle. However only moisture content and hue angle were significantly different at 5% level. From subsequent background investigation it was determined that the commercial puree was made from substandard plums, therefore, the lower quality was were predictable. No PPO activity was detected in either puree. This indicated that the preheating temperature (95°C) with 10 minutes holding time was sufficient to inactivate PPO in Stanley plums. Siddiq (1993) also reported that heating at 75°C for 5 minutes rendered Stanley plum PPO completely inactive. Microbial count showed that commercial puree was free from microorganism contamination but pilot plant puree was contaminated by yeasts and molds.

Table 2 Quality characteristics of commercial puree made from substandard plums and pilot plant puree made from standard plums

| Characteristics | Commercial puree | Pilot plant puree |
|---|---|---|
| Soluble solids (°Brix) | 9.900a[1] | 16.425b |
| Total solids (%) | 10.320a | 18.075b |
| Moisture content (%) | 89.68b | 81.92a |
| Water activity | 0.999a | 0.998a |
| pH | 3.50a | 3.45a |
| Titratable acidity (% malic acid, wet basis) | 0.784a | 1.357b |
| Hunter color | | |
| L | 24.397b | 21.915a |
| a | 27.720b | 39.230a |
| b | 12.650a | 12.610a |
| Hue angle | 0.428b | 0.311a |
| Chroma | 30.473a | 41.207b |
| PPO activity ($\Delta$420nm/minx$10^{-1}$) | nd[2] | nd |
| Total anthocyanins (mg/100g, wet basis) | 8.846a | 18.455b |
| Total pectin (g/100g, wet basis) | 0.330a | 0.722b |
| Protopectin (g/100g, wet basis) | 0.048a | 0.722b |
| Apparent viscosity ( Pa s) | 0.921a | 4.048b |
| Consistency index (K) | 7.090a | 20.872b |
| Flow behavior index (n) | 0.138a | 0.306b |
| Standard plate count (CFU/g) | 0 | 0 |
| Coliform count (CFU/g) | 0 | 0 |
| Yeast and mold count (CFU/g) | 0 | 200 |

1 Values with the same latters in horizontal rows are not significantly different at 5% level of significance

2 not detected

## Paste Production

Our preliminary experiment showed that it was not feasible to concentrate plum pastes beyond 40°Brix. However, Wani et al. (1990) stated that the pulp from 3 plum varieties in his studies could not be concentrated beyond 26°Brix. The difference may come from the different varieties and characteristics of fruits. Pastes higher than 30°Brix were very thick and almost did not flow, but lower than 25°Brix were too thin. It was found that plum paste with 25-30°Brix had most attractive color and best consistency. Therefore, pastes with the soluble solids of 25 and 30°Brix became the standards for all subsequent work. Relatively longer processing times were needed for pastes with higher soluble solids. Also, due to the high acidity of paste, it was necessary to add sweetener to ameliorate the flavor. Pastes sweetened with sugar addition to increase 5, 10, 15 and 20°Brix were evaluated. According to the results from preliminary sensory test, sweetened pastes with sugar addition to increase 15°Brix were best accepted. Therefore, unsweetened and sweetened pastes with 15°Brix increase were used for subsequent study.

### Yield

Table 3 shows the yields of pastes from commercial puree and pilot plant puree. The yields of pastes from commercial puree were 38.73% for 25°Brix paste and 31.60% for 30°Brix paste. The yields of paste from pilot plant puree were 59.62% for 25°Brix and 50.23% for 30°Brix, calculated based on puree weight. The lower yields of paste from commercial puree were due to their lower soluble solids, which meant that more water had to be evaporated to reach the same degree of soluble solids. The yields of paste from pilot plant puree were

Table 3 Yields of plum pastes from commercial puree and pilot plant puree

| Treatment | Yield from fruit (%Wt) | Yield from puree (%Wt) | Sugar addition (%Wt) |
|---|---|---|---|
| From commercial puree | | | |
| 25°Brix | - | 38.73 | - |
| 30°Brix | - | 31.60 | - |
| 25°Brix, sugar added to 40°Brix | - | - | 17.75 |
| 30°Brix, sugar added to 45°Brix | - | - | 19.43 |
| From pilot plant puree | | | |
| 25°Brix | 42.47 | 59.62 | - |
| 30°Brix | 35.78 | 50.23 | - |
| 25°Brix, sugar added to 40°Brix | - | - | 20.08 |
| 30°Brix, sugar added to 45°Brix | - | - | 21.53 |

42.47% for 25°Brix and 35.78% for 30°Brix, calculated based on fruit weight. The sugar amounts needed to increase 15°Brix soluble solids were a little higher for paste from commercial puree. The average was 19.70% of weight.

Soluble Solids and Total Solids

During manufacture it is important to know the degree of concentration of puree or paste for the quality control (Goose, 1964). The commercial puree contained lower soluble solids (9.90°Brix) as compared to the pilot plant puree (16.42°Brix). Therefore, the heating time required to produce the paste with the same degree of soluble solids was longer for the production of pastes from commercial puree. Also, the 30°Brix pastes needed longer heating time than 25°Brix pastes. Time required for heat concentration process, at 100°C, to 25 and 30°Brix was approximately 50 and 70 minutes for commercial puree and 30 and 45 minutes for pilot plant puree, respectively. Heat concentration increased soluble solids of the pastes made from commercial puree by 14.55 and 20.50 units for 25 and 30°Brix paste, respectively, and by 8.08 and 13.27 units for 25 and 30°Brix paste from pilot plant puree, respectively. The longer heating time resulted in higher soluble solids, total solids and less moisture content, as has been reported previously ( Shol'ts et al., 1990; Exama and Lacroix, 1989a).

The pattern of soluble solids and total solids change, due to processing is shown in Table 4. Degree of soluble solids and percent total solids were increased by heat evaporation which removed water from puree and sugar addition which resulted in an increase of the

Table 4 Effect of processing conditions on soluble solids, total solids, moisture content, and water activity of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| Soluble solids (°Brix) | 9.90a[1] | 9.90a | 24.45b | 30.40b | 39.40c | 44.95c |
| Total solids (%) | 10.32a | 10.32a | 25.89b | 31.82b | 40.50c | 46.50c |
| Moisture content (%) | 89.68c | 89.68c | 74.11b | 68.18b | 59.50a | 53.50a |
| Water activity | 0.999c | 0.999c | 0.986b | 0.970b | 0.955a | 0.940a |
| | | | From pilot plant puree | | | |
| Soluble solids | 16.42a | 16.42a | 24.50b | 29.69b | 39.55c | 44.95c |
| Total solids | 18.08a | 18.08a | 25.73b | 30.69b | 40.75c | 46.06c |
| Moisture content | 81.92c | 81.92c | 74.27b | 69.31b | 59.25a | 53.94a |
| Water activity | 0.998c | 0.998c | 0.978b | 0.973b | 0.949ca | 0.931a |

[1] Values with the same letters in same soluble solids (°Brix) in horizontal rows are not significantly different at 5% level of significance

soluble solids. The total solids increased significantly ($p<0.05$) with increase of soluble solids.

Moisture Content and Water Activity (aw)

Moisture content and aw loss were inversely ($p<0.05$) related to the increase of soluble solids due to heat evaporation and sugar addition (Table 4). After heat evaporation, plum pastes still had relatively high aw: 0.986 and 0.978 for 25°Brix pastes made from commercial puree and from pilot plant puree, and 0.970 and 0.973 for 30°Brix pastes from commercial puree and from pilot plant puree. The result was parallel to that of Troller and Christian (1978). They pinpointed that the concentration of foods did not always produce measurable reduction in aw and the principle advantage in concentrating this material was to increase nutrient contents and achieve economic reductions in volume and weight. They reported aw of 0.99 for tomato paste, 0.92 for orange juice, 0.99 for evaporated milk and 0.98 for canned vegetable soup.

The addition of sugar to food products has been applied to enhance taste and prevent microbial growth by reducing water activity (Jay, 1992). The aw of foods containing up to 60% sucrose fall into the range of 1.0 to 0.90 (Troller and Christian, 1978). Plum pastes with sucrose added contained approximately 20% sucrose and had aw of 0.955, 0.949 for 40°Brix pastes from commercial puree and from pilot plant puree, and 0.949 and 0.931 for 45°Brix pastes from commercial puree and from pilot plant puree, respectively. The aw decreased by an average of 0.33 due to sugar addition.

Water activity is an important factor with respect to chemical and physiological reactions as well as microbial stability during

storage. Preventing or retarding the microbial spoilage of food products can be achieved by pH, moisture content and temperature. Approximate minimum aw values for growth of most spoilage bacteria is 0.90, and for most spoilage yeast and mold is 0.80 (Troller and Christian, 1978). Although under the range of aw (0.986-0.931), only some spoilage bacteria can not grow. The low pH of plum pastes (3.45-3.50) is considerably below the minima for most food spoilage and all food poisoning bacteria (Jay, 1992). Therefore, yeast and mold spoilage would be more important for plum pastes, and this can be controlled by heat destruction and low temperature storage.

pH

The pH values of purees and pastes are shown in Table 5. pH values remained unchanged during heat concentration and sucrose addition, at 3.50 for commercial puree and pastes made from it and 3.45 for pilot plant puree and pastes made from it. Minor changes in pH during concentration process has been reported in literature (Wani et al., 1990; Exama and Lacroxi, 1989a). The effect of sugar addition on pH values agree with the that of Bash et al. (1984) who indicated that pH of tomato pastes was affected very little by the addition of sugar.

Titratable Acidity

The titratable acidity (TA) expressed as percent of malic acid is shown in Table 5. According to the data on wet basis, evaporation process had significant concentrating effect ($p<0.01$) on the percent of TA for all pastes, but sugar addition showed significant dilution effect ($p<0.01$) on them. This is confirmed by Bash et al. (1984). While

Table 5 Effect of processing conditions on pH and titratible acidity of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| pH | 3.50a[2] | 3.50a | 3.50a | 3.50a | 3.50a | 3.50a |
| Titratable acidity[1] | | | | | | |
| (Wet basis) | 0.784a | 0.784a | 1.819c | 2.191c | 1.551b | 1.832b |
| (Dry basis) | 7.596c | 7.596c | 7.026b | 6.886b | 3.830a | 3.941a |
| Loss (%, Dry basis) | | | 7.50 | 9.35 | | |
| | | | From pilot plant puree | | | |
| pH | 3.45a | 3.45a | 3.45a | 3.45a | 3.45a | 3.45a |
| Titratable acidity | | | | | | |
| (Wet basis) | 1.357a | 1.357a | 1.873c | 2.230c | 1.621b | 1.837b |
| (Dry basis) | 7.506c | 7.506c | 7.278b | 7.266b | 3.979a | 3.989a |
| Loss (%, Dry basis) | | | 3.04 | 3.20 | | |

[1] calculated as % malic acid

[2] Values with the same letters in same soluble solids (°Brix) in horizontal rows are not significantly different at 5% level of significance

comparing the data on dry basis, heat process decreased the content of TA. Commercial puree has higher TA (on dry basis) than pilot plant puree. The degradation of TA was a function of heating time and pastes made from commercial puree lost much more TA as compared to pastes made from pilot plant puree.

Polyphenoloxidase (PPO) Activity

Table 6 shows that no PPO activity of purees and pastes was detected, which indicated that the possibility of enzymatic browning in these products was negligible. However, Wesche-Ebeling and Montgomery (1990) indicated that even when enzyme activity is inhibited, the quinones and intermediate oxidation products formed before the enzyme was inactivated could be sufficient to initiate polymerization reactions and degradation of ACYs. The enzymatic reaction could occur during thawing of the frozen fruit, as well as during preheating before the inactivation temperature reached. Enzymes derived from mold contamination (Pilando et al., 1985) should also be considered in addition to native fruit enzymes. Minimizing mold contamination, enzyme inactivation, rapid thawing and preheating procedures are recommended to reduce browning reaction.

Hunter 'L' Value

The common methods used to measure the extent of browning are spectral absorbance measurements at 420nm and Hunter 'L' readings. The changes in 'L' values have been proven to have very high correlation with the extent of browning for fruit and vegetable products, such as potato (Jiang and Ooraikul, 1989) and plum juice

Table 6 Effect of processing conditions on polyphenoloxidase activity, Hunter "L", and ΔL of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| PPO activity[1] | nd[2] | nd | nd | nd | nd | nd |
| Hunter 'L' | 24.40c[3] | 24.40c | 18.68b | 17.24b | 14.74a | 14.46a |
| ΔL | | | -5.72[4] b | -7.14b | -3.94[5]a | -4.34a |
| | | | From pilot plant puree | | | |
| PPO activity | nd | nd | nd | nd | nd | nd |
| Hunter 'L' | 21.92c | 21.92c | 17.24b | 16.36b | 14.46a | 13.49a |
| ΔL | | | -4.68b | -5.56b | -2.78a | -2.87a |

[1] unit is Δ420nm/minx$10^{-1}$

[2] not detected

[3] Values with the same letters in same soluble solids (°Brix) in horizontal rows are not significantly different at 5% level of significance

[4] $\Delta L = L_{\text{after heat concentration}} - L_{\text{before heat concentration}}$

[5] $\Delta L = L_{\text{after sugar addition}} - L_{\text{before sugar addition}}$

(Chang, 1993). The advantages of using Hunter 'L' values as browning index is the simpler procedure as well as elimination of the interference problem caused by non-browning pigment (Baloch et al., 1973).

Hunter 'L' values indicate the lightness and darkness. White color has the value of 100 and black color, 0 (Anon, 1987). A decrease in 'L' values is indicative of browning (Monsalve-Gonzalez et al., 1993; Sapers et al., 1990). The extent of darkening effect resulting from processing conditions is more clear when expressed as $\Delta L$. Commercial puree was lighter in color than pilot plant puree. Pastes from commercial puree also had lighter color compared to pastes from pilot plant puree (Table 6). Hunter 'L' values were significantly ($p<0.01$) decreased by heat concentration for all pastes. Processing browning increases as a function of heating time (Friedman and Molnar-Perl, 1990; Velisek et al., 1989) were also observed in this study. The addition of sugar significantly ($p<0.01$) darkened pastes, which is supported by Bash (1984). According to Leszkowiat et al. (1990), sucrose contributes to the non-enzymatic browning by thermal hydrolysis to yield glucose and fructose, which are the main reactants in the Maillard reaction (Jiang and Ooraikul, 1989). The darkening could be caused by pigment polymerization, such as anthocyanin-phenolic condensation, Maillard reaction, ascorbic acid degradation, and caramelization during processing.

Hunter 'a' Value

Hunter 'a' values show red when positive and green when negative. Plum purees and pastes had positive Hunter 'a' values

which significantly decreased ($P<0.05$) by heat concentration and sugar addition (Table 7). This result is supported by Bash (1984).

Hunter 'b' Value

Hunter 'b' values shows yellow when positive and blue when negative. Both positive values of Hunter 'a' and 'b' indicated that color of plum puree and pastes were red-yellow. The values were significantly decreased ($P<0.05$) by processing, as shown in Table 7. Bash (1984) observed that tomato paste color went to less red and less yellow when the sucrose level increased and explained that the change may have been caused by heat processing after sucrose addition.

Hue Angle

Hue angle, defined as tan-1 (b/a) while it was in the yellow-red quadrant (Little, 1975), is the attribute of color perception by which an object is judged to be red, yellow, green, blue, and so forth (Anon., 1987). Smaller the hue angle, more red than yellow the object is. Heat concentration showed increasing effect ($P<0.05$) on hue angle of pastes from commercial puree, but decreasing effect ($P<0.05$) on pastes from pilot plant puree (Table 7). Hue angles of pastes from pilot plant puree were significantly decreased ($P<0.05$) due to sugar addition.

Chroma

Chroma (saturation index) determines how far is the color from the gray toward the pure hue (Anon, 1987) and is calculated as $(a^2+b^2)^{1/2}$. It is negatively correlated to percentage of polymeric color

Table 7 Effect of processing conditions on Hunter 'a', 'b' values, hue angle, and chroma of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| Hunter 'a' | 27.72c[3] | 27.72c | 21.86b | 18.48b | 19.46a | 17.71a |
| Hunter 'b' | 12.65b | 12.65b | 12.36b | 13.20b | 11.45a | 10.37a |
| Hue angle[1] | 0.428a | 0.428a | 0.515b | 0.620c | 0.532c | 0.530b |
| Chroma[2] | 30.47c | 30.47c | 25.12b | 22.71b | 22.57a | 20.52a |
| | | | From pilot plant puree | | | |
| Hunter 'a' | 39.23c | 39.23c | 27.73b | 24.05b | 22.91a | 19.40a |
| Hunter 'b' | 12.61c | 12.61c | 7.99b | 7.03b | 6.63a | 5.70a |
| Hue angle | 0.311b | 0.311b | 0.281a | 0.284a | 0.282a | 0.286a |
| Chroma | 41.21c | 41.21c | 28.86b | 25.06b | 23.85a | 20.22a |

1 Calculated as $\tan^{-1}(b/a)$

2 Chroma was calculated as $(a^2 + b^2)^{1/2}$

3 Values with the same letters in same soluble solids (°Brix) in horizontal rows are not significantly different at 5% level of significance

(Rommel et al., 1992). Significant decrease ($P<0.05$) of chroma due to heat concentration and sugar addition was detected. Similar pattern of chroma and T ACY change implied that loss of T ACYs was due more to degradation than polymerization.

Total Anthocyanins (T ACYs)

Table 8 shows effect of processing on the content of T ACYs in samples. pilot plant puree had higher T ACYs than commercial puree. The fact that pastes had higher T ACYs than purees indicated that heat processing had a concentrating effect on the content of T ACYs. However, the degradation of pigment can be seen from the T ACYs based on dry weight. Commercial puree lost 25.34% and 42.48% of T ACYs when making 25 and 30°Brix pastes, respectively. pilot plant puree lost 23.90% and 44.76% while producing 25° and 30°Brix pastes, respectively. Siddiq (1993) reported that plum juice lost 16% of T ACYs after heat treatment at 65°C for 70 minutes. Meschter (1954) reported that the half-life was only 1 hour for the pigments in strawberries heated at 100°C.

ACYs are the major color source of plums. For pH 3.45-3.50 of plum purees and pastes, the ACYs were in the form of $AH^+$ and represent red color (Brouillard and Delaporte, 1977). The dilution effect of sucrose addition on T ACY contents was significant ($p<0.01$).

Pectin Content

Table 9 shows the changes in pectin content during processing. Pilot plant puree contained significantly higher level ($p<0.01$) of total pectin than commercial puree. Heat process resulted in a significant degradation ($P<0.05$) of total pectin. Loss of pectin in commercial

Table 8 Effect of processing conditions on total anthocyanins of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| Total anthocyanins[1] | | | | | | |
| (Wet baisi) | 8.85a[2] | 8.85a | 15.63c | 13.76c | 12.51b | 11.32b |
| (Dry basis) | 85.72c | 85.72c | 60.38b | 43.24b | 30.88a | 24.34a |
| Loss (Dry basis) | | | 29.56 | 49.56 | | |
| | | | From pilot plant puree | | | |
| Total anthocyanins | | | | | | |
| (Wet baisi) | 18.46b | 18.46c | 20.12c | 17.60b | 15.35a | 14.13a |
| (Dry basis) | 102.11c | 102.11c | 78.21b | 57.35b | 37.68a | 30.69a |
| Loss (Dry basis) | | | 23.41 | 43.84 | | |

[1] Unit is mg/100g

[2] Values with the same letters in same soluble solids (°Brix) in horizontal rows are not significantly different at 5% level of significance

Table 9 Effect of processing conditions on pectin content of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| Total pectin[1](Wet baisis) | 0.330a[2] | 0.330a | 0.494c | 0.552c | 0.409b | 0.420b |
| (Dry basis) | 3.199c | 3.199c | 1.909b | 1.736b | 1.010a | 0.903a |
| Loss (% Dry basis) | | | 40.32 | 45.73 | | |
| Protopectin[1](Wet basis) | 0.048 | 0.048 | nd[3] | nd | nd | nd |
| (Dry basis) | 0.465 | 0.465 | nd | nd | nd | nd |
| | | | From pilot plant puree | | | |
| Total pectin (Wet baisis) | 0.722a | 0.722a | 0.982c | 1.111c | 0.811b | 0.838b |
| (Dry basis) | 3.996b | 3.996c | 3.816b | 3.622b | 1.990a | 1.820a |
| Loss (% Dry basis) | | | 4.50 | 9.40 | | |
| Protopectin (Wet basis) | 0.317 | 0.317 | nd | nd | nd | nd |
| (Dry basis) | 1.754 | 1.754 | nd | nd | nd | nd |

[1] Unit is g/100g

[2] Values with the same letters in same soluble solids (°Brix) are not significantly different at 5% level of significance

[3] not detected

puree was much higher (40.32% loss for 25°Brix paste and 45.73% loss for 30°Brix paste), when compared to a 4.50% loss for 25°Brix paste and 9.40% loss for 30°Brix paste from pilot plant puree. Luh et al. (1954) stated that marked losses in pectic substances occurred when tomato pastes were processed. However, negligible decrease in pectin content during plum pulp and juice concentrating process was reported by Wani et al. (1990). Sawayame and Kawabata (1989) studied the effect of pH and heat on the physicochemical properties of pectic substances and stated that heating induced acid-hydrolysis of pectin in the pH range of 2 to 5 which results in lower molecular size distribution of pectin. Gubenkova et al. (1988) also stated that heating caused deformation of pectin polymers. Our study showed that the commercial puree consisted of significantly ($P<0.01$) lower protopectin than the pilot plant puree. No protopectin was detected in either paste. It is possible that heat process caused depolymerization to segments and then decomposition. Since commercial puree contained less high molecular pectic substances and had to be heated for a longer period of time during processing, the pectic substances depolymerized as well as decomposed, resulting in marked losses in total pectin contents. Pilot plant puree contained more high molecular pectic substances, the heat process caused depolymerization but less decomposition, resulting in small losses in total pectin content.

Rheological Properties

The response of decreasing shear stress to time at constant shear rate indicated that plum paste exhibited time-dependent thixotropic behavior (Figure 9). The time scale was about 5 minutes and plum

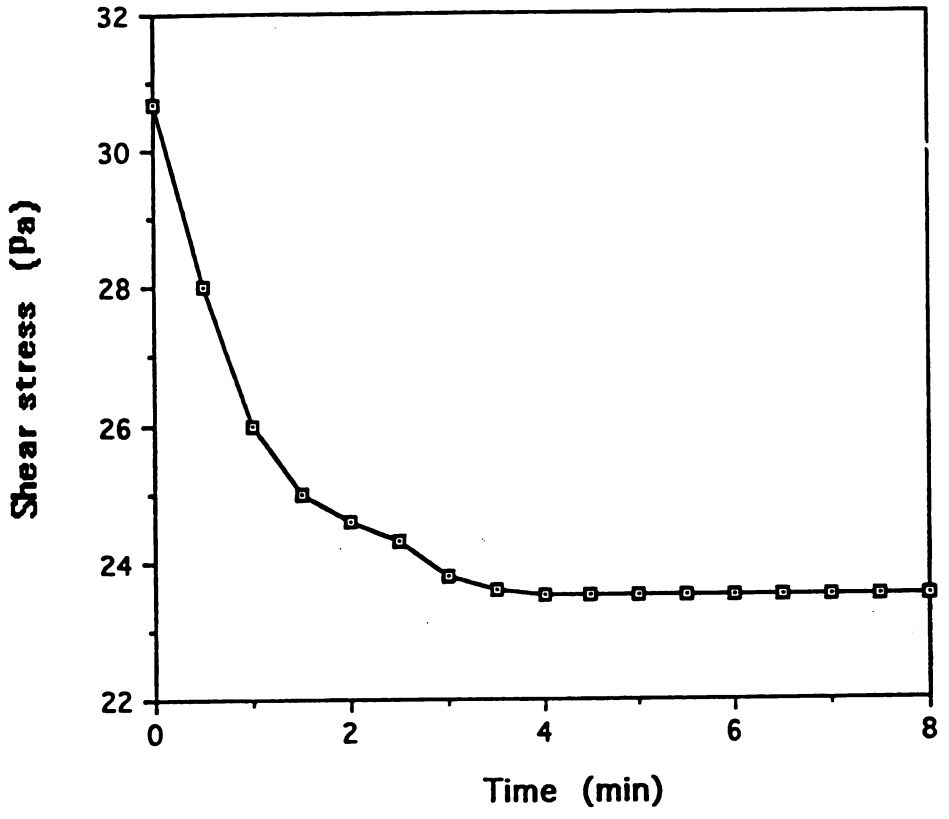



Figure 9 Rheogram of plum paste at constant shear rate (20 rpm) and constant temperature (30°C)

pastes and purees showed time-independent behavior after the time period. Rao and Anantheswaran (1982) showed that the time span related to this time-dependent behavior is relatively short, and because of various mechanical operations in a processing line, the behavior will not persist for long. Therefore, they suggested that the magnitudes of rheological parameters measured after the time span could be used to describe fluid phenomena and for equipment design. The study was based on time-independent properties and data was collected after time-independent period reached. Shear stresses required to induce a given rate of shear on pastes are shown in Figure 10. At shear rates in the order of 20 to 100 rpm in increasing heat concentration generally resulted in increased resistance to flow, but sugar addition resulted in a slightly lower resistance flow. Apparent viscosity is defined as shear stress divided by shear rate (Steffe, 1992). Pastes requiring higher shear stress to have a given shear rate are thicker and have higher apparent viscosity. The apparent viscosity can be used to express the thickness (or consistency) of pastes. The apparent viscosities at different rpms showed similar tendency (Figure 11), therefore, the apparent viscosity at 50 rpm was used to illustrate the viscosity of samples.

Table 10 shows the effect of heat concentration and sugar addition on the rheological properties of pastes. The magnitude of the apparent viscosity ($\eta_a$), consistency index (K) increased significantly ($P<0.01$) with an increase in heat concentration. Increasing heat concentration resulted in significantly ($P<0.01$) decreased flow behavior index (n). Sugar addition showed little effect on rheological behavior of either paste. This corresponded to the results reported previously that higher apparent viscosity is positively

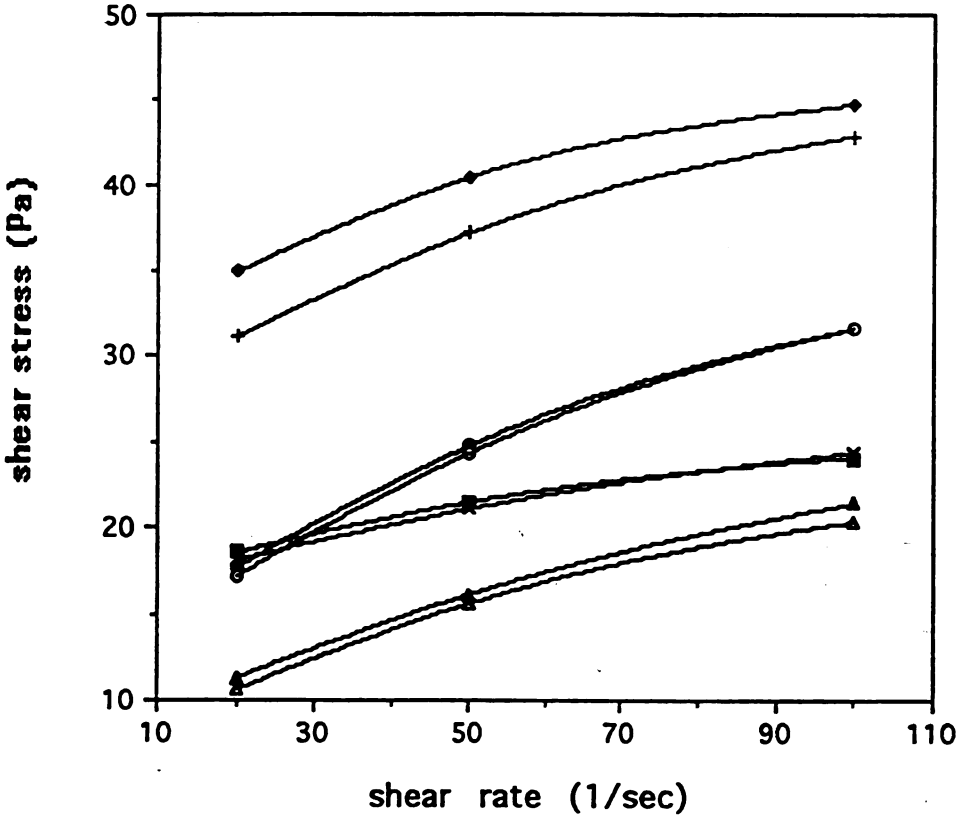



Figure 10 Shear stress as a function of shear rate of pastes from commercial puree and pilot plant puree

Plum pastes from commercial puree
- ■ 25°Brix
- ◆ 30°Brix
- × 25°Brix, sugar added to 40°Brix
- \+ 30°Brix, sugar added to 45°Brix

Plum pastes from pilot plant puree
- ▲ 25°Brix
- ● 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ○ 30°Brix, sugar added to 45°Brix

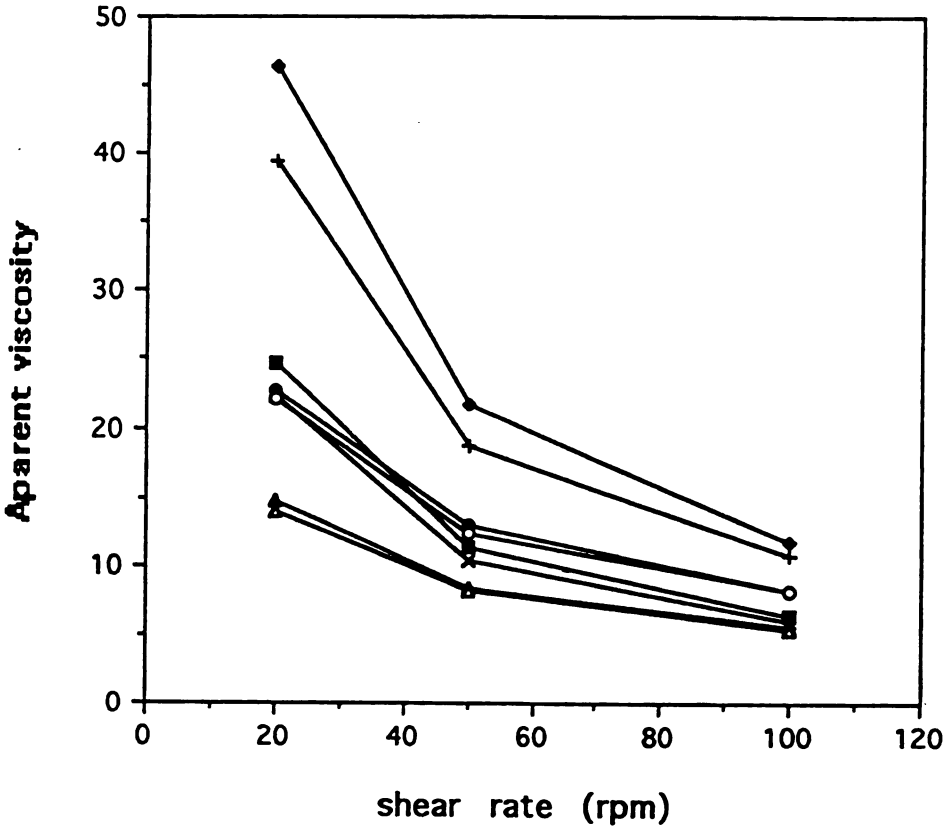



Figure 11 Apparent viscosity of plum pastes at different shear rates

Plum pastes from commercial puree
- ■ 25°Brix
- ◆ 30°Brix
- × 25°Brix, sugar added to 40°Brix
- \+ 30°Brix, sugar added to 45°Brix

Plum pastes from pilot plant puree
- ▲ 25°Brix
- ● 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ○ 30°Brix, sugar added to 45°Brix

Table 10 Effect of processing conditions on rheological properties of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| Apparent viscosity[1] ($\eta_a$) | 0.920a[4] | 0.920a | 11.16b | 20.99c | 10.95b | 19.30b |
| Consistency index[2] (K) | 7.09a | 7.09a | 79.72b | 152.33c | 75.01b | 127.01b |
| Flow behavior index[3] (n) | 0.138a | 0.138a | 0.162ab | 0.154a | 0.184b | 0.198b |
| | | | From pilot plant puree | | | |
| Apparent viscosity ($\eta_a$) | 4.05a | 4.05a | 8.36b | 12.86b | 8.08b | 12.64b |
| Consistency index (K) | 20.87a | 20.87a | 34.66b | 56.46b | 32.29b | 54.03b |
| Flow behavior index (n) | 0.306a | 0.306a | 0.397b | 0.367b | 0.406b | 0.381b |

[1] Unit is Pa s

[2] Unit is Pa $s^n$

[3] Dimensionless

[4] Values with the same letters in same soluble solids (°Brix) are not significantly different at 5% level of significance

correlated to higher solid content (Steffe and Morgan, 1986) but sugar does not greatly influence texture (Canellas et al., 1993; Exama and Lacroix, 1989a; Nusrten, 1986). Values obtained for the flow behavior index (n) of the plum pastes ranged from 0.1 to 0.5, confirming the pseudoplastic nature of the samples. Similar pseudoplastic behavior ($0<n<1$) was found in fruit puree and juice concentrate (total solids ranged from 5.8 to 58.4%) (Rao et al., 1986; Steffe and Morgan, 1986). The general consesus that the consistency index is higher for the more pseudoplastic fluids (Rao et al., 1986) was confirmed in this study.

Commercial puree had lower soluble solids and apparent viscosity (0.92 Pa s) as compared to Pilot plant puree (4.05 Pa s). Similar results were reported by Rao et al. (1986) who found the rheological properties of apple sauce is dependent on the soluble solids. However, the pastes made from commercial puree with a lower pectin content (dry basis) had significantly ($P<0.01$) higher apparent viscosity than those made from pilot plant puree. In this study, no significant relationship was found between apparent viscosity and pectin content. Pectin has been demonstrated to be an important contributor to the consistency of tomato pastes (Liu and Luh, 1979; Sherkat and Luh, 1977,1976). However Luh et al. (1954) studied the consistency of tomato pastes and puree from different varieties and found that besides pectin other high non-pectin carbohydrate constituents may also be effective in determining consistency. Luh et al. (1984) confirmed the above research by finding that the thicker consistency of tomato pastes contained higher molecular weight pectic fractions and other carbohydrates, such as fiber, cellulose, lignin and cutins in tomato which are all important in imparting consistency. Marsh et al. (1980) also indicated that total solids of tomato

concentrate are involved to a much higher extent in determining consistency than are the percentage of water-soluble compounds, such as water-soluble pectin which is the major type of pectin in plum paste.

Microbial Analysis

Table 11 shows the content of bacteria, yeast, and mold in purees and pastes under different processing conditions. Standard plate count as well as yeast and mold count are mainly used to monitor the microbial contamination from raw materials and equipment. Coliform count is mainly used to control the microbial contamination from water (Pestka, 1993). There were no microorganisms detected in commercial puree or the pastes made from it. Although pilot plant puree was contaminated with yeasts and molds, pastes made from it were free from microbial contamination. These results were expected because the heat process necessary for concentration of the puree to paste was sufficient to destroy yeasts and molds (Jay, 1992). The results indicated that the sanitation during processing was under control.

Sensory Evaluation

Four types of pastes made from pilot plant puree were used to evaluate color, acidity, sweetness, consistency, flavor, and overall acceptance in the sensory evaluation. Mean values of the sensory scores are shown in Table 12, and P values of analysis of variance are shown in Table 13. The interaction of heat concentration and sugar addition were not significant.

Color The effect of heat processing and sugar addition on lightness of pastes was perceived by panelists ($P<0.01$). 30°Brix paste

Table 11 Effect of processing conditions on microbial content of pastes from commercial puree and from pilot plant puree

| Treatment/ Characteristics | Puree | | Heat concentration | | Sugar addition | |
|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix | 30°Brix | 25°Brix to 40°Brix | 30°Brix to 45°Brix |
| | | | From commercial puree | | | |
| Standard plate count[1] | 0 | 0 | 0 | 0 | 0 | 0 |
| Coliform count[1] | 0 | 0 | 0 | 0 | 0 | 0 |
| Yeast and mold count[1] | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | From pilot plant puree | | | |
| Standard plate count | 0 | 0 | 0 | 0 | 0 | 0 |
| Coliform count | 0 | 0 | 0 | 0 | 0 | 0 |
| Yeast and mold count | 200 | 200 | 0 | 0 | 0 | 0 |

[1] Unit is CFU/g

Table 12 Mean values of sensory attributes for plum pastes made from pilot plant puree

| Treatment/ Sensory attributes | Heat concentration 25°Brix | Heat concentration 30°Brix | Sugar addition 25°Brix to 40°Brix | Sugar addition 30°Brix to 45°Brix |
|---|---|---|---|---|
| Color | 8.16 | 10.53 | 10.60 | 12.02 |
| Acidity | 9.60 | 10.35 | 5.38 | 5.23 |
| Sweetness | 4.34 | 4.34 | 8.76 | 8.74 |
| Consistency | 7.98 | 10.34 | 8.85 | 10.63 |
| Flavor | 8.35 | 9.11 | 9.26 | 9.10 |
| Overall acceptance | 5.98 | 5.58 | 10.24 | 9.80 |

Table 13 P values of analysis of variance for sensory attributes of plum pastes made from pilot plant puree on sensory evaluation

| Source | Sensory Attributes | | | | | |
|---|---|---|---|---|---|---|
| | Color | Acidity | Sweetness | Consistency | Flavor | Overall acceptance |
| A[1] | 0.0001 | 0.4071 | 0.9784 | 0.0001 | 0.4564 | 0.2097 |
| B[2] | 0.0001 | 0.0001 | 0.0001 | 0.0497 | 0.2679 | 0.0001 |
| AxB | 0.0887 | 0.2147 | 0.9849 | 0.3332 | 0.2553 | 0.9652 |

A Heat concentration
B Sugar addition

was darker than 25°Brix paste. Sugar addition also darkened the pastes, with higher difference of score (2.44) on 25°Brix paste than 30°Brix paste (1.49).

Acidity Acidity was significantly affected by the addition of sugar ($P<0.01$), but not by heat concentration. Taste panel scores indicating the decrease in intensity of acidity due to sugar addition was 4.22 for 25°Brix paste and 5.12 for 30°Brix paste.

Sweetness Similar results were shown by panelists for acidity and sweetness. Sugar addition decreased acidity rating and increased sweet perception of pastes, by score of 4.42 and 4.42 for 25 and 30°Brix pastes, respectively. This may due to the increased Brix/acid ratio of plum pastes by sugar addition. The addition of sugar increased Brix/acid ratio from 13.08 to 24.40 and from 13.31 to 24.47 for 25 and 30°Brix pastes, respectively.

Consistency Heat concentration showed a significant effect ($P<0.01$) on consistency as compared to that of sugar addition ($P=0.0497$). Consistency score was higher for 30°Brix paste (10.34) than for 25°Brix paste (7.98). Sugar addition gave only a slight increase in consistency ratings of plum pastes.

Flavor Both heat concentration and sugar addition showed little influence on flavor of plum pastes. The average score of 8.96 for all plum pastes indicated that panelists considered plum pastes to be characterized by a relatively strong plum flavor.

Overall acceptance Only sugar addition showed significant influence on overall acceptance ($P<0.01$). The sweetened 25°Brix paste had the highest score (10.24) of overall acceptance, while unsweetened 25°Brix paste had a score of 5.98 only. Sugar addition also elevated the score of overall acceptance from 5.58 for unsweetened 30°Brix

paste to 9.80 when sweetener added. The increase in mean score by an average of 4.24 due to sugar addition indicated that people accepted sweetened plum pastes better than the unsweetened counterpart. These results agree with Chang (1993) who reported that the higher the sweetness the higher acceptability of plum juices.

Panelists commented that unsweetened plum pastes were too sour to accept. The correlation coefficient between overall acceptance and other sensory attributes (Table 14) confirmed this concept. For unsweetened pastes, the overall acceptance was significantly ($P<0.01$), negatively correlated to acidity and positively correlated to sweetness. But for sweetened plum pastes, people graded the overall acceptance based on not only sourness and sweetness but also on flavor, color, and thickness, in order of significance. Flavor intensity was correlated to overall acceptance of sweetened 25°Brix paste by $r=0.439$ ($P<0.01$) and sweetened 30°Brix paste by $r=0.682$ ($P<0.01$). Color had significant correlation ($P<0.01$) with overall acceptance for both sweetened plum pastes. Thickness was significantly correlated ($P<0.05$) to overall acceptance of sweetened 25°Brix paste.

The results indicated that plum pastes could be characterized by acidity, sweetness, thickness sensations, but the preference could be adequately predicted by flavor and color under suitable brix/acid ratio.

Table 14 Correlation coefficients of overall acceptance with color, acidity, sweetness, consistency, and flavor of pastes made from pilot plant puree on sensory evaluation

| Treatment/ Sensory attributes | Heat concentration 25°Brix | Heat concentration 30°Brix | Sugar addition 25°Brix to 40°Brix | Sugar addition 30°Brix to 45°Brix |
|---|---|---|---|---|
| Color | -0.058 | -0.056 | 0.326** | 0.335** |
| Acidity | -0.347** | -0.482** | -0.393** | -0.091 |
| Sweetness | 0.508** | 0.435** | 0.447** | 0.349** |
| Consistency | 0.106 | -0.078 | 0.293* | 0.245 |
| Flavor | 0.090 | 0.105 | 0.439** | 0.682** |

* Significance at 5% level
** Significance at 1% level

## II. Storage Effect

Soluble Solids and Total Solids

The measurement of solid content is fundamental for examining the quality of fruit pastes during storage (Goose, 1964). No substantial changes were detected in soluble solids or total solids of plum pastes during storage (Figure 12 and 13). Changes in composition during storage which result in variation of soluble solids and total solids have been reported by Kanujoso and Luh (1967) and O'Brien (1989). However, no significant differences in soluble solids and total solids of plum pastes were found in this study.

Moisture Content and Water Activity (aw)

Moisture content and aw of plum pastes were not significantly influenced by storage temperature and time, as shown in Figure 14 and 15. Like solid content, the changes in moisture content and aw may be related to composition variation. Canellas et al. (1993) postulated that water released in Maillard browning reactions under acidic conditions and the crystallization of sugar is highly responsible for an increase in water activity of food products during storage. However, water is needed in degrading reactions of pectin, ACYs, and other components (Markakis, 1982; Kertesz, 1951). Changes in aw of fruit paste packaged in polypropylene film and stored at different RH environment was also reported (Exama and Lacroix, 1989b).

pH

Storage time showed significant influence on pH of plum pastes ($P<0.05$), while no significant effect by storage temperature was

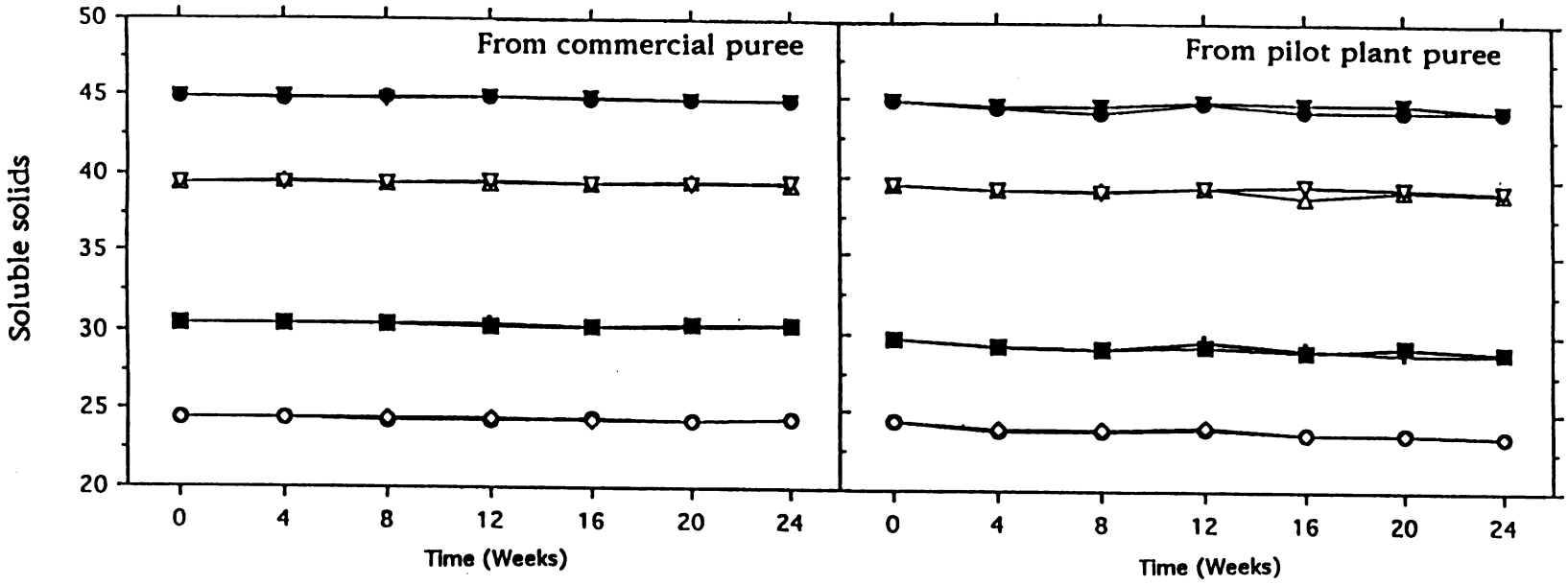



Figure 12 Effect of storage time and temperature on soluble solids of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

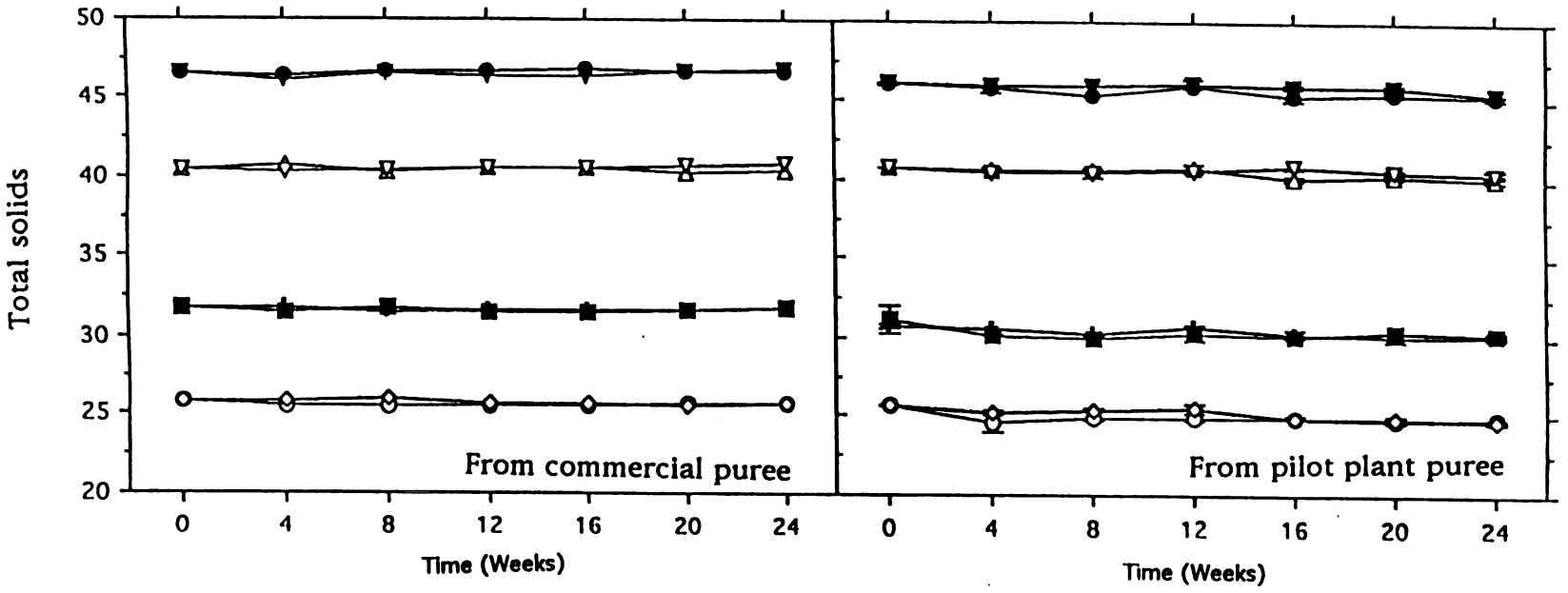



Figure 13 Effect of storage time and temperature on total solids of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

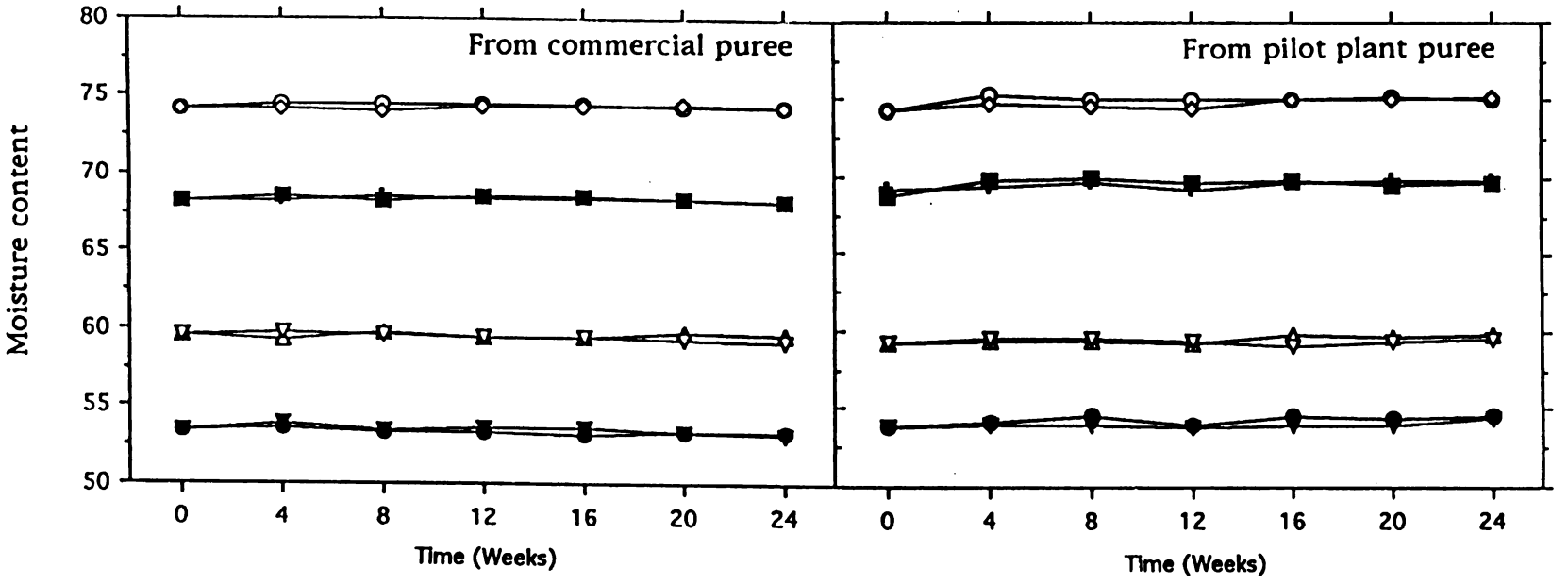



Figure 14 Effect of storage time and temperature on moisture content of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

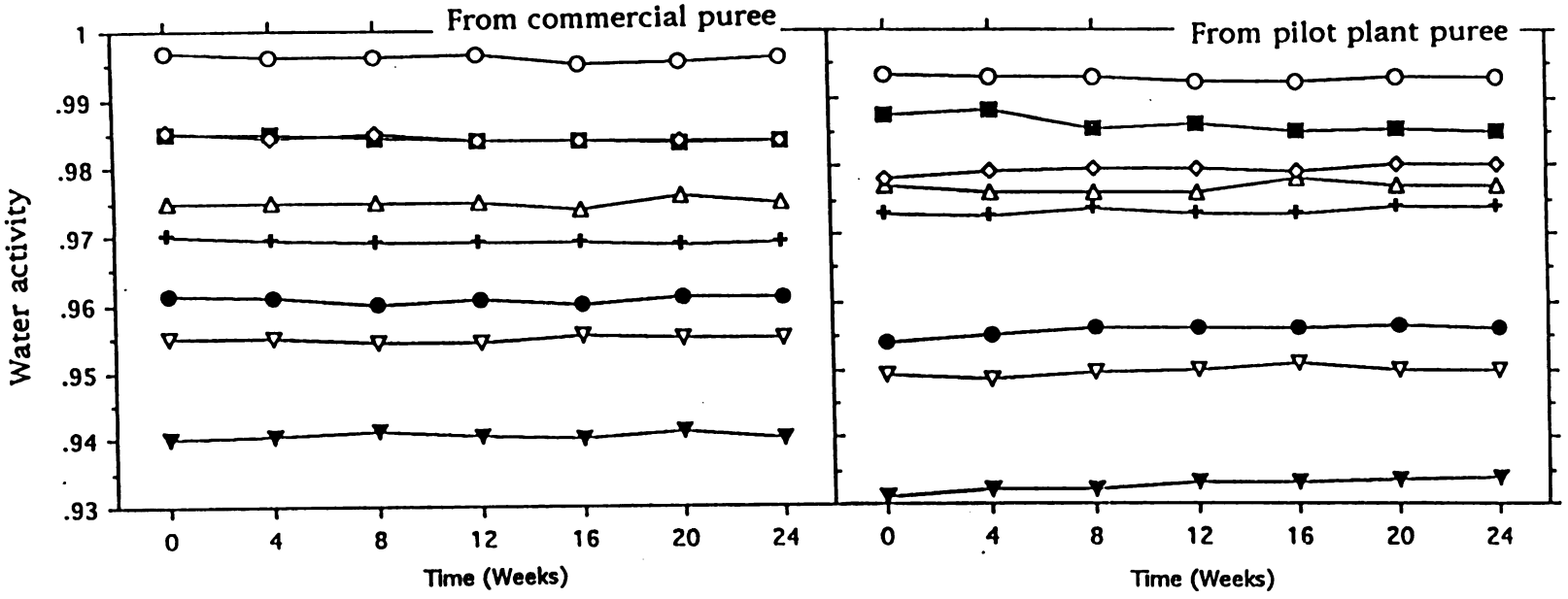



Figure 15 Effect of storage time and temperature on water activity of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- ○ 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

observed. Variations in pH of plum pastes during storage are shown in Figure 16. pH was stable in all samples during the first weeks of storage, then increased for most plum pastes at the end of storage, except the sweetened 25°Brix plum paste made from pilot plant puree. An increase in pH of 0.05 was observed for pastes made from both commercial puree (3.50 to 3.55) and from pilot plant puree (3.45 to 3.50). However, the effect of type of puree, heat concentration, and sugar addition on pH of plum pastes were not significant.

Titratable Acidity (TA)

Significant decrease ($P<0.05$) as a function of storage time in TA was observed, as shown in Figure 17. However, no significant difference was found between samples stored at different temperatures. No processing parameters (i.e. type of puree, concentration, and sugar addition) showed effect on the stability of TA.

Correlation coefficients between pH and titratable acidity as well as total pectin are listed in table 15. The decrease in titratable acidity and total pectin (mainly water-soluble) of plum pastes was significantly related to the increases in pH. Similar relation was observed by Kanujoso and Luh (1967) who found the increase in acidity was accompanied by a decrease in pH and an increase in water-soluble pectin. Rommel et al. (1992 and 1990) also concluded that titratable acidity and pectin content showed similar trends and a pattern of change opposite to pH in fruit juice and wine.

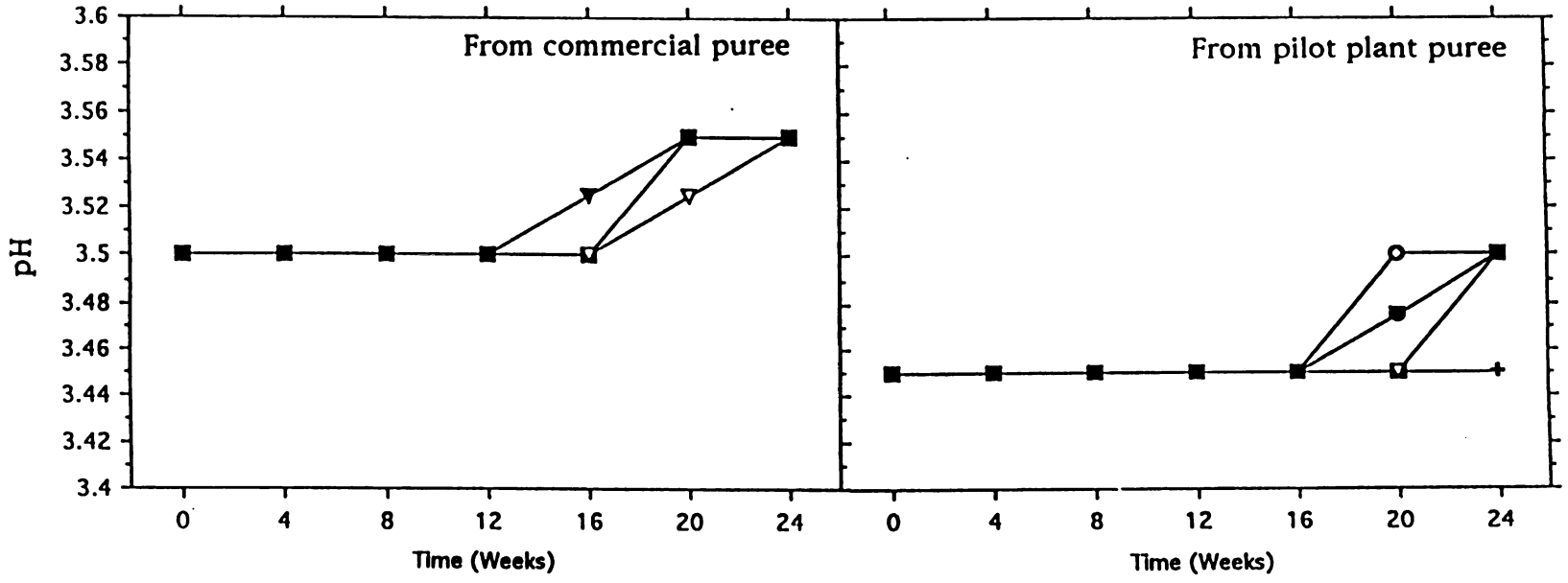



Figure 16 Effect of storage time and temperature on pH of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- \+ 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

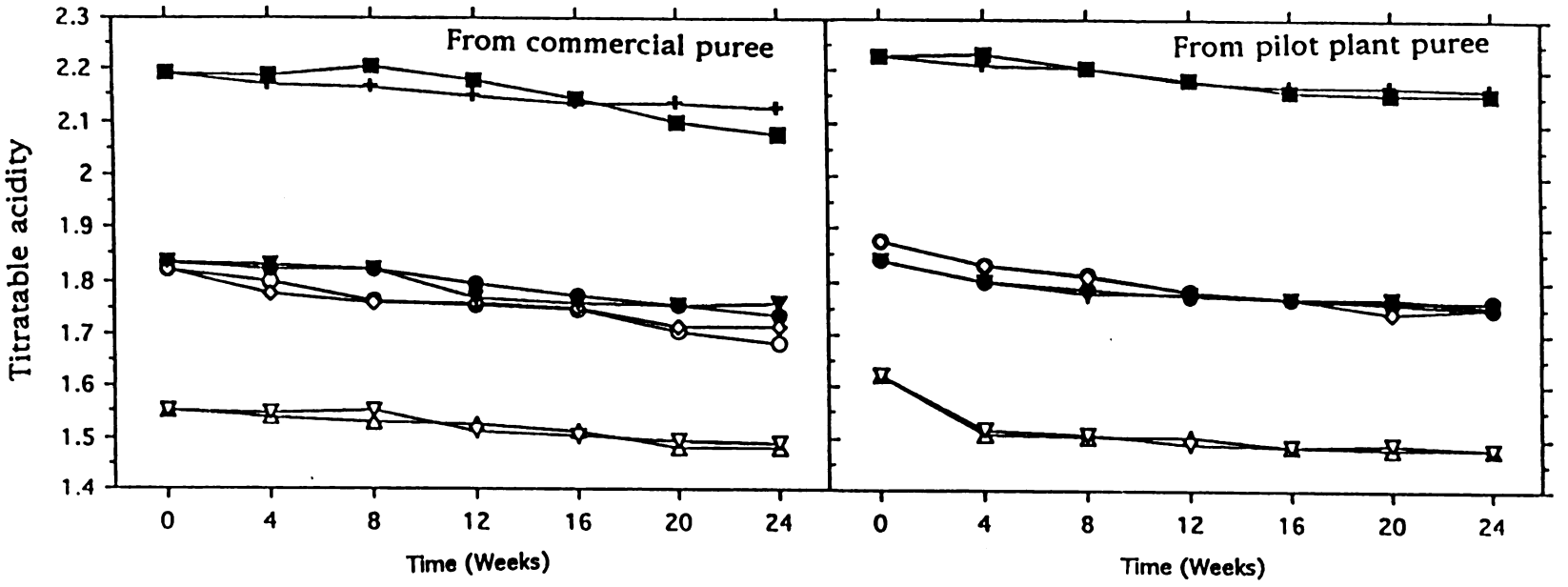



Figure 17 Effect of storage time and temperature on titratable acidity of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- ○ 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

Table 15 Correlation coefficients of titratable acidity, total pectin and pH of plum pastes made from commercial puree and from pilot plant puree

| Characteristics | From commercial puree | | | | From pilot plant puree | | | |
|---|---|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix |
| pH-TA[1] | -0.78** | -0.75** | -0.76** | -0.74** | -0.65** | -0.27 | -0.32 | -0.46* |
| pH-TP[2] | -0.91** | -0.61** | -0.52** | -0.72** | -0.53** | -0.44* | -0.23 | -0.44* |
| TA-TP | 0.83** | 0.92** | 0.67** | 0.90** | 0.88** | 0.81** | 0.96** | 0.41* |

1 Titratable acidity
2 Total pectin
* Significance at 5% level
** Significance at 1% level

Hunter 'L' Value

Figure 18 shows changes in Hunter 'L' (lightness index) values of plum pastes during storage. For pastes from commercial puree stored at 22°C, increase in Hunter 'L' values ranged from 0.99 to 1.68. Changes in Hunter 'L' values ranged from 0.09 to -0.09 at the end of storage was deteced in samples from commercial puree stored at 4°C. However, the Hunter 'L' values of samples from pilot plant puree kept decreasing during the 24 weeks of storage, with higher rate of change for samples stored at 4°C. Canellas et al. (1993) observed no browning during the first 3 months of storage in fruit and vegetable products. They indicated that after 3 months of storage, the browning began. This is similar to the results from pastes made from commercial puree. Increasing browning as a function of storage time, especially over a long time, was observed in raisin (Canellas et al., 1993), citrus fruit products (Handwerk and Coleman, 1988) and carrot (Baloch et al., 1973), which was confirmed in this study, too.

Hunter 'L' values increased with degradation of T ACYs and decreased with browning or polymerization reactions (Rommel, 1992). For plum pastes made from commercial puree, high negative correlation of Hunter 'L' with T ACYs (Table 17) and Hunter 'a' values (Table 16) indicated that lightness in color was related to degradation of T ACYs. Negative correlation of Hunter 'L' values and chroma (Table 16) indicated polymerization reactions occurred during storage, however, the extent of browning was less than degradation of T ACYs resulting in lightening of plum pastes. For plum pastes made from pilot plant puree, higher positive correlation of Hunter 'L' values (Table 16) with chroma than T ACYs (Table 17) and Hunter 'a' values (Table 16) implied that polymerization reactions overpowered

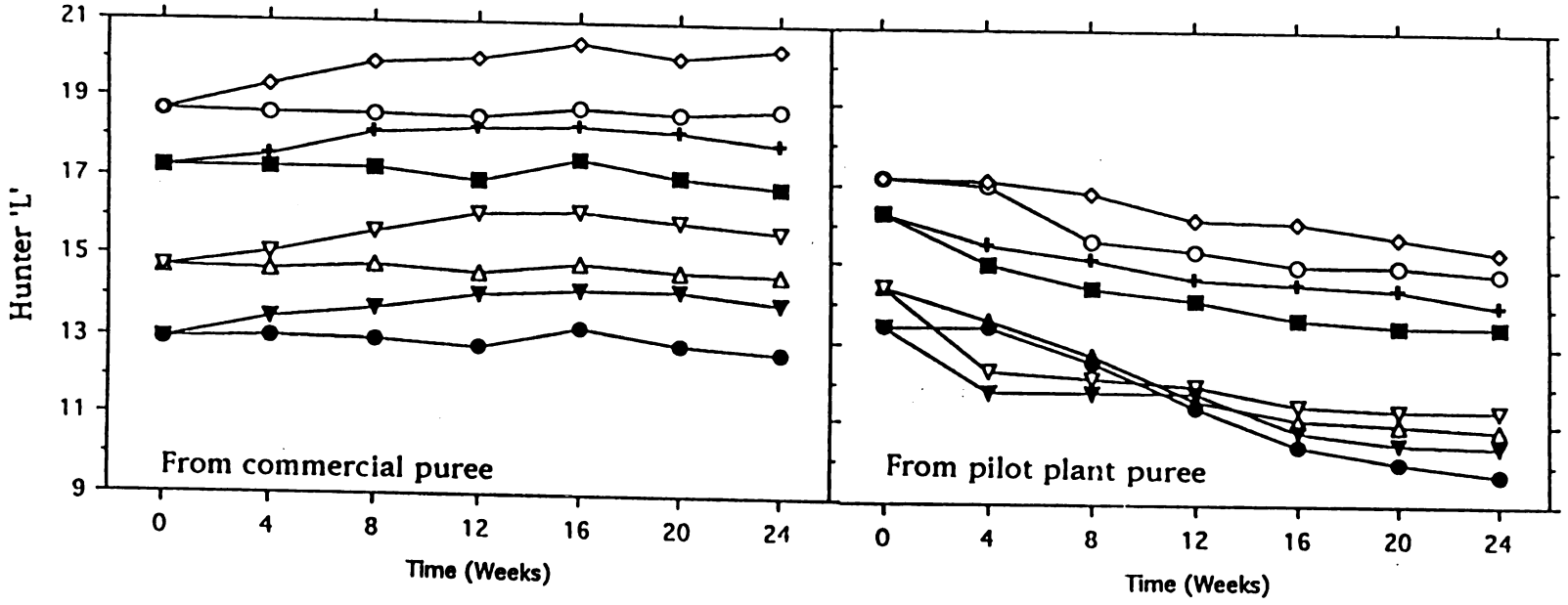



Figure 18 Effect of storage time and temperature on Hunter 'L' of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- \+ 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

Table 16 Correlation coefficients of Hunter 'L' values with other Hunter CDM values of plum pastes made from commercial puree and pilot plant puree

| Characteristics | From commercial puree | | | | From pilot plant puree | | | |
|---|---|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix |
| Hunter 'a' | -0.86** | -0.73** | -0.61** | -0.76** | 0.49** | 0.78** | 0.66** | 0.83** |
| Hunter 'b' | 0.98** | 0.94** | 0.84** | 0.85** | -0.62** | -0.85** | -0.51** | -0.91** |
| Hue angle | 0.93** | 0.84** | 0.71** | 0.81** | -0.50** | -0.81** | -0.56** | -0.88** |
| Chroma | -0.71** | -0.53** | -0.34 | -0.67** | 0.47** | 0.76** | 0.69** | 0.80** |

* Significance at 5% level
** Significance at 1% level

Table 17 Correlation coefficients between Hunter CDM values and total anthocyanins of plum pastes made from commercial puree and from pilot plant puree

| Characteristics | From commercial puree | | | | From pilot plant puree | | | |
|---|---|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix |
| Hunter 'L' | -1.00** | -0.92** | -0.83** | -0.83** | 0.27 | 0.60** | 0.28 | 0.60** |
| Hunter 'a' | 0.96** | 0.92** | 0.93** | 0.97** | 0.94** | 0.93** | 0.88** | 0.89** |
| Hunter 'b' | -0.98** | -0.98** | -0.97** | -0.98** | -0.55** | -0.51** | -0.91** | -0.70** |
| Hue angle | -0.99** | -0.98** | -0.97** | -0.98** | -0.94* | -0.88** | -0.93** | -0.84** |
| Chroma | 0.84** | 0.78** | 0.75** | 0.93** | 0.94** | 0.94** | 0.90** | 0.92** |

* Significance at 5% level
** Significance at 1% level

degradation of T ACYs. We could assume that the browning effect observed was mainly nonenzymatic since no PPO activity was detected in any of the samples at the beginning of storage. The number of potential condensation reactions which could contribute to pigment polymerization and then browning are numerous: ACY copigmentation, ACY-phenolic condensation, Maillard reaction and ascorbic acid degradation all are possible (O'Brien, 1989; Makakis, 1982).

Wrolstad et al. (1990) indicated that sugar has protective effect on color retention during storage. The positive influence of sucrose could be steric, with sucrose serving as a diluent, interfering with condensation reactions. However, no significant protective effect of sugar was found in this study.

Hunter 'a' Value

Figure 19 shows the effect of storage conditions on Hunter 'a' values, which represent redness. As storage time increased, the Hunter 'a' values of plum pastes decreased, which means a reduction in redness. The rate of change significantly increased ($P<0.05$) with storage temperature, which is similar to change pattern of T ACYs. These results indicated that as expected low temperature storage was better for color retention of plum pastes. However, sugar addition did not show obvious protective effect on the Hunter 'a' values of plum pastes.

Hunter 'b' Value

The effects of storage time and temperature on Hunter 'b' (yellowness index) values of plum pastes are shown in Figure 20. The

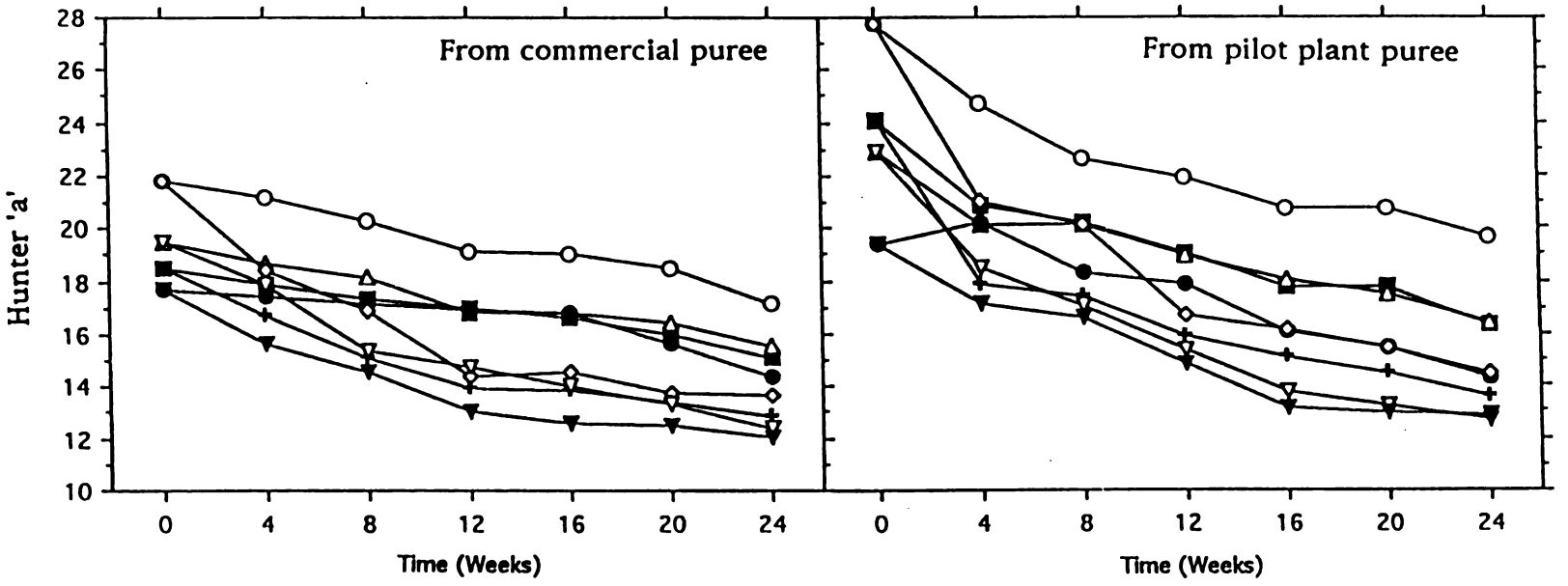



Figure 19 Effect of storage time and temperature on Hunter 'a' of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- ○ 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

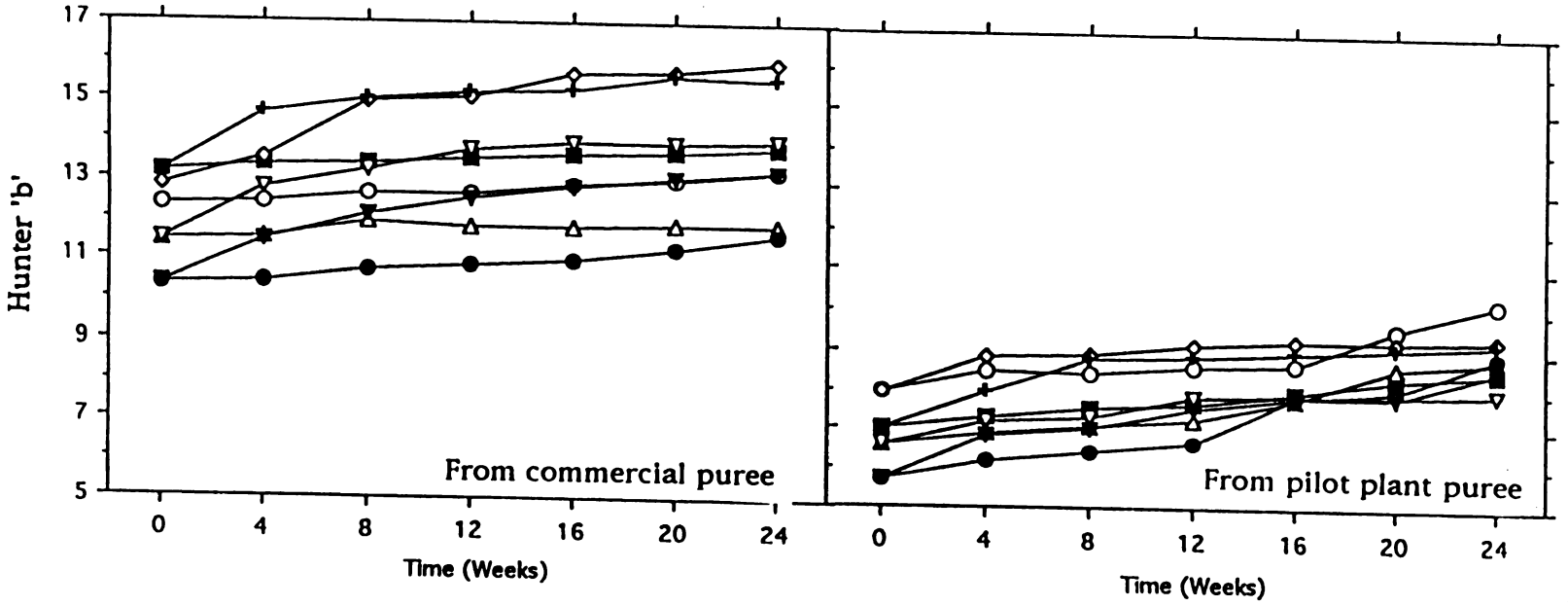



Figure 20 Effect of storage time and temperature on Hunter 'b' of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- ○ 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

Hunter 'b' values of all plum pastes kept increasing during storage time. The retarding effect of storage temperature was significant ($P<0.05$) on plum pastes from commercial puree, however, not on plum pastes from pilot plant puree. Neither source of pastes, concentration of pastes, or sugar addition had obvious interaction with storage time and temperature.

Hue Angle

Influence of storage time as well as temperature on hue angle of plum pastes are shown in Figure 21. As the storage time increased, the hue angle of plum pastes increased, with a significantly higher increasing rate of samples stored at 22°C ($P<0.05$). Type of purees, concentration of pastes, or sugar addition had no obvious interaction with storage time and temperature.

Chroma

All paste samples showed a similar decreasing pattern, which was significantly influenced ($P<0.05$) by source of pastes, storage temperature and time (Figure 22) , with higher decreasing rate for samples from pilot plant puree. Rommel et al. (1992) reported that chroma decreased with increasing percentage of polymeric color and browning, which was confirmed by high positive relation between Hunter 'L' values and chroma (Table 16) of pastes made from pilot plant puree.

Total Anthocyanins (T ACYs)

Figure 23 shows the changes in T ACYs of plum pastes due to storage conditions. The results indicated that room temperature

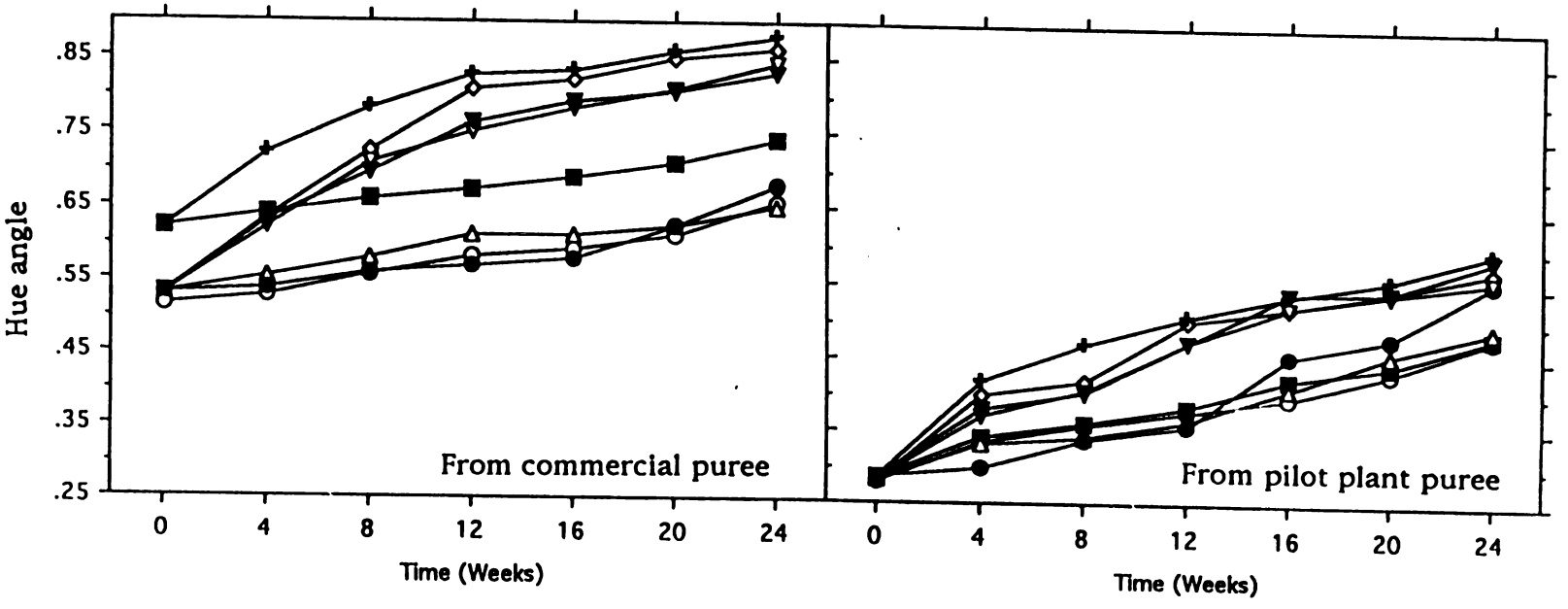



Figure 21 Effect of storage time and temperature on hue angle of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

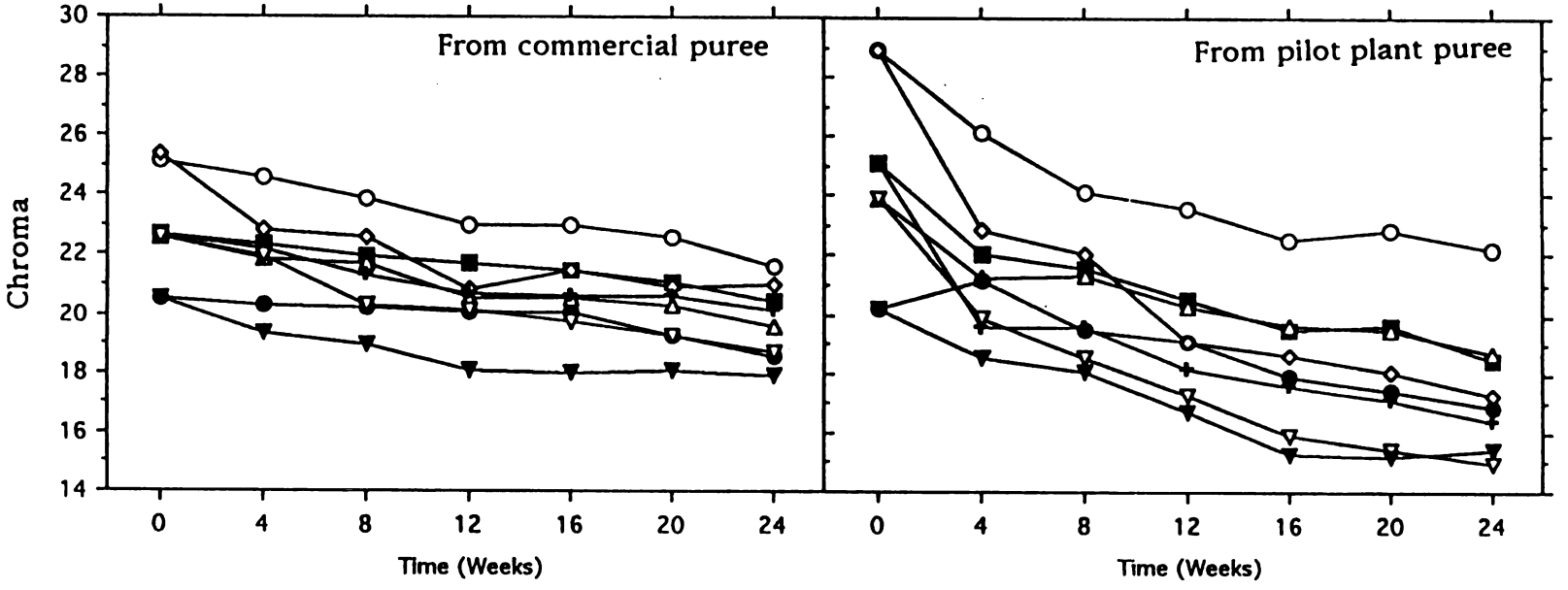



Figure 22 Effect of storage time and temperature on chroma of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- ○ 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

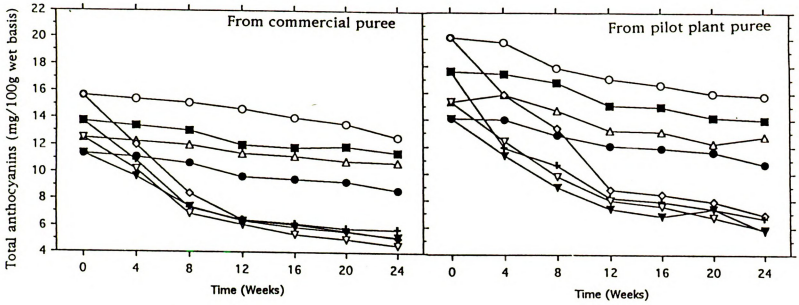



Figure 23 Effect of storage time and temperature on total anthocyanins of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- \+ 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

storage had a tremendous influence ($P<0.01$) on T ACYs. During the first 12-week storage period, all plum pastes stored at 22°C showed much higher decreasing rate of T ACYs ($P<0.01$). Then the rate slowed down to the rate similar to that of plum pastes stored at 4°C. Similar results for higher retention of T ACYs in samples stored at refrigerated temperature than those stored at nonrefrigerated temperature were also observed in blackberry juice and wine (Rommel et al., 1992), in raspberry juice and wine (Rommel et al., 1990), and in grape pigments (Palamidis and Markakis, 1975). Protective effect of sugar on ACY pigment of strawberries during storage as reported by Wrolstad et al. (1990) was not significant in this study.

Table 17 shows the correlation coefficients between T ACYs and Hunter CDM values. High positive correlations of both Hunter 'a' values and hue angle with T ACYs confirmed that ACY pigments are the major color source of plums (Timberlake and Bridle, 1982) and appear as red in acidic medium (like plum paste) (Brouillard, 1982). ACY pigments may be degraded to colorless components or may undergo polymerization (Markakis, 1982). Negative correlation of Hunter 'L' and Hunter 'b' values and T ACYs implied degradation of ACY pigments to colorless components. High positive correlation of T ACYs with chroma indicated that loss of T ACYs also contributed to polymerization.

Pectin Content

Figure 24 shows the changes in total pectin during storage. The changes in total pectin were significantly influenced ($P<0.05$) by storage time and type of purees, but not by temperature, sugar or concentration. Plum pastes from pilot plant puree showed higher

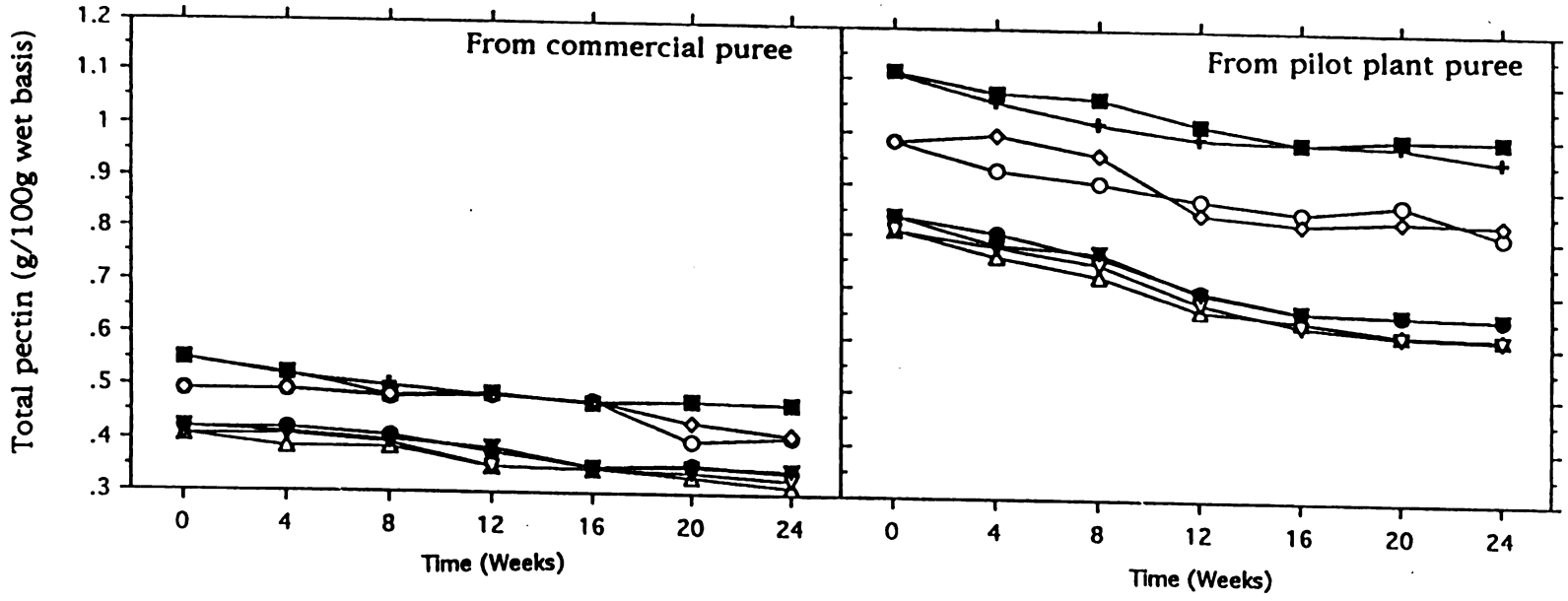



Figure 24 Effect of storage time and temperature on total pectin of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- \+ 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

degradation rate during the first 12-week storage than those from commercial puree ($P<0.05$). After that, only slight changes in total pectin content of plum pastes were observed. Pectin degradation accompanied with texture loss during storage has been observed in a number of fruit products (Reid et al., 1986; Kanujoso and Luh, 1967). However, parallel decreasing pattern of total pectin and consistency was not observed in this study.

Rheological Properties

Storage conditions had significant effect ($P<0.05$) on apparent viscosity ($\eta_a$), consistency index (K), and flow behavior index (n) of pastes made from commercial puree (Figure 25, 26 and 27), however, the tendency of change was not constant. No significant influence of storage on rheological properties of plum pastes made from pilot plant puree was detected. Samples from pilot plant puree were better homogenized than those from commercial puree. Both particle size and air bubbles had interference with rheological parameters. Alviar and Reid (1990) reported that for high consistency samples loading is quite difficult without incorporation of air bubbles, which affect the flow behavior of fluids. However, during actual processing of pastes, the presence of air bubbles can be expected, so the K and n values that were obtained through this test may be more practical than if they had been obtained for samples which were degassified.

Microbial Analysis

Appendices III to V list the results of standard plate count, coliform count and yeast and mold count of plum pastes. During 24 weeks of storage, only 3 samples had yeast and mold contamination.

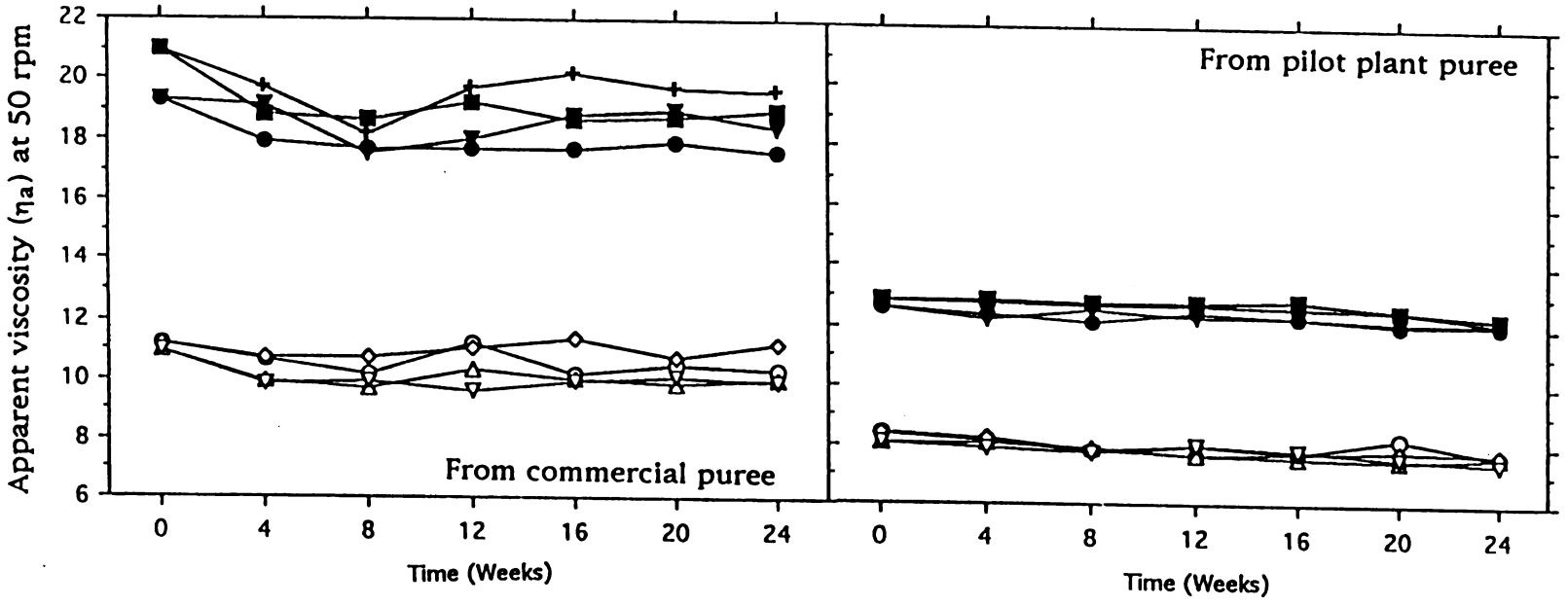



Figure 25 Effect of storage time and temperature on apparent viscosity ($\eta_a$) of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- ○ 25°Brix
- ■ 30°Brix
- △ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

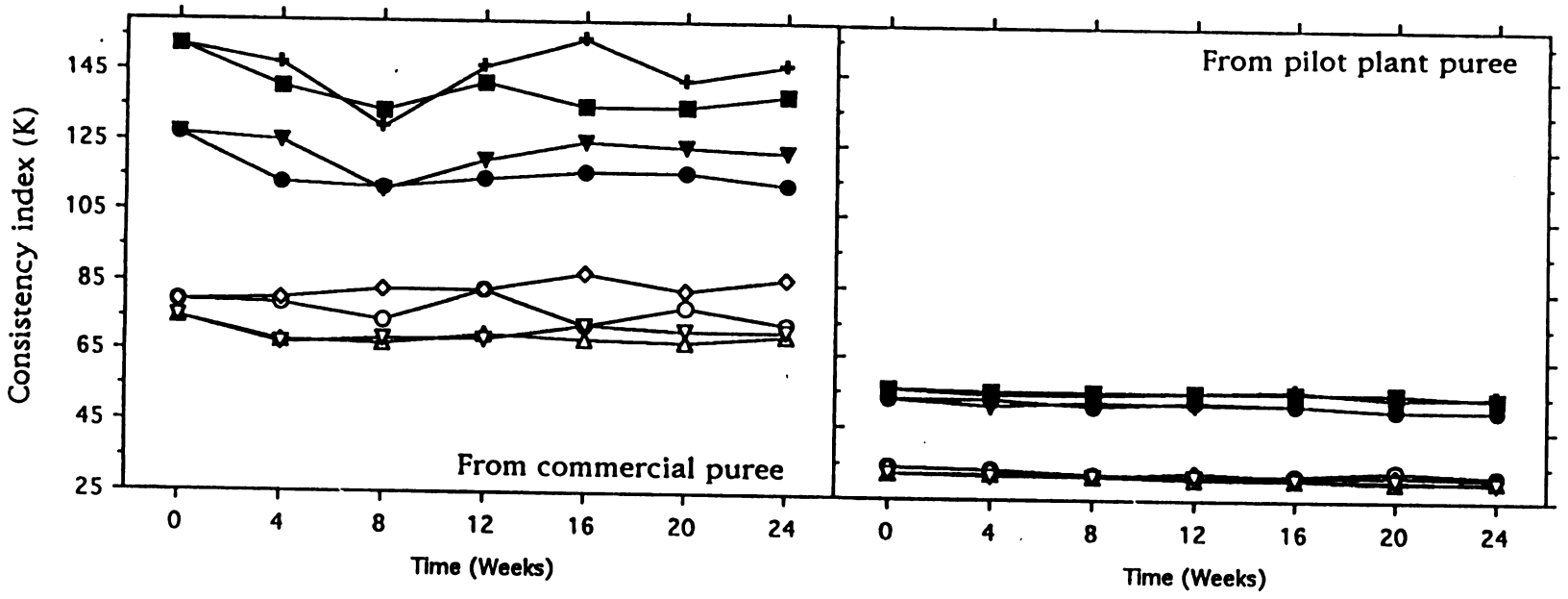



Figure 26 Effect of storage time and temperature on consistency index (K) of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

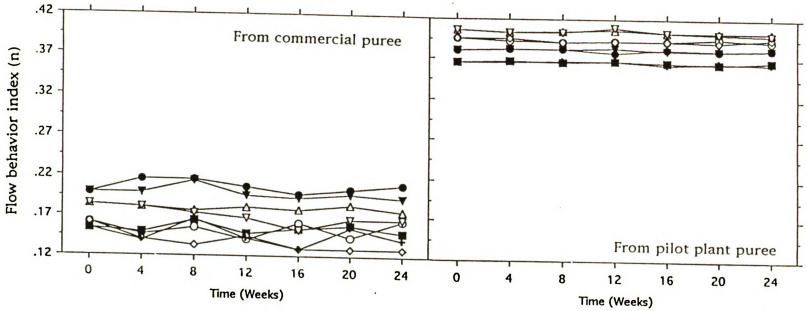



Figure 27 Effect of storage time and temperature on flow behavior index (n) of plum pastes from commercial puree and from pilot plant puree

Plum pastes stored at 4°C
- o 25°Brix
- ■ 30°Brix
- Δ 25°Brix, sugar added to 40°Brix
- ● 30°Brix, sugar added to 45°Brix

Plum pastes stored at 22°C
- ◇ 25°Brix
- + 30°Brix
- ▽ 25°Brix, sugar added to 40°Brix
- ▼ 30°Brix, sugar added to 45°Brix

This contamination may have happened during preparing samples for measurement. Since most of the plum pastes contained no live microorganisms from 0 to 24 weeks of storage, it can be assumed that they indicated that microorganisms were destroyed during processing procedure and products were not contaminated during storage.

Sensory Evaluation

Sensory tests were conducted at 0 and 24 weeks of storage. Before determining effect of storage time and temperature on sensory quality of plum pastes made from pilot plant puree, the interference of processing parameters in the effect of storage conditions were measured using 2-way analysis of variance. Table 18 shows the p values of ANOVA measuring the difference between storage times and temperatures for sensory attributes and these results indicate that the interference of concentration and sugar addition were not significant at 5% level.

The effect of storage time and temperature on sensory characteristics are shown in Table 19. Storage for 24 weeks at 4°C significantly decreased ($P<0.05$) color of unsweetened and sweetened 30°Brix pastes, acidity of pastes except 25°Brix paste, sweetness of pastes, and overall acceptance of all pastes except 25°Brix paste. Except for 25°Brix paste, thickness also increased significantly ($P<0.01$) for all pastes.

However, the results in part II of Table 19 show that most sensory characteristics were not significantly affected by 24 weeks of storage at 22°C, except for increased color and acidity of 30°Brix paste and decreased thickness of sweetened 30°Brix paste.

Table 18 P values of analysis of variance for difference in sensory attributes of pastes made from pilot plant puree between different storage conditions

| Source | Sensory Attributes | | | | | |
|---|---|---|---|---|---|---|
| | Color | Acidity | Sweetness | Consistency | Flavor | Overall acceptance |
| I | | | | | | |
| A | 0.377 | 0.731 | 0.446 | 0.522 | 0.955 | 0.288 |
| B | 0.069 | 0.100 | 0.868 | 0.898 | 0.766 | 0.934 |
| AxB | 0.076 | 0.056 | 0.427 | 0.553 | 0.441 | 0.063 |
| II | | | | | | |
| A | 0.600 | 0.620 | 0.494 | 0.356 | 0.786 | 0.548 |
| B | 0.283 | 0.092 | 0.910 | 0.690 | 0.983 | 0.479 |
| AxB | 0.592 | 0.593 | 0.787 | 0.660 | 0.335 | 0.994 |
| III | | | | | | |
| A | 0.720 | 0.897 | 0.971 | 0.789 | 0.741 | 0.658 |
| B | 0.455 | 0.101 | 0.965 | 0.794 | 0.752 | 0.514 |
| AxB | 0.242 | 0.180 | 0.628 | 0.317 | 0.832 | 0.061 |

I Difference between the beginning and the end of storage at 4°C
II Difference between the beginning and the end of storage at 22°C
III Difference at the end of storage between 4°C and 22°C storage
A Heat concentration
B Sugar addition

Table 19 Values of t-test of mean scores of difference in sensory attributes of plum pastes made from pilot plant puree on sensory evaluation between storage conditions

| Treatment/ Sensory attributes | Heat concentration 25°Brix | Heat concentration 30°Brix | Sugar addition 25°Brix to 40°Brix | Sugar addition 30°Brix to 45°Brix |
|---|---|---|---|---|
| I | | | | |
| Color | 0.244 | -5.088** | 0.339 | -2.131* |
| Acidity | 1.340 | -3.195** | 4.120** | -7.357** |
| Sweetness | -3.976** | -3.911** | -2.716** | -5.831** |
| Consistency | -1.242 | 3.717** | 2.690** | 2.783** |
| Flavor | -0.394 | -1.828 | -1.346 | -0.311 |
| Overall acceptance | -6.371** | -0.509 | -2.473* | -4.075** |
| II | | | | |
| Color | 1.222 | 3.347** | 0.142 | 0.122 |
| Acidity | 1.923 | 3.986** | 0.385 | 0.459 |
| Sweetness | -1.447 | -0.613 | -1.759 | 0.150 |
| Consistency | 0.400 | -0.569 | 0.480 | -2.248* |
| Flavor | -0.773 | 1.703 | 1.202 | 0.188 |
| Overall acceptance | 0.722 | -0.466 | -0.679 | -1.902 |
| III | | | | |
| Color | -1.283 | -1.779 | -0.435 | -2.064* |
| Acidity | -3.062** | -0.634 | -3.667** | -6.618** |
| Sweetness | -5.240** | -4.343** | -4.359** | -5.404** |
| Consistency | -1.593 | -3.064** | -3.078** | -0.531 |
| Flavor | -1.176 | -0.090 | -0.119 | -0.119 |
| Overall acceptance | 5.651** | -0.996 | -3.192** | 6.069** |

I. Difference between the beginning and the end of storage at 4°C
II. Difference between the beginning and the end of storage at 22°C
III. Difference at the end of storage between 4°C and 22°C storage
* Significance at 5% level
** Significance at 1% level

Effect of storage temperature is listed in part III of Table 19. After 24 weeks of storage, plum pastes stored at 22°C had significantly ($P<0.05$) lighter color for sweetened 30°Brix paste, lower acidity for all pastes except 30°Brix paste, lower sweetness for all pastes, and lower thickness for pastes except 25°Brix paste, as compared to pastes stored at 4°C. 25°Brix and sweetened 30°Brix pastes stored at 22°C had significantly higher overall acceptance ($P<0.01$) as compared to samples stored at 4°C. Sweetened 25°Brix paste stored at 4°C had significantly higher overall acceptance ($P<0.01$) .

In conclusion from the sensory evaluation, storage time decreased quality and overall acceptance of plum pastes, but storage temperature showed variable effect. However, those results that lower titratable acidity, lower T ACYs, darker color, and constant rheological properties determined by objective analysis were not confirmed by subjective evaluation. Less sensitive results from sensory evaluation was also observed for plum juice (Arnold, 1992) and canned tomato paste (Eckerle et al., 1984).

# SUMMARY AND CONCLUSIONS

In this study, two batches of Stanley plums (different quality) were processed to purees using similar procedure. Commercial puree was processed using substandard fruit by Cherry Central Inc. (Traverse City, MI). Pilot plant puree was processed using standard quality fruit in our pilot plant. Both purees were heat concentrated to 25°Brix and 30°Brix in our pilot plant, respectively. Sucrose was added to give a 15°Brix increase. Samples were stored at refrigerated and nonrefrigerated temperatures in the dark for up to 24 weeks.

Physical and chemical characteristics including soluble solids, total solids, moisture content, water activity, PPO activity, Hunter color values, total anthocyanins, pectin content, rheological properties and microbial content were measured. Sensory evaluation was also conducted for plum pastes from pilot plant puree.

Comparing quality of two batches of purees, pilot plant puree was significantly higher in soluble solids, titratable acidity, Hunter 'a' value, chroma, total anthocyanins, total pectin, protopectin, apparent viscosity ($\eta_a$), consistency index (K), and flow behavior index (n). However, significantly higher moisture content and hue angle were found in commercial puree. No PPO activity was detected in any of the puree samples. Only yeasts and molds were detected in pilot plant puree.

Heat concentration resulted in component degradation, such as titratable acidity, total anthocyanins and pectin content, as well as concentration of these components. On the other hand, sugar

addition showed dilution effect on compositions. Both of heat concentration and sugar addition decreased lightness of color. Rheological properties were significantly increased by heat concentration but not by sugar addition. The extent of influence of these characteristics was a function of heat processing. pH values were constant during processing procedure. Sensory evaluation indicated that plum pastes from pilot plant puree could be characterized by acidity, sweetness, and consistency sensation, but the preference could be adequately predicted by flavor and color under suitable Brix/acid ratio.

As storage time increased, concentration of titratable acidity, total anthocyanins and total pectin decreased. Among them, only higher degradation rate in total anthocyanins was found in samples stored at nonrefrigerated temperature. Decrease in consistency as a function of storage conditions was not found. Comparing color of plum pastes stored at different temperatures showed that the refrigerated samples were of higher quality than nonrefrigerated samples.

Further areas of research could be done in following areas:

1. Application of vacuum equipment to heat concentration processing to shorten time and lower heating temperature, and hence to minimize negative characteristics caused by heat, such as browning and degradation of anthocyanins and pectin.
2. Variation of pastes with other ingredients, such as protein, other fruit pastes, or different amount of sugar addition.
3. Utilization of substandard fruit to make acceptable product using blends of higher quality fruit.

4. Development of the application of plum pastes in other products, such as candy fillings, reconstituted juice, ingredients in bakery, etc.
5. Investigation of the contribution of components to consistency of pastes.
6. Study of changes in anthocyanin composition during processing and storage and its relationship to Hunter color values. Once the relation is set up, the anthocyanin stability may be monitored by Hunter color values, an easier measurement.

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# BIBLIOGRAPHY


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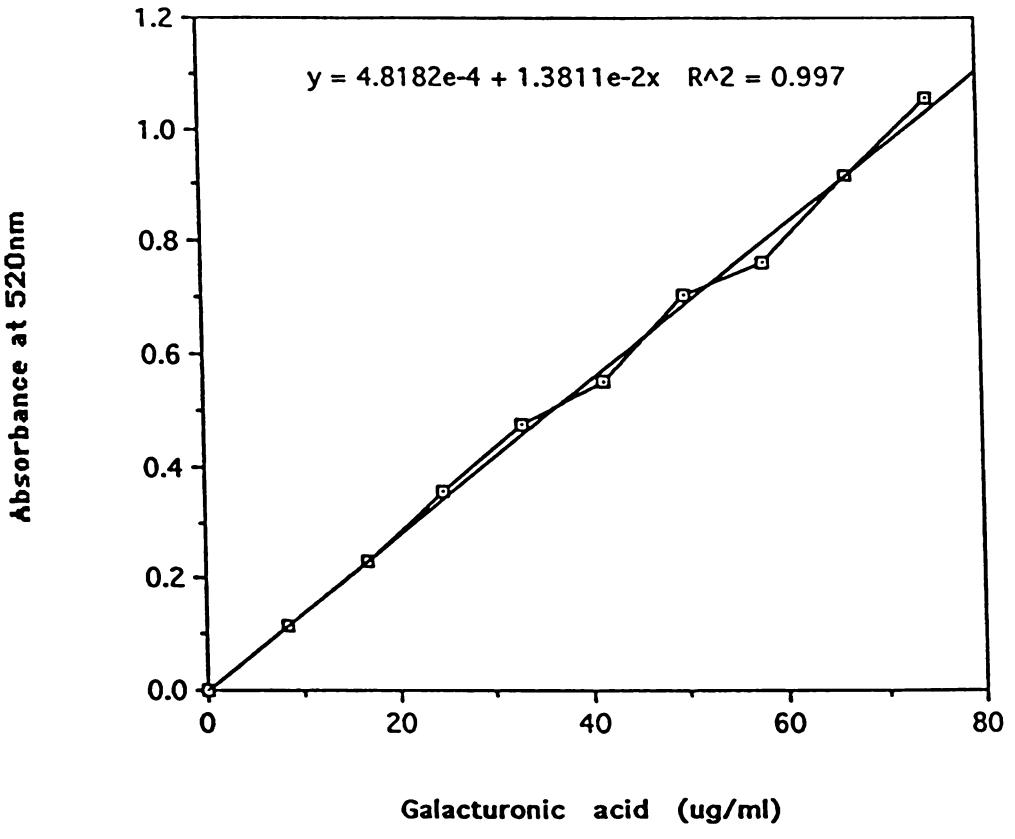
# APPENDICES

Appendix I Standard curve of galacturonic acid



Appendix II Questionnair for sensory evaluation

SENSORY EVALUATION OF PLUM PASTE

Name : _____ Date : _____Product : Plum Paste

Direction :

1. Listed below are 6 descriptors. Please scale the first 5 descriptors for intensity only, not your liking or disliking.
2. Before tasting the samples and between each sample, rinse your mouth with water. You may also use the crackers to remove the flavor from your mouth at any time.
3. Taste the samples in the order listed on your questionnaire. You may either swallow or spit out the samples.
4. Indicate your rating on this ballot by placing a Cross on the horizontal line scale ( e.g. ___X___ ). The anchor point is located at center of each line.

Sample code : _____

**Color :**

light — dark

**Acidity :**

slightly acid — extremely acid

**Sweetness :**

slightly sweet — extremely sweet

**Consistency:**

very thin — very thick

**Flavor :**

slight — strong

**Overall acceptance :**

unacceptable — very acceptable

**Comments :**

Appendix III Standard plate count of plum pastes from commercial puree and from pilot plant puree during storage period

| Storage time (Weeks) | From commercial puree | | | | From pilot plant puree | | | |
|---|---|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix |
| 4°C storage | | | | | | | | |
| 0 | 0[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22°C storage | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Unit is CFU/g sample

Appendix IV Coliform count of plum pastes from commercial puree and from pilot plant puree during storage period

| Storage time (Weeks) | From commercial puree | | | | From pilot plant puree | | | |
|---|---|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix |
| 4°C storage | | | | | | | | |
| 0 | 0[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22°C storage | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Unit is CFU/g sample

Appendix V Yeast and mold count of plum pastes from commercial puree and from pilot plant puree during storage preriod

| Storage time (Weeks) | From commercial puree | | | | From pilot plant puree | | | |
|---|---|---|---|---|---|---|---|---|
| | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix | 25°Brix | 30°Brix | 25°Brix sugar added to 40°Brix | 30°Brix sugar added to 45°Brix |
| 4°C storage | | | | | | | | |
| 0 | 0[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22°C storage | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 20 | 0 | 20 | 0 |
| 8 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Unit is CFU/g