AN ABSTRACT OF THE THESIS OF

David S. Lundahl for the degree of Doctor of Philosophy in Food Science and Technology presented on January 27, 1989.

Title: Interrelationships Among Changes in Aroma and Flavor, and Composition of Stored Strawberry Juice Concentrate

Abstract approved: _____

Dr. Mina McDaniel

Sensory evaluation and instrumental methods were applied to the evaluation of strawberry juice concentrate (68°Brix) stored at 20°C which had been produced both commercially (C-SJC) and in a pilot plant (SJC). Sensory evaluation included taste and aroma ratings by intensity scaling and time-intensity of taste, and visual colorimetry by matching Munsell color chips. Instrumental analyses included tristimulus colorimetry (i.e. Hunter colorimeter), spectrophotometric colorimetry for pigment analyses, titrametric analyses for acidity (pH and titratable acidity) and free α-amino acids (formol number), and headspace gas analyses for CO_2 and O_2.

During six days storage of C-SJC, a decrease in concentration of anthocyanins and increase in polyphenolics (tannin) was associated with an increase in astringency. Free α-amino acids were observed to decrease, while CO_2 was released. These changes were associated with an increase in musty/moldy and pungent aromas. Free sugars and titratable acidity did not change.

The pilot plant SJC was processed from blanched and unblanched fruit to evaluate the relative importance of oxidase activity (i.e. polyphenoloxidase) prior to pasteurization. The blanching treatment increased the astringency and sourness in unstored SJC. These affects were associated with an increase in concentration of polyphenolics (tannin). During storage, the blanch treatment decreased the rate of anthocyanin loss and decreased the release rate of CO_2, yet degradation rates were still high. The O_2 concentration in headspace did not change significantly during storage indicating that polyphenoloxidase (PPO) activity during storage was low. The musty/moldy and pungent aromas increased similarly to C-SJC.

A chemical mechanism accounting for these changes is proposed where products from the oxidative degradation of ascorbic acid contribute directly or indirectly to the degradation of anthocyanins to yield browning. Further, high initial concentrations and subsequent decreases during C-SJC storage of free α-amino acids indicate that Strecker degradation is a participating mechanism. Associations of browning with the development of off-flavors suggest this chemical mechanism forms odor-active volatile compounds.

Interrelationships Among Changes in Flavor and Aroma, and Composition of Stored Strawberry Juice Concentrate

by

David S. Lundahl

A THESIS

submitted to

Oregon State University

in partial fulfillment of

the requirements for

the degree of

Doctor of Philosophy

Completed January 27, 1989

Commencement June, 1989

APPROVED:

Professor of Food Science and Technology in charge of major

Head of Department of Food Science and Technology

Dean of Graduate School

Date thesis presented January 27, 1989

Typed by the author David S. Lundahl

ACKNOWLEDGEMENTS

I express my sincere gratitude to the two individuals most responsible for my academic growth: my major professor, Dr. Mina McDaniel, and my minor professor and advisor for my M.S. program in Statistics, Dr. Lyle Calvin. Through their guidance, I have learned to apply scientific thought to problem solving in a complicated, yet intriguing world.

I thank my committee members, Dr. Ron Wrolstad, Dr. Mike Penner and Dr. Larry Curtis for their advice and diligent work during the various stages of my Ph.D. program.

For their support and friendship, I thank the faculty, staff and graduate students at the OSU Department of Food Science and Technology, especially Siti Omar and Andy Wuehler who assisted in the collection of data and the sensory group who provided positive critique of my research.

I thank the many individuals who participated on my sensory panels.

I thank my family for their support and encouragement during my years of physical, mental and spiritual growth.

Finally, but not least, I thank my wife, Michelle, for her many gifts to me: her love, support and fortitude during my Ph.D. program.

Contribution of Authors

Dr. Mina McDaniel contributed to this text by serving as my major advisor. Dr. Ronald Wrolstad was a key Ph. D. committee member and contributed laboratory space and materials for some analytical research. Dr. McDaniel and Dr. Wrolstad provided both insight and direction in matters pertaining to sensory evaluation and food chemistry, respectively. Therefore, both names appear as co-authors in the body of this Dissertation.

Table of Contents

	Page
INTRODUCTION	1
LITERATURE REVIEW	4
Composition of Strawberry Fruit and Juice	4
Free sugars	4
Solids	5
Acidity and Organic Acids	6
Vitamins	6
Free Amino Acids	7
Flavonoids	8
Lipids	11
Volatile Compounds	11
Compositional Changes During Juice Processing	14
Juice Extraction and Clarification	14
Heat Processing	16
Concentration	17
Theories Related to Compositional Changes	21
Stability of the Anthocyanin Pigment	21
Non-enzymatic Browning	28
Enzymatic Browning	45
Color and Color Measurement	53
Sensory Evaluation of Strawberry Juice Flavor	59
Intensity and Time-intensity Evaluation	59
Taste Evaluation	63
Aroma Evaluation	66
FLAVOR, AROMA AND COMPOSITIONAL CHANGES IN STRAWBERRY JUICE STORED AT 20°C	69
Abstract	70
Introduction	71
Materials and Methods	73
Concentrate Processing	73
Storage Treatments	73
Sensory Evaluations	74
Colorimetric Determinations	78
Compositional Analyses	78
Results	80
Sensory Evaluations	80
Colorimetric Analyses	83
Other Compositional Changes	83
Discussion	85
References Cited	91
Acknowledgment	96

Table of Contents (continued)

	Page
CHANGES IN FLAVOR, COLOR, AND COMPOSITION DURING PROCESSING AND STORAGE OF CONCENTRATE FROM BLANCHED STRAWBERRIES	97
Abstract	98
Introduction	99
Experimental	101
Processing and Storage Treatments	101
Sensory Evaluation	104
Colorimetric and Pigment Determinations	109
Compositional Analyses	111
Results	113
Color Determinations	113
Aroma and Taste Determinations	114
Compositional Changes	129
Discussion	135
Comparisons to Commercially Produced Concentrate	135
Processing Effects on SJC Degradation	138
Major Findings	141
Conclusions	143
References Cited	144
BIBLIOGRAPHY	152
APPENDIX	170

List of Figures

Figure	Description	Pages
1.1	Major flavonoid compounds occurring in strawberry fruit and products	9
1.2	Equilibrium between four anthocyanins in aqueous solution	23
1.3	Oxidation of anthocyanins by a Baeyer-Villiger reaction to form the o-benzoylphenylacetic acid ester product	26
1.4	Destabilization of the anthocyanin by loss of the sugar moity and spontaneous degradation to a ketone of the pseudobase carbinol aglycone	27
1.5	Addition reaction of sulfite to the C2 position of anthocyanins	29
1.6	Mechanism for the indirect and direct roles of ascorbic acid on the degradation of anthocyanins	32
1.7	Schematic diagram of ascorbic acid degradation pathways	36
1.8	Polymerization reaction by electrophilic substitution involving a carbonium cation and dimeric proanthocyanin	38
1.9	Strecker degradation mechanisms involving α-dicarbonyls and dehydroascorbic acid and α-amino acids	42
1.10	Proposed condensation reactions of furfural with anthocyanidins	43
1.11	Acetaldehyde reaction with catechin and anthocyanin by a Baeyer-type condensation mechanism	46
1.12	Oxidation mechanism catalyzed by polyphenoloxidase of o-quinones to mono and o-dihydroxyphenols	49
2.1	Scheme for presentation of samples to panelists for aroma and taste difference evaluations	76
2.2	Change in aroma and taste attributes during storage of strawberry juice concentrate	82
2.3	Percent CO_2 released into a 25 mL N_2 filled headspace during storage of 10g of strawberry juice concentrate	87

List of Figures (continued)

Figure	Description	Pages
3.1	Schematic diagram of the processing steps used for the production of single strength and full strength concentrate from strawberries and storage conditions of the concentrate	103
3.2	Parameters from the curve of the instantaneous perceived intensity over time (time-intensity)	110
3.3	Sensory panel ratings of strawberry juice concentrate using Munsell color chips	115
3.4	Hunter "L" and hue angle ($\tan^{-1}$b/a) readings of strawberry juice concentrate samples stored for 0, 3 and 6 days at 20°C	116
3.5	Aroma changes for significant aroma descriptors in stored strawberry juice concentrate from fruit that had been blanched (BLN) or unblanched (CON)	118
3.6	Astringent taste differences in stored strawberry juice concentrate	121
3.7	Sweet taste (Fig. A) in stored strawberry juice concentrate (SJC) for control or blanched fruit and the change in control SJC adjusted for one panelist (#8) with a different response pattern	122
3.8	Sweetness maximum intensity (I_{peak}) and time to maximum intensity (T_{peak}) for blanch or control treatment strawberry juice samples during storage	124
3.9	Sweet and sour time-intensity curves from the averaged values from sensory evaluations of stored strawberry juice samples that had or had not undergone a blanched process	125
3.10	Association between two principle components from sweet and sour time-intensity variables for strawberry juice samples from control (CON) or blanched (BLN) fruit	128
3.11	Color difference relationships between Munsell hue by sensory evaluation and browning index (A_{420}) in strawberry juice samples processed from control or blanched fruit	130
3.12	Pigment changes in stored strawberry juice concentrate by colorimetric analyses from blanched and control strawberries	131

List of Figures (continued)

Figure	Description	Pages
3.13	Differences in rates of CO_2 production in stored strawberry juice concentrate from blanched or control processed fruit.....	134

List of Tables

Table	Description	Page
2.1	Analysis of variance results for aroma and taste difference evaluations on strawberry juice reconstituted to 8°Brix after storage at 68°Brix...	81
2.2	Color and pigment changes during storage of strawberry juice concentrate.....	84
2.3	Compositional changes in free amino acids, titratable acidity, pH and carbohydrates during the storage of strawberry juice concentrate.....	86
3.1	Pairs of samples of reconstituted strawberry juice concentrate which were evaluated during then same session (designated by X) for taste and color attributes.....	108
3.2	Free sugars, acidity (pH and titratable acidity) and free amino acid concentrations in stored strawberry juice concentrate (adjusted to 8°Brix)..	133

List of Appendix Figures

Figure	Description	Pages
4.1	Diagram of the booth for evaluation of color differences	172
4.2	Ballot for the aroma and taste evaluations of strawberry juice	175
4.3	Ballot for the sensory evaluations of reconstituted stored strawberry juice concentrate samples: aroma evaluations (page 1 of 3)	176
4.4	Ballot for the sensory evaluations of reconstituted stored strawberry juice concentrate samples: taste evaluations (page 2 of 3)	177
4.5	Ballot for the sensory evaluations of reconstituted stored strawberry juice concentrate samples: color evaluations (page 3 of 3)	178
4.6	SAS® program for the reduction of each time-intensity curve to eight points: including initial time, time to peak, end of peak intensity and final time	179
4.7	SAS® program for the analysis of variance of time-intensity data	182
4.8	SAS® program for the analysis of variance for the process and storage within process effects Satterthwaite approximation	183
4.9	SAS® program for the merging and analysis of time-intensity data by principle components analysis and analysis of variance	184

List of Appendix Tables

Table	Description	Pages
4.1	Total soluble solids measured as °Brix for strawberry juice and concentrate from different batch and pre-liquefaction process treatments	170
4.2	Temperature and pressure conditions during the concentration in two passes from single strength strawberry juice to full concentrate (68°Brix)	171
4.3	Definitions of descriptors used for sensory evaluation of strawberry juice and concentrate	173
4.4	Preparation of 15-point scale reference samples for aroma evaluations	174
4.5	F-values to test for the detection of color differences by sensory evaluation in strawberry juice samples	186
4.6	Process and batch cross classification means and standard deviations for sensory evaluations of strawberry juice color differences	187
4.7	F-values for testing Hunter L-a-b indices for strawberry juice color measurements	188
4.8	Means, standard deviations and least significant difference (LSD) for Hunter L-a-b data for evaluation of batch and processing effects on strawberry juice color	189
4.9	F-values for the detection of color differences among strawberry juice concentrate samples by sensory evaluation	190
4.10	Means and standard deviations of color parameters of reconstistuted strawberry juice concentrate under different processing and storage treatments as rated by the sensory panel	191
4.11	F-values from ANOVA of color parameters for strawberry juice concentrate samples by Hunter L-a-b	192
4.12	Hunter L-a-b means and standard deviations from reconstituted strawberry juice concentrate samples after processing and storage	193
4.13	F-values for testing the aroma and taste differences among strawberry juice samples	194

List of Appendix Tables (continued)

Table	Description	Pages
4.14	Process and batch means and standard deviations from sensory evaluations of taste and aroma of strawberry juice	195
4.15	F-values for testing aroma differences among strawberry juice concentrate samples evaluated by 11 panelists	196
4.16	Means and standard deviations from the sensory evaluation of aroma from reconstituted strawberry juice concentrate after processing and storage treatments	197
4.17	Correlation coefficients for linear associations of aroma variables and principle components for strawberry juice concentrate	198
4.18	F-values for testing aroma principle components for differences among strawberry juice concentrate samples	199
4.19	Means and standard deviations of aroma principle components from reconstituted strawberry juice concentrate after processing and storage treatments	200
4.20	F-values for testing taste differences among strawberry juice concentrate samples	201
4.21	Means and standard deviations for sensory evaluation for taste of reconstituted strawberry juice concentrate after processing and storage treatments	202
4.22	F-values for testing for differences in the sweetness time-intensity perception among samples of strawberry juice concentrate	203
4.23	Means and standard deviations of time-intensity (TI) curve parameters for sweetness perception from reconstituted strawberry juice concentrate after processing and storage treatments	204
4.24	F-values for testing for differences in the sourness time-intensity perception among samples of strawberry juice concentrate	205

List of Appendix Tables (continued)

Table	Description	Pages
4.25	Means and standard deviations of time-intensity (TI) curve parameters of sourness perception from reconstituted strawberry juice concentrate after processing and storage treatments	206
4.26	Correlation coefficients for linear associations of time-intensity variables and principle components from those time-intensity variables	207
4.27	F-values for testing sweet/sour time-intensity principle component differences among strawberry juice concentrate samples	208
4.28	Means and standard deviations of time-intensity (TI) curve parameters of sweet/sour time-intensity principle components from reconstituted strawberry juice concentrate after processing and storage treatments	209
4.29	F-values for testing differences in the astringency time-intensity perception among samples of strawberry juice concentrate	210
4.30	Means and standard deviations of time-intensity (TI) curve parameters of astringency perception from reconstituted strawberry juice concentrate after processing and storage treatments	211
4.31	F-values for testing differences in the bitterness time-intensity perception among samples of strawberry juice concentrate	212
4.32	Means and standard deviations of time-intensity (TI) curve parameters of bitterness perception from reconstituted strawberry juice concentrate after processing and storage treatments	213
4.33	F-values to test for differences in anthocyanin concentration ([ACN]), browning index (BI), degradation index (DI), polymeric color (PC) and the percent contribution of polymeric color to color density (%PC:CD) among strawberry juice samples	214
4.34	Process and batch cross classification means and standard devaitions for spectrophotometric evaluations of strawberry juice color	215

4.35 F-values to test for differences in anthocyanin concentration ([ACN]), browning index (BI), degradation index (DI), polymeric color (PC) and the percent contribution of polymeric color to color density (%PC:CD) among strawberry juice concentrate samples..... 216

4.36 Means and standard deviations from spectrophotometric determinations of pigments from reconstituted strawberry juice concentrate samples after processing and storage..... 217

4.37 F-values for detection of significant differences in free sugars among strawberry juice samples..... 218

4.38 Means, standard deviations and least significant difference (LSD) for free sugar evaluation of batch and processing effects on strawberry juice color... 219

4.39 F-values for testing for differences in free sugars among strawberry juice concentrate samples..... 220

4.40 F-values for testing for differences in pH, titratable acidity (TA) or free amino acids by the formal number (FN) in strawberry juice samples..... 221

4.41 Means, standard deviations and least significant difference (LSD) for pH, titratable acidity (TA) and free α-amino acids by formal number (FN) from batch and processing effects on strawberry juice..... 222

4.42 F-values for testing differences in pH, titratable acidity (TA) and free amino acids as measured by the formal number (FN) among samples of strawberry juice concentrate..... 223

4.43 F-values for testing differences in the headspace CO_2 and O_2 gasses among samples of strawberry juice concentrate..... 224

4.44 Means and standard deviations from headspace CO_2 and O_2 gas determinations strawberry juice concentrate samples after processing and storage... 225

INTERRELATIONSHIPS AMONG CHANGES IN FLAVOR AND AROMA, AND COMPOSITION OF STORED STRAWBERRY JUICE CONCENTRATE

INTRODUCTION

According to a recent survey (Schutz, 1988), strawberries are one of the five most popular foods consumed in the United States. Therefore, strawberry flavor is of great commercial importance to the food industry. Strawberry juice (SJ) and concentrate (SJC) are commercially produced as natural flavorings and are added to a wide variety of products. SJ is often concentrated to 68°Brix as a matter of convenience and expense in transportation and storage. Preservation from microbial degradation is also increased by the concentration of solids through an increase in osmotic pressure.

It is well known that the quality of SJC is unstable upon storage at room temperature. Relative to other fruit concentrates, it undergoes more rapid color and flavor degradation. This fact has stimulated considerable research over the past 40 years. However, in spite of the extensive body of research data on this subject, the problem has yet to be fully characterized.

There are many reasons for the failure to fully characterize SJC degradation. One reason is the complexity of the system. Various enzymatic and non-enzymatic degradation pathways have been shown to contribute to storage instability, however the relative importance of these pathways is difficult to determine. The composition and

concentration of substrates and reactants affects the degradation properties as do processing and storage conditions.

A second reason is that biochemical assays and sensory evaluation methods available during the 40's through 60's differed greatly from those currently. Advancements in analytical equipment have greatly enhanced the detection and identification of compositional changes. The advancement of the micro-computer and the use of a more scientific approach to sensory research has greatly enhanced characterization and quantification of sensory attributes. Further, through statistical techniques (e.g., multivariate methods), great strides have been made in the development of methods to relate compositional change to sensory attributes.

This dissertation is an extension of ongoing research at Oregon State University into the strawberry juice degradation problem. The research goals are to investigate the interrelationships among sensory and compositional variables which could further the characterization of this degradation process. Secondly, the relative importance of enzymatic and non-enzymatic quality degradation pathways was investigated under simulated industrial processing and storage conditions. The objectives chosen to meet these goals include:

1) characterize the sensory changes in color, taste and aroma during the degradation of industrially produced concentrate.
2) interrelate change in composition to color, taste and aroma change during the storage of industry produced concentrate by associating sensory evaluation with compositional assays.

3) develop a pilot plant process which simulates the industrial process.

4) modify the process to investigate the relative effects of enzymatic activity on the degradation of SJC.

5) characterize the differences in processing and storage with respect to sensory time-intensity and scaled intensity and compositional change.

6) compare commercially produced to pilot plant produced concentrate before and after storage.

LITERATURE REVIEW

Composition of Strawberry Fruit and Juice

Strawberries, including the wild and cultivated species and varieties, belong to the genus Fragaria. The composition of strawberry fruit has been reported by Wrolstad et al. (1970a) for five varieties from the Pacific Northwest, and Goodall and Scholey (1975) for 33 varieties found world-wide. From these reports it is clear that strawberries vary considerably in composition. Coefficients of variation ranged from 12% (total solids) to 100 and 148% for some amino acids (Goodall and Scholey, 1975). Compositional differences are due to variety, maturation level, and factors affecting growth (i.e. environmental conditions). What will follow will be a brief overview of the major compositional characteristics of strawberries.

Free Sugars

Whiting (1970) reports that the free glucose, fructose and sucrose content in strawberry fruit is 2.59, 2.32 and 1.30 g/100g, respectively. In an article compiled from seven sources, Wrolstad and Shallenberger (1981) report free sugars in strawberry at a 1:1 ratio of glucose to fructose with glucose, fructose and sucrose ranging from 1.02-3.20, 1.48-3.40 and 0.20-1.56 g/100g fruit. Sorbitol was reported in trace quantities.

Solids

Strawberries have a very low solids content. Insoluble solids range from 1.1 to 3.3% (w/w), soluble solids range from 6.0-11.6%, and total solids range from 7.9 to 14.4% (Goodall and Scholey, 1975). Insoluble solids are primarily due to seeds (Green, 1971). In spite of this low solids content, strawberries can still form a rigid structure. Therefore, the network of pectic substances, and other polysaccharide fractions have a high water holding capacity. Knee and Bartley (1981) reported the cell wall of strawberry to contain: galacturonic acid (40.3%), glucose (31.1%), amino acids (10.7%), galactose (7.6%), arabinose (6.5%), xylose (1.9%), mannose (1.7%), rhamnose (1.1%) and hydroxyproline (0.1%). Buerger (1986) found cell wall neutral sugars to vary greatly among four varieties and different cell wall fractions. Wesche-Ebling et al. (1985) reported water-soluble polysaccharides to increase, while chelator-soluble fractions to decrease during ripening.

Goodall and Scholey (1975) determined the ash and mineral content for 54 samples of strawberries from various cultivars. The ash, P, K, Na, Ca and Mg content were reported to range 0.34-0.58, 14.2-30.8, 107-222, 0.57-2.38, 14.5-41.4 and 7.6-14.4 mg/100g fruit (dry basis), respectively. In the Hood and Tioga cultivars grown in Oregon, Abers and Wrolstad (1979) report K, P, Ca and Mg at 1.45, 0.26, 0.10 and 0.06 mg/100g dry fruit. Green (1971) points out that mineral content is greatly influenced by agricultural conditions and practices. Various metal ions are not only important in structure,

but are important in regulating and affecting enzymatic and non-enzymatic biochemical pathways.

Acidity and Organic Acids

The acidity of strawberry is primarily due to its non-volatile organic acids. The pH and titratable acidity (TA), as % citric acid, have been reported as ranging from 3.21-3.81 and 0.61-1.21 (Wrolstad et al., 1970a), respectively. Green (1971) reported a pH of 3.26 and TA to range 0.57-2.26 with the major organic acids including citric, malic, ascorbic, succinic, and quinic. Ascorbic acid will be covered in the discussion of vitamins. Citric (10-18%, meq/ 100 g), malic (1-3%), succinic (0.1%), and quinic (0.1%) acids have been reported by Ulrich (1970). Other organic acids in lesser quantities include succinic, shikimic, glyceric, glycolic, salicylic, gentisic and vanillic (Hulme and Wooltorton, 1958; Stohr and Herrmann, 1975).

Vitamins

Various vitamins are reported in strawberry. The most notable is vitamine C (ascorbic acid). Ascorbic acid has been reported to range from 28.5 to 94.3 mg/100 g fruit (Wrolstad et al., 1970a). Vitamin A (carotene) has been reported ranging from 0.03 to 0.15 mg/100 g (Green, 1971). The B complex vitamins have been reported to be 0.03, 0.03-0.07, and 0.6 mg/100 g for thiamine, riboflavin, and nicotinic acid, respectively (Green, 1971).

Free Amino Acids

Free amino acids are found in relatively high concentrations in strawberry juice. Rockland (1958) found asparagine, glutamine and alanine to be in higher concentration than glutamic acid, aspartic acid and serine. Asparagine (59%, mg/100 ml juice)), glutamine (14%), alanine (12%), and glutamic acid (3%) were present in greatest quantities with lesser amounts (<2%) of serine, threonine, valine, leucine/isoleucine and cysteic acid for the Marshall variety (Tinsley and Bockian, 1959). Burroughs (1970) reports glutamine > asparagine > glutamic acid > aspartic acid, alanine > serine > threonine, amino-butyric acid >> valanine, leucine. Gallander (1979) reported asparagine to be greatly reduced in concentration during fruit maturity for four varieties (Robinson, Midway, Guardian, Raritan). Early fruit ranged from 64 to 218 mg/100 ml juice, while late fruit ranged from 60 to 136 mg/100 ml juice. Amino acids were hypothesized to be catabolized during the ripening process. Compared to other soft berry fruit, strawberries have a slightly lower total nitrogen content (mg/100 g). This point, however, is overshadowed by the fact that strawberries have a greater water content than other berry fruits. It may also be important to note that the distribution of amino acids favor those with reactive secondary amino groups.

For the Hood and Tioga varieties in Oregon, Abers and Wrolstad (1979) reported glutamine and asparagine concentrations of 269 and 242 umoles/100 g of fruit, respectively. For these two varieties, other free amino acids, in addition to those reported above, include amino sugars (68.6 and 23.3, respectively), histadine (4.24 and

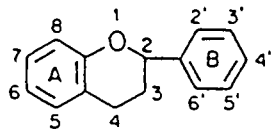
1.25), glycine (2.43 and 3.45), tyrosine (1.36 and 2.95), methionine (trace) and proline (trace).

The free α-amino acid concentration, measured by the formol titration method, was reported to range from 0.2-1.85 meq/100 g fruit (strained and diluted 50% v/v with water) by Goodall and Scholey (1975). Ryan and Dupont (1973) also used the formol titration and reported α-amino acids ranging 0.43-2.37 meq/100 g fruit.

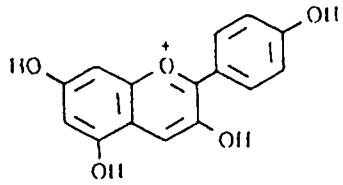
Flavonoids

The flavonoid compounds of importance in strawberries include anthocyanins (ACN), catechins (flavan-3-ols), flavanols, leucoanthocyanins, and cinnamic acid derivatives (Figure 1.1). The pigment responsible for the red color of strawberries was isolated and identified as pelargonidin (pg)-3-glucoside (Sondheimer and Kertesz, 1948). Lukton et al. (1956) report pg and cyanidin (cn) -3-glucoside. Wrolstad et al. (1970b) reported a third ACN. Hong (1987) noted five anthocyanins in strawberry juice with pg and cn-3 glucoside confirmed and pg-3-rutinoside, a pg derivative and pg-3-glucoside acylated with acetic acid tentativly identified.

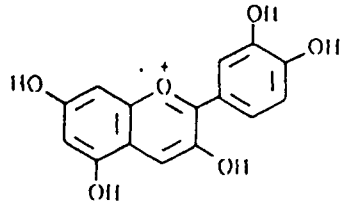
Van Buren (1970) noted that strawberry had considerable less ACN pigment than other red berry fruits such as raspberries, blackberries, cranberries, and grapes. The total ACN content has been reported to range from 343 to 966 uM/g (Wrolstad et al., 1970a). Hassanein (1982) report a total ACN concentration (pg-3-glucoside equivalent) of 19.48 mg/100 ml from unblanched strawberry juice. The relative composition of ACN pigments were



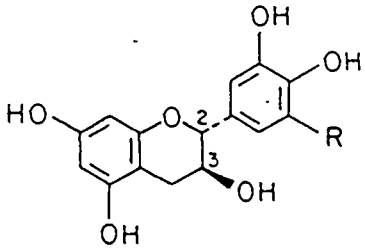
Skeleton and numbering system
for most flavonoids



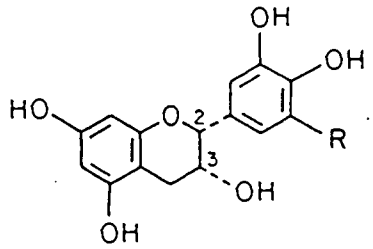
PELARGONIDIN



CYANIDIN

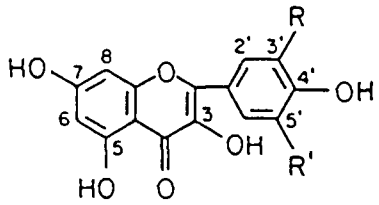


(+)-Catechin (R=H)
(+)-Gallocatechin (R=OH)



FLAVAN-3-OLS

(−)-Epicatechin (R=H)
(−)-Epigallocatechin (R=OH)



FLAVONOLS

Kaempferol (R=R'=H)
Quercetin (R=OH, R'=H)
Isorhamnetin (R=OMe, R'=H)
Myricetin (R=R'=OH)

Figure 1.1. Major flavonoid compounds occurring in strawberry fruit and products.

reported as 72-95% pg-3-glucoside (Wrolstad and Erlandson, 1973). Wrolstad et al. (1970a) reported the pg:cn -3-glucoside ratio to be 20:1.

The flavanols first identified were quercitrin-3-glucoside and kaempferol-3-glucoside (Williams and Wender, 1952). Co and Markakis (1968) identified catechin (flavan-3-ol), and isolated five different leucoanthocyanins and four unknown flavanoids. Leucoanthocyanins are defined as those flavanoids which yield anthocyanidins upon acid hydrolysis. Leucoanthocyanins were found at 67 mg/100 g (cyanidin) and represented the largest fraction of "tannin" (Co and Markakis, 1968). Green (1971) reported "tannin" to represent 0.11-0.15% (w/w) of the fruit where tannin is the material oxidized by potassium permanganate under standard conditions. It may include various polyphenolic and proteinaceous material, as well as leucoanthocyanins. Ryan (1971) concluded that the major flavanols in one or more "Ottawa market" varieties of strawberry were: quercetin (qu) -β-3-glucuronic acid, qu-β-3-glucose, kaempferol (km) -β-3-glucuronic acid, km-β-3-glucose, km-7-glucoside, and km-7-glucose. The major flavan-3-ol in the Tioga variety of strawberry was found to be D-catechin (Wesche-Ebeling, 1984), while L-epicatechin, and D-gallocatechin were also found by Stohr and Herrmann (1975). Stohr and Herrmann (1975) identified cinnamic acid derivatives and other phenolic substances to include: gallic acid, 4-hydroxybenzoic acid > p-coumaric acid, methyl gallate, ellagic acid > protocatechuic acid >> chlorogenic and neochlorogenic acids.

Lipids

Nothing was found in the literature regarding the lipid content of strawberry fruit. Seed composition is generally comprised of very different fatty acids from those in the rest of the fruit. Strawberry does not have a fleshy outer pericarp to encase seeds such as in other fruit (grapes, cranberry, current and apple). Therefore, the lipid content may be expected to be less.

Many lipids, including aliphatic fatty acids and phospholipids, are associated with cell wall structure and various proteins. Mazliak (1970) notes that all fruits contain oleic acid (octadecanoic acid). Small chain fatty acids, which are volatile, are covered in a discussion of volatile components.

Volatile Components

More than 150 volatile components were detected from strawberry pomace (McFadden et al., 1965). This research involved the concentration of ten tons of vapor condensate into a few milliliters of "strawberry oil". From this list, more than 130 have been identified including at least 50 esters (ethyl hexanoate, methyl hexanoate, methyl butyrate, ethyl butyrate, ethyl-2-methylbutyrate, ethyl benzoate, and benzyl acetate), 20 acetals, 20 aldehydes and ketones, 23 alcohols (mostly aliphatic), 11 acids, and 10 hydrocarbons (Buttery, 1979). Mussinan and Walradt (1975) identified 33 acids from fresh strawberries.

In spite of this large list of volatile components, the source for strawberry aroma has not been reported in the literature. Nursten (1970) mentions that a synthetic "strawberry aldehyde" (ethyl 1-methyl-2-phenylglycidate) is important commercially for artificial strawberry aroma. Pickenhagen et al. (1981) detected 2,5-dimethyl-4-hydroxy-3(2H)-furanone (Furaneol) in wild and cultivated strawberry cultivars. Furaneol was believed to be a major flavor component to strawberries. Dirinck et al. (1977) found esters to be the major fraction of headspace volatile compounds from strawberry fruit upon liquefaction in a blender. Their claim, however, that these esters are the major components of fresh strawberry aroma was unsubstantiated by sensory evaluation. Research has not been reported regarding the "odor-activity" (Acree et al., 1984) of the volatile components of strawberry fruit.

Enzymatic activity has been found responsible for the development of some strawberry aromas. Yamashita et al. (1975) found seventy esters to be formed from the incubation of nine aliphatic alcohols (C1-C6) with whole strawberries. The incubation of alcohols resulted in the formation of their respective esters and other esters. No ester formation was observed when the strawberry was crushed or homogenized. Amino acids may be precursors to some volatile components. Isoamyl acetate (banana aroma component), formed in the strawberry/aliphatic alcohol mix, was hypothesized to be formed from leucine (Yamashita et al., 1975). Amino acid analysis of strawberry found 0.4 mg/100 g of leucine, compared to 16.8 mg/100 g for banana. Later work by Yamashita et al. (1976a, 1976b, 1977) found aldehydes to be precursors to various aroma components via

alcohol dehydrogenase systems. Therefore, aldehydes can be formed from the degradation of free amino acids.

Schen (1978) found changes in the aroma of strawberry pomace under various treatments of incubation temperature, incubation time and pH. Incubation temperature had the greatest effect on strawberry aroma "quality" (undefined sensory attribute) over 20-40° C. A loss of "quality" was observed at 50° C, especially at a pH>6. In general, as pH increased, intensity decreased. This "quality" attribute approached a maximum when the strawberry pomace was incubated greater than 4 hr at pH 4.0 and 40°C. These results were hypothesized to relate to changes in enzyme activity.

Compositional Changes During Juice Processing

Juice Extraction, Clarification

During juice extraction procedures, the cellular structure of the strawberry is disorganized, bringing into contact active enzymes and their respective substrates. Possible substrates for enzymatic activity include ascorbic acid (Hooper and Ayres, 1950); various phenolics (Wesche-Ebeling, 1984); amino acids (Yamashita et al., 1976); sugars or phenolic glycosides (Huang, 1955,1956); or organic acids, aliphatic alcohols and fatty acids (Yamashita et al., 1976). Enzyme catalyzed reactions may form products which directly or indirectly affect juice color, taste and aroma through various coupled reactions. These degradation pathways are to be discussed in the next section. For this reason, Wesche-Ebeling (1984) proposed that pre-liquefaction blanching be employed to minimize enzymatic activity. Processing steps discussed below often require long time periods (8-10 hr) at temperatures optimal for enzyme activity.

The addition of various pectinase enzymes to facilitate juice extraction is a routine processing step in many commercial operations (Pollard and Timberlake, 1971). During this liquefaction step, various combinations of pectinesterase, polygalacturonase, and pectin-trans-eliminase enzymes are used. Whitaker (1984) reviews

other pectinases including many different pectate lyases and arabinases. These enzymes are often prepared from fungus strains, especially Aspergillus niger. The result is the breakdown of cellulose, pectic substances, hemicelluloses and other polysaccharides into sacchrides of low degree of polymerization.

Once liquefaction has been completed, juice extraction by pressing (i.e. hydrolic rack and cloth method) removes insoluble solids (i.e. seeds, cell wall constituents). Soluble strawberry components remain in solution. Part of this includes inherently unstable colloidal suspensoids (Pollard and Timberlake, 1971). The removal of these colloidal suspended components is desirable in strawberry processing where a clear juice is required. Methods used to accomplish this include depectinization, fining and/or filtration. Commercial depectinization is facilitated further by the addition of pectinases. Byrde et al. (1960) noted that some berry fruits many show some resistance to depectinization due to the presence of fungal proteolytic enzymes which cleave and inactivate pectinases. Lea (1984) mentions that procyanidins ("true tannins") can inhibit the action of some pectolytic enzymes in apple juice processing.

Clarification is the final step in achieving a clear juice. Fining is often used in the stabilization of juices by complexing via electostatic forces with colloidal suspensoids of the opposite charge (Pollard and Timberlake, 1971). The complex then dissociates from solution in the form of a precipitate. Other processes include filtration which removes suspensoids via size exclusion properties. Possible processes used include filtration or ultrafiltration

(Heatherbell et al., 1982).

Heat Processing

Many fruit products where the cell structure has been damaged are exposed to heat processes to inactivate enzymes such as polyphenoloxidase (Vamos-Vigyazo, 1981). Polyphenoloxidase (PPO) inactivation temperature from 70-90°C for various times have been reported. Apple PPO half-life at 70°C was 12 min. Instantaneous (6 sec) inactivation was found over 89.5°C (Vamos-Vigyazo, 1981). Wesche-Ebeling (1984) found the half-life of strawberry PPO to be 2.78, 0.92, and 0.75 min at 70, 80, and 90°C, respectively.

Heating, however, must be done with caution as to not cause non-enzymatic browning reactions. Markakis et al. (1957) found color degradation of buffered solutions of pg-3-glucoside to be of first order over 20-100°C. In strawberry preserves, similar degradation rates were observed by Meschter (1953). It was recommended to use high temperature short time (HTST) processing for optimal color quality.

Other reactions, promoted by heat, will be discussed in the next section. A few worth quick mention are the production of hydroxy-5-methlyfurfural and furfural from Maillard or ascorbic acid degradation. These reactive species have been shown to react directly with ACN (Daravingas and Cain, 1968). Beattie et al. (1943) found ascorbic acid to degrade more rapidly at higher temperatures. Maillard reactions procede more rapidly when heat is applied (Shallenberger and Birch, 1975).

Concentration

Fruit juices are often concentrated by vacuum distillation as a matter of convenience and decreased cost in transportation. In addition, the increase in osmotic pressure decreases their susceptibility to microbial spoilage (Pollard and Timberlake, 1971). Concentrates are used for reconstituted juice formulation, fruit juice drinks and as an ingredient in a variety of other products. However, they are labile to non-enzymatic, oxidative and occasionally microbial instability, especially when held in storage at elevated temperatures (Pollard and Timberlake, 1971).

Many changes occur in juices during and after concentration which increase the susceptibility of the beverage system to these deleterious effects. The most obvious change is the removal of the solvent (water). Many studies have related degradation rates to changes in moisture content. These include pathways involving ascorbic acid browning (Hendel et al., 1955; Dennison and Kirk, 1982; Kristberggson, 1985), Maillard and Strecker reactions (Wolfrom and Rooney, 1953; Kearsley and Rodriguez, 1981; Seow and Cheah, 1985), enzyme activity (Drapron, 1985) and anthocyanin instability (Markakis et al., 1957). Often the juice has already undergone some degradation prior to concentration as noted by Beveridge and Harrison (1984). The result is the concentration of reactive products which may become more important with respect to degradation in a concentrate, rather than a juice.

The relationship of water to degradation has received considerable attention in the literature. Water affects degradation

rates in many ways by: (1) acting as a reactant, (2) acting as a solvent through diluting or imparting mobility to reactants, (3) hydrogen bonding or complexing with reactive species, and (4) affecting the conformation of proteins or the transition between crystaline and amorphous states of sugars and starches (Leung, 1987). Labuza et al. (1970) describes three states of water based on their availability to interact with food components. At 0-20% equilibrium relative humidity (ERH) all water is tightly associated with other food constituents as a tightly bound monolayer. The bonding energies are greater than the free energy of the system to allow water to be available for interaction with other food components. At intermediate moisture levels (ERH 20-55%), intra-molecular water molecule associations increase as they form multilayers around food constituents. Therefore, availability increases. At high ERH (>55% ERH) capillary condensation and free water movement increases. The availability to interact depends on the concentration of other reactants.

Fennema (1985) notes that water bondedness depends on several factors including: water structure (e.g. entropy related to factors such as hydrophobic interactions), mobility, bond-dissociation energies, and water activity (i.e., mole fractions of water). Gilbert (1986) uses the concept of "available water" in a thermodynamic context to discuss the importance of water binding energy at these moisture levels. As clusters of water molecules form, the energy to free water decreases since intra-molecular bonds (10-12 Kcal/mole) are more easily broken than bonds between other food components. The enthalpy of activation energy is also decreased

due to an increase in randomness among the food components (decreased entropy).

Juice concentrates exist at the boundary of intermediate to high moisture water activity. Apple juice concentrated to 65 and 75°Brix, reached an a_w of 0.78 and 0.67, respectively (Toribio and Lozano, 1984). Pear juice concentrated to 65.1 and 72.5°Brix, reached an a_w of 0.77 and 0.67, respectively (Beveridge and Harrison, 1984). Iglesias and Chirife (1982) give the sorption isotherms for freeze-dried strawberry from puree at 25°C, and compared it to other sorption isotherms of strawberry at 10°C and sucrose solutions at 20°C. An a_w of 0.7 (20°C) can be achieved with solutions of sucrose and water at only 0.05% MC, while freeze-dried strawberry puree at 25°C required 30% MC. Temperature had little effect on the isotherm; however, as noted above the increase of high molecular solids decreased the a_w. Therefore, strawberry juice concentrate (68°Brix) would be expected to fall close to the sorption isotherm of freeze-dried puree, with some differences depending of composition change due to depectinization and filtration.

Literature sources have addressed the issue of degradation rates with increases in concentration. Erlandson and Wrolstad (1972) demonstrated that anthocyanin degradation rates increased with increased relative humidity over freeze-dried strawberry puree. In apple juice concentrate, Toribrio and Lozano (1984) found the activation energy for browning to decrease and browning rate to increase as °Brix increases (65-75°Brix) and a_w decreases (0.78 to 0.67 a_w), respectively. Eichner and Karel (1972) found browning

to reach a maximum in sugar-glycine solutions at a_w between 0.3 and 0.7. In glycerol/water model solutions, anthocyanin degradation was least in the range of 0.63 to 0.79 a_w (Kearsley and Rodriguez, 1981). Lee and Labuza (1975) found ascorbic acid degradation to increase over the range of 0.2 to 0.7 a_w due to increased solute mobility. At the same a_w, Kristberggson (1985) found the ascorbic acid rate to decrease in the presence of components that bind water more tightly.

Theories Related to Compositional Changes

Considerable attention has been given to compositional changes in processed and stored strawberry juice and concentrate. Since the early 1940's various hypotheses have been proposed to account for changes in color, taste and flavor. Compositional change related to color has received the most attention in the literature. This may be due, in part, to the applications of colorimetry to food science. It may also be due to the relative importance of color to overall quality assessment. Kostyla and Clydesdale (1978) review psychophysical relationships bewteen color and flavor perception. However, taking into account the masking effects that natural and artificial colorings can provide, taste and flavor can also be argued to be of great importance to quality. In any case, color change is a clear indication of compositional change and, therefore, quite often indicative of changes in taste and flavor.

Both enzymatic and non-enzymatic mechanisms have been investigated where compositional change has been followed in model and strawberry systems. The basis for color changes appear to be due to destabilization and loss of the anthocyanin (ACN) red pigment and the formation of various brown pigments. Various other mechanisms related to browning can also form products which impart off-flavors.

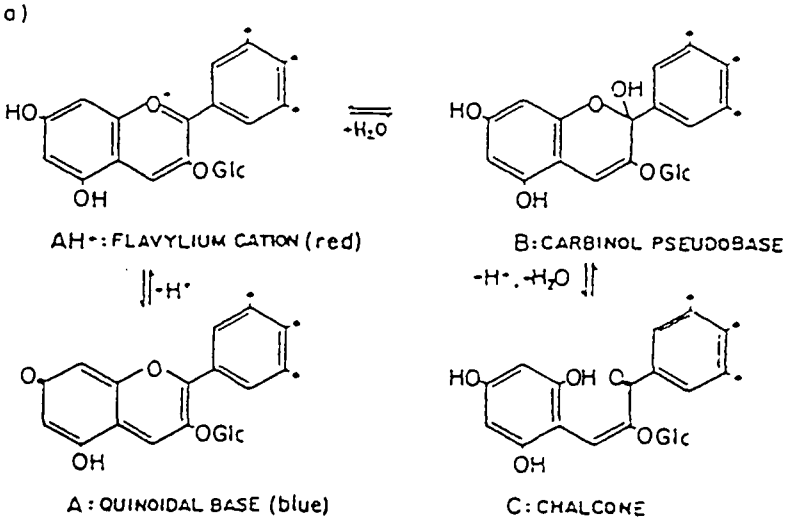
Stability of the Anthocyanin Pigment

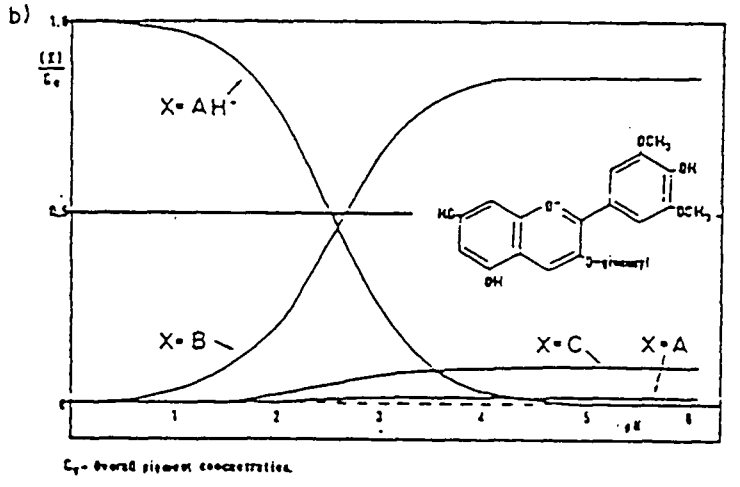
The red color of the ACN pigment is due to the absorbance spectra resulting from the resonance stabilization of the flavilium

cation (AH^+). In solution, this molecular species exists in equilibria with at least four other molecules (Figure 1.2).

Equilibria Shifts in Aqueous Solution. Meschter (1953) found spectral shifts in absorbance at 500 nm to vary with pH in freeze concentrated strawberry juice (67° Brix). Absorbance reached a maximum at pH 1, while over the range of pH 5-6 no further decrease occurred. This indicated that the red pigment was most stable at pH 1 with complete loss of color at pH's above 5. Sondheimer (1953) proposed that an equilibrium exists between the red flavilium cation (AH^+) of pg-3-glucoside and the colorless carbinol pseudobase (B). In model systems and strawberry juice, Lukton et al. (1956) noted the rate of pigment decrease (measured at 500 nm) to be pH dependent in the presence of O_2 at 45° C. However, in a N_2 headspace over a pH range of 3.05 to 4.30, pigment decrease was comparatively independent of pH. This suggested that B or one of its breakdown products was labile to oxidative degradation. These results were more apparent in the juice system.

Markakis et al. (1957) investigated color loss in purified model systems of ACN and proposed that color loss in strawberry juice is related to an acid hydrolysis of pg-3-glucoside. This was based of the observation that ACN was stable in dry (anhydrous), crystalline form. Acid hydrolysis was proposed to occur by either hydrolysis of the glucose moity or a ring opening at the 1-2 position to form a chalcone (C). The later reaction was believed more prevalent since free glucose was not detected during the degradation process in conditions of 80 to 100° C and pH 2.0 to 3.4. Jurd (1963a) proposed an equilibrium exists between the flavilium cation (AH_2),





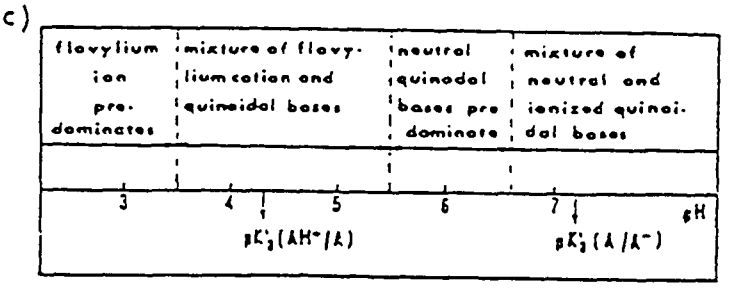


Figure 1.2. Equilibrium between five anthocyanins in aqueous solution.

carbinol pseudobase (B), and chalcone (C). Timberlake and Bridle (1966) expanded this by proposing a pH dependent equilibria between four compounds: AH^+, a quinoidal base (A), B, and C.

Adams (1973a,b) found cn-3-glucoside to form the pseudobase glucoside (B) faster than the cyanidin aglycone in acidified (pH 1-4) solutions at 100° C. A mechanism was postulated where B was further degraded to C-glucoside and, subsequent, to the C-aglycone. Under aerobic conditions, the C was irreversibly oxidized to an α-diketone. The rate limiting step was the hydration reaction to form B. Therefore, oxidation of C resulted in loss of AH^+ resulting in greater loss of color.

Shrikhande (1976) proposed a equilibrium scheme to incorporate the quinoidal base (A) where:

$$AH_2 \rightleftharpoons B \rightleftharpoons A \rightleftharpoons C.$$

This involved the successive change in color of aqueous solutions from red (AH_2), to colorless (B), to blue (A) as pH increases from 1, to 4-5, to 7-8, respectively. Brouillard and Delaporte (1977) proposed a different scheme based on shifts in absorbance spectra at different temperature and pH:

$$A \rightleftharpoons AH_2 \rightleftharpoons B \rightleftharpoons C.$$

For malvidin-3-glucoside, they determined rate constants for a proton transfer reaction from AH_2 to A, a hydration reaction between AH_2 and B, and a tautomeric reaction between B and C. The AH_2, A, and B can be distinguished by absorbance differences at 520 nm, while the C form is distinct from the rest with a greater absorbance at 360 nm. At pH greater than 4, the B and C forms were favored. At the most acidic pH's, only the AH_2 and B are stable, while a pH jump to

5 resulted to progressively slower shifts to the A and C forms, respectively. Heating was found to shift the reaction in favor of the chalcone (C), while cooling takes much longer for the C to shift back to the B, than B to the AH_2. These results were explained by a hypothesis that the hydration reaction, which is slower, is kinetically flavored as pH increases due to the A form being less stable than B. This scheme suggests that under conditions where water is less avaliable for the hydration reaction (i.e. concentrates), equilibrium shifts may favor A as pH is increased.

Oxidation by Hydrogen Peroxide. Sondheimer and Kertesz (1952) proposed a mechanism for the oxidation of pg-3-glucoside by hydrogen peroxide. Jurd (1966, 1968) reports the oxidation of anthocyanin-3-glucosides to o-benzoyloxyphenylacetic acid esters (Figure 1.3A). This was further substantiated by Hrazdina and Franzese (1974) as a product formed by hydrogen peroxide oxidation of the anhydro base (A) in acidified solutions (pH 1-3).

Hydrolytic Loss of Glycolytic Moiety. Loss of the ACN sugar moiety has been shown to result in destabilization of the ACN molecule. Lukton et al. (1956) noted the half-life for pelargonidin to be only 5 minutes at pH 3.4 and 25°C. Huang (1955,1956) noted decolorization in pigment extracts from strawberry and other fruit with addition of crude fungal preparations due to enzymatic loss of the glucose moiety from the flavilium cation (AH_2). The result was destabilization of the cation and spontaneous degradation to the ketonic tautomer of pseudobase carbinol (B) aglycone (Figure 1.4). This degradation product was observed to undergo further oxidative degradation.

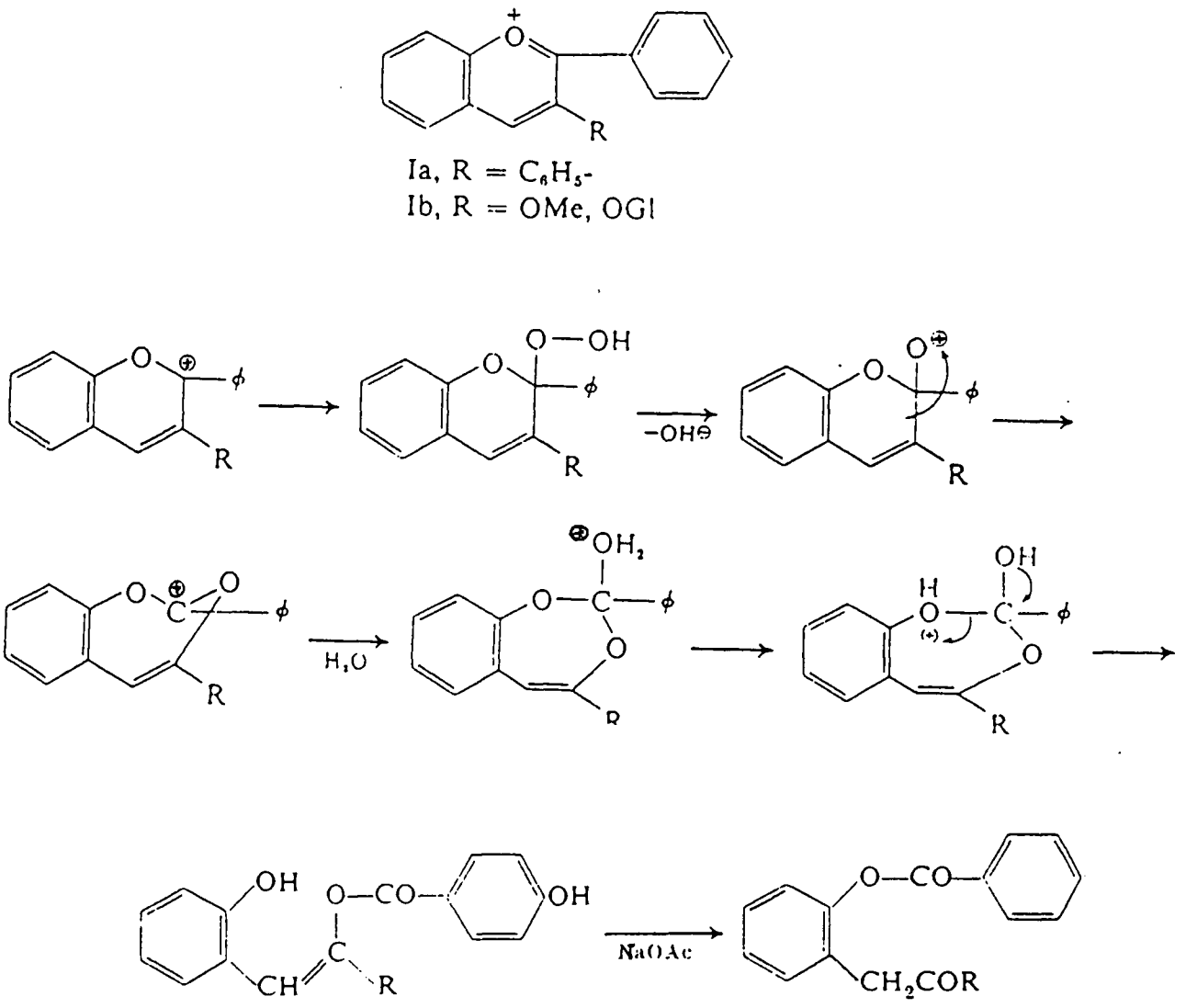


Figure 1.3. Oxidation of anthocyanins by a Baeyer-Villiger reaction to form the o-benzoylphenylacetic acid ester product (Jurd, 1966).

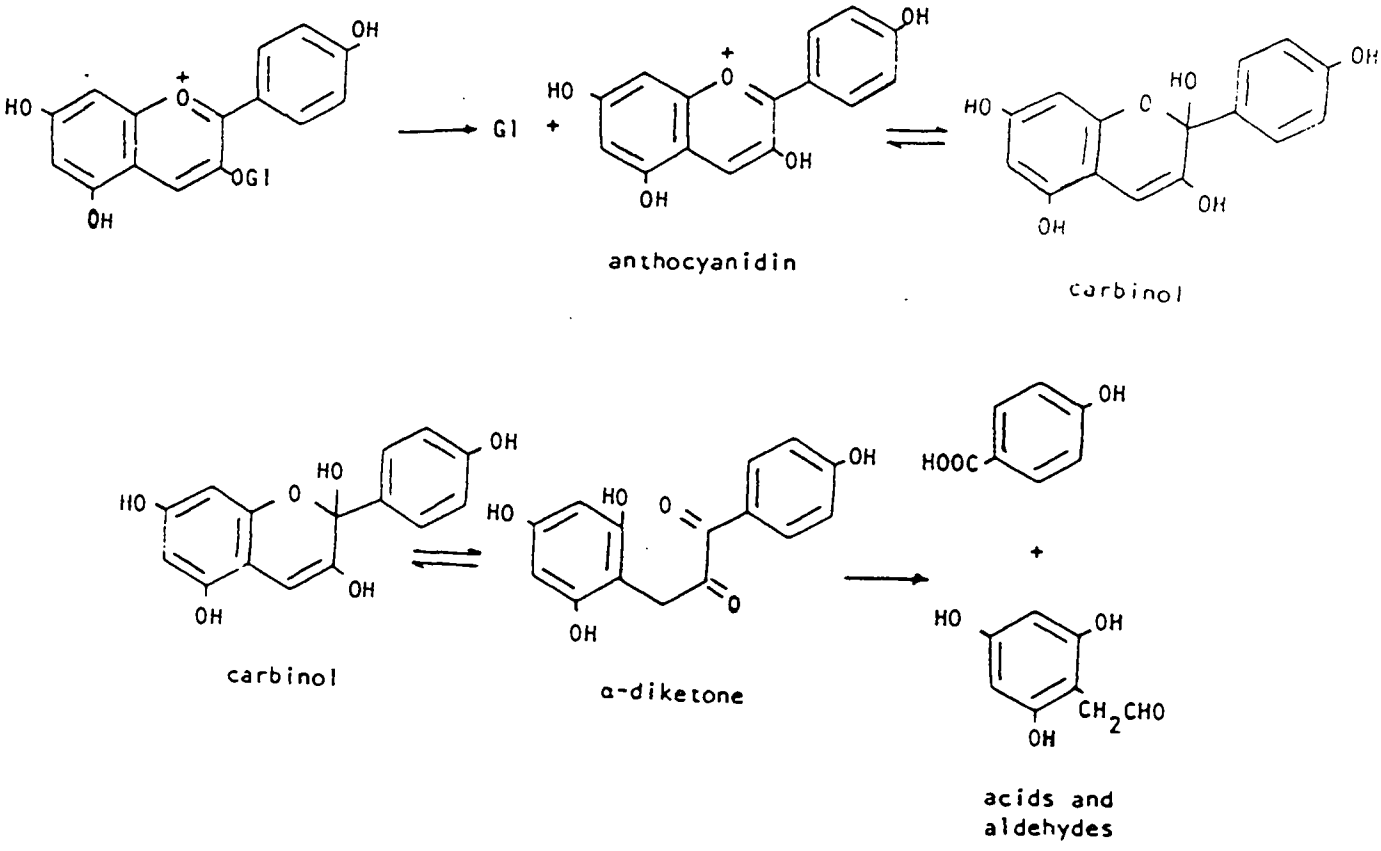


Figure 1.4. Destabilization of the anthocyanin by loss of the sugar moiety and spontaneous degradation to a ketone of the pseudobase carbinol aglycone (Huang, 1955b).

Nucleophilic Attack. Debicki-Pospisil et al. (1983) studied the relative reactivities to nucleophilic attack of different atomic positions on the cyanidin cation, keto-pseudobase, anhydrobase and chalcone. The cation had the lowest pie electron charge distribution at the C2 position (with the C4 position also low). This supports the model proposed by Huang (1955b) that the ACN aglycone is very labile to nucleophilic attack at the C2 position.

Jurd (1963b) found addition of sodium bisulfite to reversibly react with the flavilium cation by nucleophilic attack at the C2 position (Figure 1.5). This addition, which quickly bleaches out the red color, is reversed in strong acid with heating. Adams and Woodman (1973) found sulphite addition to stabilize cn-3-rutinoside by effectively competing with the hydration reaction which forms the pseudobase (B). Proposed was sulfite addition to the C2 position and an equilibrium set up between the cation, pseudobase and sulfite-flavilium compound.

Electrophilic Attack. Timberlake and Bridle (1976) indicate that addition reactions also can occur at the C6 or C8 positions. This is the basis for an electrophilic attack by a catechin-catechin complex (discussed later under the role of aldehydes).

Non-enzymatic Browning

There are many different non-enzymatic degradation pathways involved in the food chemistry of strawberry juice and concentrate. The relative importance of different pathways depend on the conditions which compositional substituents are subject to under

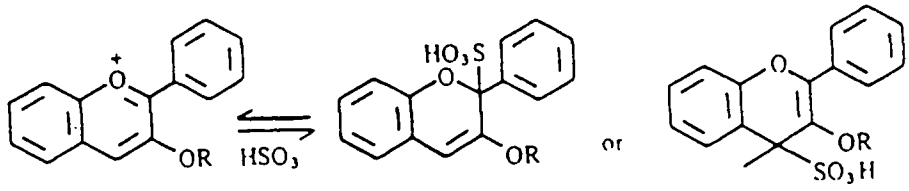


Figure 1.5. Addition reaction of sulfite to the C2 position of anthocyanin-3-glucosides or the C4 positions of anthocyanidins (Jurd, 1963).

processing and storage. In the presence of catalyzing enzymes, some non-enzymatic pathways increase greatly in their relative contribution to browning.

Color change is attributed by loss of the red flavilium cation and the development of brown (yellow/red) pigments. The web of complexity of non-enzymatic browning can be catagorically classified by pathways associated with compositional change in the red flavilium cation, various colorless phenolics, ascorbic acid, reducing sugars, and free amino acids. As reviewed above, the equilibrium between various flavilium derivatives changes with processing and storage conditions. The relative reactivities of these different compounds to oxidative destruction and nucleophilic attack depend also on these conditions, as well as the reactivities and availability of other compositional components in the strawberry juice or concentrate.

Role of Ascorbic Acid. During the 1940's, ascorbic acid (AsA) received some attention since it was found to be very liable to oxidative degradation. Hydrogen peroxide and dehydroascorbic acid (dHAsA) were found to be formed by the copper and iron catalyzed oxidative decomposition of AsA (Dekker and Dickenson, 1940; Silverblatt et al., 1943; Weissberger and LuValle, 1944). Eison-Perchonok and Downes (1982) determined oxidation of AsA followed second order kinetics. The O_2 dissociation rate was dependent on the headspace O_2 partial pressure and temperature. At this same time strawberry juice color loss was receiving attention since its degradation was reported to more dramatic than other fruit juices (Beattie et al., 1943; Sondheimer and Kertesz, 1948). Beattie et al. (1943) demonstrated that the color loss in strawberry juice

was more severe in the presence of an oxygen filled headspace. In addition, AsA loss was shown to parallel this color change. Sondheimer and Kertesz (1948) found brown color formation to be preceded by major losses of red pigments. In addition, they supported contention by Beattie et al. (1942) that AsA was related to color loss. Later studies by Starr and Francis (1968), Shirkhande and Francis (1974), Calvi and Francis (1978), and Poei-Langston and Wrolstad (1981) have confirmed this relationship.

Sondheimer and Kertesz (1953) proposed a mechanism for the indirect oxidative degradation of pg-3-glucoside by AsA with hydrogen peroxide participating as an oxidizing agent (Figure 1.6A). Jurd (1972) and Poei (1979) proposed a mechanism exists for the direct condensation of AsA and ACN. The proposed mechanism is an addition reaction at the C4 position (Figure 1.6B).

The roll of AsA and its degradation products were further elucidated by studies of various additives. Markakis et al. (1957) found the addition of AsA into strawberry juice accelerated pigment loss. Meschter (1953) agreed with these results, while noting that the addition of dHAsA contributed to accelerated pigment loss. The degradation rate, however, was less than for equivalent additions of AsA. These results suggested that degradation products of AsA may also contribute to ACN degradation.

Therefore, it can be concluded that the relationship of AsA on the degradation of ACN is very complex. It is now reasonable to conclude that direct condensation reactions can occur between AsA radicals and ACN pigments. However, the addition of dHAsA also resulted in ACN degradation. Therefore, decomposition products of

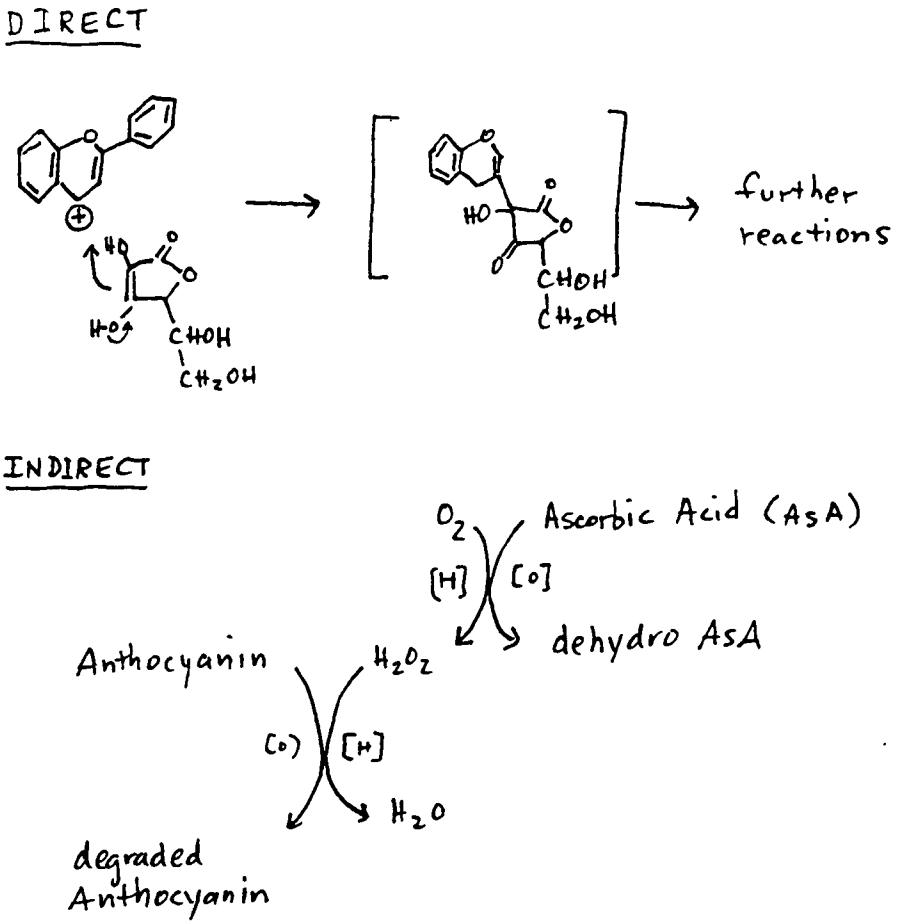


Figure 1.6. Mechanism for the indirect and direct roles of ascorbic acid on the degradation of anthocyanins.

dHAsA may be further involved in ACN degradation.

Redox Stabilization. In model systems containing anthocyanin (ACN) pigments, riboflavin (another redox constituent of strawberry) was found to accelerate the destruction of AsA, while not in the absence of ACN pigments (Pratt et al., 1954). In strawberry juice, however, Markakis et al. (1957) found that the addition of riboflavin into strawberry juice decelerated color loss. This suggests that riboflavin can act as an anti-oxidizing agent, free radical quencher, or be involved in reducing dHAsA back to AsA. The rate of pigment degradation was also slowed by the addition of cystine, a redox constituent (Sondheimer and Kertesz, 1953; Markakis et al., 1957). Ascorbic acid was observed to protect model systems including ACN from browning only up to 6 hours storage at 50° C (Sistrunk and Cash, 1968). However, after 18 hours storage the browning was greater in the presence of AsA.

Thiourea, a metal complexing agent, reduced the rate of ACN degradation as measured by change in absorbance at 500 nm (Sondheimer and Kertesz, 1953; Markakis et al., 1957). Sistrunk and Cash (1970) investigated ascorbic acid and ACN degradation after addition of various metal chelating additives. Addition of $SnCl_4$ was found to stabilize the red color. Wrolstad and Erlandson (1973), however, concluded that $SnCl_4$ protected color by formation of a red complex with leucoanthocyanins or their oxidative products, while ACN degradation rates were not changed.

Hooper and Ayres (1950) investigated black current since AsA was found to be more stable in this system. At least two components were isolated which were believed to be responsible: one associated with

the red pigments, the other a yellow material believed to be a flavanone. Davidek (1960) found the flavonols rutin and quercitin to have a stabilizing effect on AsA degradation. It was hypothesized the protective effect was by forming a metal complex with Cu ions. Clegg and Morton (1968) found equal AsA protection with or without Cu salts in the presence of flavonol aglycones and quercitrin. Harper et al. (1969), however, demonstrated the stabilizing effect to be due to anti-oxidation properties of flavonols. Free radical chain initiated reactions of AsA, catalyzed by Cu metal ions, were proposed which result in the production of dHAsA, hydrogen peroxide or free radicals of AsA. Skalski and Sistrunk (1973) found cysteine to have a protective effect on AsA and ACN degradation; and, proposed this to be due, in part, to increasing the reducing potential of the system. Likewise, Shrikhande and Francis (1974) noted a protective effect on pg-3-glucoside and AsA by the addition of quercitin or quercitrin in either the absence or presence of Cu metal ions. Poei-Langston and Wrolstad (1981) found the major strawberry flavonol, catechin, to reduce the degradation rate of pg-3-glucoside in the presence of excess AsA and O_2.

Ascorbic Acid Breakdown Components. The further breakdown of dHAsA has been investigated by many researchers. Fearon and Kawerau (1943) reported the spontaneous anaerobic formation of a red pigment in an unheated solution of dHAsA. It was hypothesized the pigment was various furfural derivatives. Lambden and Harris (1950) found AsA decrease to be related to a decrease in O_2, CO_2 evolution, and an increase in absorbance at 410 nm in model solutions heated at 50°C. Diketogulonic acid was hypothesized as an intermediate with

the formation of furfural. Huelin et al. (1971) found AsA to degrade anaerobically to form CO_2 and furfural at both 50 and 100°C in the pH range of strawberry. The oxidation of AsA was inhibited by adding potassium cyanide. Kurata and Sakurai (1967) proposed two possible pathways for the production of furfural and CO_2 from dHAsA at 100°C and storage at room temperature. In both cases intermediates were identified as 2-keto-L-gulonic acid (KGA), 2,3-diketo-L-gulonic acid (dKGA), L-xylosone (X), and 3-deoxy-L-pentosone (DP). Tannenbaum (1976) schematically presents the possible mechanisms responsible for AsA browning (Figure 1.7).

Condensation Reactions With Other Phenolics. Various oxidized phenolic components have been shown to form condensation reactions with ACN. Lukton et al. (1956) noted that ACN degradation products formed an insoluble red-brown precipitate and a soluble brown material. The aglycone alone did not form a red-brown precipitate. In nitrogen, only a small precipitate was formed. Therefore, it was postulated that an oxidative reaction was responsible for possible polymerization reactions involving the pseudobase of the glucoside. Livingston and Markakis (1956) found up to 85% of ^{14}C labeled ACN in the insoluble precipitate.

Somers (1966, 1967, 1968) separated monomeric and polymeric wine pigments by gel filtration and evaluated their absorbance spectra. Wine aging increased the polymeric and decreased the monomeric pigments (Somers, 1968). Polymers with molecular weights above 2000 were hypothesized to be comprised of 5-20 flavanol units. Leucoanthocyanin: ACN ratios within these polymers were found to be 4:1 with ACN believed to be loosely associated by physical, rather

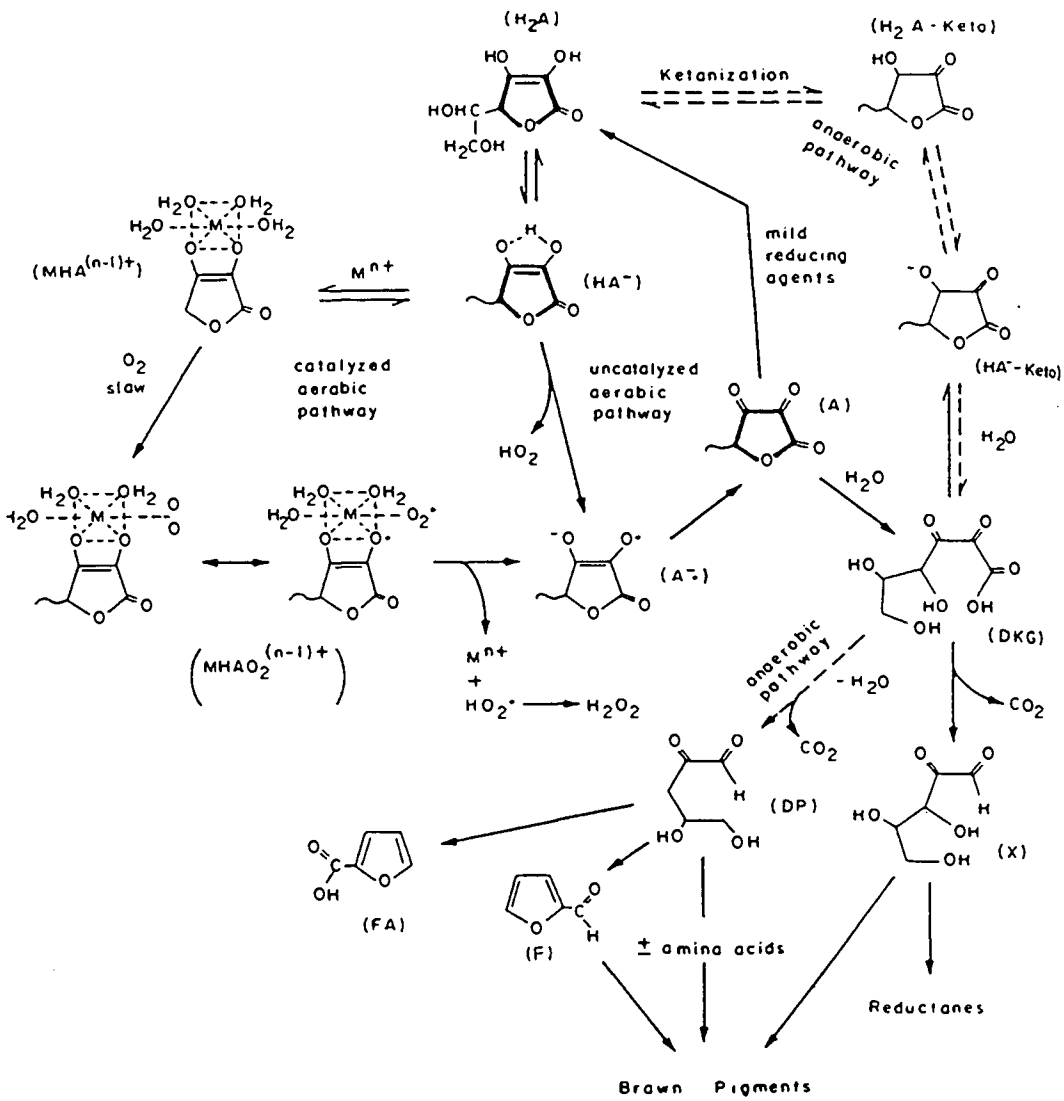


Figure 1.7. Schematic diagram of ascorbic acid degradation pathways (Tannenbaum, 1976).

than covalent bonding (Jurd, 1966). Jurd (1967) detected the formation of condensation products from a 2:1 mixture of a synthetic flavilium salt (aglucone) and catechin. Formed was a condensation product, which was detected by a 50% decrease in absorbance at 429 nm, and a reduction product (i.e. flavene). The reaction mechanism scheme assumed that the flavilium salt was the oxidant in the condensation reaction. Erlandson and Wrolstad (1972) found red-brown insoluble residue from strawberry puree to form three fractions from eluted methanol extracts by gel filtration. All three fractions had similar chromatographic migration behavior as pg-3-glucoside.

Somers (1971) proposed a mechanism where flavylium salts undergo condensation reactions at the C4 position by electrophilic substitution from the C6 or C8 position of dimeric proanthocyanins. The resulting poly-flavene is oxidized to a condensed ACN, which then undergoes deprotonation to a stable quinoidal polymeric pigment (Figure 1.8). Further substitution can occur by this mechanism to further build the polymer.

Maillard Reactions. The influence of Maillard reactions involving reducing sugars in beverage systems has received considerable attention in the literature. In dilute solutions, it appears that Maillard reactions are of minor consequence compared to juice concentrates. Pollard and Timberlake (1971) suggest that Maillard reactions are not a major degradation pathway in fruit juices due to the dilution effect of reactants and low acidity. Ellis (1959) determined the amino group of amino acids is protonated in high acid solutions, reducing glycosylamine formation (rate determining step). Barnes and Kaufman (1947) found a 50% decrease in

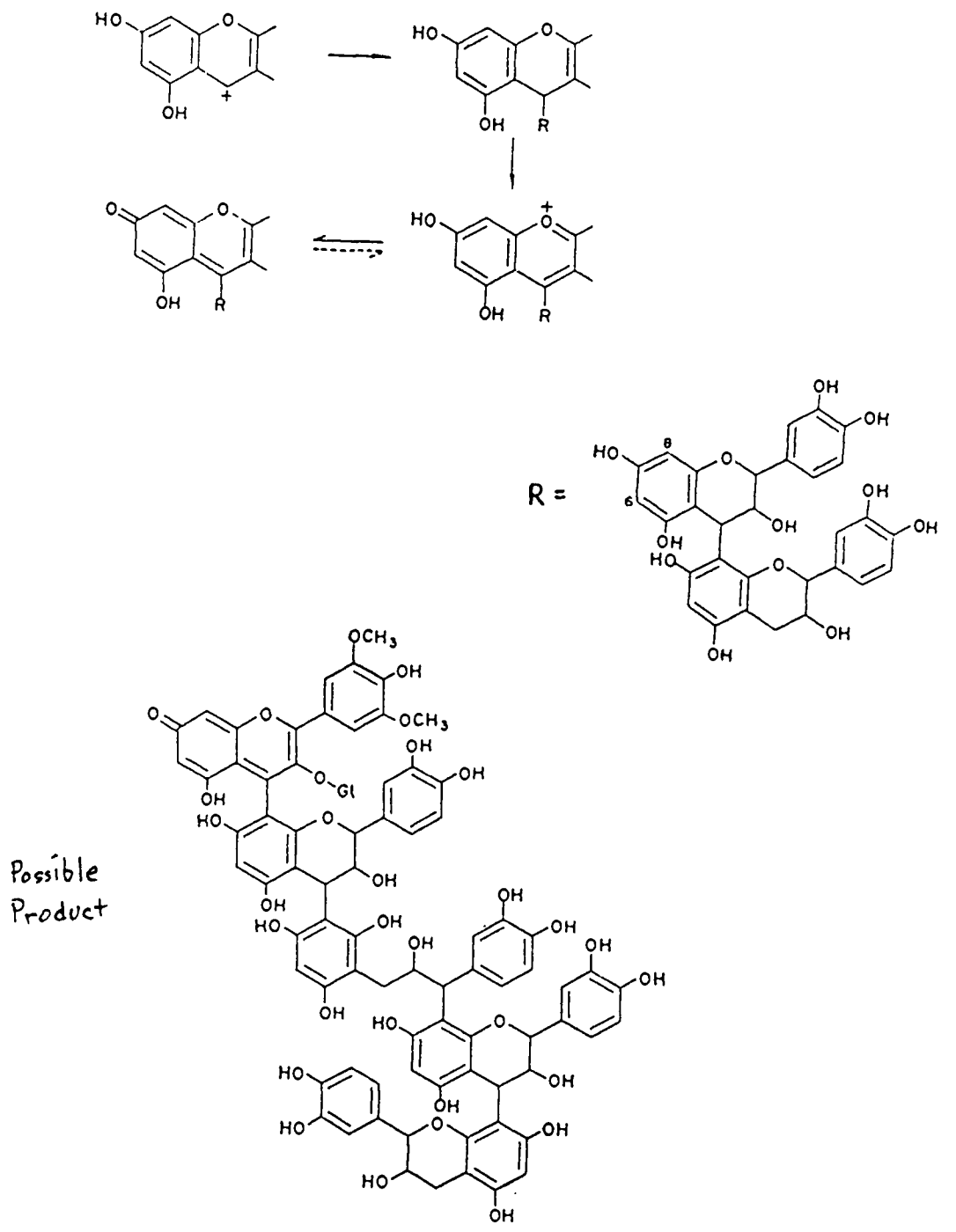


Figure 1.8. Polymerization reaction by electrophilic substitution involving a carbonium cation and dimeric proanthocyanidin (Somers, 1971).

color development as pH decreased from 6 to 4 in 50% glucose/glycine and water. The Maillard reaction also depends greatly on moisture content, heat treatment and sugar profile. In model systems, browning rates have Q_{10} rate increases of 2-3 with temperature, while this can increase exponentially with increase in sugar content (Shallenburger and Birch, 1975). Wolfrom and Rooney (1953) found Maillard reactions of a xylose/glycine solutions to be maximum at 30% moisture content. Fennema (1984) places fruit juice concentrates at water activities (a_w) of 0.80-0.87, near the maximum browning rate. Susceptability to browning is inversely related to the relative stability of the hemiacetal ring structure with pentoses being less stable than hexoses (Burton and McWeeney, 1963).

Meschter et al. (1953) observed browning in solutions of strawberry pigment and various carbohydrates (40% solids and pH 3.0). The pigment half-life was found to be proportional to ring stability (mannose, sucrose and maltose > arabinose and levulose > sorbose). The effect of added sugar has been confirmed by Tinsley and Bockian (1960). Calvi and Francis (1978) found sucrose to affect ACN degradation in heated (185-203^{o} C, pH 3.2) solutions of grape skin extract (GSE), while glucose had little effect. Singh et al. (1948) noted that glucose exhibits a stabilty optimum to thermal treatment over a pH range of 2.5-3.5. Acid hydrolysis of sucrose to invert sugar formed more carbonyl degradation products (absorbance at 285 nm), presumably through Maillard reactions of fructose.

It has been proposed that sugar degradation products (i.e., 5-hydroxymethyl-2-furfural, furfural) are responsible for degrading ACN (Daravingas and Cain, 1968; Debicki-Pospisil et al., 1983). This

reaction is covered in more detail in the discussion of aldehydes. The detected levels of carbonyl compounds, measured as HMF, by Calvi and Francis (1978) were much lower (10^{-3}) than levels used by Daravingas and Cain (1968) and Debicki-Pospisil et al. (1983). This raises the point that some other factor, rather than direct condensation by furfural or HMF, may be responsible for ACN degradation.

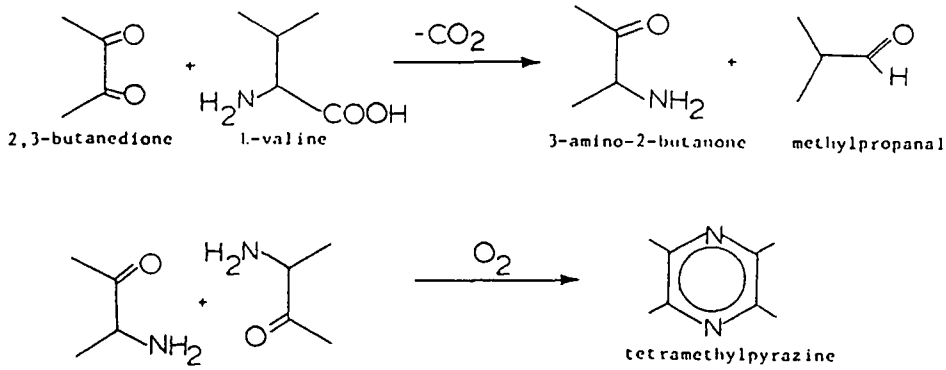
Role of Amino Acids. Free α-amino acids (AA) also have been found to contribute to the formation of brown pigments. The GSE in Calvi and Francis (1978) may have had appreciable levels of free amino acids to catalyze various deleterious reactions. It is known that AA can react with α-dicarbonyls via Strecker degradation (Figure 1.9A). Carbonyls can be formed from Maillard reactions involving reducing sugars or from ascorbic acid browning.

Koppanyi et al. (1945) observed AA to react with AsA in the presence of hydrogen peroxide at 100°C to form a red color. In model systems of citric acid and AsA, Clegg (1964) found absorbance at 400nm increased with the addition of amino acids at pH 2.5 and 4.5. However, in this study no "obvious reduction in concentration" of AA nitrogen content was observed. Lalikainen et al. (1958) found a smaller proportion of CO_2 from labeled glycine (less than 4%), than from AsA in model systems of AsA, glycine and citric acid (pH 3.7 or 7, 50°C, presence or absence of O_2). No aldehydes (e.g., formaldehyde) was detected as a product. These results suggest that the presence of AA can catalyze the degradation of dHAsA; however, the mechanism for degradation is unclear.

In contrast, Ranganna and Setty (1968) noted a decrease in AA

and an increase in red color in solutions ranging from 0 to 9% ethanol at various temperatures and pH. Aldehydes were present indicating a Strecker degradation mechanism. The Strecker reaction was preferred under conditions of high concentration of reactants and low moisture (i.e. increased percent ethanol) at 37°C. Glycine produced formaldehyde, while alanine produced acetaldehyde. During storage the red product broke down to form a brown precipitate and CO_2. Clegg (1966) found greater browning in model systems of citric acid and AsA when AA were added. Kurata et al. (1973) noted a red pigment to form from heated mixtures of all α-amino acids (except L-proline) and dHAsA (Figure 1.9B). This reaction was preferred at neutral pH since dHAsA undergoes rapid acid hydrolysis to diketogularic acid. However, at low moisture content this reaction may be of greater relative importance. These studies indicate that Strecker degradation of dHAsA degradation products and AA could become an important degradation pathway in fruit juices, especially when stored as a concentrate. Cornwell and Wrolstad (1981) found AsA and deHAsA more stable when AA had been removed by a cation exchange resin.

Role of Aldehydes. Various accounts in the literature have noted the increased degradation of ACN in the presence of various aldehydes. Aldehydes can be formed from Maillard reactions of reducing sugars, AsA browning, and Strecker Degradation reactions. Furfural (FUR) and 5-hydroxymethylfurfural (HMF) are both products of Maillard reactions of reducing sugars, while FUR can be formed from AsA browning. In citrus products, furfural production is believed to be the main product of AsA degradation ans in solution has been



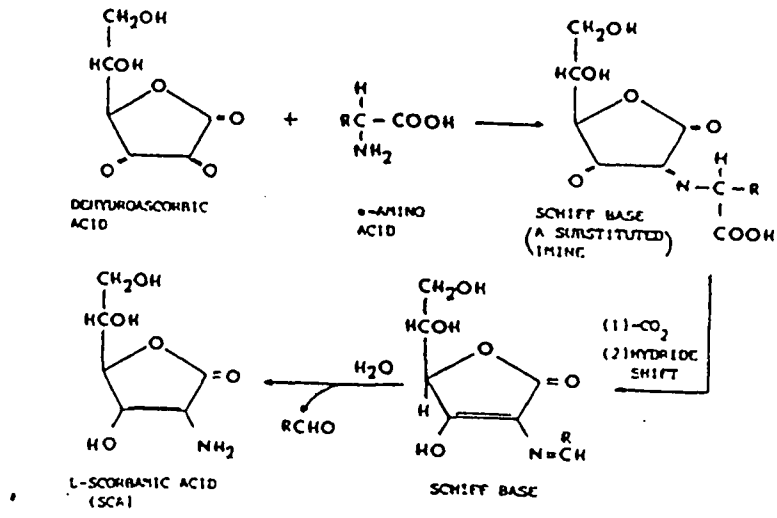


Figure 1.9. Strecker degradation mechanisms involving α-dicarbonyls and α-amino acids (Whistler and Daniel, 1985) or dehydroascorbic acid and α-amino acids (Liao and Seib, 1988).

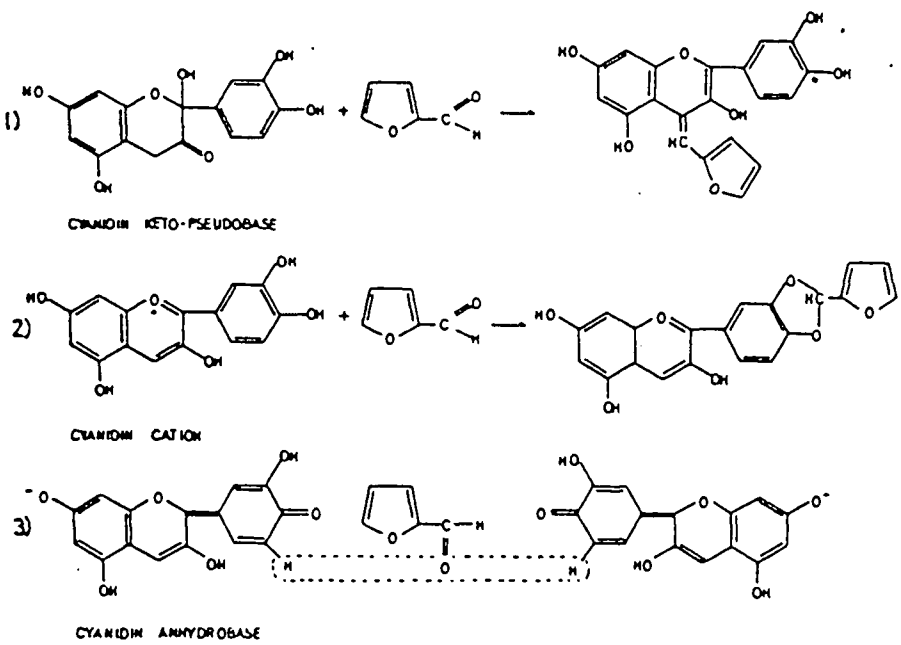


Figure 1.10. Proposed condensation reactions of furfural with anthocyanidin compounds (Debicki-Pospisil et al., 1983).

related to quality loss (Handwerk and Coleman, 1988). Formaldehyde, acetaldehyde and other aldehydes can be formed from the decomposition of α-amino acids through Strecker degradation. Meschter (1953) found increased concentration of either FUR or HMF to contribute to an increase in color loss. It was noted that FUR had a greater detrimental effect than HMF. Tinsley and Bockian (1960) noted a decrease in pg-3-glucoside with additions of FUR and HMF; and, they proposed a condensation reaction with the keto-pseudobase of the aglycone (Figure 1.10). Other reports confirming similar effects of HMF and FUR on cn-3-glucoside have been reported by Daravingas and Cain (1968) and Debicki-Pospisil et al.(1983).

Timberlake and Bridle (1977) observed increased color density in strawberry juice by the addition of acetaldehyde. As the ratio of catechin to ACN ratio increased, more bridges were formed. Therefore, catechin was assumed to be related to the rate determining step. Chen and Wrolstad (1980) determined the reaction resulted in decreased monomeric pigments, stable polymeric color, but increased darkening. The proposed mechanism was a Baeyer-type condensation reaction between pg-3-glucoside and catechin, linked by a CH_3CH-bridge (Figure 1.11). When acetaldehyde was added to strawberry juice, color density (absorbance at 420 nm) was enhanced, but samples darkened and lost more ACN pigment during storage.

Other aldehydes have shown similar effects on ACN stability. Debicki-Pospisil (1983) found the order of reactivity in degrading cn-3-glucoside at 70°C in model systems as follows: formaldehyde > acetaldehyde > benzaldehyde. This reaction was greater in the presence of O_2, than in a N_2 headspace, suggesting oxidative

mechanisms may be involved in these reactions.

Enzymatic Browning

Enzymes can be inherent components of the system or introduced into the system from another source (i.e. fungal contamination) as noted by other researchers (Huang, 1955a; Pilando, 1982). Determining the roles of enzymes in degradation require first the consideration of the non-enzymatic nature of chemical reactions since enzyme catalyzed reactions must also obey the laws of chemistry (Hamilton, 1974). These enzymes reduce the activation energy needed to drive reactions forward. Therefore, when activated, they can greatly increase the rates of browning and other pathways which reduce the quality of strawberry products.

In an early review paper, Joslyn and Ponting (1951) cite early work by plant phytochemists who studied the role of enzymes in plant tissue repairing mechanisms. In the presence of oxygen, injured tissues of some plants turned brown. Onslow (1931) classified plants based on enzyme systems with different rates of browning. Plants with oxygenases and catechol (apple, apricot, banana, cherry, peach, pear, fig, grape and strawberry) discolored more rapidly than plants with only peroxidase systems (citrus, red currents, melon, pineapple and tomato). Huang (1955) reports a decolorization problem with use of crude pectinase preparations from fungal origin. The subsequent research found enzymatic hydrolysis of anthocyanin-β-glucosides to their subsequent aglycone responsible for the destabilization and loss of the red color. The presence of polyphenoloxidase (PPO) in

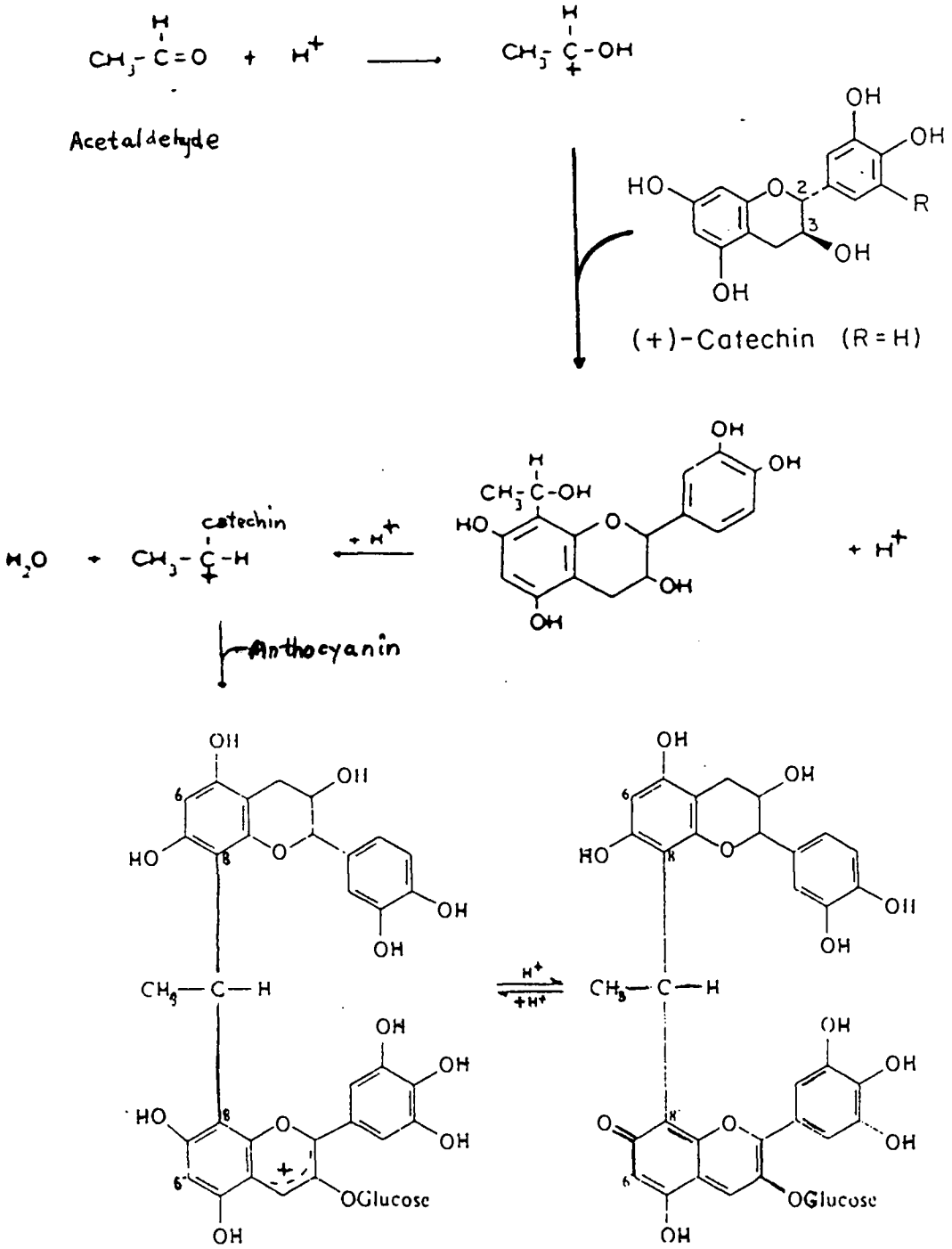


Figure 1.11. Acetaldehyde reaction with catechin and anthocyanin by a Baeyer-type condensation mechanism (Timberlake and Bridle, 1976).

strawberry juice has been reported by several researchers (Cash and Sistrunk, 1971; Drewert et al., 1974; Wesche-Ebeling, 1984). Prior research on other juice systems had reported PPO to accelerate ACN degradation and browning (Joslyn and Ponting, 1951; Peng and Markakis, 1963). Drawert et al. (1974) reported peroxidase (PER) in strawberry. Prior research by Grommeck and Markakis (1964) found added extracts of horseradish peroxidase to ACN from strawberries and red tart cherries to increase their rates of browning.

Polyphenoloxidase. The activity of PPO in fruit and fruit beverage systems has received the most extensive coverage in the literature, because it is believed to exert the greatest effect on strawberry degradation. The most convincing evidence for this assertion is the accelerating effect of oxygen on the degradation of strawberry juice and concentrates (Beattie et al., 1948; Sondheimer and Kertesz, 1948). However, oxygen in its natural triplet state is fairly unreactive towards organic compounds. Hamilton (1974) explains two cases in which oxidative reactions can proceed: (1) in the presences of transition metals which form complexes with oxygen and (2) through in initial reaction that forms a free radical. In the former case, the free electron orbitals of the metal overlap with those of oxygen to increase the reactivity of the whole complex. In the later case, a highly conjugated, resonance stabilized cofactor (e.g. catechol) with electron orbitals in a singlet state react with triplet oxygen to form highly reactive free radicals.

In the presence of transition metals, non-enzymatic oxidative degradation of various strawberry components have already been discussed. The PPO and PER enzyme systems in strawberry utilize

similar mechanisms in catalyzing oxidative pathways. The PPO enzyme is a multi-subunit complex requiring several Cu (cuprous) ions for activity. Hamilton (1974) proposed a mechanism that explains the ability of PPO to convert phenols with o-dihydroxybenzene rings (o-dihydroxy phenols) to o-quinones and monohydroxybenzene rings (monophenols) to o-dihydroxyphenols (Figure 1.12). Vamos-Vigyazo (1981) mentions that the enzyme catalyzed hydroxylation reaction of monophenols occurs only after a lag period in the absence of o-dihydroxy phenols. Trace amounts of o-dihydroxy phenols allow the reaction to proceed substantiating the mechanism proposed by Hamilton (1974). Another feature of PPO is that is becomes inactivated during the oxidative reaction. Vamos-Vigyazo (1981) attributes that phenomena to a covalent linkage between the quinone and PPO near the active site. Therefore, it has been proposed that PPO functions more as an initiator of oxidative mechanisms, than as a direct contributor to oxidative degradation (Wesche-Ebeling, 1984).

Vamos-Vigyazo (1981) reports the most natural PPO substrates are catechins, cinnamic acid esters, 3,4-dihydroxy phenylalanine, and tyrosine. From crude extracts of strawberry, Wesche-Ebeling (1984) found the major PPO substrates in strawberry juice as D-catechin >> caffeic acid, chlorogenic acid > protocatechuic acid. To a lesser degree, from experiments with model systems, cd-3-glucoside was shown to be oxidized in the presence of PPO, while pg-e-glucoside (without an o-dihydroxy group on its B-ring) was not. However, phenolic glycosides (e.g. ACN) have been reported to be poor substrates for PPO (Herrmann, 1976; Vamos-Vigyazo, 1981)

If ACN are not good substrates for PPO activity, then the

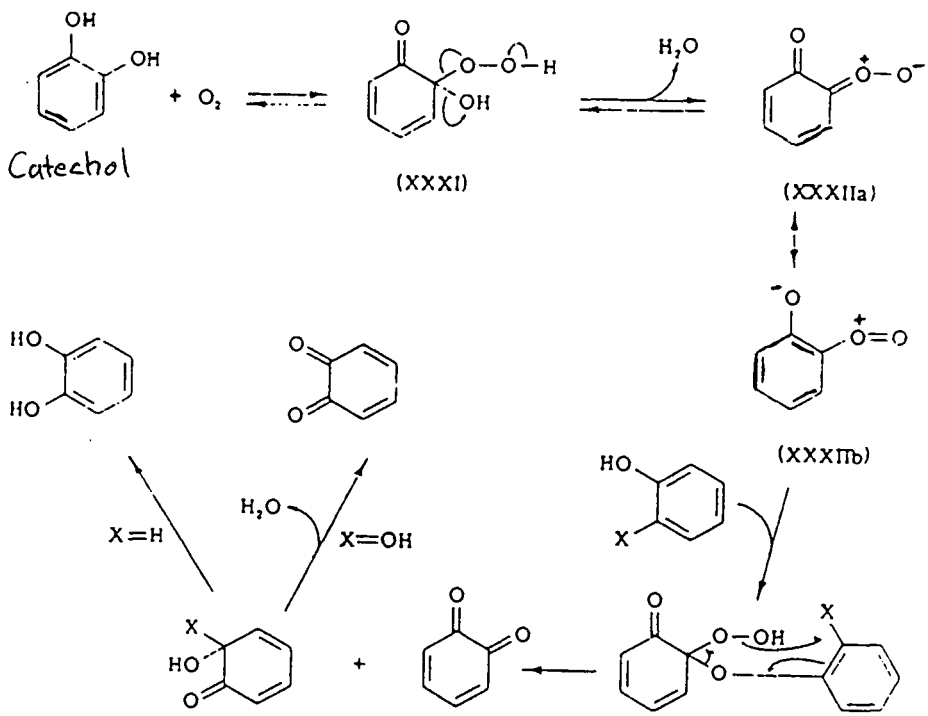
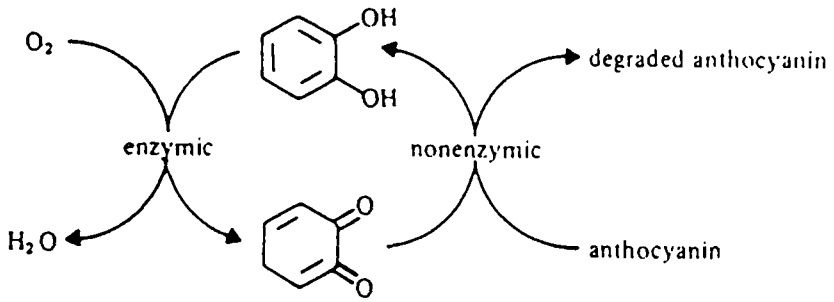


Figure 1.12. Oxidation mechanism catalyzed by polyphenoloxidase of o-quinones to mono and o-dihydroxyphenols (Hamilton, 1974).

question remains as to how they are degraded in the presence of enzymes. Joslyn and Ponting (1951) mention that PPO can catalyze the oxidation of phenolics such as catechol to quinones in the presence of O_2; and, these oxidized substances then oxidize other oxidative labile substances such as ascorbic acid or other phenolics. The final brown pigments could be due to the oxidation of the same phenolics or the induced oxidation of others.

This claim has since been substantiated by others. Peng and Markakis (1963) found catechol to increase the degradation ACN from tart cherry ACN in the presence of mushroom PPO. Excess catechol inhibited the reaction. They diagrammed the mechanism as below.



Skalski and Sistrunk (1973) observed increased degradation of AsA and ACN from solutions containing Concord grape PPO. During the first 90 min (43° C), AsA inhibited the degradation of ACN; however, after AsA was degraded (storage > 5 hr), the degradation rate of ACN was increased. Catechol increased the degradation of ACN. In solutions with sweet cherry PPO, the ACN degradation rate was found proportional to the concentration of quinone (Pifferi and Cultera, 1974). Ascorbic acid also exerted a protective effect of ACN degradation. Results obtained by Cash and Sistrunk (1971) did not observe a significant browning rate increase when catechol was added to strawberry puree with active PPO. However, Wesche-Ebeling (1984)

found 4-methyl-catechol to require much greater concentration for activity (higher K_m) and 9% less activity than catechin. In model solutions containing purified strawberry PPO, D-catechin alone was oxidized more rapidly than either cd or pg-3-glucoside; while, combinations of these ACN with D-catechin resulted in considerable ACN degradation (Wesche-Ebeling, 1984)

As already discussed, some phenolics (i.e. quercitin) have been shown to exert protective effects on AsA and ACN. These results suggests a similar mechanism whereby AsA protects ACN. The simultaneous AsA oxidation and reduction of o-quinones is preferred over reactions that degrade ACN in the presence of o-quinones. As more AsA is degraded to dHAsA, the competition for protons decreases and the catechin-quinone is available for other reaction pathways. Non-enzymatic reactions already discussed can then proceed between o-quinones, leucoanthocyanins, proanthocyanins, and ACN to form various polymeric pigments and the observed browning during storage.

Peroxidase. Hamilton (1974) lists four possible reactions catalyzed by peroxidases: (1) peroxidatic, (2) oxidatic, (3) catalatic, and (4) hydroxylatic. The first reaction involves the simultaneous reduction of peroxides to alcohols and water, with the oxidation of an organic compound; the second is oxidation of organics in the presence of O_2, rather than peroxides, and a cofactor; the third is the reduction of hydrogen peroxide to water with the liberation of O_2; and the last is similar to PPO in the oxidation of monophenols in the presence of O_2, yet it requires a factor. The catalytic effect of PER enzymes was studied by Grommock and Markakis (1964). Addition of horseradish peroxidase to model

solutions demonstrated that ACN was oxidized. However, the order of activity with different substrates found hydroquinone > catechol >> ACN >> AsA. Therefore, in the presence of peroxide and PER, ACN may be more reactive than AsA. Various non-enzymatic oxidative mechanisms involving hydrogen peroxide have already been discussed.

Glycosidases. The occurrence of indigenous β-glucosidase activity in strawberry has not been reported. Huang (1955) reported the hydrolytic glycolysis of ACN to the aglycone from various fungal preparations. The result was a greater reactivity of the anthocyanidins to oxidative degradation and loss of solubility. Erlandson and Wrolstad (1972) speculated on the presence of β-glucosidase activity in freeze-dried strawberry puree under various degrees of relative humidity. Huang (1956) noted that increased glucose content competitively inhibited the enzyme's hydrolytic activity. Therefore, even in the presence of indigenous β-glucosidase activity, concentration may inhibit its activity.

COLOR AND COLOR MEASUREMENT

Color and Color Differences

Approaches to Colorimetry. In a review paper, Clydesdale (1978) gives an excellent historical overview of the development and use of methods for color evaluation. The evaluation of transparent foods such as strawberry juice for color change can be conducted through the use of spectrophotometric methods, tristimulus colorimetry or visual colorimetry i.e., sensory evaluation. Spectrophotometric methods detect the absorbance spectra of diffuse light, a function of color, through the sample. Tristimulus colorimetry is based on comparisons of transmitted light through a sample against the color from light through each of three filters (red, green, blue). Visual colorimetry uses panelists to quantitatively and/or qualitatively evaluate color or color differences. Various mathematically related systems have been developed to measure color which utilize spectrophotometric, tristimulus or visual colorimetric data.

The Munsell Classification System (Munsell, 1905) is the basis for the most popular visual colorimetric scale. It is defined by a three dimensional, visually uniform color space with true color (hue), color intensity (chroma) and lightness of color (value) as

axes. Standard observers (panelists with normal color vision) match perceived colors against color chips that are scaled in hue, value and chroma Munsell notation. Since panelists are all susceptible to psychological sources of error, specific controlled lighting and testing conditions must be implemented and referenced if reproducibility is to be achieved. Control of light source, viewing angle and object size all can affect visual perception (Hunter and Harold, 1987).

The CIE System (1931 Commission Internationale de l' Eclairage) was developed to use information regarding the absorbance spectra of samples. This color system is based on an integration of the product of standard observer response from one of three primary colors, an illuminant absorbance and sample absorbance over the visible spectrum (Clydesdale, 1978). The color primaries were defined to matched by color by a mixture of two primaries and a luminosity (lightness) factor. In contrast to the Munsell system, the color space in not visually uniform.

The most popular color system in use is that developed by R.S. Hunter. Lea (1984) contends that tri-stimulus colorimetry is more discriminating of hue and chroma than A_{420}in products such as apple juice which have no definite 420nm spectral peak. Further, measurements are quick, standardized and accurate. This tristimulus colorimetric system expresses color also as a three dimensional color space. Hunter "L", "a" and "b" parameters are functions of color lightness, red (+) vs. green (-) color and yellow (+) vs blue (-) color, respectively (Hunter and Harold, 1987). The system uses a uniform opponent-colors scale which can be easily read from a Hunter

colorimeter (Hunter, 1958). Hunter parameters can be converted mathematically into CIE coordinates or Munsell notation. At constant value and chroma, Munsell hues can be plotted to form approximately a circle in the Hunter system at constant "L" (Hunter and Harold, 1987). Therefore, the Hunter L-a-b system is approximately, yet not completely visually uniform.

Relationships to Visual Colorimetry. Various relationships have been found between ACN absorbance spectra and Hunter L-a-b indices. The L index is inversely related to absorbance with the wavelength of maximum absorbance, λ_{max}, near 555 nm since it is functionally related to the intensity of light reaching the observer after passing through a green filter (Hunter and Harold, 1987). Van Buren et al. (1968) found the λ_{max} to vary with ACN, pH and ACN concentration. Anthocyanins, which typically absorb in the 500 and 535 range, will yield lower L values at higher λ_{max}. As pH decreases the concentration of the red flavilium cation increases, causing increased absorbance at the absorbance maximum and a decrease in L. Further, at high concentrations of ACN a shift in absorbance maximum is observed with a decrease in pH. A similar, yet less pronounced shift is observed in solutions of lower concentration. The Hunter chromaticity parameters "a" and "b" have been used to measure hue changes. Francis (1952) used the $\tan^{-1}$ (a/b) function to measure hue changes in McIntosh apples. Later, Little (1975) suggested the change to $\tan^{-1}$ (b/a) as more appropriate for measuring hue since it is positively correlated to parameters related to hue in other color systems.

Ponting et al. (1960) related the absorbance ratio A_{520}/A_{420}

and Hunter indices to visual evaluations during the degradation of strawberry and other berry juices. Absorbance ratios above one were perceptually different. Diluting strawberry juice 10% was easily distinguishable by sensory difference testing and had a euclidian Hunter L-a-b color distance of 6.3. A similar change in Hunter L-a-b distance as the diluted juice was used as a color difference indicator. This change was noted in strawberry juice after 18 hr storage at 20°C. The time for this same color loss was decreased linearly with increased temperature to 8 min at 100°C.

Color Thresholds. The Hunter L-a-b and CIE systems do not readily give information regarding colorimetric thresholds. Whereas the Hunter color space is approximately uniform, the euclidian distance in Hunter space (color difference, ΔE) does not give any information regarding the smallest colorimetric difference which is visually perceptible (i.e. difference threshold). For the CIE system, MacAdam (1943) developed a series of complex elliptical equations which can define areas of constant chromaticity (hue and chroma) for a given lightness. However, these equations require high powered computers to solve. For threshold problems, visual colorimetry may be the best approach. Munsell units are by definition the smallest perceivable color change (Hunter and Harold, 1987). Thus, they can be applied to determine the degree of change which is perceivable under specific testing conditions. However, control and standardization of conditions and parameters is a major problem. Considerable sensory research is lacking in this area.

Color Acceptability. The psychological validity of color differences has been questioned by Clydesdale (1978). He doubts that

color acceptability correlates well with color differences, especially with respect to thresholds. His argument is that conditions under which foods are viewed (e.g. illumination conditions) can vary enough to significantly alter the relationships between color difference and acceptance.

Properties of Juice Composition. Transparent liquids present various problems in color evaluations. Clydesdale (1972) noted that object-light interactions may affect color perception by reflection from the surface, refraction into the object, transmission through the object, diffusion or absorption. Diffusion is inversely related to particle size down to a lower threshold of 1/2 the size of the shortest wavelength of visible light (Hunter and Harold, 1987). In solutions of highly concentrations of pigment (e.g. greater than 1 mg/mL), Eagerman et al. (1973) found the Hunter chromaticity parameters to reach a maximum, then begin a gradual decrease. The measurements were related more to lightness (value) than to hue and chroma. Therefore, photocells do not adequately measure the perceived change in color at high pigment concentration.

Prediction of Color Change. Various models have been used to relate colorimetric parameters to time of storage of juice concentrates under specific conditions. Toribio and Lozano (1984) fit the change in browning during storage of apple juice concentrate as:

$$A_{420}=a-(b*\exp^{(-kt)})$$

where "a" and "b" are parameters, "k" is a rate constant and "t" is the time of storage. This model implies that precursors react only to form brown products and that brown products do not react further.

The loss of red color in strawberry juice and concentrate followed first order equations (Meschter, 1953). In model solutions of ACN and the presence or absence of AsA or catechin, the ACN decrease followed first order kinetics (Poei-Langston and Wrolstad, 1981). Therefore, this decrease could be modeled as:

$$A_{520,t}=A_{520,i}*\exp^{(-kt)}$$

where $A_{520,i}$ and $A_{520,t}$ are the initial and time "t" absorbance at 520, respectively. Speers et al. (1987) confirmed both findings for strawberry juice concentrate stored at 35 and 45°C for browning and 20, 35 and 45°C for red coloration. An attempt to model the ratio A_{520}/A_{420} did not result in a good fit to a first order equation. No other attempts in the literature were found to use both browning increase and red color decrease in models for the prediction of color.

Various color indices have been used to follow color degradation in strawberry products. Hassanein (1982) noted Hunter "L" values of SJ to increase during storage (get lighter) at 21°. In SJC, however, "L" decreased with storage. This was explained as the polymerization and precipitation from solution of brown pigments in SJ, whereas in SJC, the higher viscosity kept polyphenolics in solution and samples became darker. Little (1977) observed an increase in lightness in both strawberry preserves and canned strawberries. Her explanation was that ACN associated with polyphenolic complexes and were released, and subsequently degraded during processing by acid hydrolysis. Degradation resulted in loss of ACN and a lighter solution.

Intensity and Time-intensity Evaluation

Intensity Scales. The measurement of taste perception for food science applications has undergone considerable evolution during the past two decades. Sensory intensity data has been acquired through the use of various scales which have been classified as nominal, ordinal, interval or ratio (Stone and Sidel, 1985; O'Mahoney, 1987). Nominal scale data are numbers assigned to names which are qualitative, rather than quantitative. Ordinal scales represent rank orders. Interval and ratio scales represent real quantities with equal distances between intervals. Ratio scales are further distinguished from interval scales since they represent the quantitation of a difference as an intensity ratio (i.e. twice or 1/2 the intensity) and where zero (log 1) represents a "true zero" (O'Mahoney, 1986). O'Mahoney (1986) explains this difference using temperature scales which are interval, rather than ratio scales. The difference between 0 and 50^{o}C equals the difference between 50 and 100^{o}C, but 100^{o}C is not twice as hot as 50^{o}C since 0^{o}C is not zero heat content.

The use of ratio scales to rate the magnitude (e.g., twice or half the intensity of a reference intensity) of a sensory difference was developed by psychologists. This scale is widely known as magnitude estimation (ME). Stevens (1953) related ratio scaled responses to increases in stimuli. This lead to the development of

psychophysical response curve known as the power function or Steven's psychophysical law. Moskowitz (1968, 1974) first applied ratio scales to food science. Ratio scores from each panelist were normalized by dividing by the geometric mean of all ratio scores during a session to form the magnitude estimate (ME) parameter.

Two types of interval scales are the category and line (graphic) scale. As described by Stone and Sidel (1985), category scales segment the intensity spectrum into partitions with differences among intervals assumed to be of constant differences in perceived intensity. Line scales do not segment the intensity spectrum, yet have the same assumption with respect to constant differences in perceived intensity.

Giovanni and Pangborn (1983) compared the differences between interval line scales (graphic scaling) and magnitude estimation. Category scales were easier to administer and to understand, yet were subject to psychological sources of error that violate the assumption of equal intervals. Magnitude estimation was more difficult for panelists to use due to rounding biases and was found inappropriate for bidirectional scaling (e.g. like vs dislike). O'Mahoney (1986) notes that magnitude estimates are not normally distributed, therefore are inappropriate for analysis of variance. This may not always be true since the means of magnitude estimates tend to be normally distributed as the number of observations increase. Further, transformations (i.e. logarithmic) may increase the normality of the ME data.

Time-intensity Evaluations. The time component of sensory perception has been found to be particularly important in studies

involving taste and, to a lesser degree, aroma. Early time-intensity (TI) research relied on the use of chart recorders where the intensity of perception was drawn on paper (Larson-Powers and Pangborn, 1978). Birch and Munton (1981) used a dial potentiometer linked to a chart recorder. Typical acquisition of information from TI curves required the measurement of lengths and areas with a planimeter. Schmitt et al. (1984) used a digitizer to input data from a chart onto a computer. Guinard et al. (1985) reported the use of a joy-stick (potentiometer) linked to a mainframe computer with an internal clock for the acquisition of sensory data. Lee (1985) report the use of a "game paddle" (potentiometer) interfaced with an Apple microcomputer. Yoshida (1986) used a "mouse" (potentiometer) interfaced with a Mitsubishi microcomputer.

All above sensory evaluations used line scales to measure the TI responses. Except for two sources cited above, all researchers structured their scales with "none" and "extreme" at the ends. Birch and Munton (1981) left the upper scale end unstructured. The scale was referred only as a "magnitude estimation" on a 10 point continuous line scale (from the dial potentiometer). Lee (1985) labelled the scale ends as "weak" and "strong", respectively.

TI curves have been analyzed in different ways. Pangborn et al. (1983) compared intensity responses against the following components of the TI curve: maximum intensity (I_{peak}), total duration time from onset to extinction (D_{total}), total area under the curve (A_{tot}) and total curve perimeter (P_{total}). Birch and Munton (1981) report the use of time of "persistence" (T_f). Birch (1981) used the time of initial perception, "reaction time" (T_i), and

plotted the inverse of the initial rate of intensity increase,

$$[I_{peak}/(T_{peak}-T_i)]^{-1},$$

against the inverse of sucrose concentrations. Leach and Noble (1986) measured the linear rates of increase and decrease by least squares analysis. Schmitt et al. (1984) separated the curves into three sections: increasing slope, peak and decreasing slope. The increasing slope segments were fit to a simple linear model of intensity vs time. The decreasing slope segments were fit to a negative exponential model. The peak data was not used. Overbosch et al. (1986) reports a curve averaging procedure. The procedure calculates the geomtric means (GM) of both the time and intensity components from samples taken at 2% intervals along the time axis. The time and intensity GM are then plotted for each sample to yield an averaged TI curve.

Theoretical relationships between TI response variation and psychophysical or physical factors were discussed by Overbosch (1986). Perception was modeled according to Steven's power law under various states of adaptation noting that intensity follows an exponential decay at constant stimulus and as the stimulus increases, the time of duration (D_{tot}) is longer. Birch and Latymer (1980) viewed this relationship as strictly physical. A stimulus (pharmacophore) queuing mechanism was hypothesized to account for the TI of sweetness. This model was based on observations that time to maximum intensity (T_{peak}) approached a maximum faster over increasing concentrations of stimuli than the initial time (T_i) and time of duration (D_{total}), respectively. This aspect of TI perception was explained by diffusion of pharmacophores to the taste

pore receptor site. At the receptor site a queue is set up where stimuli were cycled through the taste pore opening. As theconcentrations of stimuli remained high at the many receptor sites, the duration of maximum intensity (time of peak duration, D_{peak}) was observed to be longer.

Taste Evaluation

Bitterness and Relationships to Astringency. Bitterness is one of the basic tastes, astringency is a mouth feel. Lea and Timberlake (1974) and Lea and Arnold (1978, 1983) noted changes in astringency and bitterness during the oxidation and polymerization of phenolics in three different Dabinett ciders. Procyanidin oligomers (2-5 units) and polymers (6-10 units) were hypothesized to be responsible for bitterness and astringency, respectively. Arnold and Noble (1978) found an increase in phenolic content (gallic acid equivalent) during wine oxidation associated with an increase in astringency. Bitterness was not observed to increase. Hodge (1967) notes that 5-hydroxymethyl-2-furaldehyde (HMF), a degradation compound related to non-enzymatic browning is both bitter and astringent.

Astringency has been proposed to be due to hydrogen bonding between o-diphenolics and salivary proteins resulting in complex precipitation (Bate-Smith, 1973). Under this hypothesis, Bate-Smith (1973) developed a relative astringency index based on the ability of compounds to precipitate blood proteins. Dimers, trimers, tetramers and higher order oligomers of D-catechin and L-epicatechin were found to increase in relative astringency with increased polymerization.

Small peptides have been found to be bitter (Guigoz and Solms, 1976). The relative bitterness was related to the hydrophobicity of side chains. Beart et al. (1985) found small phenols to have a lower affinity for proteins than large polyphenols. This led Clifford (1987) to propose that small phenolic substances have a greater affinity for the bitter receptor site. Therefore, solutions prior to oxidation may be perceived as bitter, while oxidation and polymerization would increase astringency.

Both astringency and bitterness have a long TI component to their taste (Guinard et al., 1986a, 1986b). The long TI of perception results in a carry-over effect with repeated ingestion for both tastes. This could result in signal confusion due to overlapping TI curves. Lea and Timberlake (1978) reported that some panelists had difficulties in distinguishing between these stimuli.

Sweetness. Shallenberger (1980) discusses the theory of sweetness perception from a chemoreception perspective. Sweet pharmacophores must have both a proton donor and proton receptor approximately three angstroms apart. In addition, there must be present a lipophilic center combined with a hydrophilic function. The lipophilic center must also relate geometrically to the proton donor and receptor in a certain way. These requirements are believed to explain why D-amino acids are generally sweet, while L-amino acids are not. The L-amino acids do not fit the geometric requirements. Free sugars (i.e. glucopyranose, fructopyranose) are sweet as either L- or D- forms due to the cyclic nature of their structure. In strawberry juice free sugars (sucrose, glucose and fructose) can affect sweetness perception as well as other compounds which satisfy

these chemoreception requirements. Other factors can affect sweetness. Pangborn et al. (1973) found visocity to reduce sweetness perception only at high concentrations. Shamil et al. (1988) did not find this to be due to the intrinsic property of a sweet compound.

Sourness. Sourness chemoreception mechanisms are not as complex as those for sweetness since only a proton donor is required (Beets, 1978). However, other factors complicate the relative sourness characteristics of sour pharmacophores. Harvey (1922) related pH and total acidity to sourness. Plane et al. (1980) noted that total acid concentration and pH both contribute to sourness since associated and dissociated acids affect perception. Buffer capacity, dissociation constants and number of carboxylic groups from several organic acids were compared for differences in sourness intensity (Nobel et al., 1986). Buffer capacity was concluded as an unlikely contributor to sourness intensity. Citric acid, the major acid of strawberry juice, was found to be less sour than equinormal concentrations of fumaric, tartaric, malic and lactic acids. This data was based on paired comparisons of mixtures of two acids where pH and titratable acidity were equal. Therefore, the number of carboxylic groups is not a major factor influencing sourness intensity.

Interactions of Taste Components. The complexity of beverage solutions such as strawberry juice involve interactions among compositional components that can contribute to taste perception by direct or indirect mechanisms. As already mentioned, there is evidence for a compositional relationship between the degree of polymerization of phenolics and the perception of bitterness and

astringency in ciders (Lea and Timberlake, 1974; Lea and Arnold, 1978).

Guinard et al. (1986) noted that increasing the level of acidity (pH and titratable acidity measurements) increased the relative astringency of model solutions of tartaric and tannic acids and of white wine. This interaction was explained as an increase in tannins in the phenol form and an increase in hydrogen bonding between the dihydroxyphenol groups of the tannin and mouth proteins. Clegg (1966) hypothesized that citric acid tends to associate with brown pigment complexes. However, Straub (1989) found aqueous solutions of citric, lactic, fumaric, malic and tartaric acids all astringent. Therefore, the saliva proteins may be affected by acidic solutions and acheive an astringent response in the absence of phenolics.

In wine studies, Pangborn et al. (1964) found citric acid to exhibit a strong inhibitory effect on apparent sweetness. In canned tomato juice (Pangborn and Chrisp, 1964) and lima bean puree (Pangborn and Trabue, 1964) sucrose and citric acid have shown mutual suppression or masking effects. Perng (1988) noted the sweetness:sourness ratio to follow a linear relationship with sucrose-citric acid concentration ratios. Therefore, this sweet/sour effect may be indicative of psychophysical rather than chemical (physical) factors.

Aroma Evaluation

Aromas Related to Degradation. Various aroma constituents of strawberry have been found to develop only from fruit which have

undergone damage. Winter and Willhalm (1964) note the presence of 2-hexenal, the main carbonyl of crushed strawberry, and diacetyl ("buttery" aroma) in only crushed and damage fruit. These aroma components are indications of compositional change from active enzyme systems in strawberry (discussed previously) which are activated upon crushing or damage of strawberry fruit.

Musty/moldy Aromas. It is generally known in the industry that strawberry juice and concentrate develop an off-aroma upon storage. However, a detailed sensory evaluation of this off-aroma has not been found in the literature. Preliminary evaluations of this off-aroma indicate the formation of a "musty/moldy" aroma.

The presence of aromas that are described to be musty and/or moldy have been reviewed by Maga (1987). A large range of compounds have been found to be responsible for these aramas. Maga (1987) lists several with thresholds in the range of 10^{-9} (ppm) to 10^{-12} (ppb). Most of these sources were microbial in origin. However, this does not eliminate the possibility for musty/moldy odor active substances of non-microbial origin. Maga (1987) lists geosmin, 2-methyl-isoborneol and some pyrazines as sources. It has already been discussed that pyrazines can be formed by Strecker degradation reactions involving α-amino acids and α-dicarbonyl compounds from free sugars or ascorbic acid decomposition.

Pungent Aromas. Another component of aroma is the sensation generally known as pungency. This sensation accounts for such descriptors as stinging, cooling, irritating, burning, prickling, tingling, etc. (Cometto-Muniz and Noriega, 1985). Sensations such as this are known to be related to the stimulation of the trigeminal

nerve and can illicit respiratory reflex responses (Angell-James and Daly, 1975). Strong irritants are known to yield pungent responses (Cometto-Muniz and Cain, 1982). Gender differences have been found in sensitivity to pungent stimuli with males less sensitive (Cometto-Muniz and Noriega, 1985).

Pungency has a time-intensity (TI) component. The onset of sensation and time to peak has been described to be quicker than other aromas (Cometto-Muniz and Cain, 1984). The same stimuli were found to illicit both aroma and pungent responses (Cometto-Muniz and Cain, 1984). Therefore, it is possible that strong unpleasant off-aromas can yield pungent responses. Cometto-Muniz and Cain (1982) and Cometto-Muniz and Noriega (1984) used CO_2 to illicit a pungent response. Therefore, another source for pungency is CO_2, a known product from the Strecker degradation and ascorbic acid browning reactions.

Flavor, Aroma and Compositional Changes in Strawberry Juice Concentrate Stored at 20°C

D.S. Lundahl, M.R. McDaniel and R.E. Wrolstad

Department of Food Science and Technology

Oregon State University

Corvallis, OR 97331

RUNNING HEAD: Stored Strawberry Concentrate

ABSTRACT

Strawberry juice concentrate (68°Brix) was stored at 20°C for 0-6 days. Samples were analyzed for changes in taste, aroma and color degradation, and these changes were related to composition change. Astringent taste, musty/moldy and pungent aromas and brown color developed rapidly over six days. This decrease in quality was accompanied by CO_2 production and a decrease in free amino acids, while reducing sugar and titratable acidity concentrations remained stable. Results supported Strecker degradation and ascorbic acid browning as possible degradation pathways.

INTRODUCTION

STRAWBERRY JUICE CONCENTRATE (SJC) is widely produced as a natural flavoring. However, its use is hindered by a susceptability to browning and undesirable flavor changes when held for short periods of time at room temperature and longer periods at refrigeration temperatures. In spite of the general popularity of natural strawberry flavor, this problem has hindered the application of SJC to foods and beverages.

Color degradation of strawberry products has received considerable attention in the literature (Kertesz and Sondheimer, 1948; Decareau et al., 1956; Wrolstad et al., 1970, 1980; Spayd and Morris, 1981; Sistrunk et al., 1982; Speers et al., 1987). Color degradation is accompanied by decreases in red pigmented anthocyanins and increases in red-brown pigments (Wrolstad et al., 1980). Several researchers noted that ascorbic acid degradation is often related to color loss (Starr and Francis, 1968; Wrolstad et al., 1970; Abers and Wrolstad, 1979; Spayd and Morris, 1981). The rate of browning increased with reduced water activity (Erlandson and Wrolstad, 1972), increased storage temperature (Hassanein, 1982) and decreased concentrations of antioxidants such as phenolics (Shirkhande and Francis, 1974; Poei-Langston and Wrolstad, 1981).

Both enzymatic and non-enzymatic pathways have been proposed for the initiation of and/or contribution to color degradation in juice beverage systems. Non-enzymatic pathways have been tested by experimentation involving model solutions (Eichner and Karel, 1972; Shirkhande and Francis, 1974; Poei-Langston and Wrolstad, 1981; Reyes

et al., 1982). Possible pathways include Maillard reactions, Strecker degradation and ascorbic acid browning. Enzymatic systems have also been proposed. Oxidases, such as polyphenol oxidase, may accelerate oxidation-reduction reactions involving ortho-quinones, ascorbic acid and monomeric anthocyanins (Wrolstad et al., 1980). Protein modifications initiated by oxidases and peroxidases could be involved in cross linking and complexing with anthocyanins (Lea and Timberlake, 1974; Matheis and Whitaker, 1984).

In spite of the efforts to understand color degradation in SJC, there is a lack of information regarding the simultaneous change in flavor, color and composition. A few studies have noted flavor degradation in strawberry products. Kertesz and Sondheimer (1948) reported color loss preceded undesirable flavor changes in strawberry preserves. Decareau et al. (1956) noted degradation in flavor with increased temperature and processing time in strawberry jellies. Spayd and Morris (1981) found thaw time (at 30°C), acid concentration, and a temperature by storage time interaction to significantly affect color, flavor and overall acceptability of strawberry jam.

The understanding of relationships between composition and flavor characteristics in SJC may aid in the development of a degradative pathway theory. Taste attributes such as astringency and bitterness have been related to the polymerization of phenolics (Bate-Smith, 1973; Lea and Timberlake, 1974; Lea and Arnold, 1978; Hagerman and Butler, 1981; Lea, 1984; Delcour et al., 1985; Clifford, 1987). Odor active compounds may be formed by pathways that relate to color degradation (e.g., Maillard reactions, Strecker degradation, and

ascorbic acid browning). Therefore, this study was conducted to profile the sensory changes occurring in SJC during storage and to relate these changes to compositional indices.

MATERIALS & METHODS

Concentrate Processing

Strawberry juice concentrate (SJC) was obtained from a local commercial juice processor (Kerr Concentrates, Inc.; Salem, OR). The fruit consisted of locally grown, mixed cultivars common to the Pacific Northwest. The fruit had been frozen in 55 gallon (208.2 L) drums and stored for two months at -15°C. Juice was processed from thawed fruit by: liquefaction with pectinase at 50°C for 2 to 2 1/2 hrs, pressing with a cellulose press aid, enzymatic depectinization at 40°C for 8 hrs, pasteurization at 100°C for 3-4 sec with an Inter-Drive (Model No. Z11E-15SS, Rodney-Hunt Machine Co., Orange, Mass.) falling film evaporator and clarification by filtration with diatomaceous earth. Concentration to 68°Brix in one pass was accomplished using an Centra-Therm (Model No. CT6, α-LaVal, Lund, Sweden) centrifugal evaporator. The essence was recovered but not added back to any samples.

Storage treatments

The SJC was transported in 5 gallon (18.9 L) containers to Oregon

State University within 1 hr after processing. This material was divided into 50-60 mL sample aliquots and stored in 60 mL glass vials at -40°C. Samples were coded and randomly assigned to various storage treatments.

Storage treatments included removing samples from frozen storage at -40°C, transfering them to 20°C for 0, 1, 2, 3, 4, 5 or 6 days and refreezing them at -40°C until evaluation. All samples were stored in the dark.

Sensory Evaluations

Eleven volunteers (four males and seven females) participated on a trained panel to evaluate reconstituted juice samples that were subjected to storage treatments as a concentrate. Panelists were graduate students, faculty and staff from the Oregon State University Department of Food Science and Technology with varying degrees of sensory evaluation experience. Nine sessions were used for descriptor generation, four sessions for ballot development and training and fourteen sessions for descriptive analyses.

Samples (50-60 mL) of SJC that were subjected to storage treatments of 0, 1, 2, 3, 4, 5 or 6 days at 20°C were thawed, then reconstituted to 8°Brix for sensory evaluation one hour prior to each panel session. Initially, 32 descriptive terms were generated by the panel to describe differences between a control (0 days storage) and samples with storage treatments. This list of terms was narrowed to four descriptors for taste (sweet, sour, bitter and astringent) and four descriptors for aroma (musty/moldy, sulfury, cooked and

pungent).

Panelists were trained to respond to detected differences on a nine point difference from control scale (0="no difference", 8="extreme difference"). Panelists also indicated the direction of change (e.g. greater than or less than control); therefore, including the direction of difference, data were evaluated as a seventeen point scale.

Experimental Design. With seven treatments (0-6 days storage), a balanced incomplete block (BIB) design with three samples presented per session was employed to reduce sensory adaptation and fatigue. This design required seven sessions which resulted in three replications of treatments. Each panelist replicated this design twice over fourteen sessions.

Samples were presented to panelists in three rows, evaluated from left to right within rows and from front to back over rows (Figure 2.1). Within each row, aroma evaluations included a randomly arranged hidden control (same as the reference control) and storage treatment sample. Both samples within a row were evaluated against the reference control in their row. Control of sensory adaptation was further facilitated by fixing the presentation order such that samples of less storage were evaluated before those of longer storage. Any resulting order effect was removed statistically by subtracting the difference response on the hidden control from the difference response from storage treatment samples.

To minimize fatigue, taste difference evaluations did not include hidden controls. Once the aroma differences were completed, panelists returned the samples to the sensory attendent, who removed the hidden

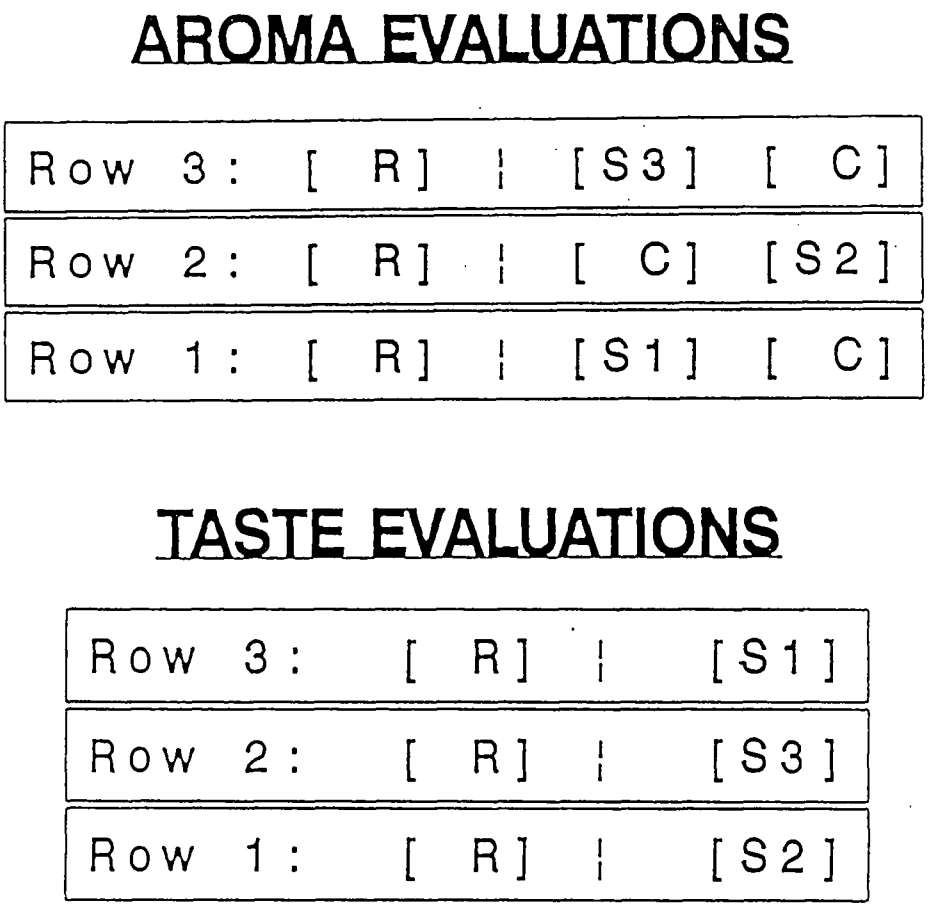


Figure 2.1. Scheme for presenting samples to panelists for aroma and taste difference evaluations. Sample evaluations for aroma include three samples (S_1, S_2, and S_3) and three hidden controls (C) evaluated against reference controls (R) in the same row. Taste evaluations included samples evaluated against reference controls without hidden controls.

controls and randomized the order of samples to be evaluated against the reference controls.

Statistical Analyses. Panelists were first individually evaluated for consistency in their difference responses on the hidden controls for aroma, and on the storage treatment samples for taste. Panelists guessing that aroma differences exist, when they are not present (false non-zero difference from control response), may inflate their mean square error, which can violate the ANOVA assumption of homogeneity of variances (Cochran and Cox, 1950). To test this assumption, Bartlett's test of homogeneity of variances (Snedecor and Cochran, 1980) was applied to individual panelist mean square errors. Panelists contributing significantly to heterogeneity were removed from the analysis on only that descriptor.

The ANOVA on the eight descriptors were conducted by first adjusting each panelists' responses for the incomplete blocks as suggested by Gacula and Singh (1984). Since each panelist replicated the BIB design, that replication could be used to conduct a two-way ANOVA. The mean square for panelist by storage interaction was used as the appropriate "error" for testing for storage effects as suggested by Lundahl and McDaniel (1988). When the storage source of variation was significant, mean responses at each of the seven storage times were tested with a two-tailed t-test of differences from zero or the sample with 0 days storage for aroma or taste analyses, respectively.

Colorimetric Determinations

Samples were stored as SJC for 0, 3 or 6 days at 20°C, reconstituted to 8°Brix with double distilled deionized water and then assessed in triplicate for differences in color and pigment composition.

Determination of Hunter Indices. A Model DP-25P-2 (Hunter Instruments, Reston, VA) color difference meter was used to measure color (transmission mode, spectral component included-Arrangement III). The instrument was calibrated as described by the manufacturer. Hunter L, a, b values were measured in a 2.0 cm pathlength cell, converted to C.I.E. coordinates and expressed as Munsell hue, value and chroma values assuming an incandescent light illuminant.

Spectral Analyses. A Model DMS 100 interfaced with DS-15 data station (Varian) UV-visable spectrophotometer was used for measuring the monomeric anthocyanin pigment concentration, browning index, color density and polymeric color by the pH differential and bisulfite bleaching methods (Wrolstad, 1976). Haze formation was evaluated at 700 nm absorbance. Anthocyanin concentration, expressed as mg/100 mL pelargonidin-3-glucoside, was determined from absorbance at 520 nm, E=22,400.

Compositional Analyses

Titratable Acidity, pH and Free Amino Acids. Changes in reconstituted juice samples after 0 or 6 days storage as a concentrate were evaluated in triplicate, with replicated evaluations

on each sample. Evaluations were conducted on a 1.0 mL capacity Metrohm Model 655 auto-titrator with a motor-driven piston burette and microprocessor-control and a pH electrode (Ross Model 81550) with a microprocessor pH/mV meter (Orion Model 811). Samples were reconstituted to 8°Brix with double distilled, deionized, CO_2-free water. Titratable acidity was determined using a glass electrode to an end-point titration of pH 8.2 (AOAC, 1984) and expressed as percent (w/v) citric acid. Free amino acids were evaluated by the formol titration method to an end-point back titration at pH 8.4 (AOAC, 1984). Amines were expressed as mg/100mL α-amino nitrogen (glycine equivalent).

Sugar Analyses. A Varian Model 5000 high performance liquid chromtograph (HPLC) equipped with column heater and refractive index detector (Varian Instrument Group, Walnut Creek, CA) was used to monitor changes in glucose, fructose, sucrose and sorbitol. A Biorad Aminex HPX-87C carbohydrate column and mobile phase of 200 mg/L calcium nitrate were used for separation of these carbohydrates. Quantitation was facilitated with an internal standard of mannitol and external standards of sucrose, glucose, fructose and sorbitol. Sample preparation included removal of pigments with a Waters C-18 sep-pak cartridge and removal of organic acids with Biorex-5 anion exchange resin (Spanos and Wrolstad, 1987).

CO_2 Determinations. The evolution of CO_2 was measured by gas-liquid chromatography (GLC) of the headspace above 10 g of SJC in a 25 mL Erlyenmeyer flask with a serum septum stopper. The headspace was purged under vacuum and filled with N_2 at atmospheric pressure. The headspace was sampled by extracting 10 uL from the flask in

a 20°C water bath. The sample was then injected directly into onto a Carle Analytical Gas Chromatograph Model 311 (Hach Co., Loveland, CO) with a 182.9 m by 0.3175 cm OD stainless steel sieve Porapak-R column (80/100 mesh). The ratio of CO_2 to N_2 was measured with a thermal conductivity detector (Hach Co., Loveland, CO). The ratio of CO_2 to N_2 peak area was transformed into % CO_2 by a standard curve from known standard mixtures of CO_2 and N_2 in a 25 mL headspace at 20°C.

RESULTS

Sensory Evaluations

Analysis of Variance. The ANOVA F-values for sensory evaluations are presented in Table 2.1. The panel found significant ($p \leq 0.05$) increases in musty/moldy and pungent aromas after three days storage, while astringency increased after one day storage (Figure 2.2). There was a significant panelist effect from all descriptors except "sulfury" aroma. No panelist by storage treatment interaction was observed.

Panelist Evaluations. Applying Bartlett's test for homogeneity resulted in rejection ($p<0.05$) of the hypothesis that the mean square error for responses to the hidden control were homogenous over all panelists for only the musty/moldy descriptor. One panelist had a mean square error of 11.027, whereas the remaining panelists ranged from 0.082 to 2.018. Since heterogeniety of mean square errors among

Table 2.1. Analysis of variance results for aroma and taste difference evaluations on strawberry juice reconstituted to 8°Brix after storage at 68°Brix. The Panelist and Storage sources of variation were tested by comparing their respective mean squares against the Panelist by Storage interaction mean square.

SOURCE OF VARIATION	MUSTY/ MOLDY	COOKED/ CARAMEL	PUNGENT	SULFURY	SWEET	SOUR	BITTER	ASTRINGENT
PANELIST	3.717^{**}	2.912^{**}	3.310^{**}	1.793^{NS}	8.256^{***}	5.018^{***}	8.913^{***}	4.309^{***}
STORAGE	9.393^{***}	0.736^{NS}	6.806^{***}	0.313^{NS}	0.540^{NS}	1.706^{NS}	0.418^{NS}	3.798^{**}
PAN*STO	1.104^{NS}	1.265^{NS}	1.119^{NS}	1.238^{NS}	0.613^{NS}	0.395^{NS}	0.466^{NS}	1.032^{NS}

* = significant at 5% level
** = significant at 1% level
*** = significant at 0.1% level

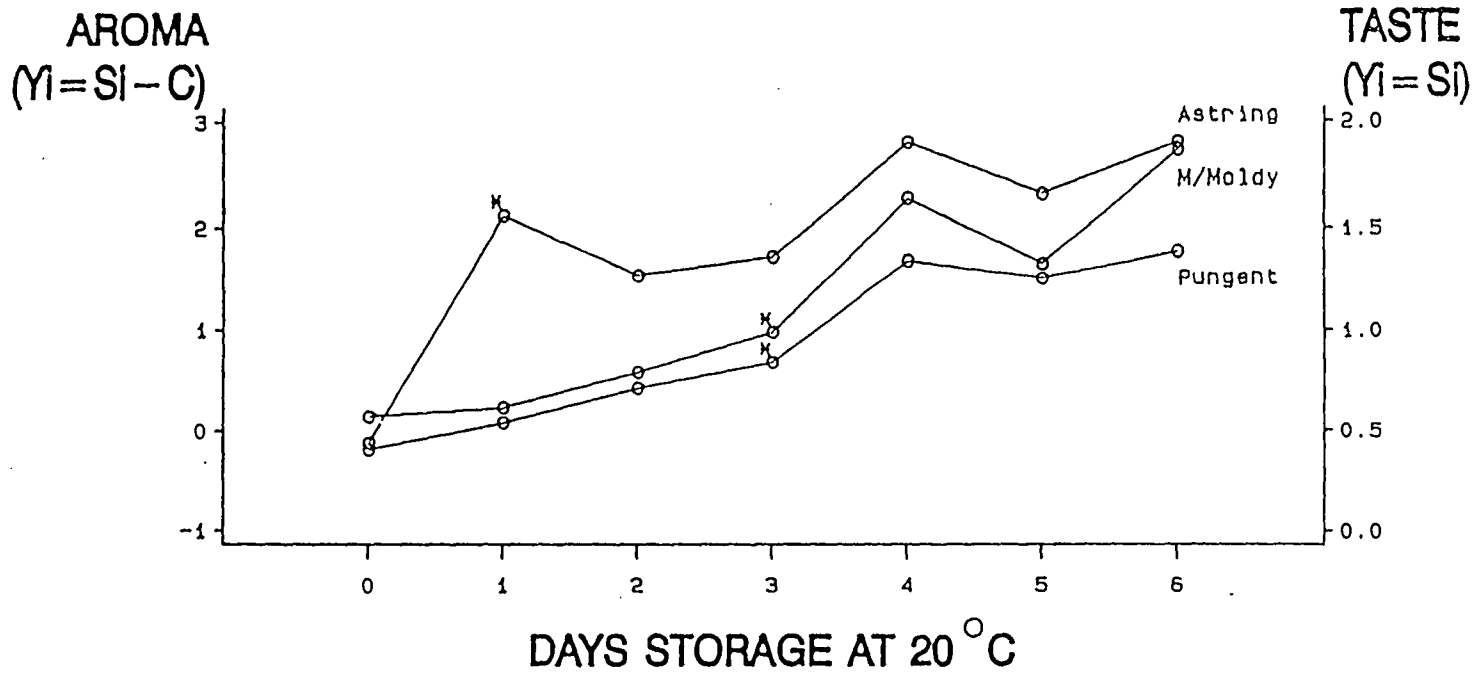


Figure 2.2. Change in aroma and taste attributes during storage of strawberry juice concentrate. The aroma attributes are adjusted for presentation order by subtraction of the hidden control score (C) from the sample score (S_i, i=1-6), while the taste attribute scores were not adjusted for presentation order. The storage time were samples scores are first significantly different from C are marked by asterisk.

panelists violate a basic ANOVA assumption, we were forced to remove this panelist from further analyses on this descriptor. Re-testing for homogeniety of variances after removing this panelist resulted in no rejection ($p>0.05$) of the hypothesis of homogeniety.

Colorimetric Analyses

Color Measurements. Changes in color were noticeable with visual inspection after three days storage at 20°C and was substantiated by the colorimetric data (Table 2.2). The Hunter L-a-b values, expressed in Munsell notation, show changes from red (10R) to red-brown (1YR) in hue, darkening (decreased value) and decreased color intensity (chroma). None of the samples showed visual evidence of haze or sediment formation.

Pigment Composition. There was a 46% linear decrease in monomeric anthocyanin pigment which was accompanied by increases in polymeric color and color density (Table 2.2). The correlation between ACN and polymeric color over the storage period was $r=-0.999$ ($p<0.05$). Measurment of absorbance at 700 nm (0.02 ± 0.016) substantiated that there was no haze formation during the six day period.

Other Compositional Changes

CO_2 Analysis. The formation of gas bubbles in the sample vials was evident during the storage experiment. Headspace analysis by gas-liquid chromatography revealed the presence of substantial

Table 2.2. Color and pigment changes during storage of strawberry juice concentrate. All evaluations conducted on juice reconstituted to 8°Brix.

DAYS STORED		HUNTER COLORIMETER[1] L	a	b	HUE	VALUE	CHROMA	ANTHOCYANINS[2] (mg/100 ml) juice	COLOR[2] DENSITY (CD)	POLYMERIC[2] COLOR (PC)	PERCENT[2] PC:CD	BROWNING[2] INDEX
0	$\bar{X}$	37.9	51.4	25.5	10R	4.34	15.36	13.08	0.40	0.23	56.93	0.34
	SD							0.196	0.005	0.010	1.988	0.003
3	$\bar{X}$	34.4	45.5	23.6	1YR	3.97	14.91	10.06	0.48	0.33	67.98	0.26
	SD							0.425	0.006	0.022	4.552	0.019
6	$\bar{X}$	31.5	41.8	21.7	1YR	3.66	13.98	7.03	0.55	0.42	76.18	0.34
	SD							0.257	0.004	0.008	1.277	0.005

1 = duplicate observations, only one sample per storage time
2 = duplicate observations, three samples measured each storage time

quantities of CO_2 in the stored samples (Figure 2.3). The headspace gases reached 17.2% CO_2 after six days.

Sugars. Glucose and fructose remained relatively stable over six days storage as a concentrate (Table 2.3). Sucrose and sorbitol were not found in measurable quantities, although a small peak for sucrose was detected in some control (unstored) samples. This suggested that some hydrolysis of any remaining sucrose might have occurred during storage.

Free Amino Acids and Acidity. Samples evaluated at 8°Brix decreased significantly ($p \leq 0.05$) in formal number from 14.565 to 14.099 mg/100mL after six days storage. Titratable acidity and pH levels remained relatively constant (Table 2.3).

DISCUSSION

Flavor, color and chemical composition of SJC changed dramatically during six days storage at 20° C. Under these relatively mild storage conditions, the 68° Brix concentrate was expected to be microbiologically stable. This expectation was supported by the stability of organic acids and sugars and lack of any visual signs of growth within the concentrate. Further, the strawberry juice had undergone a pasteurization step before concentration.

The increase in headspace CO_2 during storage is not believed to be a metabolic byproduct from either mold or osmophilic micro-organisms. This increase, however, could have evolved from a

Table 2.3. Compositional changes in free amino acids, titratable acidity, pH, and carbohydrates during the storage of strawberry juice concentrate. All samples adjusted for evaluation at 8°Brix.

DAYS STORED		AMINO ACIDS mg/100ml free amine	TITRATABLE ACIDITY mg/100ml citric	pH	CARBOHYDRATES (g/100ml) GLUCOSE	FRUCTOSE	SUCROSE	SORBITOL
0 days	$\bar{X}$	14.56	0.71	3.58	1.18	1.35	trace	ND
	SD	(0.078)	(0.005)	(0.004)	(0.063)	(0.074)		
2 days	$\bar{X}$	---	---	---	1.27	1.42	ND	ND
	SD				(0.034)	(0.030)		
4 days	$\bar{X}$	---	---	---	1.28	1.42	ND	ND
	SD				(0.052)	(0.052)		
6 days	$\bar{X}$	14.10*	0.70	3.60*	1.24	1.39	ND	ND
	SD	(0.259)	(0.002)	(0.005)	(0.022)	(0.019)		

* = significantly different from unstored sample at 5% level
ND = not detected with high performance liquid chromatography

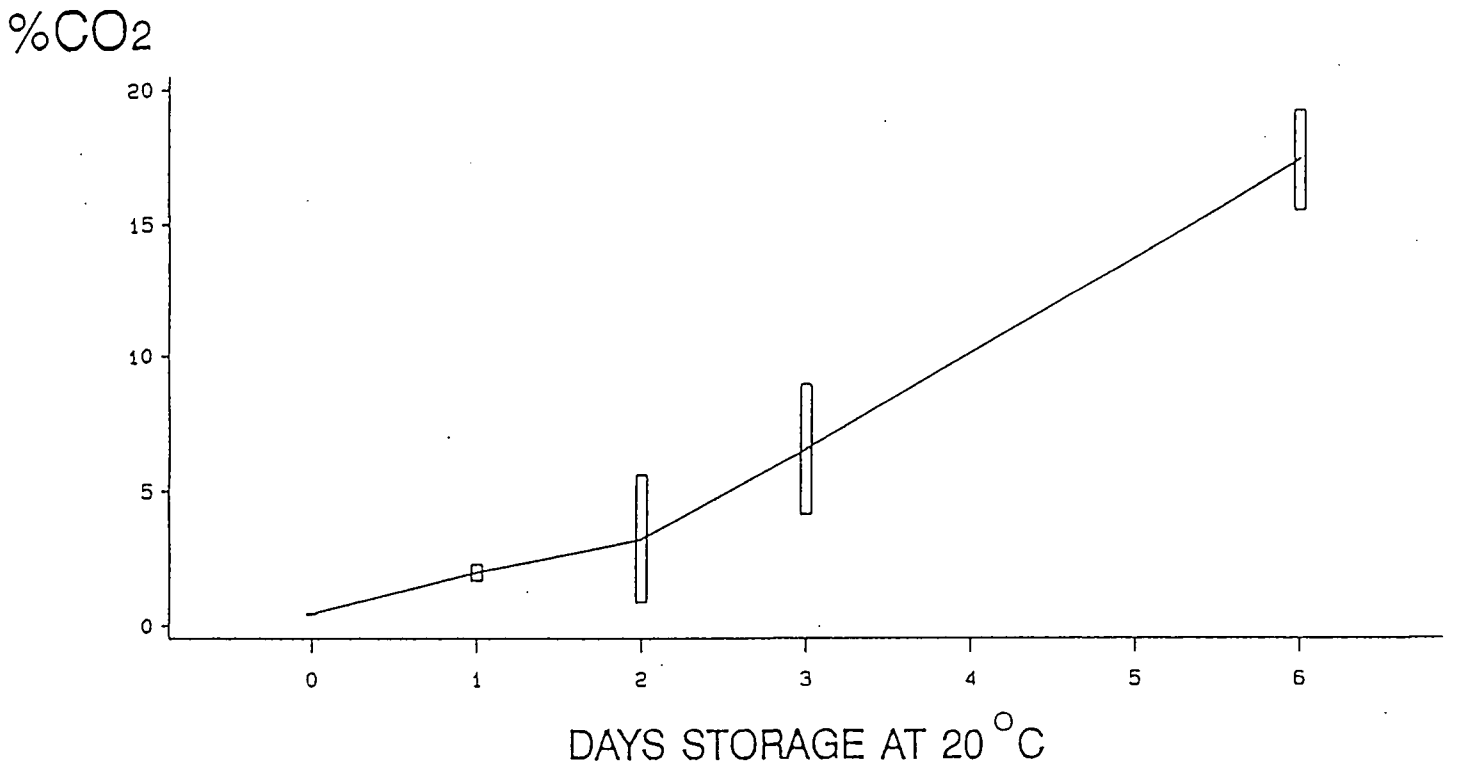


Figure 2.3. Percent CO_2 released into a 25 mL N_2 filled headspace during storage of 10 g of strawberry juice concentrate. Boxes around means are 95% confidence intervals for the mean.

Strecker degradation (transamination reaction of amino acids and α-dicarbonyls) reaction. The documented decrease in free amino acids would support this possibility, with intermediates from Maillard browning reactions being a possible source of α-dicarbonyls. Strawberry was reported to be high in free amino acids, with formal numbers ranging from 0.31 to 2.55 mEq/100g fruit (Goodall and Scholey, 1975). However, CO_2 formation has not been reported for other fruit juice concentrates such as pear which also contain substantial amounts of free amino acids and readily undergo nonenzymic browning (Cornwell and Wrolstad, 1981, Beveridge and Harrison, 1984).

Ascorbic acid is another potential source for CO_2. One proposed reaction sequence yielding CO_2 being oxidation of ascorbic acid to dehydroascorbic acid, then hydrolysis to diketogulonic acid which undergoes decarboxylation to form 3-deoxypentosone or xylosone and CO_2 (Tannenbaum, 1976). While ascorbic acid content was not measured in this investigation, strawberries are a good source of ascorbic acid. Wrolstad et al. (1970) reported a range of 28.5-94.3 mg / 100 g fruit in a 40 sample study. Ascorbic acid is particularly unstable in strawberry juice and concentrate, rapidly degrading to dehydroascorbic (Wrolstad et al., 1980). These α-dicarbonyls (especially 3-deoxypentosone) could subsequently undergo Strecker degradation by reacting with free amino acids to form additional quantities of CO_2.

While enzymic catalyzed reactions should also be considered as a possible source of CO_2, we do not believe that they played a major role in its formation in this investigation. The pasteurization step

in processing (100°C for 3-4 seconds) was expected to inactivate by denaturation many of the enzymes present in the strawberry juice. However, enzymatic reactions prior to pasteurization could form precursors which subsequently break down during storage.

Ascorbic acid and it breakdown products might also be involved in the mechanisms facilitating nonenzymatic browning. The α-dicarbonyls from dehydroascorbic acid decomposition can further degrade form meloidin (brown) pigments. This may have contributed to the observed increase in color density. It has also been demonstrated both in model systems and in strawberry juice and concentrate that ascorbic acid accelerates anthocyanin degradation (Shrinkhande and Francis, 1974; Wrolstad et al., 1980; Poei-Langston and Wrolstad, 1981).

The increase in astringency, detectable after one day of storage, could be the result of polymerization of anthocyanins and other phenolics. However, this association between anthocyanin loss, polymeric color formation and increased astringency does not establish causation. Other factors could also increase the astringent taste. Proteins can complex with phenolics (Lea and Timberlake, 1974; Matheis and Whitaker, 1984) to form complexes which can elicit an astringent taste (Lea and Timberlake, 1974; Clifford, 1987). The lack of haze formation in this investigation did not rule out the possibility for protein-phenolic interaction, only that if any such complexes were formed, they did not result in insolubility.

The "musty/moldy" descriptor was chosen by the panel as the best general description of the perceived aroma. It was not intended to imply a microbial off-flavor source. A large range of compounds might

be responsible for this aroma. Maga (1987) lists many possible sources including geosmin, 2-methylisoborneol and pyrazines. Pyrazines can be formed during Strecker degradation or ascorbic acid browning. Many compounds producing "musty/earthy" aromas have thresholds in the 10^{-9} (ppm) to 10^{-12} (ppb) range (Maga, 1987). Therefore, identification of the musty/moldy source could be difficult.

This investigation established that a number of flavor, color and compositional changes occurred during short-term storage of SJC. Future research should be directed to identify the source(s) of CO_2 and the compounds responsible for increased astringency and flavor change. Determining the causes for these deleterious changes and the relative importance of nonenzymic vs. enzymic reactions should be pursued. The findings may suggest improved processing methods and alternative storage conditions for minimizing these changes.

REFERENCES CITED

Abers, J.E. and Wrolstad, R.E. 1979. Causative factors of color deterioration in strawberry preserves during processing and storage. J. Food Sci. 44:75.

AOAC. 1984. "Official Methods of Analysis," 14th ed. Association of Official Agricultural Chemists, Washington, DC.

Bate-Smith, E.C. 1973. Haemanalysis of tannins: The concept of relative astringency. Phytochemistry 12:907

Beveridge, T. and Harrison, J.E. 1984. Nonenzymatic browning in pear juice concentrate at elevated temperatures. J. Food Sci. 49:1335.

Clifford, M.N. 1987. Phenol-protein interactions and their possible significance for astringency. Ch. 10. In "Interactions of Food Components," G.G. Birch and M.G. Lindley (Ed.), p. 143. Elsevier Applied Science Publishers, New York.

Cochran, W.G. and Cox, G.M. 1950. "Experimental Designs," John Wiley and Sons, Inc., New York.

Cornwell, C. J. and Wrolstad, R. E. 1981. Causes of browning in pear juice concentrate during storage. J. Food Sci. 56:515.

Decareau, R.V., Livingston, G.E. and Fellers, C.R. 1956. Color changes in strawberry jellies. Food Technol. 10:125.

Delcour, J.A., Vandenberghe, M.M., Corten, P.F. and Dondeyne, P. 1985. Formation of ethyl esters of tartaric acid during wine aging: chemical and sensory effects. Am. J. Enol: Vitic. 35(3):134.

Eichner, K. and Karel, M. 1972. The influence of water content and water activity on the sugar-amino browning in model systems under various systems. J. Agric. Food Chem. 20(2):218.

Erlandson, J.A. and Wrolstad, R.E. 1972. Degradation of anthocyanins at limited water concentration. J. Food Sci. 37:592.

Gacula, M.C., Jr. and Singh, J. 1984. "Statistical Methods in Food and Consumer Research," Academic Press, Inc. London.

Goodall, H. and Scholey, J. 1975. The analysis of strawberries as a means of determining the fruit content of manufactured products. J. Food Technol. 10:39.

Hagerman, A.E. and Butler, L.G. 1981. The specificity of proanthocyanin-protein interactions. J. Biol. Chem. 256:4494.

Hassanein, S.M. 1982. Color of strawberry juice concentrate as influenced by heating and storage temperature. M.S. thesis, Oregon State Univ., Corvallis, OR.

Kertesz, Z.I. and Sondheimer, E. 1948. To reduce color losses in strawberry preserves. Food Ind. 20(9):106.

Lea, A.G.H. 1984. Tannin and colour in English cider apples. Flussiges Obst 8:137.

Lea, A.G.H. and Timberlake, C.F. 1974. The phenolics of ciders: 1. procyanidins. J. Sci. Food Agric. 25:1537.

Lea, A.G.H. and Arnold, G.M. 1978. The phenolics of ciders: bitterness and astringency. J. Sci. Food Agric. 29:478.

Lundahl, D.S. and McDaniel, M.R. 1988. The panelist effect: fixed or random? J. Sensory Stud. 3:113.

Maga, J.A. 1987. Musty/earthy aromas. Food Rev. Int. 3(3):269.

Matheis, G. and Whitaker, J.R. 1984. Modification of proteins by polyphenol oxidase and peroxidase and their products. J. Food Biochem. 8:137.

Poei-Langston, M.S. and Wrolstad, R.E. 1981. Color degradation in an ascorbic acid-anthocyanin-flavanol model system. J. Food Sci. 46:1218.

Reyes, G.R., Poocharoen, B. and Wrolstad, R.E. 1982. Maillard browning reaction of sugar-glycine model systems: changes in sugar concentration, color and appearance. J. Food Sci. 47:1376.

Shrikhande, A.J. and Francis, F.J. 1974. Effect of flavonols on ascorbic acid and anthocyanin stability in model systems. J. Food Sci. 39:904.

Sistrunk, W.A., Morris, J.R. and Kozup, J. 1982. The effect of chemical treatments and heat on color stability of frozen machine-harvested strawberries for jam. J. Am. Soc. Hort. Sci. 107:693.

Snedecor, G.W. and Cochran, W.G. 1980. "Statistical Methods," 7th Ed. The Iowa State Univ. Press, Ames, IA

Spayd, S.E. and Morris, J.R. 1981. Influence of immature fruits on stawberry jam quality and storage stability. J. Food Sci. 46:414.

Spanos, G. and Wrolstad, R.E. 1987. Anthocyanin pigment, non-volatile acid, and sugar composition of red raspberry juice. J. Assoc. Off. Anal. Chem. 70:1036.

Speers, R.A., Tung, M.A., and Jackman, R.L. 1987. Prediction of colour deterioration in strawberry juice. Can. Inst. Food Sci. Technol. J. 20(1):15.

Starr, M.S. and Francis, F.J. 1968. Oxygen and ascorbic acid effect on the relative stability of four anthocyanin pigments in cranberry juice. Food Technol. 22:91.

Tannenbaum, S.R. 1976. Vitamines and Minerals. Ch. 7. In "Principles of Food Science," O.R. Fennema (Ed.), p. 347. Marcel Dekker, Inc., New York.

Wrolstad, R.E., Lee, D.D., and Poei, M.S. 1980. Effect of microwave blanching on the color and composition of strawberry concentrate. J. Food Sci. 45:1573.

Wrolstad, R.E., Putnam, T.P., and Varsevald, G.W. 1970. Color quality of frozen strawberries: effect of anthocyanin, pH, total acidity and ascorbic acid variability. J. Food Sci. 35:448.

Wrolstad, R.E. 1976. Color and pigment analyses in fruit products. Station Bulletin No. 624, Agric. Exper. Sta., Oregon State Univ., Corvallis.

ACKNOWLEDGMENTS

This research was supported by a grant from Kerr Concentrates, Inc.; Salem, Oregon. This is an Oregon State University publication (Oregon Agricultural Experiment Station Technical Report Number 8676).

Changes in Flavor, Color and Composition During Processing and Storage of Concentrate from Blanched Strawberries

D.S. Lundahl, M.R. McDaniel and R.E. Wrolstad

Department of Food Science and Technology

Oregon State University

Corvallis, Oregon 97331

RUNNING HEAD: Concentrate from Blanched Strawberries

----------ABSTRACT----------

Strawberries, blanched or unblanched prior to liquefaction, were processed into pasteurized juice and concentrated to 68°Brix. Concentrate (SJC), after storage at 20°C (0-6 days), and juice (SJ) were evaluated for blanch effect on taste, aroma and color, as well as composition. Compositional and sensory changes due to blanching were not detected in SJ. Blanching reduced the loss of anthocyanins (ACN) and CO_2 release. Changes in free sugars, free amino acids, acidity and headspace oxygen were not detected in either blanched or unblanched SJC samples. Rates of change in sensory properties were not found to be influenced by the blanching process. However, during storage, musty/moldy and pungent aromas increased, and buttery aroma decreased; while color changes included the formation of a red-brown hue, lighter color, and lower color intensity. Lack of blanch effect on sensory attributes indicate the importance of non-enzymatic pathways to quality degradation under these experimental conditions.

INTRODUCTION

Strawberry juices and concentrates rapidly change in composition and quality upon storage (Sondheimer and Kertesz, 1948, 1953; Meschter, 1953; Wrolstad et al., 1980; Hassanein, 1982). In prior research (Lundahl et al., 1989), commercially produced concentrate (68^{o} Brix) stored at $20^{o}C$ (0-6 days) changed in hue (browning), becoming darker and less intense; developed musty/moldy and pungent aromas; and increased in astringency. These sensory changes were associated with CO_2 evolution, decreases in free α-amino acids (AA) and anthocyanins (ACN), and an increase in polymeric pigments. Organic acids and free sugars did not change.

These compositional changes suggest ascorbic acid (AsA) degradation by Strecker mechanisms involving AA and dehydroascorbic acid, deHAsA, (Kurata et al., 1973) or α-dicarbonyls (Tannenbaum, 1976) to yield CO^2, aldehydes and other products. Ranganna and Setty (1968) found reaction rates between AsA and AA quicker under high concentrations of reactants and low moisture. Hydrolysis of deHAsA is favored over Strecker degradation in acid (Kurata et al., 1973). In the absence of Strecker degradation, Feather and Harris (1973) noted that AsA can degrade to yield CO^2 and furfural (FUR).

Various mechanisms have been proposed which relate AsA to ACN degradation. Ascorbic acid can condense directly with ACN (Jurd, 1968; Poei-Langston and Wrolstad, 1981). Hydrogen peroxide, a good nucleophile produced from AsA oxidation, can degrade ACN (Sondheimer and Kertesz, 1952, 1953; Jurd, 1966, 1967; Hrazdina and Franzese, 1974). FUR, from AsA degradation has also been implicated in ACN

degradation (Meschter, 1953; Tinsley and Bockian, 1960; Daravingas and Cain, 1968; Debicki-Pospisil et al., 1983). Other aldehydes, possibly from Strecker degradation of AsA products, can react to form dimers between catechin and ACN (Timberlake and Bridle, 1977; Chen and Wrolstad, 1980; Debicki-Pospisil, 1983).

Enzymes have also been shown to catalyze reactions which can indirectly affect AsA and ACN degradation. Polyphenoloxidase (PPO) in strawberry oxidizes the B-ring of catechol (flavan-3-ol) to an o-quinone derivative (Wesche-Ebeling, 1984). Several researchers have proposed schemes where o-quinones degrade AsA (Joslyn and Ponting, 1951; Skalski and Sistrunk, 1973; Pifferi and Cultera, 1974) and ACN (Joslyn and Ponting, 1951; Peng and Markakis, 1963; Pifferi and Cultera, 1974; Wesche-Ebeling, 1984). AsA was found to be more liable to oxidative degradation than ACN. ACN degradation rates did not increase until AsA had been consumed (Skalski and Sistrunk, 1973; Pifferi and Cultera, 1974).

The role of PPO in strawberry is thought to be primarily an initiator of oxidative reactions since it has been found to lose its activity during catalysis (Vamos-Vigyazo, 1981; Wesche-Ebeling, 1984). Once initiated, free radical propagation can continue by the oxidation of various phenolics of varying degrees of polymerization. Therefore, it has been suggested that strawberry juice and concentrate quality can be improved by inactivation of PPO before it initiates the oxidative cycle (Vamos-Vigyazo, 1981; Wesche-Ebeling, 1984). Such a step must occur before the disorganization of the cell wall structure, where PPO and substrate come into contact with one another (Pollard and Timberlake, 1971; Wesche-Ebeling, 1984).

An experiment was devised to evaluate the effects of heat inactivation of PPO before the initiation of oxidative reactions. Compositional, as well as color, taste and aroma changes were evaluated during the processing and storage of concentrate from strawberries that had or had not been blanched.

EXPERIMENTAL

Processing and Storage Treatments

Strawberry Juice. Strawberry fruit (Benton cultivar) were commercially hand picked at similar maturity (same field area, two consecutive days) during the mid-1987 season. Fruit were spray washed; sorted to remove soft, bruised or defective berries; individually quick frozen (IQF) at -40°C; and double bagged (plastic polymer) and stored at -40°C. Before processing into juice, frozen strawberries were ground through a hammermill (Model D Comminuting Machine, W.J. Fitzpatrick Co.) equipped with a 3/4" diameter circular pore mesh at 418 rpm, and then, in a jacketed double boiler kettle (manual temperature control with steam and cold water) given one of two process treatments: (1) heating to 50°C for a control (CON) or (2) blanching (BLN) by heating to 85°C (12-15 minutes, steam on), holding at 85°C ($\pm$2°C) for 3.0 minutes (steam off), then cooling to 50°C (6-9 min, cold water on).

After receiving either process treatment, the strawberry slurry

was processed into single strength juice as in Figure 3.1. Processing steps included liquefaction with a 1:1 mixture of Rohmpect® (Rhom Tech Inc., New York, NY) BIL:MB pectinase enzymes (200 mL/10,000 Kg, 1.5-2.0 hr, 50°C) and pressing in a Willmes bag press (Type 60, Moffet Co., San Jose, CA) using filter cloth and 3% (w/w) wood fiber press aid. Depectinization of juice was accomplished by addition of a 1:1 mixture of Rohmpect® BIL:MB pectinase enzymes (200 mL/1000 gal, 8.0-8.5 hr, 40°C). Depectinization was observed to be complete after 4 hr by absence of pectin flock in a 50% alcohol:juice solution. The eight hour treatment was followed to simulate commercial processing conditions. Depectinized juice then received a high temperature short time (HTST) process at 88°C for 0.9 min through a Junior Paraflow heat exchanger (The APV Company LTD, England) with input and output temperatures of 40°C and 13°C, and it was then filtered with 0.3% diatomaceous earth at a rate of 50 to 200 mL/min. Juice samples were saved in sterile, 1.0 L glass bottles with ca. 15% headspace and frozen at -40°C until their evaluation.

Strawberry Juice Concentrate. The remaining juice was transported (frozen) to the Agricultural Research Canada station in Summerville, B.C., thawed and concentrated by passing through a centrifugal evaporator (Model CT-1B α-LaVal, Sweden). Concentration was accomplished by batch processing juice in two steps: concentration from single strength (10.5-11.0°Brix) to 20.1°Brix ($\pm$0.4°Brix), then to 68.0°Brix ($\pm$3.0°Brix) (Appendix 1). The conditions used for concentration are noted in Appendix 2. Concentrate was then placed into sterilized, 60 mL glass

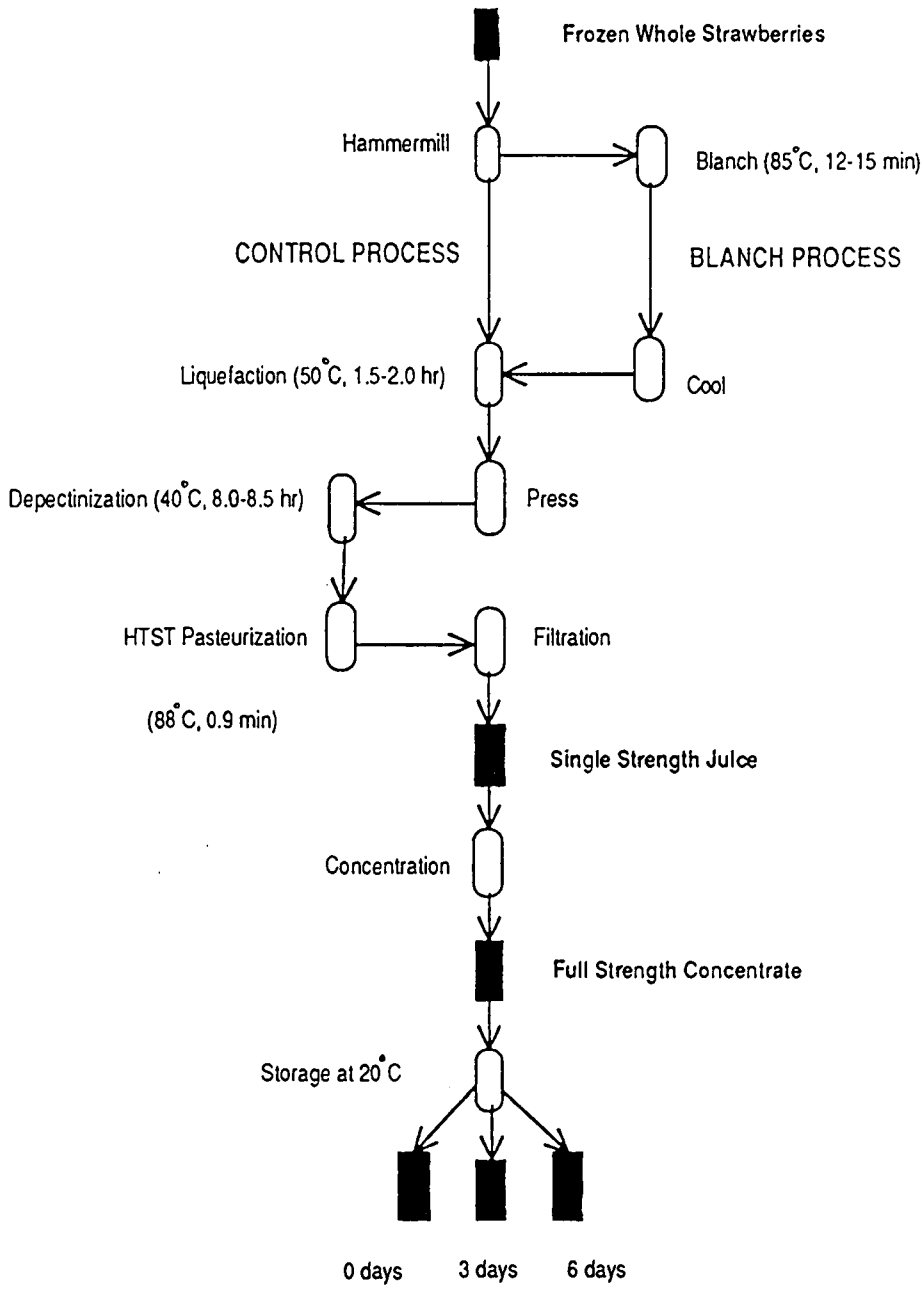


Figure 3.1. Schematic diagram of the processing steps used for the production of single strength juice and full concentrate from strawberries and the storage conditions of the concentrate.

containers with ca. 15% headspace, frozen at -40°C, transported back to Oregon State University and then kept frozen at -40°C.

Storage Treatments. Samples within treatment and batch groups were then randomly assigned to storage treatments at 20°C in the dark for 0, 3 or 6 days. After each storage treatment was complete, samples were returned to -40°C for frozen storage until evaluation.

Sensory Evaluations

Color Determinations. Panels of size 14 and 9 were used to evaluate processed/stored samples of juice (SJ) and juice from reconstituted (8°Brix) concentrate (SJC), respectively. The SJC samples were reconstituted with bottled water (Aqua-Cool Pure Bottled Water, Eugene, Oregon). Panelists were all volunteers and either students or faculty from Oregon State University's Department of Food Science and Technology. All panelists were screened for color anomalies with standard Ishihara color plates (Ishihara, 1971) and trained to match Munsell color chips (1929 Munsell Student Chart, Munsell Color Co., Baltimore, MD) with the transmitted color of each sample through a 1 cm path length cell. Scales for evaluation depended on the selected Munsell chip with hue recorded on a 30 point scale (1=1R, 11=1YR, 21=1Y, 30=10Y), value recorded on a 10 point scale of increasing lightness, and chroma recorded on a 20 point scale of increasing color intensity. Twelve color cards (each constant hue, varying value and chroma) were available for matching the color of incandescent light transmitted through the sample. Samples were matched in a MacBeth Executive viewing hood (Model No.

BBX324, MacBeth Corp., Newburgh, N.Y.) under incandescent light where the sample and color chips were compared as in Appendix 3.

Aroma and Taste Intensity. Panels of 11 and 9 volunteers were used to evaluate processed/stored samples of SJ and SJC, respectively. Panelists were either students or faculty from the OSU Department of Food Science and Technology and had varying degrees of sensory evaluation experience. The SJ and SJC panels evaluated their respective samples to determine descriptors that best characterized the aroma and taste of the samples. The selected taste and aroma standards and definitions of descriptors are given in Appendix 4.

All panelists were trained to evaluate SJ or SJC samples for aroma intensity using a 15 point scale with intensity rated 0="none", 3="slight", 7="moderate", 11="large" and 15="extreme". For each sample, panelists scored aroma attributes by matching or extrapolating between the overall intensity of reference standards as suggested by Meilgaard et al. (1987). These reference samples are listed in Appendix 5. Taste evaluations for SJC were based on a 15 point intensity scale as above, but without the scale structured with reference samples. The ballots used for SJ taste/aroma evaluations, and SJC aroma, taste and color evaluations are presented in Appendix 6 and 7, respectively.

Time-intensity Evaluations. For the SJC samples, panelists were also trained to rate their time-intensity (TI) perceptions of sweet, sour, astringent and bitter tastes. A computer program was written in BASIC and Assembly language to facilitate the collection and analyses of TI data. Panelists were prompted to select a three digit coded sample and then evaluate it for a specific taste

attribute. The computer instructed panelists when to place the sample in the mouth (after a 20 sec countdown) and then expectorate (after a 7 sec countdown). The instantaneous intensity of perception was scored by moving a pointer along a linear 15 cm scale with reference points of "none" and "extreme" at the ends and "moderate" in the middle. After the taste was no longer perceived, panelists pressed a button on the input device which began a 60 sec waiting (resting) period. The computer then prompted the panelist to begin evaluation of another sample.

All samples were evaluated in random order for the same attribute. When evaluation for one attribute was completed, another attribute was randomly selected and a new random sample evaluation scheme was specified. Before evaluating samples for a new attribute, panelists were presented a warm-up standard of sucrose (0.500 g/100 mL) for "sweetness", citric acid (7.2 mg/100 mL) for "sourness", caffeine (2.5 mg/100 mL) for "bitterness", or alum (2.5 mg/100 mL) for "astringency". These standards were agreed by panel consensus to approximate "moderate" intensity strength.

Experimental Designs and Analyses of SJ. Color evaluations were conducted over two sessions (SES) on SJ samples presented randomly to each panelist in sets of eight: two process replications (BAT), two process treatments (PRC), and two evaluation replications (REP). Averaging over the SES and REP, data were analyzed as a randomized block design (RBD) with PAN as blocks, and PRC nested within BAT. Aroma and taste evaluations were conducted over two sessions (SES) on SJ samples presented in sets of four: two BAT levels and two PRC levels. All PAN and BAT effects were considered

random, therefore analysis of variance (ANOVA) was conducted according to the mixed random and fixed effects model described by Anderson and Bancroft (1952). Panelists were considered random samples because they were from a population of panelists without color vision anomalies (i.e. color panels were screened) and with general taste/aroma acuity (taste/aroma panels were not screened) according to Lundahl and McDaniel (1988).

Experimental Design and Analysis for SJC. The SJC samples were evaluated for color and taste over ten sessions (SES) in sets of two as in Table 3.1. This presentation scheme resulted in a design with proportional replication over the 2x2x3 factorial treatment set from levels of the BAT, PRC and STO sources of variation. The SES effects were not included in the analyses, resulting in an ANOVA with PAN, BAT, PRC, and STO/PRC as main effects. The ANOVA was furthered by determining the storage time (STO) variation separately for each PRC treatment. Pairwise comparisons were conducted using Fischer's (protected) least significant difference (LSD) test (Steel and Torrie, 1980). As with color evaluations, the PAN and BAT effects were treated as random yielding a mixed random and fixed effects model (Bancroft and Anderson, 1956).

The SJC aroma evaluations were conducted by the same panel during the same ten sessions as the taste and color evaluations. However, within each session panelists were presented complete replicates of all six samples (three STO by two PRC levels) from either of two BAT levels. Further, these six samples were randomly presented to each panelist in sets of two samples (BLK) such that over the five sessions, fifteen BLK levels completed a balanced

Table 3.1. Pairs of samples of reconstituted strawberry juice concentrate which were evaluated during the same session (designated by X) for taste and color attributes.

BATCH	SESSION	CONTROL PROCESS 0 DAYS	CONTROL PROCESS 3 DAYS	CONTROL PROCESS 6 DAYS	BLANCH PROCESS 0 DAYS	BLANCH PROCESS 3 DAYS	BLANCH PROCESS 6 DAYS
1	1	X			X		
	8	X	X				
	7	X		X			
	10				X	X	
	2				X		X
2	5	X			X		
	6	X	X				
	3	X		X			
	9				X	X	
	4				X		X
NUMBER OF REPLICATIONS		6	2	2	6	2	2

incomplete block (BIB) design (plan 11.3, Cochran and Cox, 1950). The BIB design was employed to remove effects due to presentation order by adjusting the six sample means from the same PAN and BAT as suggested by Gacula and Singh (1984). These adjusted means were then used for ANOVA with main effects of PAN, PRC and STO/PRC as described for taste and color analyses.

The curve of instantaneous response intensity vs time (Figure 3.2) was used to evaluate perceived attributes including: time of initial perception or "lag time" (T_i), time when intensity reached its maximum or "time to peak" (T_{peak}), time to end of perceived intensity or "final time" (T_f), peak intensity (I_{peak}), total duration time ($D_{tot}=T_f-T_i$), total area under the curve (A_{tot}), total curve perimeter (P_{tot}), peak duration time (D_{peak}) and peak area under the curve (A_{peak}). This time-intensity data was analyzed as univariate data (Appendix 8) by the methods described for taste evaluations, and as multivariate data (Appendix 9) by principal components analysis (PCA) with PC-SAS® (SAS Institute, Inc., Cary, N.C.).

Colorimetric and Pigment Determinations

Sample Preparation. For spectrophotometric evaluations of pigments, the SJC samples were thawed and warmed to 20°C, then reconstituted to 8°Brix with double distilled, deionized (DDD) water. All samples were prepared in duplicate for evaluation. Tristimulus Hunter colorimetric data were recorded from the same samples as were evaluated by sensory evaluation yielding five sample

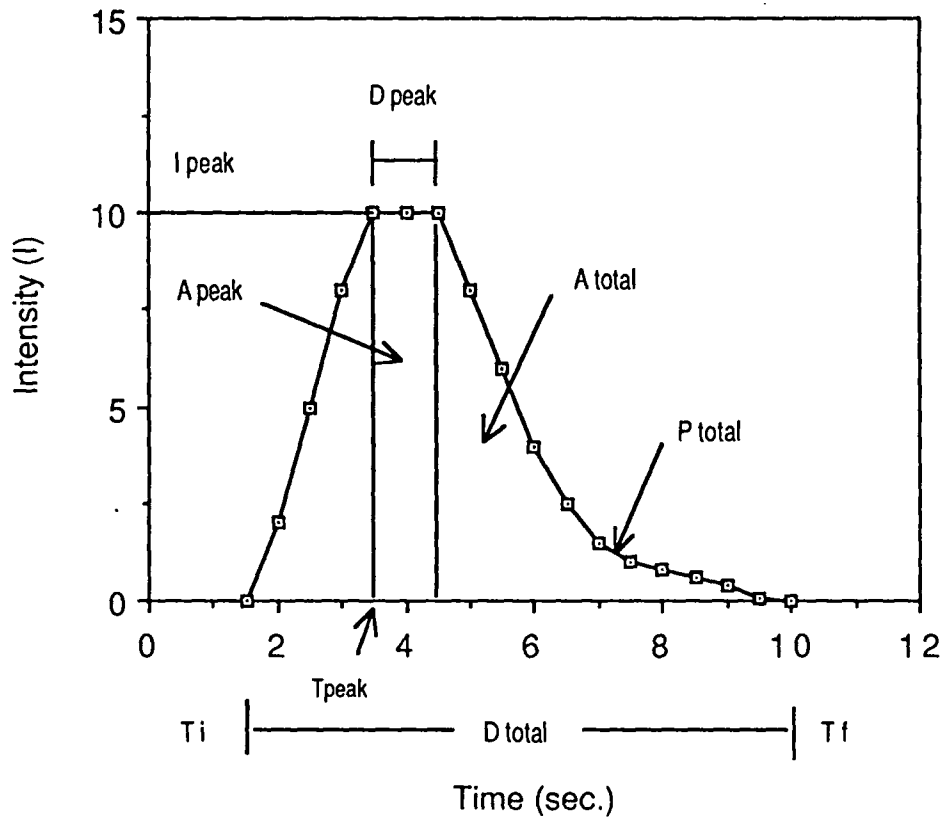


Figure 3.2. Parameters from the curve of the instantaneous percieved intensity over time (time-intensity). Time parameters include the time to initial perception (T_i), time to peak intensity (T_{peak}), time to end of perception (T_f), total duration of perception (D_{total}) and duration of peak (D_{peak}). Other parameters include intensity of peak (I_{peak}), total area under the curve (A_{total}), peak area under the curve (A_{peak}) and total duration curve parimeter (P_{total}).

replicates for analysis.

Tristimulus Colorimetry. A Model DP-25P-2 (Hunter Instruments, Reston, VA) color difference meter was used to measure color (transmission mode, spectral component included - Arrangement III). The instrument was calibrated as described by the manufacturer. Values were recorded in duplicate for samples in a 1.0 cm pathlength cuvette. The ANOVA for averaged values (over samples and recordings) for L, a, b, and hue angle [$\tan^{-1}(b/a)$] included main effects for BAT and PRC SOV for the SJ data, and, in addition, STO/PRC for the SJC data.

Spectrophotometric Colorimetry. A Model DMS 100 UV-visable spectrophotometer interfaced with a DS-15 data station (Varian Instrument Group, Walnut Creek, CA) was used for measuring the monomeric anthocyanin (ACN) concentration, browning index (BI), degradation (A_{520}/A_{420}), color density (CD), polymeric color (PC) and percent PC:CD by the pH differential and bi-sulfite bleaching methods (Wrolstad, 1976). Haze formation was evaluated by absorbance at 700 nm. Monomeric ACN concentration was determined with λ=520 nm, E=22,400 and expressed as mg/100 mL pelargonin-3-glucoside.

Compositional Analyses

Titratable Acidity, pH and Free Amino Acids. The SJ and SJC (8^{o} Brix, DDD water) samples stored for 0 or 6 days at 20^{o}C were evaluated in duplicate on a 1.0 mL capacity Metrohm Model 655 auto-titrator with a motor-driven piston burette and microprocessor-control, and a Ross® Model 8104 pH electrode

(Orion Research, Inc., Cambridge, MA) with a microprocessor pH/mV meter (Orion Model 811). The initial pH was recorded, then titratable acidity (TA) was determined by titration with 1.0 N NaOH to an end-point of pH 8.2 using the glass pH electrode method (AOAC, 1984). The TA was expressed as meq/100 mL citric acid. Free amino acid (AA) content was evaluated by the formol titration method to an end-point back titration of pH 8.4 (AOAC, 1984) and expressed as mg/100 mL α-amino nitrogen (glycine equivalent). The ANOVA included BAT and PRC main effects for the SJ and, in addition, the STO/PRC effect for the SJC data.

Free Sugar Determinations. Samples of SJ and SJC (8^{o}Brix, DDD water) were prepared in duplicate and analyzed for glucose, fructose, sucrose and sorbitol with a Varian Model 5000 high performance liquid chromatograph (HPLC) equipped with column heater and refractive index detection (Varian Instrument Group, Walnut Creek, CA). A Biorad Aminex HPX-87C carbohydrate column and mobile phase of 200 mg/L calcium nitrate were used for separation of these free sugars. An internal standard of mannitol and external standards of sucrose, glucose, fructose and sorbitol was used. Sample preparation included removal of pigments with a Waters C-18 sep-pak cartridge, and removal of organic acids with Biorex-5 anion exchange resin (Spanos and Wrolstad, 1987).

CO_2 and O_2 Headspace Determinations. The percentages of CO_2 and O_2 were determined in the headspace above 12 g ($\pm$1 g) of concentrate in a 25 mL Erlyenmeyer flask with a serum septum stopper. The headspace was air at ambient atmospheric pressure and 20^{o}C. After storage of 0, 3 or 6 days in the dark at 20^{o}C,

samples were placed in frozen storage at -40°C until their evaluation. Samples were evaluated by injection of 1 mL of headspace directly into a Model 311 Carle® Analytical Gas Chromatograph (Hach Co., Loveland, CO) with two 6 ft by 1/8 in ID columns, Hayesep-R (80-100 mesh) and Molecular Sieve 5A (60-80 mesh), in series with a thermal conductivity detector (Hach Co., Loveland, Co). Peak areas of O_2, CO_2, and N_2 were adjusted for constant N_2 area (N_2 treated as an internal standard) and volume percent determined by plotting areas of known volumes of 100% air and CO_2.

RESULTS

Color Determinations

Strawberry Juice Evaluation. The sensory panel did not detect any significant differences in color parameters between the blanched and unblanched samples (Appendix 10A). There was a significant BAT*PRC interaction for hue caused by the control PRC level from the second batch being greater than the other levels, suggesting greater color degradation (Appendix 10B). There were no statistically significant differences in color with Hunter L-a-b data (Appendix 11A,B).

Stored Juice Concentrate. Results from sensory evaluation show that SJC from both blanched and unblanched fruit underwent similar changes in color indicating degradation (Appendix 12A). Hue,

value and chroma ratings underwent considerable change during storage (Appendix 12B), with the major change occurring between days 1 and 3. Hue shifted to brown, color intensity decreased and samples became lighter (Figure 3.3).

These color changes were confirmed by tristimulus colorimetry. ANOVA of Hunter "L", "a" and hue angle data resulted in significant changes during storage for both blanched and unblanched fruit (Appendix 13A). Differences between PRC treatments were not significant (Appendix 13B). The greatest change also occurred between days 1 and 3 (Figure 3.4).

Aroma and Taste Determinations

Strawberry Juice Evaluation. The sensory panel detected some significant aroma and taste differences among SJ samples. Batch differences were significant for overall aroma and cooked strawberry, a significant blanching PRC effect was found for sour taste and a PAN*BAT interaction was significant for buttery aroma (Appendix 14A). Sour taste was greater from SJ prepared from blanched fruit (Appendix 14B). This increase in sourness could indicate the formation of sour components by heating (i.e. blanch processing) or the loss of sourness by interfering or interacting components with sourness perception in the unblanched fruit. Batch 2 was rated higher than batch 1 in both cooked and overall aroma indicating processing or compositional differences between batches (Appendix 14B). The PAN*BAT interaction for buttery aroma indicates general disagreement among panel members (panel inconsistency) on the rating

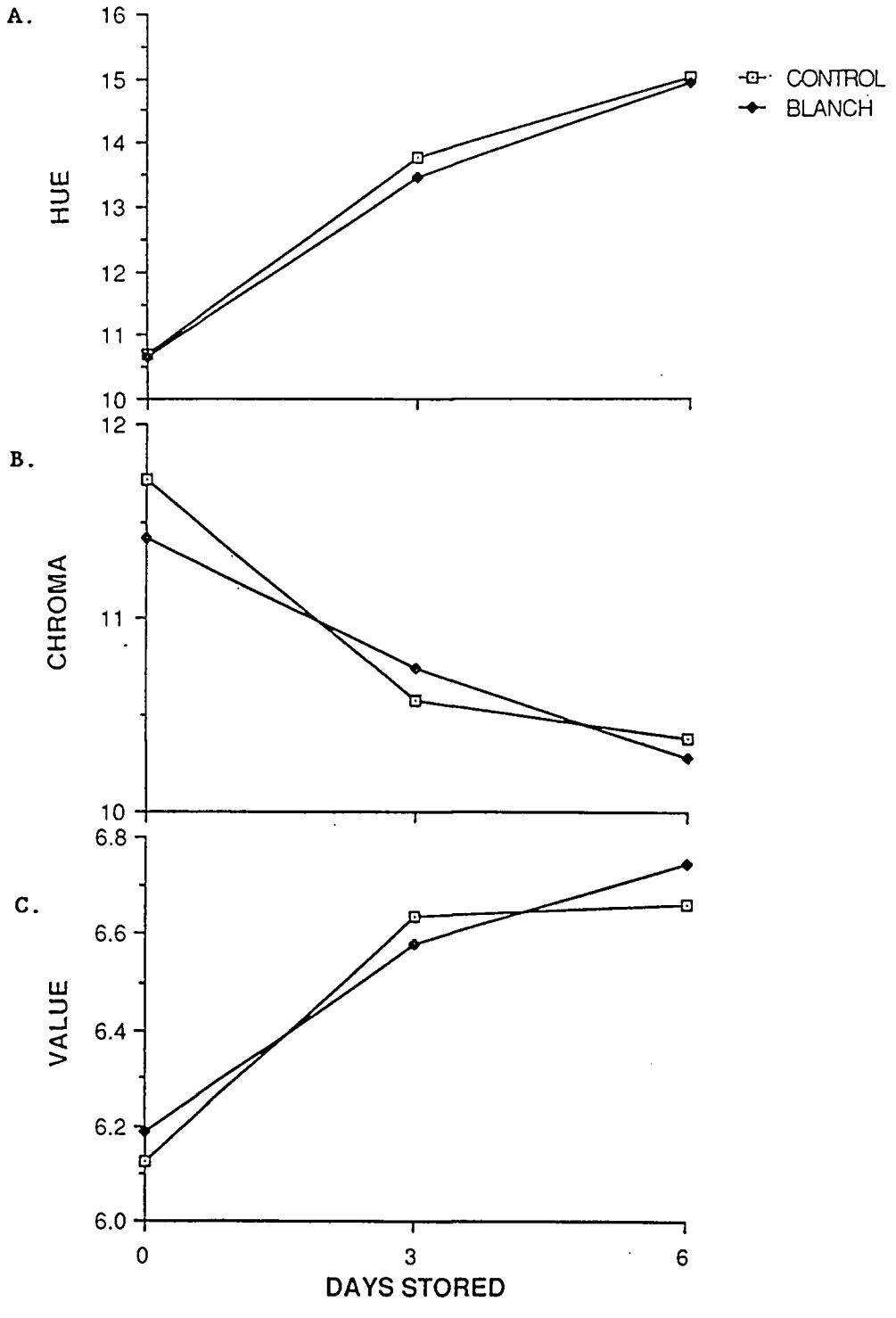


Figure 3.3. Sensory panel ratings of strawberry juice concentrate using Munsell color chips. Hue was measured on a 30 point scale where 10="10R (red)", 11="1YR (brown) and 15="5YR. Value (lightness) and chroma (color intensity) were measured on 10 and 15 point scales, respectively.

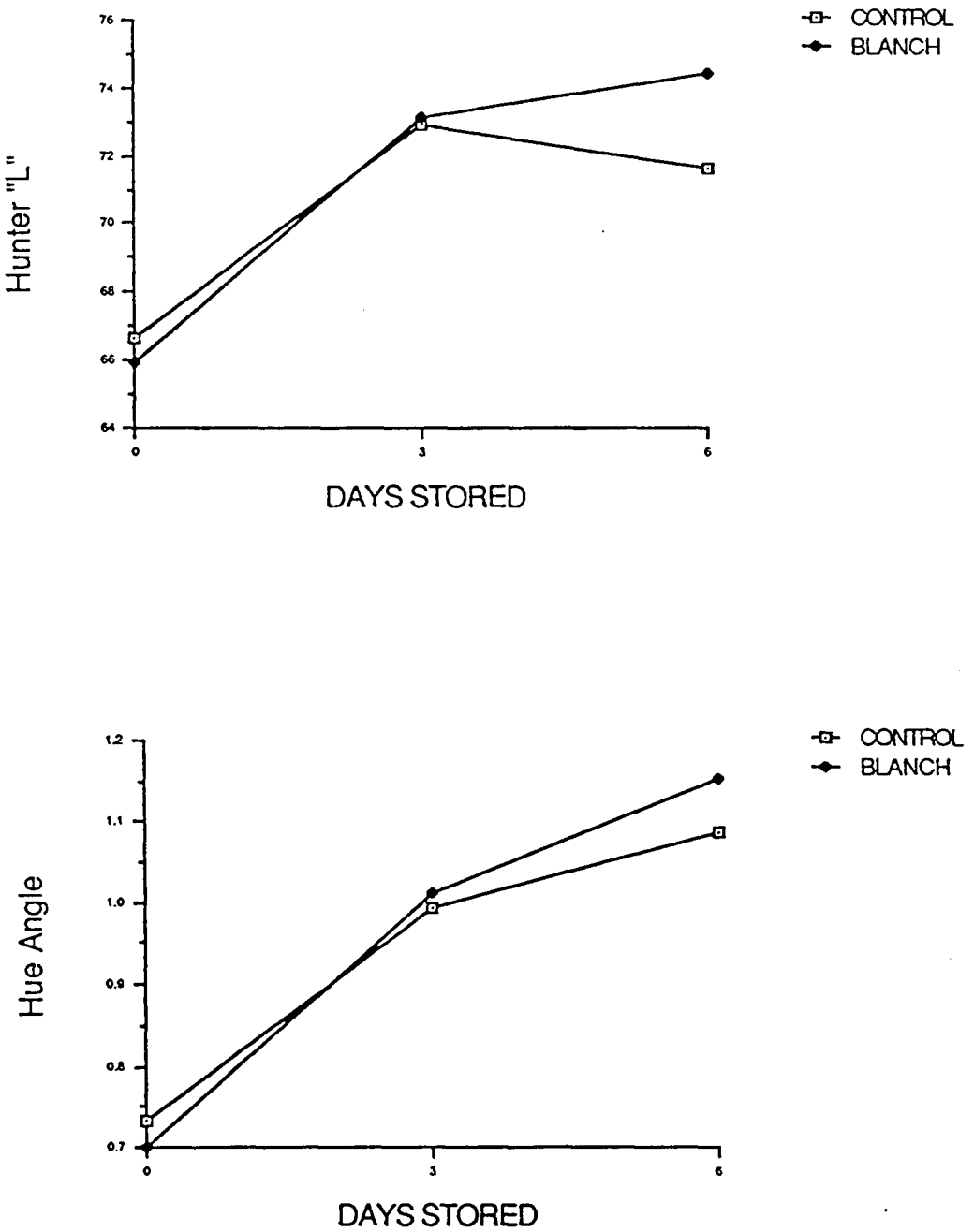


Figure 3.4. Hunter "L" and hue angle ($\tan^{-1}$ b/a) readings of SJC samples stored for 0, 3 and 6 days at 20°C.

of this attribute.

Aroma Evaluation of Stored Concentrate. Sensory evaluation detected significant differences among storage treatments in pungent, musty/moldy and buttery aromas (Appendix 15A). Aroma changes were similar for both PRC levels with musty/moldy increasing and buttery aroma decreasing (Appendix 15B). Aroma changes were greater between days 1 and 3 suggesting the depletion of some precursor (Figure 3.5A). Pungency increased significantly during storage of SJC from only blanched fruit (Appendix 14B). The pungent increase in aroma was greater between days 3 and 6 suggesting a different pathway of formation from the musty/moldy aroma (Figure 3.5B).

Neither pungent nor musty/moldy aromas were present in the SJ or unstored concentrate. Therefore, it can be hypothesized that these aromas are related to the storage of the concentrate. This also suggests these aroma changes are from non-enzymatic processes since SJC from both blanched and unblanched fruit increased in musty/moldy aroma. The formation of a pungent aroma in only the blanched fruit indicates the formation of odorless precursors during blanching (also non-enzymatic) with subsequent formation of pungent compounds.

The panel also detected a significant batch difference in artificial strawberry (Appendix 15A). Batch 1 was rated 1.63 (S.D. 1.60), while batch 2 was rate 1.49 (S.D. 1.64). This difference, while statistically significant, is not very meaningful due to the small relative difference and the small intensity magnitude (i.e., 1="just detectable" and 3="slight").

Panel inconsistency in response patterns to samples with different storage treatments were noted for six of the ten aroma

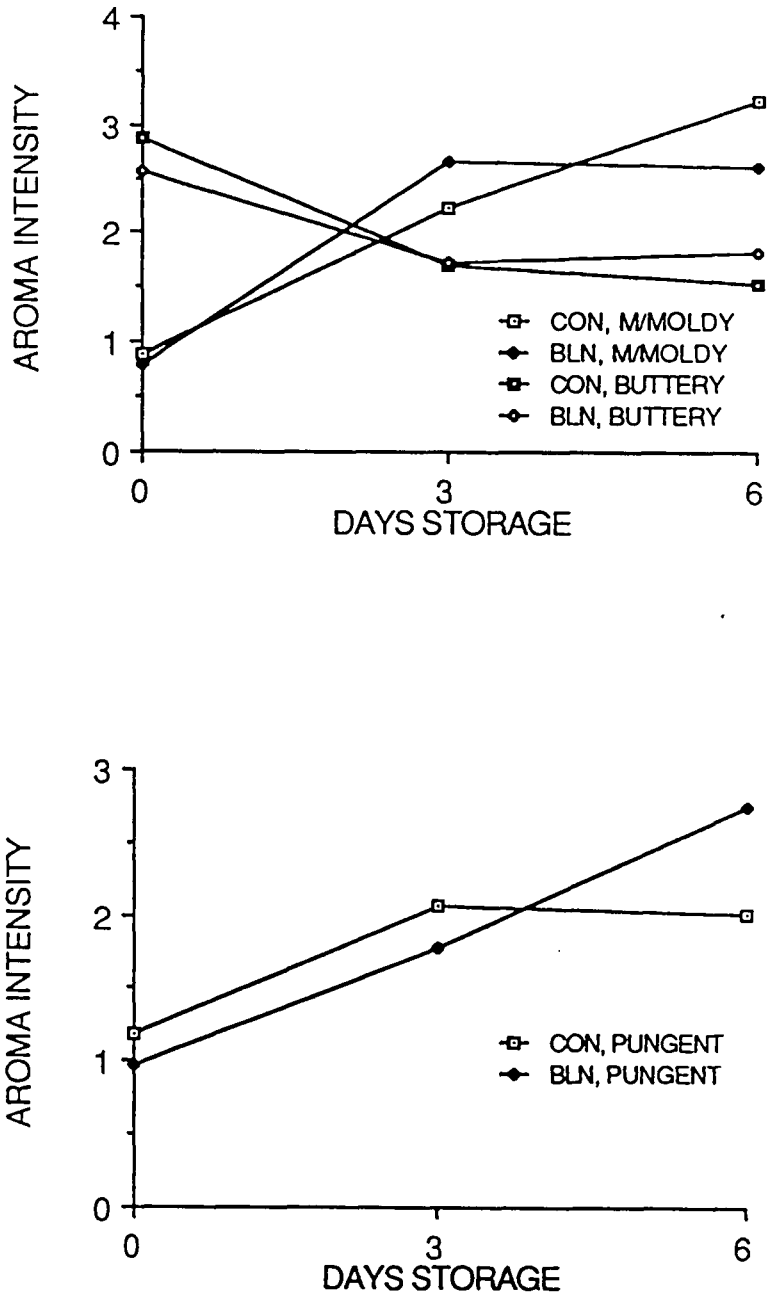


Figure 3.5. Aroma changes for significant aroma descriptors in stored strawberry juice concentrate from fruit that had been blanched (BLN) or unblanched (CON). Intensity was evaluated on a 15 point intensity scale with 0="not detected", 1="just detectable", 3="slight intensity", 7="moderate", 11="large" and 15="extreme".

descriptors (Appendix 15A) The PAN*STO/PRC variation was significant for samples which changed during storage, i.e. musty/moldy, buttery and pungent. Since panelists were treated as random effects these variation sources were accounted for in testing the STO/PRC variation. In addition, inconsistent response patterns were observed among panelists for the caramel, sweet/jammy and overall aromas. These inconsistencies are indicative of differences in panelist sensitivity to odor active compounds or in the use of descriptors.

To further evaluate the inconsistency from different use of descriptors, the multivariate relationships among aroma descriptors were analyzed with principle components analysis (PCA). PCA for the SJC aroma data resulted in four components which accounted for 79% of the variation among the ten aroma descriptors. These four components (PC1-PC4) were described as "overall juice aroma", "off-aromas", "cooked and buttery" and "pungent and buttery", respectively, by correlating each principle component to each original variable (Appendix 16).

Each component was then tested by ANOVA to determine which variation sources (e.g., SJC treatment or panelist effect) affect its variation (Appendix 17A). A significant change in the second and fourth components occurred during SJC storage. PC2 (off-aromas) increased, while PC4 (pungent, buttery and sweet/jammy aromas) decreased after three days storage (Appendix 17B). Since cooked and caramelized aromas were negatively correlated to PC4, the decrease in PC4 indicated these aromas increased during storage. In addition, the PAN*STO/PRC variation was significant for PC2 indicating the panel inconsistency observed for pungency and musty/moldy variables

were related to differences in sensitivity, rather than the use of descriptors. Panelists responding to the same stimuli, but using a different descriptor (same principle component), would not be expected to contribute to the PAN*STO/PRC variation of the principle component.

Intensity Scale Taste Evaluations on SJC. Appendix 18A presents the F-values from taste evaluations of SJC samples rated on a 15-point intensity scale. The slight difference in sourness detected by sensory evaluation in the SJ samples did not carry over into the SJC samples, although sour levels remained moderate (Appendix 18B). A significant PRC SOV for astringency was due to a slightly higher intensity in the blanched SJC, as compared to the control (Figure 3.6). A significant BAT*STO SOV in astringency was observed for only the control SJC samples. This indicates that the pre-liquefaction blanch reduces some batch variation (i.e., increases processing control) related to the presence of astringent precursors.

A significant change in sweetness was observed in the control samples during storage (Appendix 18A). After six days storage, sweetness decreased significantly in the control, but not in the blanched SJC (Figure 3.7A). A significant PAN*STO SOV for only the control SJC was due to one panelist giving a higher response to the sample with 3 days storage than would be expected from the remaining panel (Figure 3.7B). The response pattern for the remaining panel resulted in a linear decrease over six days storage (Figure 3.7B).

Time-intensity Taste Evaluations. The time-intensity (TI) F-values for sweetness are given in Appendix 19A. The TI of

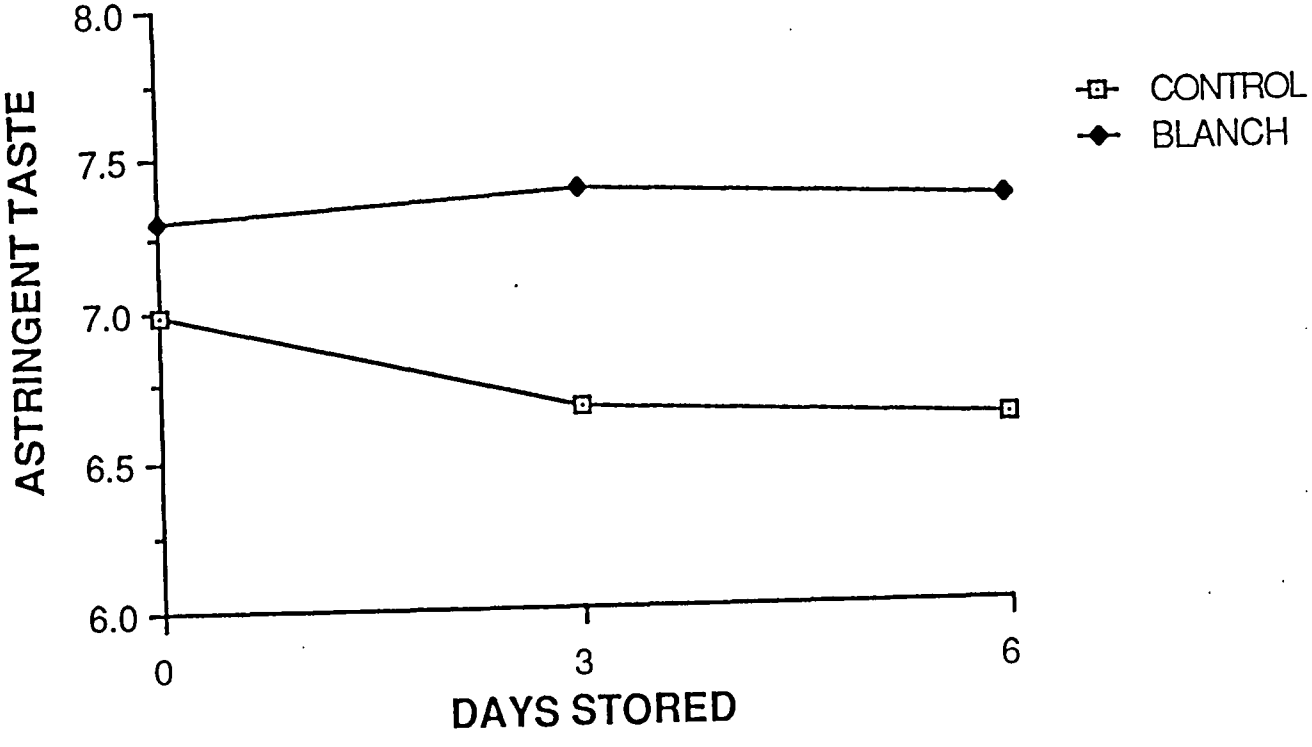


Figure 3.6. Astringent taste differences in stored strawberry juice concentrate after control from control or blanched fruit.

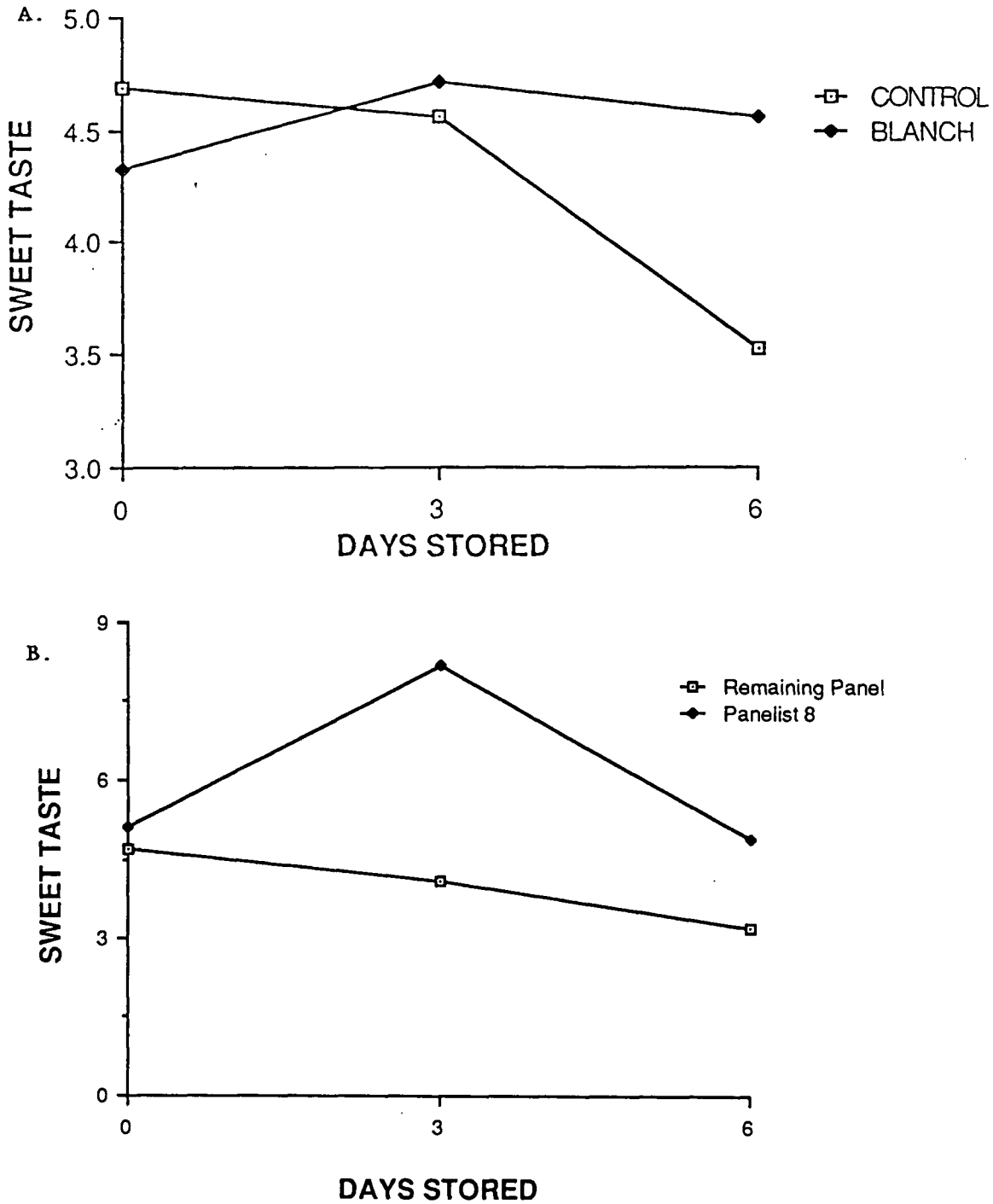


Figure 3.7. Sweet taste (Fig. A) in stored strawberry juice concentrate (SJC) for control or blanch processed fruit and the change in control SJC adjusted for one panelist (#8) with a different response pattern (Fig. B).

sweetness evaluation revealed a significant reduced peak maximum intensity (I_{peak}) and time to peak (T_{peak}) after six days storage for only the control PRC level (Appendix 19B). A comparison of the change between both PRC levels in significant sweetness TI parameters can be seen in Figure 3.8. The control PRC level had a shorter time to initial perception, T_i, (2.3 vs 2.6 sec) and longer peak duration, D_{peak}, (2.4 vs 3.0).

The validity of the significant T_i is questionable since both F-values for testing the PAN*PRC and BAT*PRC variation are smaller than expected by chance (5%) alone. These components of variation are used in calculating the denominator of the F-value. Therefore, this questions the significance of the model in the ANOVA for T_i.

The sourness TI F-values are given in Appendix 20A. As detected in the SJ samples, sourness was significantly increased by the blanch PRC with respect to total area under the curve (A_{total}), total perimeter (P_{total}) and area under the peak (A_{peak}) (Appendix 20B). These results are in contrast to those from the 15-point category scaling data which did not detect any significant PRC or STO/PRC variation. One explanation may be that the TI evaluations resulted in evaluations which were more sensitive to changes in sourness perception. With TI evaluations panelists may concentrate more on the sourness signal since response to stimulus involves a continuous reaction. Scaled responses are different as they require the assignment of perceived intensities to a category scaled value.

Another explanation is that the shape of the sourness TI curve is affected by the TI component of sweetness perception. Figure 3.9 displays the averaged values of sweetness and sourness TI curves for

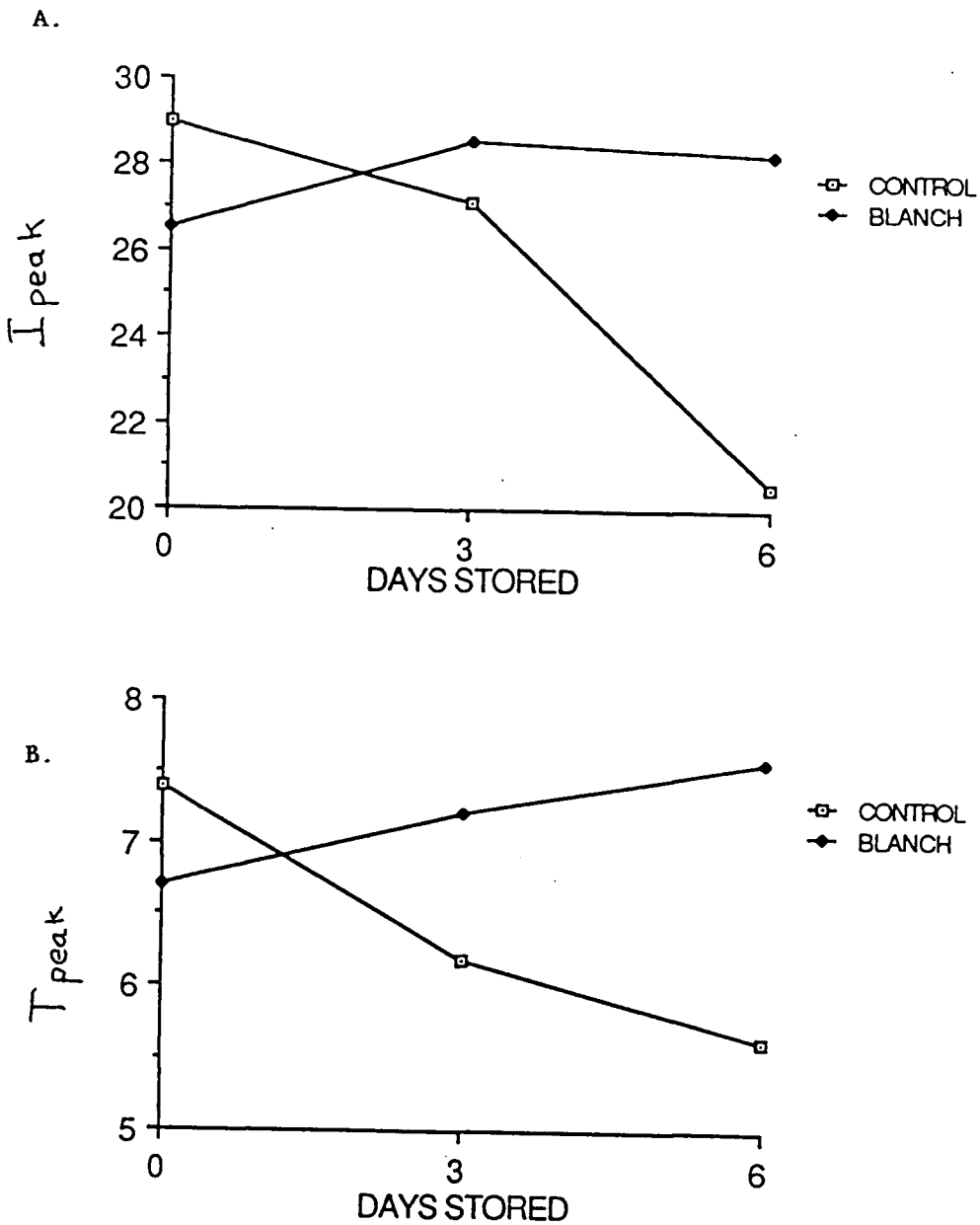


Figure 3.8. Sweetness maximum intensity (I_{peak}) and time to maximum intensity (T_{peak}) for blanch or control treatment strawberry juice samples during storage.

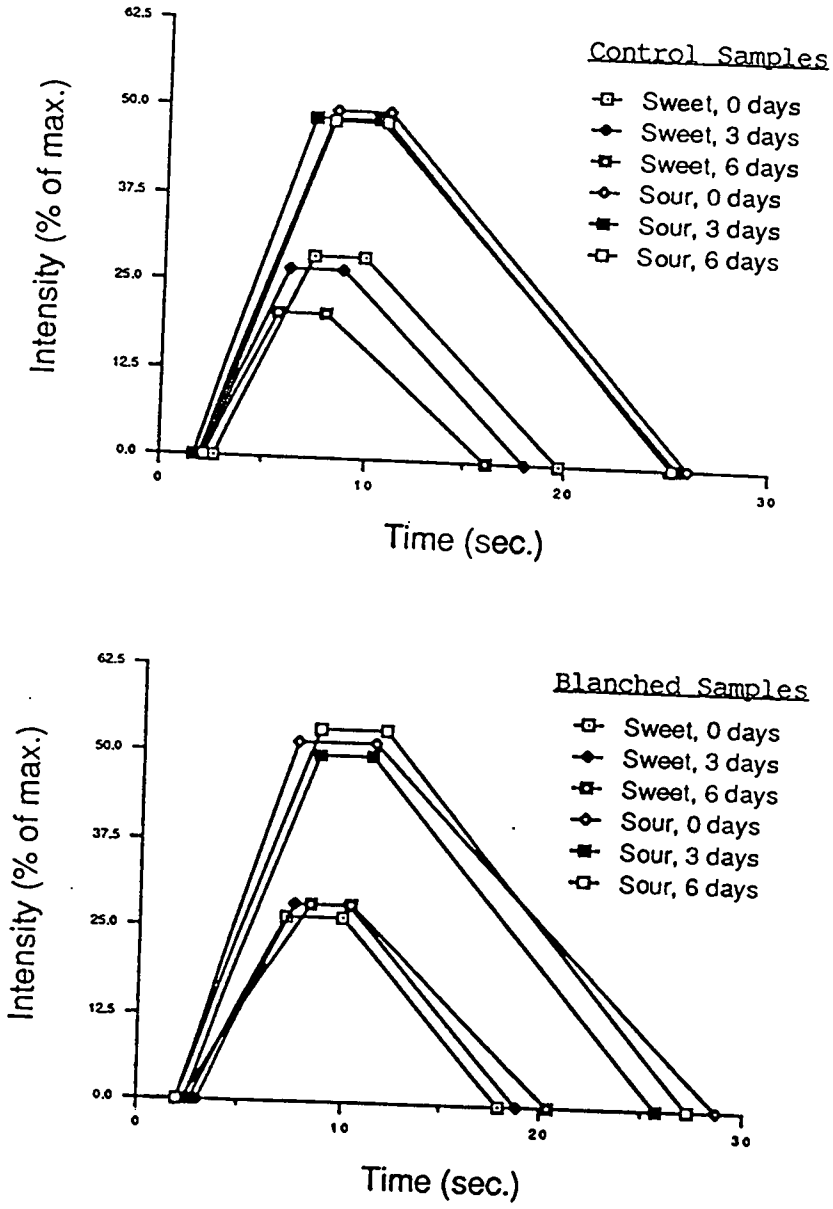


Figure 3.9. Sweet and sour time-intensity curves from the averaged values from sensory evaluations of stored strawberry juice concentrate samples that had or had not undergone a blanching process. Intensity axis is in % of a 15 in. line scale for intensity of taste.

samples with different PRC and STO levels. The TI peaks of sweetness and sourness overlap. This overlap may explain the interaction of sweetness and sourness observed by other researchers (Pangborn et al., 1964; Pangborn and Crisp, 1964; Perng, 1988).

To study the interrelationships between sweet and sour TI parameters, these data were evaluated by principle components analysis (PCA). The PCA was conducted on the 18 TI sweetness/sourness variables yielding four major components (PCS1-PCS4) which accounted for 78% of the variation among these TI variables. Each principle component was described from a correlation analysis of the TI variables with each principle component (Appendix 21). The first component, "sweetness and sourness", (41% variation) was significantly correlated to TI components associated with higher intensity scores of both sweetness and sourness. This may be related to the use of the intensity scale on the TI input device (i.e., a panelist effect). The second component (17%) was a sweet vs sour effect. The third component (13%) was related to the sharpness of the sourness peak and the fourth component (7%) was related to a longer time to initial and peak intensity of sweetness and sourness.

The ANOVA results found a significant PRC effect for PCS4 (Appendix 22A). The blanch PRC means were higher than the control indicating times to initial and peak perception of sourness and to initial perception of sweetness are increased by blanching (Appendix 22B). The remaining principle components did not detect any differences among processing or storage treatments (Appendix 22A). Therefore, while the sweetness vs sourness component (PCS2) explained 17% of the variation among the sweet/sour TI variables, this

component was not related to sample differences (Figure 3.10).

Astringent TI evaluations were not as effective in detecting differences among samples as were scaled responses since the scaled data for astringency resulted in a significant PRC effect. The TI differences in astringency were not significant ($p \leq 0.05$) for any of the PRC or STO/PRC effects (Appendix 23A). However, the F-value PRC effect had a 0.06 p-value for peak duration time (D_{peak}) indicating a possible trend towards a longer duration for the blanched PRC level (Appendix 23B). A significant BAT*STO/CON and BAT variation for maximum peak intensity suggests the presence of some batch variation in astringency for the control samples. This batch variation agrees with the results observed in the scaled intensity data.

A significant PAN*STO/PRC variation for astringency peak area was caused by one panelist (out of nine) responding with a much longer peak on the control samples stored for three days. Since astringency can persist for a long time, the presence of outlier data can influence TI parameters in units of area under the curve. This factor was even more pronounced for bitterness TI data which give even longer tails to each TI curve. No significant PRC or STO/PRC effects were detected (Appendix 24A,B). This lack of bitterness can be explained in part by considerable panel disagreement in TI components related to the peak and tail of the peak. All area TI components had significant PAN*STO/PRC effects as well as peak duration time, final time and time to peak (Appendix 24A).

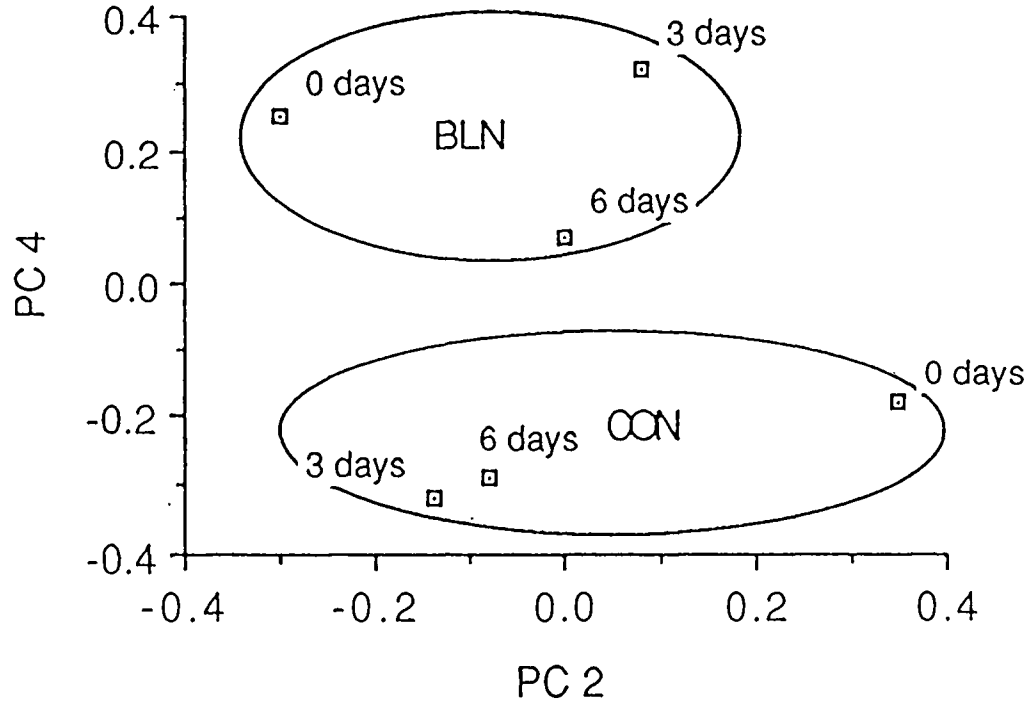


Figure 3.10. Association between two principle components from sweet and sour time-intensity variables for strawberry juice samples from control (CON) or blanched (BLN) fruit. The PC_2 component was related to intensity patterns of higher sweetness, lower sourness (+) vs. lower sweetness, higher sourness (-), while the PC_4 component was related to the time to initial perception of sweetness being faster (+) vs. slower (-).

Compositional Changes

Pigment Composition of SJ. Except for a significant BAT*PRC effect for browning index, the blanching did not significantly affect ACN and colorimetric indices in the SJ samples (Appendix 25A). Blanching resulted in a higher browning index than the control in only batch 2, probably indicating greater color degradation prior to concentration (Appendix 25B). This interaction was related to a difference in hue detected by sensory evaluation (Figure 3.11).

Pigment Composition in SJC. During storage as a concentrate the ACN concentration, degradation index and polymeric pigment and %PC:CD changed significantly (Appendix 3.26A,B). The browning index (A_{420}) increased and color density decreased during storage, but were not significant at the 0.05 level (Appendix 26A,B). ACN concentrations were stable over three days storage, but decreased thereafter (Figure 3.12A). The blanching process significantly reduced the ACN loss after six days storage. The polymeric contribution to the total color density (%PC:CD) increased during storage; however, blanching resulted in lower color density (CD) and a significant increase in %PC:CD (Figure 3.12B). The degradation index (A_{520}:A_{420}) decreased at the same rate for both PRC treatments (Figure 3.12C). Therefore, colorimetric results indicate formation of brown pigments prior to the loss of ACN. Further, a greater %PC:CD for blanched SJC, but not SJ samples, suggests formation of tannin precursors during the blanching process.

Free Sugars. The F-values for testing the effects of processing/storage treatments on SJ and SJC are listed in Appendix

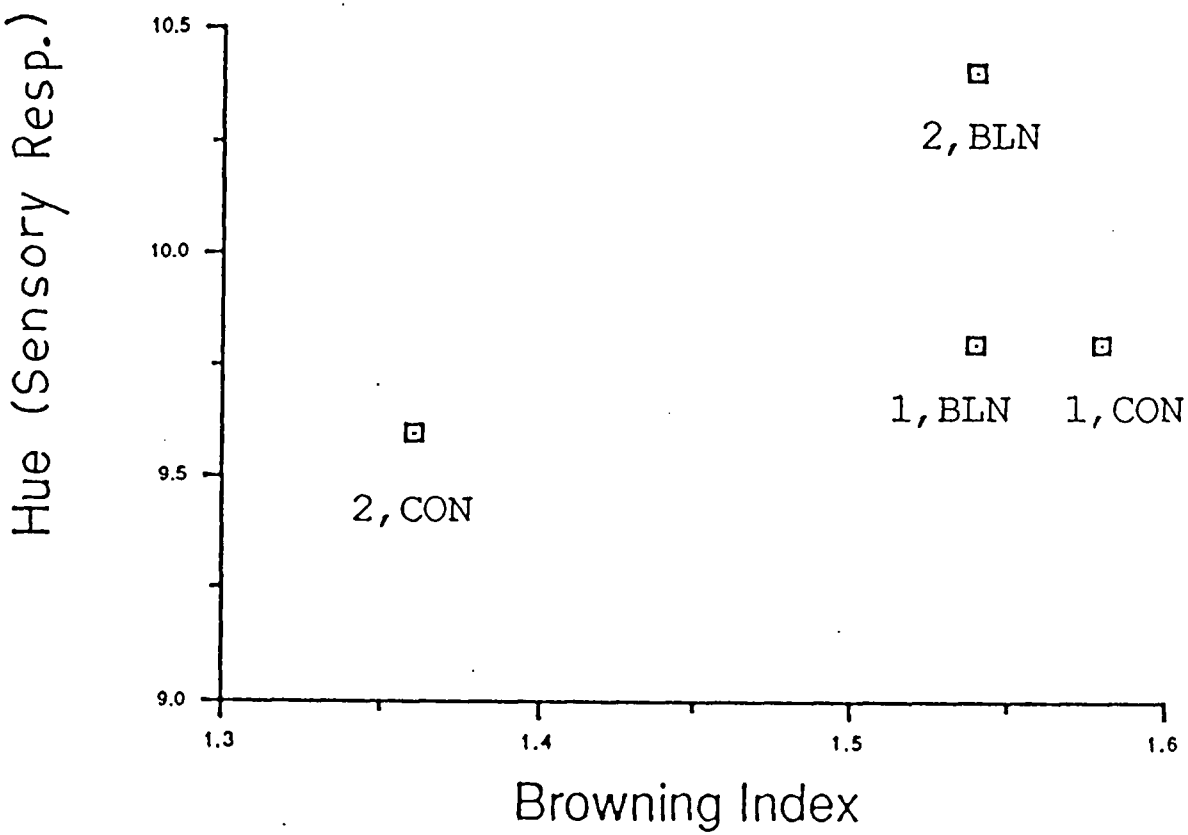


Figure 3.11. Color difference relationships between Munsell hue by sensory evaluation and browning index (A_{420}) in strawberry juice samples processed from control or blanched fruit.

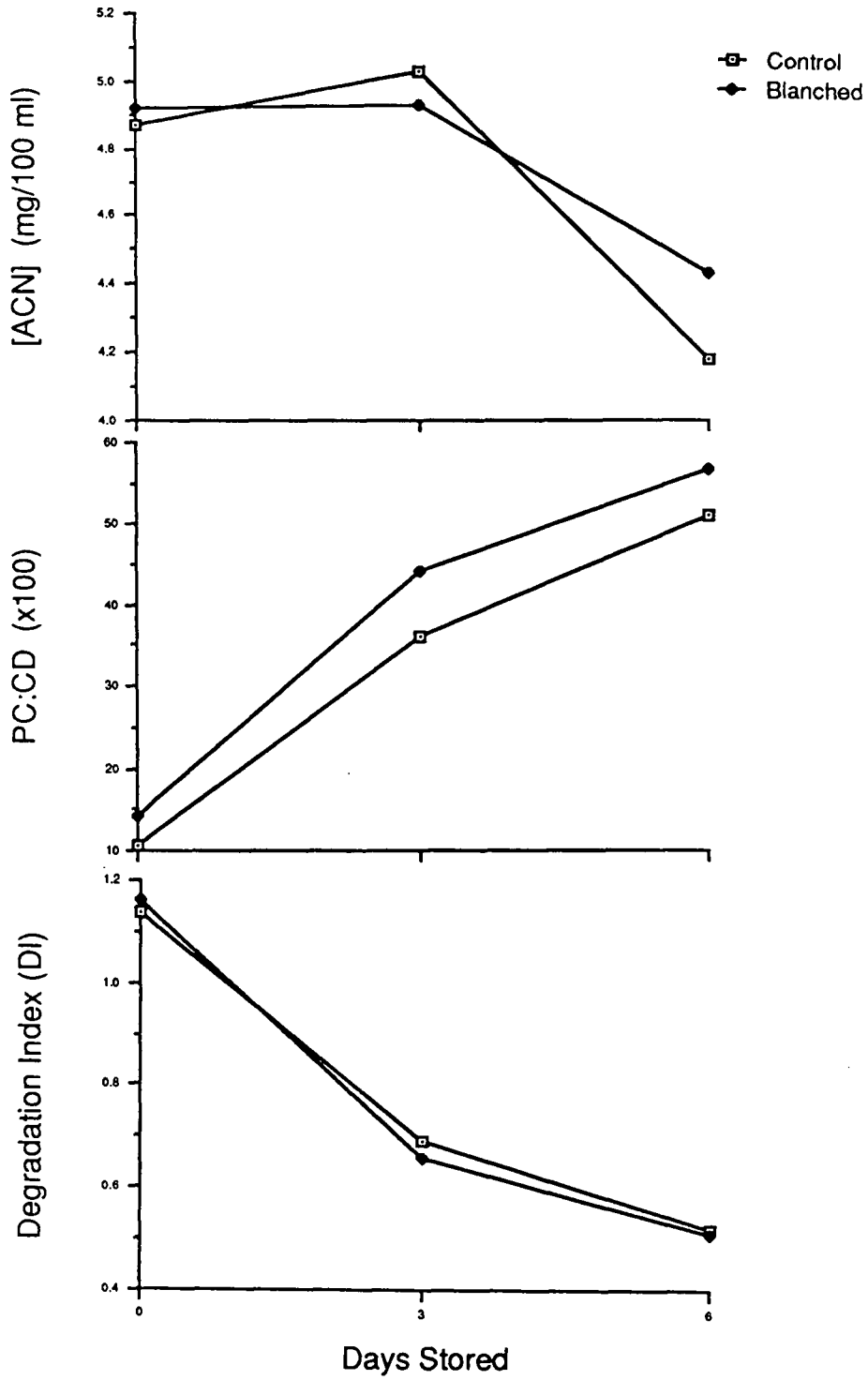


Figure 3.12. Pigment changes in stored strawberry juice concentrate by colorimetric analyses from blanched or control strawberries. Changes displayed are the monomeric anthocyanin concentration ([ACN]), polymeric pigment (not bleached by sulfite) contribution to the color density (%PC:CD) and degradation index (A_{520}/A_{420}).

27A and Appendix 28, respectively. Neither the SJ or SJC samples were affected by processing/storage treatments. The batch and processing means are listed in Appendix 27B, while SJC means are given in Table 3.2.

Free Amino Acids and Acidity. The F-values for testing processing effects on SJ and SJC samples with respect to concentration of free amino acids (AA), pH and titratable acidity (TA) are listed in Appendix 29A and 30, respectively. Blanching did not significantly affect the concentrations of AA, pH or TA in the SJ or SJC samples. The differences among means for the SJ samples are presented in Appendix 29B, while the SJC samples are listed in Table 3.2.

The composition of this SJC differs considerably from the commercially produced concentrate in the previous study (Lundahl et al., 1989). The free sugar profile of the commercial SJC lacked measurable quantities of sucrose and greater concentrations of glucose and fructose. Further, the commercial concentrate had 30% less TA and a 2.6 times the free AA concentration. Therefore, lower levels of AA may explain the observed difference in AA loss.

Headspace CO_2 and O_2. The F-values to test the process/storage treatment effects for O_2 and CO_2 are given in Appendix 31A. The O_2 content did not change significantly during storage, while the CO_2 concentration in headspace above concentrate increased linearly for both the control and blanch PRC levels (Appendix 31B). Figure 3.13 displays the differences in CO_2 content in the headspace above the concentrate. The rate of CO_2 production during storage declined significantly ($p<0.01$) for the

Table 3.2. Means and standard deviations (in parentheses) for free sugar, acidity (pH and titratable acidity) and free amino acid concentrations of stored strawberry juice concentrate (adjusted to 8°Brix). Free sugars included sucrose (SUC), glucose (GLU), fructose (FRU) and sorbitol (SOR). Free amino acids were reported by the formol number (FN). Values all reported for juice at 8°Brix.

PROCESS	DAYS STORED	FREE SUGARS (g/100 mL) SUC	GLU	FRU	SOR	ACIDITY pH	TA[1]	FN[2]
	0	1.00	1.00	1.16	0.03	3.37	0.93	5.64
		(0.02)	(0.02)	(0.03)	(0.01)	(0.02)	(0.07)	(0.50)
CONTROL	3					3.36	0.94	5.62
						(0.02)	(0.05)	(0.28)
	6	0.97	0.96	1.12	0.02	3.36	0.96	5.78
		(0.07)	(0.04)	(0.06)	(0.00)	(0.02)	(0.02)	(0.15)
	0	1.02	0.93	1.09	0.03	3.37	0.94	5.84
		(0.04)	(0.04)	(0.05)	(0.05)	(0.03)	(0.01)	(0.10)
BLANCH	3					3.36	0.94	5.57
						(0.02)	(0.03)	(0.24)
	6	1.02	0.96	1.11	0.03	3.36	0.96	5.62
		(0.02)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.10)
STO/PRC Sig. Level		NS	NS	NS	NS	NS	NS	NS

1) titratable acidity expressed as percent (w/v) citric acid
2) formal number expressed as mg/100 ml α-amino acid

NS - not significant at the 0.05 level ($p>0.05$).

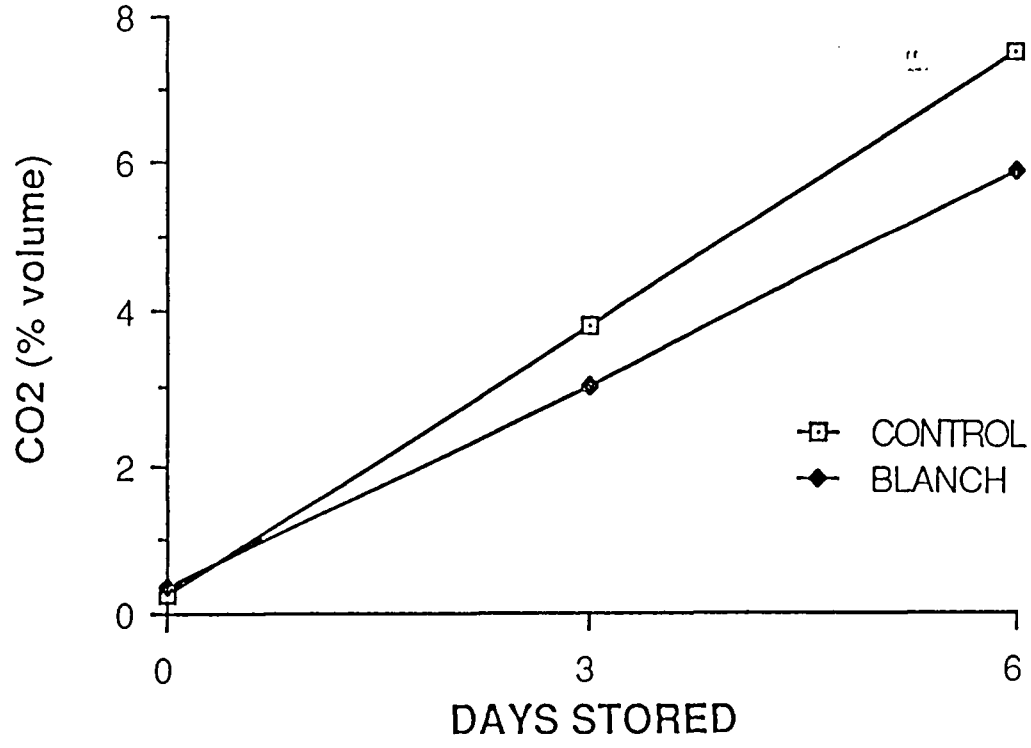


Figure 3.13. Differences in rates of CO_2 production in stored strawberry juice concentrate from blanched or control processed fruit.

pre-liquefaction blanch treatment. This inference was based on Wilks' Lambda for the PRC difference between TIM regression coefficients adjusted for the BAT and BAT*TIM sources of variation.

DISCUSSION

Comparisons to Commercially Produced Concentrate

Previous research (Lundahl et al., 1989) described the sensory and compositional changes during storage of commercially produced strawberry juice concentrate (C-SJC). The processing conditions for the present study were chosen to simulate the industrial process, however some differences might be expected due to the scale of the process operation or to fruit quality or cultivar differences.

During storage, the C-SJC increased in musty/moldy and pungent aromas; increased in astringency; and changed color hue from red to brown, darkened and a decreased in color intensity. In this subsequent study, utilizing selected strawberries and pilot plant concentration equipment, an increase in astringency or dark coloration with storage was not detected. With respect to coloration, the SJC became lighter. Hassanein (1982) noted Hunter "L" values to increase (e.g. become lighter in color) during storage at 21^{o}C in SJ, but to decrease in stored SJC. The discrepancy was hypothesized to be attributed to different rates of precipitation of polymerized compounds due to a higher viscosity in the SJC. Since

both SJC and C-SJC were 68°Brix, an alternative hypothesis is required. Little (1977) noted a similar lightening during storage of strawberry preserves and canned fruit and speculated that the color difference was related directly to loss of ACN, rather than the precipitation of phenolics. Darkening, observed in the C-SJC, may be related to another mechanism which can produce chromophores (e.g., ascorbic acid browning).

Compositional changes during storage of C-SJC included a decrease in ACN, an increase in the tannin (PC) contribution to color density (i.e. %PC:CD), the release of CO_2 and a decrease in free amino acids, while free sugars and acidity levels remained constant (Lundahl et al., 1989). This subsequent research did not detect the loss of free αamino acids (AA), however the level of amono acid concentration was much lower than in the C-SJC. Other differences included a lower rate of ACN loss, a smaller increase in the tannin contribution to color density, and a lower release rate of CO_2. The control SJC had only 14% loss of ACN compared to a 46% loss in the C-SJC. The percent tannin contribution to color density was 51.0% in the SJC after six days storage compared to 76.2 % in the C-SJC, and the percent volume of CO_2 in headspace after six days storage was also greater in the C-SJC (17.2% vs 7.5%). These results further support the assertion that the SJC underwent a lower degree of degradation than the C-SJC. The lack of a significant decrease in AA may only be indicative of the lower rate of degradation in the control SJC. Higher levels of AA in the C-SJC could have contributed to the increased rates of ACN degradation, since AA were observed to degrade during storage. Aldehydes from Strecker degradation of AA

can increase the complexing and polymerization of ACN (Timberlake and Bridle, 1977; Chen and Wrolstad, 1977; Debicki-Pospisil, 1983). Greater complexing can contribute to a color darkening as observed in the C-SJC.

Another distinction is the stability of ACN during the first three days of storage in the blanched and unblanched SJC, while the C-SJC ACN was unstable. This result suggests a mechanism protected ACN initially. If the CO_2 is related to AsA browning mechanisms, these support the hypothesis that AsA protects ACN by increasing the redox poise of the system as suggested by Skalski and Sistrunk (1973) and Pifferi and Cultera (1974). In the C-SJC, as well as the concentrate produced by Hassanein (1982), the AsA may have been degraded considerably. Therefore, ACN were no longer protected.

The lower degradation rate may be due to differences in strawberry variety, fruit quality, or processing conditions. In the latter case, processing conditions were chosen to follow commercial processing conditions. Therefore, this is not believed to be the major factor. The C-SJC were from mixed varieties of strawberries of unknown quantity which may have had higher levels of oxidative liable phenolics and lower concentrations of ascorbic acid (AsA) to protect against the degradation of ACN. Abers and Wrolstad (1979) reported the Tioga variety to have a greater degradation rate than Hood, and attributed this to Tioga having greater concentrations of catechin and leucoanthocyanin, and a lower concentration of AsA. In comparison to fruit used for SJC production, C-SJC fruit quality (i.e. microbiological and physical condition) would be expected to be lower. The fruit used for this current investigation was of the

highest possible quality. The fruit washand picked, washed, sorted and individually quick frozen to reduce to the lowest possible level the incidence of any fungal contamination. Pilando (1982) reported that strawberry wine made from mold-contaminated fruit underwent more pronounced color degradation upon storage. Huang (1955a) reported the activity of glycosidases from fungal origin in the degradation of ACN. Strawberries that have been injured during harvesting increase the possibility for the contact of substrates and enzymes that can initiate oxidative degradation mechanisms (Pollard and Timberlake, 1970; Wesche-Ebeling, 1984). The presence of proteases of fungal origin could increase the α-amino acid concentration, thereby increasing the rate of degradation by Strecker mechanisms.

Processing Effects on SJC Degradation

The effects of pre-liquefaction blanching of strawberries on the subsequent degradation of SJC can be characterized by a slower rate of ACN loss and CO_2 release. The percent tannin contribution to color density (%PC:CD) was greater after blanching; however, the rate of tannin formation was the same as the control. These results suggest that the contribution of enzymatic activity to degradation is small compared to non-enzymatic mechanisms. The %PC:CD increase with blanching suggests the formation of polyphenolics from heating. This compositional change was related to an increase in astringency (rated by scaling) and an increase in sourness (rated by time-intensity measurement). Astringency has been related to increases of procyanidins polymers (6-10 units) in ciders (Lea and Timberlake,

1974; Lea and Arnold, 1978, 1983). Polyphenolic compounds are believed to associate with and precipitate proteins in the mouth (Bate-Smith, 1973). Citric acid has been shown to associate with polyphenolic complexes in model solutions (Clegg, 1966). It is possible that the increase in sourness is due to a higher concentration of citric acid (the major strawberry acid) in the polyphenolic complexes. Since sourness has been to relate to both the unassociated and dissociated proton, hydrophobic mechanism could position these astringent polyphenolic complexes near the sour taste receptor sites.

The production of CO_2 has been well documented to relate to the loss of AsA (Lambden and Harris, 1950; Kurata and Sakurai, 1967; Huelin et al., 1971; Kurata et al., 1973). Strawberries have high levels of AsA, ranging from 28.5 to 94.3 mg/100 mL of fruit (Wrolstad et al., 1970a). The loss of AsA due to oxidative degradation has been reported related to a decrease in water activity in the range of juice concentrates (Ranganna and Setty, 1968; Erlandson and Wrolstad, 1972; Lee and Labuza, 1975), the oxidative degradation of catechol to an o-quinone (Peng and Markakis, 1963; Skalski and Sistrunk, 1973; Pifferi and Cultera, 1974; Poei-Langston and Wrolstad, 1981), and the presence of flavonols with good anti-oxidant properties (Hooper and Ayres, 1950; Davidek, 1960; Harper et al., 1969). Catechin, the major flavan-3-ol of strawberries, is the major substrate for polyphenoloxidase (PPO) (Wesche-Ebeling, 1984).

Other possible CO_2 sources include Strecker degradation from free α-amino acids (AA) and α-dicarbonyls or microbial activity. The use of high quality fruit and HTST pasteurization in

the processing of SJ should have killed any micro-organisms present in the juice. Strecker degradation is a possible source, however AA's did not significantly decrease in this study.

A decrease in sweetness perception during storage for only the control samples suggests the presence of an enzyme catalyzed reaction. Free sugar levels did not change during storage for either process level. Time-intensity evaluations and principle components analysis failed to detect a sweetness/sourness relationship associated with change in control samples during storage. Therefore, these results cannot give a succinct explanation for this phenomenon.

Polyphenoloxidase activity, as measured by headspace O_2 concentration, was not observed to be significant suggesting the pasteurization step successfully inactivated oxidases. Blanch treatment differences were assumed due to enzyme activity during or after liquefaction, but before the pasteurization processing step.

In spite of these compositional differences, aroma evaluation did not detect many processing differences. However, a musty/moldy aroma developed during storage for both PRC levels indicating that non-enzymatic mechanisms are related to this off-aroma. It is important to note that this off-aroma was not detectable in the juice or unstored SJC. Further, principle components analysis failed to select a component which indicated that another aroma component of unstored juice underwent a reaction to form a musty/moldy product. However, univariate analyses of musty/moldy and buttery aroma revealed an inverse relationship. Therefore, it is concluded that this aroma is formed from a precursor which is not musty/moldy.

MAJOR FINDINGS

1. Over six days storage at 20°C, the characterization of sensory changes in strawberry juice concentrate included:

   (a) both C-SJC and SJC increased in "musty/moldy" and "pungent" aromas, while other aromas such as "buttery" aroma decreased in the SJC.

   (b) astringency increased after one day storage in C-SJC and was greater in the SJC from blanched fruit.

   (c) the duration of the peak sourness intensity was longer in SJC from blanched fruit.

   (d) color changed from red to brown in hue and decreased in chroma (intensity) in both C-SJC and SJC, while the value (lightness) of color decreased in C-SJC and increased in SJC from blanched and unblanched fruit.

2. In SJC, the peak duration time for sourness perception from blanched fruit was related to increased astringency and increased polyphenolic (tannin) contribution to color density.

3. CO_2 was formed during storage of both C-SJC and SJC with a slight decrease in rate of release in SJC from blanched compared to unblanched fruit suggesting only a slight contribution to CO_2 production from enzyme catalyzed mechanisms.

4. CO_2 formation was associated with a decrease in free α-amino acids in C-SJC. This decrease was not observed in the SJC. However, initial concentrations of α-amino acids were lower in the SJC than the C-SJC. Further, the rate of CO_2 release was lower in the SJC suggesting that degradation of amino acids (e.g. Strecker mechanisms) could have contributed to some CO_2 formation.

5. Anthocyanin pigments decreased during storage of both C-SJC and SJC from blanched and unblanched fruit and were related to an increase in polymeric pigment (tannin) contribution to color density.

6. The rate of ACN decrease was slightly less in SJC from blanched fruit, however the relative difference was small compared to the overall decrease.

7. Free sugar and acidity levels were stable over C-SJC and SJC from blanched and unblanched fruit.

CONCLUSIONS

These experiments determined that substantial changes in color, taste and aroma occurred during six days storage of stawberry juice concentrate at 20°C. This degradation was associated with release of CO_2. A decrease in free α-amino acids when the initial concentration of amino acids was high suggests the presence of Strecker degradation mechanisms. Results from these investigations indicate that degradation mechanisms in concentrate from fruit of high quality are primarily non-enzymatic, rather than enzymatic. Therefore, future research should relate to possible processing conditions that will reduce non-enzymatic degradation mechanisms.

REFERENCES CITED

AOAC. 1984. "Official Methods of Analysis," 14th ed. Association of Official Agricultural Chemists, Washington, D.C.

Abers, J.E. and Wrolstad, R.E. 1979. Causative factors of color deterioration in strawberry preserves during processing and storage. J. Food Sci. 44:75.

Anderson, R.L. and Bancroft, T.A. 1952. "Statistical Theory in Research. Part II - Analysis of Experimental Models by Least Square." McGraw-Hill Book Co., Inc., New York.

Bate-Smith, E.C. 1973. Haemanalysis of tannins: the concept of relative astringency. Phytochem. 12:907.

Chen, W. and Wrolstad, R.E. 1980. A note on the influence of acetaldehyde on colour of strawberry juice. J. Sci. Food Agric. 31:661.

Clegg, K.M. 1966. Citric acid and the browning of solutions containing ascorbic acid. J. Sci. Food Agric. 17:546.

Cochran, W.G. and Cox, G.M. 1950. "Experimental Designs," John Wiley and Sons, Inc., New York.

Daravingas, G. and Cain, R.F. 1968. Thermal degradation of black raspberry anthocyanin pigments in model systems. J. Food Sci. 33:138.

Davidek, I. 1960. Stabilizing effect of flavonoids on L-ascorbic acid. Biokhimiya 25:1105. (Translation in Biochemistry 25:864).

Debicki-Pospisil, J., Lovric, T., Trinajstic, N., and Sabljic, A. 1983. Anthocyanin degradation in the presence of furfural and 5-hydroxymethylfurfural. J. Food Sci. 48:411.

Feather, M.S. and Harris, J.F. 1973. Dehydration reactions of carbohydrates. Adv. Carbohydr. Chem. 28:161.

Gacula, Jr. M.C. and Singh, J. 1984. "Statistical Methods in Food and Consumer Research." Academic Press, Inc., New York.

Harper, K.A., Morton, A.D., and Rolfe, E.J. 1969. The phenolic compounds of blackcurrant juice and their protective effect on ascorbic acid. J. Fd. Technol. 4:255.

Hassanein, S.M. 1982. Color of strawberry juice and concentrate as influenced by heating and storage temperatures. M.S. Thesis. Oregon State University, Coravallis, Oregon.

Hooper, F.C. and Ayres, A.D. 1950. The enzymatic degradation of ascorbic acid. Part I.-The inhibition of the enzymatic oxidation of ascorbic acid by substances occurring in black currants. J. Sci. Food Agric. 1:5.

Hrazdina, G. and Franzese, A.J. 1974. Oxidation of products of acylated anthocyanins under acidic and neutral conditions. Phytochemistry 13:231.

Huang, H.T. 1955. Decolorization of anthocyanins by fungal enzymes. Ag. and Fd. Chem. 3(2):141.

Huelin, F.E., Coggiola, I.M., Sidhu, G.S. and Kennett, B.H. 1971. The aerobic decomposition of ascorbic acid in the pH range of most foods and in more acidic solutions. J. Sci. Fd. Agric. 22:540.

Ishihara, S. 1971. "Tests for Colour Blindness." Kanehara Shuppan Co., LTD. Tokyo, Japan.

Joslyn, M.A. and J.D. Ponting. 1951. Enzyme-catalyzed oxidative browning of fruit products. Adv. Food Res. 3:1.

Jurd, L. 1966. Anthocyanidins and related compounds-X Peroxide oxidation products of 3-alkylflavylium salts. Tetrahedron 22:2913.

Jurd, L. 1967. Anthocyanidins and related compounds-XI Catechin-flavylium salt condensation reactions. Tetrahedron 23:1057.

Jurd, L. 1968. Anthocyanidins and related compounds-XII Hydrogen peroxide oxidation of flavilium salts. Tetrahedron 24:4449.

Kurata, T., Fujimaki, M., and Sakurai, Y. 1973. Red pigment produced by the reaction of dehydro-L-ascorbic acid with -amino acid. Agr. Biol. Chem. 37(6):1471.

Kurata, T. and Sakurai, Y. 1967. Degradation of L-ascorbic acid and mechanism of nonenzymatic browning reaction Part II. Non-oxidative degradation of L-ascorbic acid including formation of 3-deoxy-L-pentosone. Agr. Biol. Chem. 31(2):170.

Lalikainen, T., Joslyn, M.A., and Chichester, C.O. 1958. Mechanism of browning of ascorbic acid-citric acid-glycine systems. Ag. and Fd. Chem. 6(2):135.

Lamden, M.P. and Harris, R.S. 1950. Browning of ascorbic acid in pure solutions. Food Res. 15:79.

Lea, A.G.H. and Timberlake, C.F. 1974. The phenolics of ciders. I. Procyanidins. J. Sci. Food Agric. 25:1537.

Lea, A.G.H. and Arnold, G.M. 1978. The phenolics of ciders: bitterness and astringency. J. Sci. Food Agric. 29:478.

Lea, A.G.H. and Arnold, G.M. 1983. Bitterness, astringency and the chemical composition of ciders. In "Sensory Quality of Foods and Beverages: Definition, Measurement and Control," A.A. Williams and R.K. Atkin (Ed.), p. 203. Allis Horwood Ltd., Chichester, England.

Lee, S.H. and Labuza, T.P. 1975. Destruction of ascorbic acid as a function of water activity. J. Food Sci. 40:370.

Lundahl, D.S. and McDaniel, M.R. 1988. The panelist effect: fixed or random? J. Sensory Studies 3:113.

Lundahl, D.S., McDaniel, M.R., and Wrolstad, R.E. 1989. Flavor, aroma and compositional changes in strawberry juice concentrate stored at 20°C. J. Food Sci. (in review)

Meilgaard, M.D., Carr, T.B., and Civille, G.V. 1987. Descriptive analysis Techniques (Ch.8) In "Sensory Evaluation Techniques. Volume II." CRC Press, Inc., Boca Raton, FL.

Meschter, E.E. 1953. Effects of carbohydrates and other factors on strawberry products. J. Agric. Food Chem. 1:574.

Peng, C.Y. and Markakis, P. 1963. Effect of phenolase on anthocyanins. Nature 199:597.

Pifferi, P.G. and Cultera, R. 1974. Enzymatic degradation of anthocyanins: the role of sweet cherry polyphenol oxidase. J. Food Sci. 39:786.

Pilando, L.S. 1982. Strawberry wine color quality: influence of variety, maturity and mold contamination. M.S. Thesis, Oregon State University, Corvallis, Oregon.

Poei-Langston, M.S. and Wrolstad, R.E. 1981. Color degradation in an ascorbic acid-anthocyanin-flavanol model system. J. Food Sci. 46:1218.

Pollard, A. and Timberlake, C.F. 1971. Fruit juices. In "The Biochemistry of Fruits and Their Products," A.C. Hulme (Ed.), p. 573. Academic Press, New York.

Ranganna, S. and Setty, L. 1968. Nonenzymatic discoloration in dried cabbage. Ascorbic acid-amino acid interactions. J. Agr. Food Chem. 16(3):529.

Sistrunk, W.A. and Cash, J.N. 1968. Stabilizing the color of frozen strawberries. Arkansas Farm Res. 17(3):2.

Skalski, C. and Sistrunk, W.A. 1973. Factors influencing color degradation in concord grape juice. J. Food Sci. 38:1060.

Sondheimer, E. and Kertesz, Z.I. 1948. The anthocyanin of strawberries. J. Am. Chem. Soc. 70:3476.

Sondheimer, E. and Kertesz, Z.I. 1952. The kinetics of the oxidation of strawberry anthocyanin by hydrogen peroxide. Food Res. 17:288.

Sondheimer, E. and Kertesz, Z.I. 1953. Participation of ascorbic acid in the destruction of anthocyanin in strawberry juice and model systems. Food Res. 18:475.

Spanos, G.A. and Wrolstad, R.E. 1987. Anthocyanin pigment, non-volatile acid, and sugar composition of red raspberry juice. J. Assoc. Off. Anal. Chem. 70(6):1036.

Steel, R.G.D. and Torrie, J.H. 1980. "Principles and Procedures of Statistics. A Biometrical Approach," Second Edition, McGraw-Hill Book Co., New York.

Tannenbaum, S.R. 1976. Vitamins and Minerals (Ch. 7). In "Principles of Food Science," O.R. Fennema (Ed.) p. 347. Marcel Dekker, Inc., New York.

Timberlake, C.F. and Bridle, P. 1977. Anthocyanins: colour augmentation with catechin and acetaldehyde. J. Sci. Fd. Agric. 28:539.

Tinsley, I.J. and Bockian, A.H. 1959. Chromatographic identification and estimation of the free amino acids present in strawberry juice. Food Res. 25:410.

Vamos-Vigyazo, L. 1981. Polyphenol oxidase and peroxidase in fruits and vegetables. CRC Crit. Rev. Food Technol. 15:49.

Wesche-Ebeling, P.A.E. 1983. Purification of strawberry polyphenol oxidase and its role in anthocyanin degradation. Ph.D. Thesis, Oregon State University, Corvallis, Oregon.

Wrolstad, R.E. 1976. Color and pigment analyses in fruit products. Oregon Agric. Expt. Stn. Bull. 624, Corvallis, Oregon.

Wrolstad, R.E., Lee, D.D., and Poei, M.S. 1980. Effect of microwave blanching on the color and composition of strawberry concentrate. J. Food Sci. 45(6):1573.

Wrolstad, R.E., Putnam, T.P., and Varselald, G.W. 1970. Color quality of frozen strawberries: effect of anthocyanin, pH, total acidity and ascorbic acid variability. J. Food Sci. 35:448.

BIBLIOGRAPHY

Abers, J.E. and Wrolstad, R.E. 1979. Causative factors of color deterioration in strawberry preserves during processing and storage. J. Food Sci. 44: 1.

Acree, T.E., Barnard, J., and Cunningham, D.G. 1984. A procedure for the sensory analysis of gas chromatographic effluents. Food Chem. 14: 273.

Adams, J.B. 1973a. Colour stability of red fruits. Food Manufacture 48: 19.

Adams, J.B. 1973b. Thermal degradation of anthocyanins with particular reference to the 3-glycosides of cyanidin. I. In acidified aqueous solution at 100° C. J. Sci. Fd Agric. 24: 747-762.

Adams, J.B. and Woodman, J.S. 1973. Thermal degradation of anthocyanins with particular reference to the 3-glycosides of cyanidin. II. The anaerobic degradation of cyanidin-3-rutinoside at 100°C and pH 3.0 in the presence of sodium sulphite. J. Sci. Fd Agric. 24: 763-768.

Anderson, R.L. and Bancroft, T.A. 1952. "Statistical Theory in Research. Part II - Analysis of Experimental Models by Least Square," McGraw-Hill Book Co., Inc., New York.

Angell-James, J.D. and Daly, M. 1972. Some aspects of upper respiratory tract reflexes. Acta Otolar 79: 242. [Cited in Cometto-Muniz and Cain, 1982]

AOAC. 1984. "Official Methods of Analysis," 14th ed. Association of Official Agricultural Chemists, Washington, DC.

Arnold, R.A. and Noble, A.C. 1978. Bitterness and astringency of grape seed phenolics in a model wine solution. Am. J. Enol. Vitic. 29: 150.

Ayerst, G. 1969. The effects of moisture and temperature on growth and spore germination in some fungi. J. Stored Prod. Res. 5: 127.

Barnes, J.M. and Kaufman, C.W. 1947. Industrial aspects of the browning reaction. Ind. Eng. Chem. 39: 1167. [Cited in Shallenberger and Birch, 1975, (Ch.7).]

Barritt, B.H. 1980. Resistance of strawberry clones to botrytis fruit rot. J. Amer. Soc. Hort. Sci. 105(2): 160-164.

Bate-Smith, E.C. 1973. Haemanalysis of tannins: the concept of relative astringency. Phytochem. 12: 907.

Bauernfeind, J.C. and Pinkert, D.M. 1972. Food processing with added ascorbic acid. Adv. Food Res. 18: 220.

Beart, J.E., Lilley, T.H., and Haslam, E. 1985 Plant polyphenols - secondary metabolism and chemical defence: some observations. Phytochem. 24: 33.

Beattie, H.G., Wheeler, K.A., and Pederson, C.S. 1943. Changes occurring in fruit juices during storage. Food Res. 8: 395.

Beets, M.G.J. 1978. The sour and salty modalities. In "Structure-activity relationships in human chemoreception", p. 348. Applied Sciences: London.

Beveridge, T. and Harrison, J.E. 1984. Nonenzymatic browning in pear juice concentrate at elevated temperatures. J. Food Sci. 49: 1335.

Birch, G.G., Latymer, Z., and Holloway, M. 1980. Intensity/time relationships in sweetness: evidence for a queue hypothesis in taste chemoreception. Chem. Senses 5: 63.

Birch, G.G. and Munton, S.L. 1981. Use of the "SMURF" in taste analysis. Chem. Senses 6: 45.

Brouillard, R. and Delaporte, B. 1977. Chemistry of anthocyanin pigments. 2. Kinetic and thermodynamic study of proton transfer, hydration, and tautomeric reactions of malvidin 3-glucoside. J. Amer. Chem. Soc. 99: 8461.

Buerger, M.C. 1986. "Strawberry cell wall polysaccharides: an intervarietal comparison of compositional, physical, and textural properties," M.S. thesis, Oregon State Univ., Corvallis, OR.

Burroughs, L.F. 1970. Amino acids. In "The Biochemistry of Fruits and Their Products." Vol. 1. A.C. Hulme (Ed.), p. 119. Academic Press, Inc., New York.

Burton, H.S. and McWeeny, D.T. 1963. Non-enzymatic browning reactions: consideration of sugar stability. Nature 197: 1167.

Buttery, R.G. 1979. Vegetable and fruit flavors. In "Flavor Research: Recent Advances." Roy Teranishi and R.A. Flath (Ed.), p. 175. Marcel Dekker, Inc, New York.

Buttery, R.G. and Teranishi, R. 1963. Measurement of fat autooxidation and browning aldehydes in food vapors by direct vapor injection gas-liquid chromatography. Ag. Food Chem. 11: 504.

Byrde, R.J.W., Fielding, A.H., and Williams, A.H. 1960. "Phenolics in Plants in Health and Disease," J.G. Pridham (Ed.), p. 95. Pergamon Press, Oxford.

Calvi, J.P. and Francis, J. 1978. Stability of concord grape (V. labrusca) anthocyanins in model systems. J. Food Sci. 43: 1448.

Cash, J. and Sistrunk, W.A. 1970. Anthocyanin pigment concentration and type are important for color in strawberries. Ark. Farm Res. 19: 8.

Chen, W. and Wrolstad, R.E. 1980. A note on the influence of acetaldehyde on colour of strawberry juice. J. Sci. Food Agric. 31: 667.

Chinchester, C.O. and McFeeters, R. 1971. Pigment degeneration during processing and storage. In "The Biochemistry of Fruits and Their Products," Vol. 2, A.C. Hulme (Ed.), p. 707. Academic Press. New York.

Clegg, K.M. 1964. Non-enzymic browning of lemon juice. J. Sci. Food Agric. 15: 878.

Clegg, K.M. 1966. Citric acid and the browning of solutions containing ascorbic acid. J. Sci. Food Agric. 17: 546.

Clegg, M.K. and Morton A.D. 1968. The phenolic compounds of blackcurrent juice and their protective effect on ascorbic acid. II. The stability of ascorbic acid in model systems containing some of the phenolic compounds associated with blackcurrent juice. J. Food Technol. 3: 277.

Clifford, M.N. 1987. Phenol-protein interaction and their possible significance for astringency. In "Interactions of Food Components," G.G. Birch and M.G. Lindley (Ed.), p. 143. Elsevier Applied Science, New York.

Clydesdale, F.M. 1978. Colorimetry - methodology and applications. CRC Crit. Rev. Food Technol. 12: 243.

Co, H. and Markakis, P. 1968. Flavonoid compounds in the strawberry fruit. J. Food Sci. 33: 281.

Cochran, W.G. and Cox, G.M. 1950. "Experimental Designs," John Wiley and Sons, Inc., New York.

Cometto-Muniz, J.E. and Cain, W. 1982. Perception of nasal pungency in smokers and nonsmokers. Physiology & Behavior 29: 727.

Cometto-Muniz, J.E. and Cain, W.S. 1984. Temporal integration of pungency. Chem. Senses 8: 315.

Cometto-Muniz, J.E. and Noriega, G. 1985. Gender differences in the perception of pungency. Physiology and Behavior 34: 385.

Cornwall, C.J. and Wrolstad, R.E. 1981. Causes of browning in pear juice concentrate during storage. J. Food Sci. 46: 515.

Daravingas, G. and Cain, R.F. 1965. Changes in the anthocyanin pigments of raspberries during processing and storage. J. Food Sci, 30: 400.

Daravingas, G. and Cain, R.F. 1968. Thermal degradation of black raspberry anthocyanin pigments in model systems. J. Food Sci. 33: 138.

Davidek, I. 1960. Stabilizing effect of flavonoids on L-ascorbic acid. trans. from Bilkhimiya 25: 1105.

Decareau, R.V., Livingston, G.E., and Fellers, C.R. 1956. Color changes in strawberry jellies. Food Tech. 10: 125.

Debicki-Pospisil, J., Lovric, T., Trinajstic, N., and Sabljic, A. 1983. Anthocyanin degradation in the presence of furfural and 5-hydroxymethylfurfural. J. Food Sci. 48: 411.

Dekker, A.O. and Dickinson, R.G. 1940. Oxidation of ascorbic acid by oxygen with cupric ion as catalyst. J. Am. Chem. Soc. 62: 2165.

Delcour, J.A., Vandenberghe, M.M., Corten, P.F., and Dondeyne, P. 1985. Formation of ethyl esters of tartaric acid during wine aging: chemical and sensory effects. Am. J. Enol. Vitic. 35: 134.

Dennis, C. and Davis, R.P. 1977. Susceptibility of strawberry varieties to post-harvest fungal spoilage. J. Appl. Bact. 42: 197.

Dennison, D.B. and Kirk, J.R. 1982. Effect of trace mineral fortification on the storage stability of ascorbic acid in a dehydrated model food system. J. Food Sci. 47: 1198.

Dirinck, P., Schreyen, L., and Schamp, N. 1977. Aroma quality evaluation of tomatoes, apples, and strawberries. J. Agric. Food Chem. 25: 759.

Drapron, R. 1985. Enzyme activity as a function of water activity. In "Properties of Water in Foods in 'relation to Quality and Stability," D. Simatos and J.L. Mutton (Ed.), p. 171. Martinus Nijhoff Pub., Dordrecht, The Netherlands.

Eagerman, B.A., Clydesdale, F.M., and Francis, F.J. 1973. Comparison of color scales for dark colored beverages. J. Food Sci. 38: 1051.

Eichner, K. and Karel, M. 1972. The influence of water content and water activity on the sugar-amino browning reaction in model systems under various conditions. J. Agr. Food Chem. 20: 218.

Eison-Perchonok, M.H. and Downes, T.W. 1982. Kinetics of ascorbic acid autoxidation as a function of dissolved oxygen concentration and temperature. J. Food Sci. 47: 765.

Ellis, G.P. 1959. The maillard reaction. Adv. in Carbohydrate Chem. 14: 63.

Ennis, D.M. and Mullen, K. 1986. Theoretical aspects of sensory discrimination. Chem. Senses 11: 513.

Erlandson, J.A. and Wrolstad, R.E. 1972. Degradation of anthocyanins at limited water concentration. J. Food Sci. 37: 592.

Fearon, W.R. and Kaweray, E. 1943. The oxidation of ascorbic acid by o-dinitrobenzene and the detection of dehydroascorbic acid. Biochem. J. 37: 326.

Feather, M.S. and Harris, J.F. 1973. Dehydration reactions of carbohydrates. Adv. Carbohydr. Chem. 28: 161.

Fennema, O. 1975. Activity of enzymes in partially frozen aqueous systems. In "Water Relations of Foods," R.B. Duckworth (Ed.), p. 397. Academic Press, Inc., New York.

Fennema, O. 1985. Water and ice. In "Food Chemistry," O. Fennema (Ed.), p. 23. Marcel Dekker, Inc., New York.

Ferretti, A. and Flanagan, V.P. 1972. Steam volatile constituents of stale nonfat dry milk. The role of the maillard reaction in staling. J. Agr. Food Chem. 20: 695.

Frank, R.A. and Byram, J. 1988. Taste-smell interactions are tastant and odorant dependent. Chem. Senses 13: 445.

Francis, F.J. 1952. A method of measuring the skin color of apples. Proc. Am. Soc. Hortic. Sci. 60: 213.

Francis, F.J. 1975. The origin of $\tan^{-1}$ a/b. J. Food Sci. 40: 412.

Gacula, M.C. and Singh, J. 1984. "Statistical Methods in Food and Consumer Research," Academic Press, Inc., London.

Gallander, J.F. 1979. Fruit concentration of amino acids in several strawberry cultivars in relation to the time of harvest. HortSci. 14: 48.

Gifford, S.R. and Clydesdale, F.M. 1986. The psychophysical relationship between color and sodium chloride concentrations in model systems. J. Food Protection 49: 977.

Gilbert, S.G. 1986. New concepts on water activity and storage stability. In "The Shelf Life of Foods and Beverages," Proceedings of the 4th International Flavor Conference, Rhodes, Greece, July 1985, G. Charalambous (Ed.), p.791. Elsevier Science Publ., Amsterdam, The Netherlands.

Giovanni, M.E. and Pangborn, R.M. 1983. Measurement of taste intensity and degree of liking of beverages by graphic scales and magnitude estimation. J. Food Sci. 48: 1175.

Goodall, H. and Scholey, J. 1975. The analysis of strawberries as a means of determining the fruit content of manufactured products. J. Food Technol. 10: 39.

Green, A. 1971. Soft Fruits. In "The Biochemistry of Fruits and Their Products," Vol. 2, A.C. Hulme (Ed.), p. 375. Academic Press, New York.

Grommeck, R. and Markakis, P. 1964. The effect of peroxidase of anthocyanin pigments. J. Food Sci. 29: 53.

Guinard, J-X., Pangborn, R.M., and Lewis, M.J. 1986a. Effect of repeated ingestion on temporal perception of bitterness in beer. J. Am. Soc. Brewing Chemists 44: 28.

Guinard, J-X., Pangborn, R.M., and Lewis, M.J. 1986b. Preliminary studies on acidity-astringency interactions in model solutions and wines. J. Sci. Food Agric. 37: 811.

Guinard, J-X., Pangborn, R.M., and Lewis, M.J. 1986. The time-course of astringency in wine upon repeated ingestion. Am. J. Enol. Vitic. 37: 184.

Guinard, J-X., Pangborn, R.M. and Shoemaker, C.F. 1985. Computerized procedure for time-intensity sensory measurements. J. Food Sci. 50: 543.

Guigoz, Y. and Solms, J. 1976. Bitter peptides, occurrence and structure. Chemical Senses and Flavor 2: 71.

Hagerman, A.E. and Butler, L.G. 1981. The specificity of proanthocyanidin-protein interactions. J. Biol. Chem. 256: 4494.

Hamilton, G.A. 1974. Chemical models and mechanisms for oxygenases. In "Molecular Mechanisms of Oxygen Activation," O. Hayaishi (Ed.), p. 405. Academic Press, New York.

Handwerk, R.L. and Coleman, R.L. 1988. Approaches to the citrus browning problem. A review. J. Agric. Food Chem. 36: 231.

Hardman, T.M. 1970. Interaction of water with food components. In "The Biochemistry of Fruits and Their Products," A.C. Hulme (Ed.), p. 19. Academic Press, Inc., New York.

Harper, K.A., Morton, A.D., and Rolfe, E.J. 1969. The phenolic compounds of blackcurrent juice and their protective effect on ascorbic acid. III. The mechanism of ascorbic acid oxidation and its inhibition by flavonoids. J. Food Technol. 4: 255.

Harvey, R.B. 1922. The relation between total acidity, the concentration of the hydrogen ion, and the taste of acid solutions. J. Am. Chem. Soc. 42: 712.

Hassanein, S.M. 1982. Color of strawberry juice concentrate as influenced by heating and storage temperature. M.S. thesis, Oregon State Univ., Corvallis, OR

Heatherbell, D.A., Ngaba, P., Fombin, J., Watson, B., Garcia, Z., Flores, J., and Hsu, J. 1984. Recent developments in the application of ultrafiltration and protease enzymes to grape juice and wine processing. In "The International Symposium on Cool Climate Viticulture and Enology." D.A. Heatherbell, P.B. Lombard, F.W. Bodyfelt and S.F. Price (Ed.) OSU Agric. Exp. Sta. Tech. Publ. No. 7628, p. 419. Oregon State University, Corvallis, OR

Hendel, C.E., Silveira, V.G., and Harrington, W.W. 1955. Rates of nonenzymatic browning of white potato during dehydration. J. Food Technol. 9: 433.

Herrmann, K. 1976. Flavonols and flavones in food plants: a review. J. Food Technol. 11: 433.

Hodge, J.E. 1967. Origin of flavor in foods, nonenzymatic browning reactions. In "Symposium on Foods: The Chemistry and Physiology of Flavors," H.W. Schultz, E.A. Day and L.M. Libbey (Ed.), p. 465. Avi. Publ. Co., Westport, CT.

Hong, V. 1987. Characterization of anthocyanins in fruit juice and natural colorants. Ph.D. thesis, Oregon State Univ., Corvallis, OR.

Hooper, F.C. and Ayres, A.D. 1950. The enzymatic degradation of ascorbic acid. Part I. - The inhibition of the enzymatic oxidation of ascorbic acid by substances occurring in black currants. J. Sci. Food Agric. 1: 5.

Hrazdina, G. and Franzese, A.J. 1974. Oxidation products of acylated anthocyanins under acidic and neutral conditions. Phytochem. 13: 213.

Huang, H.T. 1955. Decolorization of anthocyanins by fungal enzymes. J. Agric. and Food Chem. 3: 141.

Huang, H.T. 1956. The kinetics of the decolorization of anthocyanins by fungal "anthocyanase." J. Amer. Chem. Soc. 78: 2390.

Huelin, F.E., Coggiola, I.M., Sidhu, G.S., and Kennett, B.H. 1971. The anaerobic decomposition of ascorbic acid in the pH range of foods and in more acid solutions. J. Sci. Food Agric. 22: 540.

Hulme, A.C. and Wooltorton, L.S.C. 1958. The acid content of cherries and strawberries. Chem. and Ind. 22: 659.

Hunter, R.S. 1958. Photoelectric color difference meter. J. Opt. Soc. Am. 48: 985.

Hunter, R.S. and Harold, R.W. 1987. "The Measurement of Appearance," 2nd Edition, John Wiley and Sons, Inc., New York.

Iglesia, H.A. and Chirife, J. 1982. Handbook of Food Isotherms: Water Sorption Parameters for Food and Food Components. Academic Press, New York.

Ishihara, S. 1971. "Tests for Colour Blindness," Kanehara Shuppan Co., Ltd., Tokyo, Japan.

Joslyn, M.A. and Ponting, J.D. 1951. Enzume-catalyzed oxidative browning of fruit products. Adv. Food Res. 3: 1.

Jurd, L. 1963a. Anthocyanins and related compounds. I. Structural transformations of flavylium salts in acidic solutions. J. Org. Chem. 28: 987.

Jurd, L. 1963b. Reactions involved in sulfite bleaching of anthocyanins. J. Food Sci. 29: 16.

Jurd. L. 1966. Anthocyanidins and related compounds - X. Peroxide oxidation products of 3-alkylflavylium salts. Tetrahedron 22: 2913.

Jurd. L. 1967. Anthocyanidins and related compounds - XI. Catechin-flavylium salt condensation reactions. Tetrahedron 23: 1057.

Jurd. L. 1968. Anthocyanidins and related compounds - XIII. Hydrogen peroxide oxidation of flavylium salts. Tetrahedron 24: 4449.

Jurd, L. 1972. Some advances in the chemistry of anthocyanin-type plant pigments. In "The Chemistry of Plant Pigments," C.O. Chichester (Ed.), p. 123-142. Academic Press, New York.

Kertesz, Z.I. and Sondheimer, E. 1948. To reduce color losses in strawberry preserves. Food Ind. 20: 106.

Kearsley, M.W. and Rodriquez, N. 1981. The stability and use of natural colours in foods: anthocyanin, β-carotene and riboflavin. J. Food Technol. 16: 421.

Knee, M. and Bartley, I.M. 1981. Compostition and metabolism of cell wall polysaccharides in ripening fruit. In "Recent Advances in the Biochemistry of Fruits and Vegetables," J. Friend and M.J.C. Rhodes (Ed.), p. 133. Academic Press, New York.

Koppanyi, T., Vivino, A.E., and Veitch, F.P. 1945. A reaction of ascorbic acid with α-amino acids. Science 101: 541.

Kostyla, A.S. and Clydesdale, F.M. 1978. The psychophysical relationships between color and flavor. CRC Crit. Rev. Food Sci. and Nutr. 10: 303.

Kristberggson, K. 1985. Effect of the State of Water in Foods on Ascorbic Acid Degradation. Ph.D. thesis, Rutgers University, New Brunswick, N.J. [Cited in Gilbert, 1986].

Kurata, T., Fujimaki, M., and Sakurai, Y. 1973. Red pigment produced by the reaction of dehydro-L-ascorbic acid with α-amino acid. Agr. Biol. Chem. 37: 1471.

Kurata, T. and Sakurai, Y. 1967. Degradation of L-ascorbic acid and mechanism of nonenzymic browning reaction. Part II. Non-oxidative degradation of L-ascorbic acid including the formation of 3-deoxy-L-pentosone. Agr. Biol. Chem. 31: 170.

Labuza, T.P., Tannenbaum, S.R., and Karel, M. 1970. Water content and stability of low-moisture and intermediate moisture foods. Food Technol. 24: 543.

Laio, M. and Seib, P.A. 1988. Chemistry of L-ascorbic acid relateed to foods. Food Chem. 30: 289.

Lalikainen, T., Joslyn, M.A., and Chichester, C.O. 1958. Mechanism of browning of ascorbic acid-citric acid-glycine systems. Agr. Food Chem. 6: 135.

Lamden, M.P. and Harris, R.S. 1950. Browning of ascorbic acid in pure solutions. Food Res. 15: 79.

Larson-Powers, N. and Pangborn, R.M. 1978. Paired comparison and time-intensity measurements of the sensory properties of beverages and gelatins containing sucrose or synthetic sweeteners. J. Food Sci. 43: 41.

Leach, E.J. and Noble, A.C. 1986. Comparison of bitterness of caffeine and quinine by a time-intensity procedure. Chem. Senses 11: 339.

Lea, A.G.H. 1984. Tannin and colour in English cider apples. Flussiges Obst 8: 356.

Lea, A.G.H. and Arnold, G.M. 1978. The phenolics of ciders: bitterness and astringency. J. Sci. Food Agric. 29: 478.

Lea, A.G.H. and Arnold, G.M. 1983. Bitterness, astringency and the chemical composition of ciders. In "Sensory Quality in Foods and Beverages: Definition, Measurement and Control," A.A. Williams and R.K. Atkin (Ed.), p. 203. Allis Horwood Ltd., Chichester, England.

Lea, A.G.H. and Timberlake, C.F. 1974. The phenolics of ciders. I. Procyanidins. J. Sci. Food Agric. 25: 1537.

Lee, S.H. and Labuza, T.P. 1975. Destruction of ascorbic acid as a function of water activity. J. Food Sci. 40: 370.

Lee, W.E...1985. Evaluation of time-intensity sensory responses using a personal computer. J. Food Sci. 50: 1750.

Leung, H.K. 1987. Influence of water activity on chemical reactivity. In "Water Activity: Theory and Applications to Food," L.B. Rockland and L.R. Beuchat (Ed.), p. 27. Marcel Dekker, Inc., New York.

Little, A.C. 1975. Off on a tangent. J. Food Sci. 40: 410.

Little, A.C. 1977. Colorimetry of anthocyanin pigmented products: changes in pigment composition with time. J. Food Sci. 42: 1570.

Livingston, G.E. and Markakis, P.M. 1956. Biosynthesis of pelargonidin-3-monoglucoside- C^{14}. Science 124: 28.

Lukton, A., Chichester, C.O., and Mackinney, G. 1956. The breakdown of strawberry anthocyannin pigment. Food Tech. 10: 427.

Lundahl, D.S. and McDaniel, M.R. 1988. The panelist effect: fixed or random? J. Sensory Stud. 3: 113.

Lundahl, D.S., McDaniel, M.R., and Wrolstad, R.E. 1989. Flavor, aroma and compositional changes in strawberry juice concentrate stored at 20°C. J. Food Sci. (in review).

MacAdam, D.L. 1943. Specifications of small chromaticity differences. J. Opt. Soc. Am. 33: 18.

Maga, J.A. 1987. Musty/earthy aromas. Food Reviews International 3: 269.

Mapson, L.W. 1970. Vitamins in fruits. In "The Biochemistry of Fruits and Their Products," Vol. 1, A.C. Hulme (Ed.), p. 369. Academic Press, Inc., New York.

Marin, A.B., Acree, T.E., and Barnard, J. 1988. Variation in odor detection thresholds determined by charm analysis. Chem. Senses 13: 435.

Markakis, P. 1974. Anthocyanins and their stability in foods. CRC Crit. Rev. Food Technol. 4: 437.

Markakis, P. Livingston, G.E., and Fellers, C.R. 1957. Quantitative aspects of strawberry pigment degradation. Food Res. 27: 117.

Marshall, M., Nagy, S., and Rouseff, R. 1986. Factors impacting on the quality of stored citrus fruit beverages. In "The Shelf Life of Foods and Beverages," Procedings of the 4th International Flavor Conference, Rhodes, Greece, July 1985. G. Charalambous (Ed.), p. 237. Elsevier Science Publ., Amsterdam, The Netherlands.

Matheis, G. and Whitaker, J.R. 1984. Modification of proteins by polyphenoloxidase and peroxidase and their products. J. Food Biochem. 8: 137.

Mazliak, P. 1970. Lipids. In "The Biochemistry of Fruits and Their Products," Vol. 1, A.C. Hulme (Ed.), p. 209. Academic Press, New York.

McFadden, W.H., Teranishi, R., Corse, J., Black, D.R., and Mon, T.R. 1965. Volatiles from strawberries. II. Combined mass spectrometry and gas chromatography on complex mixtures. J. Chromatog. 18: 10.

Meilgaard, M.D., Carr, T.B., and Civille, G.V. 1987. Descriptive analysis techniques. In "Sensory Evaluation Techniques," Vol. II. CRC Press, Inc., Boca Raton, FL.

Meschter, E.E. 1953. Fruit color loss. Effects of carbohydrates and other factors on strawberry products. J. Agric. Food Chem. 1: 574.

Moskowitz, H.R. 1968. Scales of intensity for single and compound tastes. Ph.D. thesis, Howard Univ., Cambridge, MA. [Cited in Kostyla and Clydesdale, 1978.]

Moskowitz, H.R. 1974. Sensory evaluation by magnitude estimation. Food Technol. 28: 16.

Munsell, A.H. 1905. "A Color Notation," Boston, MA. [Cited in Hunter and Harold, 1987]

Mussinan, C.J. and Walradt, J.P. 1975. Orgniac acids from fresh California strawberries. J. Agric. Food Chem. 23: 482.

Noble, A.C., Philbrick, K.C., and Boulton, R.B. 1986. comparison of sourness of organic acid anions at equal pH and equal titratable acidity. J. Sensory Studies 1: 1.

O'Mahoney, M. 1986. "Sensory Evaluation of Food. Statistical Methods and Procedures," Marcell Dekker, Inc., New York.

Onslow, M.W. 1931. "The Principles of Plant Biochemistry," p. 123. Cambridge Univesity Press, Cambridge, England. [Cited in Joslyn and Ponting, 1951]

Overbosch, P. 1986. A theoretical model for perceived intensity in human taste and smell as a function of time. Chem. Senses 11: 315.

Overbosch, P., van den Enden, J.C., and Keur, B.M. 1986. An improved method for measuring perceived intensity/time relationship in human taste and smell. Chem. Senses 11: 331.

Pangborn, R.M., Lewis, M.J., and Yamashita, J.F. 1983. Comparison of time-intensity with category scaling of bitterness of iso-α-acids in model systems and in beer. J. Inst. Brew. 89: 349.

Pangborn, R.M., Ough, C.S., and Chrisp, R.B. 1964. Tast relationships of sucrose, tartaric acid, and caffeine in white table wine. J. Am. Soc. Enol. Vit. 15: 154.

Pangborn, R.M., Trabue, A.M., and Birch, G.G. 1986. Relationships between the structure and the properties of carboyhdrates in aqueous solutions: sweetness of chlorinated sugars. Carbohydr. Res. 152:47.

Pangborn, R.M. and Chrisp, R.B. 1964. Taste interrelationships. VI. Sucrose, sodium chloride, and citric acid in canned tomato juice. J. Food Sci. 29: 490.

Pangborn, R.M. and Trabue, I.M. 1964. Taste interrelationships. V. Sucrose, sodium chloride and citric acid in lima bean puree. J. Food Sci. 29: 490.

Peng, C.Y. and Markakis, P. 1963. Effect of Phenolase on anthocyanins. Nature 199: 597.

Perng, C.M. 1988. Influence of sugar and acid on sensory qualities and desirability of blackberry juice drink using response surface methodology. M.S. Thesis, Oregon State University, Corvallis, OR.

Pickenhager, W., Velliz, A., Passerat, J.P., and Ohloff, G. 1981. Estimation of 2.5 dimethyl-4-hydroxy-3(2H)-furanone (furaeol) in cultivated and wild strawberries. J. Sci. Food Agric. 32: 1132.

Pifferi, P.G. and Cultrera, R. 1974. Enzymatic degradation of anthocyanins: the role of sweet cherry polyphenol oxidase. J. Food Sci. 39: 786.

Pilando, L.S. 1982. Strawberry wine color quality: influence of variety, maturity and mold contamination. M.S. thesis, Oregon State Univ., Corvallis, Oregon.

Pitt, J.L. and Christian, J.H.B. 1968. Water relations of xerophilic fungi isolated from prunes. Appl. Microbiol. 16: 1853.

Plane, R.A., Mattick, L.R., and Weirs, L.D. 1980. An acidity index for the taste of wines. Am. J. Enol. Vitic. 31: 265.

Poei, M. S. 1979. The role of ascorbic acid on discoloration of strawberry juice and concentrate. M.S. thesis, Oregon State Univ., Corvallis, Oregon.

Poei-Langston, M.S. and Wrolstad, R.E. 1981. Color degradation in an ascorbic acid-anthocyanin-flavanol model system. J. Food Sci. 46: 1218.

Pollard, A. and Timberlake, C.F. 1971. Fruit juices. In "The Biochemistry of Fruits and Their Products," (Ed.) Vol. 2, A.C. Hulme, p. 573. Academic Press, Inc., New York.

Ponting, J.D., Sanshuck, D.W. and Brekke, J.E. 1960. Color measurement and deterioration in grape and berry juices and concentrates. Food Res. 25: 471.

Pratt, D.E., Balkcom, C.M., Powers, J.J., and Mills, L.W. 1954. Interaction of ascorbic acid, riboflavin, and anthocyanin pigments. J. Agric. Food Chem. 2: 367.

Ranganna, S. and Setty, L. 1968. Nonenzymatic discoloration in dried cabbage. Ascorbic acid - amino acid interactions. J. Agr. Food Chem. 16: 529.

Reyes, F.G.R. Poocharoen, B., and Wrolstad, R.E. 1982. Maillard browning reaction of sugar-glycine model systems: changes in sugar concentration, color and appearance. J. Food Sci. 47: 1376.

Richard-Molard, D., Lesage, L., and Cahagnier, B. 1985. Effect of water activity on mold growth and mycotoxin production. In "Properties of Water in Foods in Relation to Quality and Stability," (Ed.) D. Simatos and J.L. Multon, p. 273. Martinus Nijhoff Publ., Dordrecht, The Netherlands.

Rockland, L.B. 1958. Free amino acids in citrus and other fruit and vegetable juices. J. Food Sci. 24: 160.

Ryan, J.J. 1971. Flavonol glycosides of the cultivated strawberry. J. Food Sci. 36: 867.

Ryan, J.J. and Dupont, J.A. 1973. Analytical constituents of strawberry and raspberry and their change in jam production. J.A.O.A.C. 56: 743.

Schen, J.A. 1978. "Essence Recovery from Strawberry Pomace," M.S. thesis, Oregon State Univ., Corvallis, OR.

Schmitt, D.J., Thompson, L.J., Malek, D.M., and Munroe, J.H. 1984. An improved method for evaluating time-intensity data. J. Food Sci. 49: 539.

Schutz, H.G. 1988. Multivariate analyses and the measurement of consumer attitudes and perceptions. Food Tech. 42: 141.

Seidel, C.F., Schinz, H., and Stoll, M. 1958. Untersuchungen uber aromastoffe. Uber das Erdbeeraroma. Helvetica Chimica Acta 41: 372.

Seow, C.C. and Cheah, P.B. 1985. Reactivity of sorbic acid and glycerol in non-enzymatic browning in liquid intermediate moistrue model systems. Food Chem. 18: 71.

Shallenberger, R.S. 1980. Predicting sweetness from chemical structure and knowledge of chemoreception. Food Tech. 34: 65.

Shallenberger, R.S. and Birch, G.G. 1975. "Sugar Chemistry," Avi Publ. Co., Inc., Westport, CT.

Shimil, S., Birch, G.G., and Njoroge, S. 1988. Intrinsic viscosities and other solution properties of sugars and their possible relation to sweetness. Chem. Senses 13: 457.

Shrikhande, A.J. 1976. Anthocyanin in foods. CRC Crit. Rev. Food Sci. 10: 193.

Shrikande, A.J. and Francis, F.J. 1974. Effect of flavonols on ascorbic acid and anthocyanin stability in model systems. J. Food Sci. 39: 904.

Silverblatt, E., Robinson, A.L., and King, C.G. 1943. The kinetics of the reaction between ascorbic acid and oxygen in the presence of copper ion. J. Am. Chem. Soc. 65: 137.

Singh, R.K., Lund, D.B., and Buelow, F.H. 1984. Computer simulation of storage stability in intermediate moisture apples. J. Food Sci. 49: 759.

Sistrunk, W.A. and Cash, J.N. 1970. The effect of certain chemicals on the color and polysaccharides of strawberry puree. Food Tech. 24: 169.

Sistrunk, W.A. and Cash, J. 1968. Stabilizing the color of frozen strawberries. Ark. Farm Res. 17: 2

Sistrunk, W.A. and Moore, J.N. 1971. Strawberry quality studies in relation to new veriety development. Agric. Exp. Station Bul., Div. Agric., Univ. of Arkansas, Fayetteville. 761: 1.

Sistrunk, W.A., Morris, J.R., and Kozup, J. 1982. The effect of Chemical treatments and heat on color stability of frozen machine-harvested strawberries. for jam. J. Amer. Soc. Hort. Sci. 107: 693.

Skalski, C. and Sistrunk, W.A. 1973. Factors influencing color degradation in concord grape juice. J. Food Sci. 38: 1060.

Snedecor, G.W. and Cochran, W.G. 1980. "Statistical Methods," 7th Ed. The Iowa State Univ. Press, Ames, IA.

Somers, T.C. 1966. Wine Tannins - isolation of condensed flavonoid pigments by gel-filtration. Nature. 209: 368.

Somers, T.C. 1967. Resolution and analysis of total phenolic constituents of grape pigment. J. Sci. Food Agric. 18: 193.

Somers, T.C. 1968. Pigment profiles of grapes and of wines. Vitis 7: 303.

Somers, T.C. 1971. The polymeric nature of wine pigments. Phytochem. 10: 2175.

Sondheimer, E. 1953. On the relation between spectral changes and pH of the anthocyanin pelargonidin-3-monoblucoside. J. Am. Chem. Soc. 75: 1507.

Sondheimer, E. and Kertesz, Z.I. 1948. The anthocyanin of strawberries. J. Am. Chem. Soc. 70: 3476.

Sondheimer, E. and Kertesz, Z.I. 1952. The kinetics of the oxidation of strawberry anthocyanin by hydrogen peroxide. Food Res. 17: 288.

Sondheimer, E. and Kertesz, Z.I. 1953. Participation of ascorbic acid in the destruction of anthocyanin in strawberry juice and model systems. Food Res. 18: 475.

Spanos, G.A. and Wrolstad, R.E. 1987. Anthocyanin pigment, nonvolatile acid, and sugar composition of red raspberry juice. J. Assoc. Off. Anal. Chem. 70: 1036.

Spayed, S.E. and Morris, J.R. 1981. Influence of immature fruits on strawberry jam quality and storage stability. J. Food Sci. 46: 414.

Speers, R.A., Tung, M.A. and Jackman, R.L. 1987. Prediction of colour deterioration in strawberry juice. Can. Inst. Food Sci. Technol. J. 20: 15.

Starr, M.S. and Francis, F.J. 1968. Oxygen and ascorbic acid effect on the relative stability of four anthocyanin pigments in cranberry juice. Food Tech. 22: 91.

Steel, R.G.D. and Torrie, J.H. 1980. "Principles and Procedures of Statistics. A Biometrical Approach," Second Edition, McGraw-Hill Book Co., New York.

Stevens, S.S. 1953. On the brightness of lights and the loudness of sounds. Science 118: 576.

Stohr, H. and Herrmann, K. 1975. Die pheonlishen Inhaltsstoffe des Obstes. V. Die phenolischen Inhaltsstoffe der Erdbeere und deren Veranderungen wahrend Wachstum und Reife der Fruchte. Z. Lebensm. Unters. Forsch. 159: 341.

Stone, H. and Sidel, J.L. 1985. "Sensory Evaluation Practices," Academic Press, Inc., New York.

Tannenbaum, S.R. 1976. Vitamins and Minerals. Ch. 7. In "Principles of Food Science," O.R. Fennema (Ed.), p. 347. Marcel Dekker, Inc., New York.

Teranishi, R., Corse, J.W., McFadden, W.H., Black, D.R., and Morgan, A.I. 1963. Volatiles from strawberries. I. Mass spectral identification of the more volatile components. J. Food Sci. 28: 478.

Timberlake, C.F. and Bridle, P. 1966. Spectral studies of anthocyanin and anthocyanidin equilibria in aqueous solution. Nature 212: 158.

Timberlake, C.F. and Bridle, P. 1977. Anthocyanins: solour augmentation with catechin and acetaldehyde. J. Sci. Food Agric. 28: 539.

Timberlake, C.F. and Bridle, P. 1983. Colour in beverages. In. "Sensory Quality in Foods and Beverages: Definition, Measurement and Control," A.A. Williams and R.K. Atkin (Ed.), p. 140. Ellis Horwood Ltd., Chichester, England.

Tinsley, I.J. and Bockian, A.H. 1959. Chromatographic identification and estimation of the free amino acids present in strawberry juices. Food Res. 25: 410.

Toribio, J.L. and Lozano, J.E. 1984. Nonenzymatic broxing in apple juice concentrate furing storage. J. Food Sci. 49: 889.

Toribio, J.L., Nunes, R.V., and Lozano, J.E. 1984. Influence of water activity on the nonenzymatic browning of apple juice concentrate during storage. J. Food Sci. 49: 1630.

Ulrich, R. 1970. Organic acids. In. "The Biochemistry of Fruits and Their Products," A.C. Hulme (Ed.), p. 89. Academic Press, Inc., New York.

Vamos-Vigyazo, L. 1981. Polyphenol oxidase and peroxidase in fruits and vegetables. CRC Crit. Rev. Food Technol. 15: 49.

Van Buren, J. 1970. Fruit phenolics. In. "The Biochemistry of Fruits and Their Products," A.C. Hulme (Ed.), p. 89. Academic Press, Inc., New York.

Van Buren, J.P., Hrazdina, G., and Robinson, W.B. 1974. Color of anthocyanin solutions expressed in lightness and chromaticity terms. Effect of pH and type of anthocyanin. J. Food Sci. 39: 325.

von Elbe, J.H. 1987. Influence of water activity on pigment stability in food products. In "Water Activity - Theory and Applications to Food," L.B. Rockland and L.R. Beuchat (Ed.), p. 55. Marcel Dekker, Inc., New York.

Weissberger, A. and LuValle, J.E. 1944. Oxidation processes. XVII. The autoxidation of ascorbic acid in the presence of copper. J. Am. Chem. Soc. 66: 700.

Wesche-Ebeling, P.A.E. 1983. "Purification of strawberry polyphenol oxidase and its role in anthocyanin degradation," PhD. thesis, Oregon State Univ., Corvallis, OR.

Wesche-E., P., Buerger, M.C., Wrolstad, R.E., and Richardson, D.G. 1985. Changes in the chemical composition of strawberry cell wall polysaccarides as influenced by variety and maturity. Poster Session, 45th Ann. Mtg. Inst. Food Tech., Atlanta, GA.

Whistler, R.L. and Daniel, J.R. 1985. Carbohydrates. Chapt. 3 In "Food Chemistry," O. Fennema (Ed.). Marcel Dekker, Inc., New York.

Whitaker, J.R. 1984. Review. Pectic substances, pectic enzymes and haze formation in fruit juices. Enzyme and Microbial Tech. 6: 341.

Whiting, G.C. 1970. Sugars. In. "The Biochemistry of Fruits and Their Products," A.C. Hulme (Ed.), p. 89. Academic Press, Inc., New York.

Willhalm, B., Palluy, E. and Winter, M. 1966. Sur l'arome des fraises fraiches. Identification des acides volatils et de quelques autres composes. Helvetica Chimica Acta 49: 65.

Williams, B.L. and Wender, S.H. 1952. The isolation and identification of Kaempferol and quercetin from strawberries (Fragaria chiloensis). J. Amer. Chem. Soc. 74: 5919.

Winter, M. and Willhalm, B. 1964. Sur l'arome des fraises fraiches. Analyse des composes carbonyles, ester et alcools volatils. Helvetica Chimica Acta 47: 1215.

Wolfrom, M.L. and Rooney, C.S. 1953. Chemical interactions of amino compounds and sugar. VIII. Influence of water. J. Am. Chem. Soc. 75: 5435.

Wrolstad, R.E. 1976. Color and pigment analyses in fruit products. Station Bulletin No. 624, Agriculture Experiment Station, Oregon State Univ., Corvallis, OR.

Wrolstad, R.E. 1983. Use of sugar, acid and pigment profiles in detecting adulteration in fruit juice concentrates. Tech. Paper No. 6851, Ore. State Univ. Agric. Exp. Stat.

Wrolstad, R.E. and Yorgey, B. 1986. Amino acid content of blueberry, red raspberry, and strawberry fruit. Unpublished, Ore. State Univ.

Wrolstad, R.E., Lee, D.D., and Poei, M.S. 1980. Effect of microwave blanching on the color and composition of strawberry concentrate. J. Food Sci. 45: 1573.

Wrolstad, R.E., Putnam, T.P., and Varseveld, G.W. 1970. Color quality of frozen strawberries: effect of anthocyanin, pH, total acidity and ascorbic acid variability. J. Food Sci. 35: 448.

Wrolstad, R.E., Hildrum, K.I., and Amos, J.F. 1970. Characterization of an additional anthocyanin pigment in extracts of strawberries, Fragaria. J. Chromatog. 50: 311.

Wrolstad, R.E. and Erlandson, J.A. 1973. Effect of metal ions on the color of strawberry puree. J. Food Sci. 38: 460.

Wrolstad, R.E. and Shallenberger, R.S. 1981. Free sugars and sorbitol in fruits - A compilation from the literature. J. Assoc. Off. Anal. Chem. 64: 91.

Yamashita, I., Nemoto, Y., and Yoshikawa, S. 1975. Formation of volatile esters in strawberries. Agr. Biol. Chem. 39: 2303.

Yamashita, I. Nemoto, Y., and Yoshikawa, S. 1976a Studies on flavor development in strawberries. Part II. Formation of volatile alcohols and esters from aldehyde in strawberries. Phytochem. 15: 1633.

Yamashita, I. Nemoto, Y., and Yoshikawa, S. 1976b Studies on flavor development in strawberries. Part III. NAD-dependent alcohol dehydrogenase and NADP-dependent alcohol dehydrogenase from strawberry seeds. Agr. Biol. Chem. 40: 2231.

Yamashita, I. Nemoto, Y., and Yoshikawa, S. 1977 Studies on flavor development in strawberries. Part IV. Biosynthesis of volatile alcohols and ester from aldehyde during ripening. J. Agri. Food Chem. 25: 1165.

Yoshida, M. 1986. A microcomputer (PC 9801/MS mouse) system to record and analyze time-intensity curves of sweetness. Chem. Senses 11: 105.

APPENDIX

APPENDIX 1

Table 4.1. Total soluble solids measured as °Brix for strawberry juice and concentrate from different batch and pre-liquefaction process treatments.

BATCH	PROCESS	STRAWBERRY JUICE	CONCENTRATE FIRST PASS	CONCENTRATE SECOND PASS[1]
1	CONTROL	10.5	19.4	65.0-68.9
1	BLANCH	10.5	20.3	65.7-68.9
2	CONTROL	10.9	19.9	66.5-68.2
2	BLANCH	11.0	19.5	67.2-71.3

1) reported as a range from all 60 mL sample containers used for sensory and instrumental analyses.

APPENDIX 2

Table 4.2. Temperature and pressure conditions during the concentration in two passes from single strength strawberry juice to full concentrate (68°Brix).

CONCENTRATION CONDITIONS	PASS 1 (± range)	PASS 2 BATCH 1 CON	PASS 2 BATCH 1 BLN	PASS 2 BATCH 2 CON	PASS 2 BATCH 2 BLN
Inlet Steam Temp. (°C)	91.5 ± 3.5	98	97	97	97
Outlet Vapor Temp. (°C)	62.0 ± 0.5	64	62	63	62
Steam Source Pressure (kPa)	70.0 ± 0.0	70	70	70	70
Vacuum (kPa)	75.0 ± 0.5	79	79	79	79
Feed Rate (% of maximum)	49.8	37.8	32.8	37.6	37.5
Sample In Temp. (°C)	9.0	19.1	19.1	19.2	19.4
Evaporation Temp. (°C)		16.9	16.7	16.6	16.6
Sample Out Temp. (°C)	16.0	12.5	12.3	12.6	12.2

APPENDIX 3

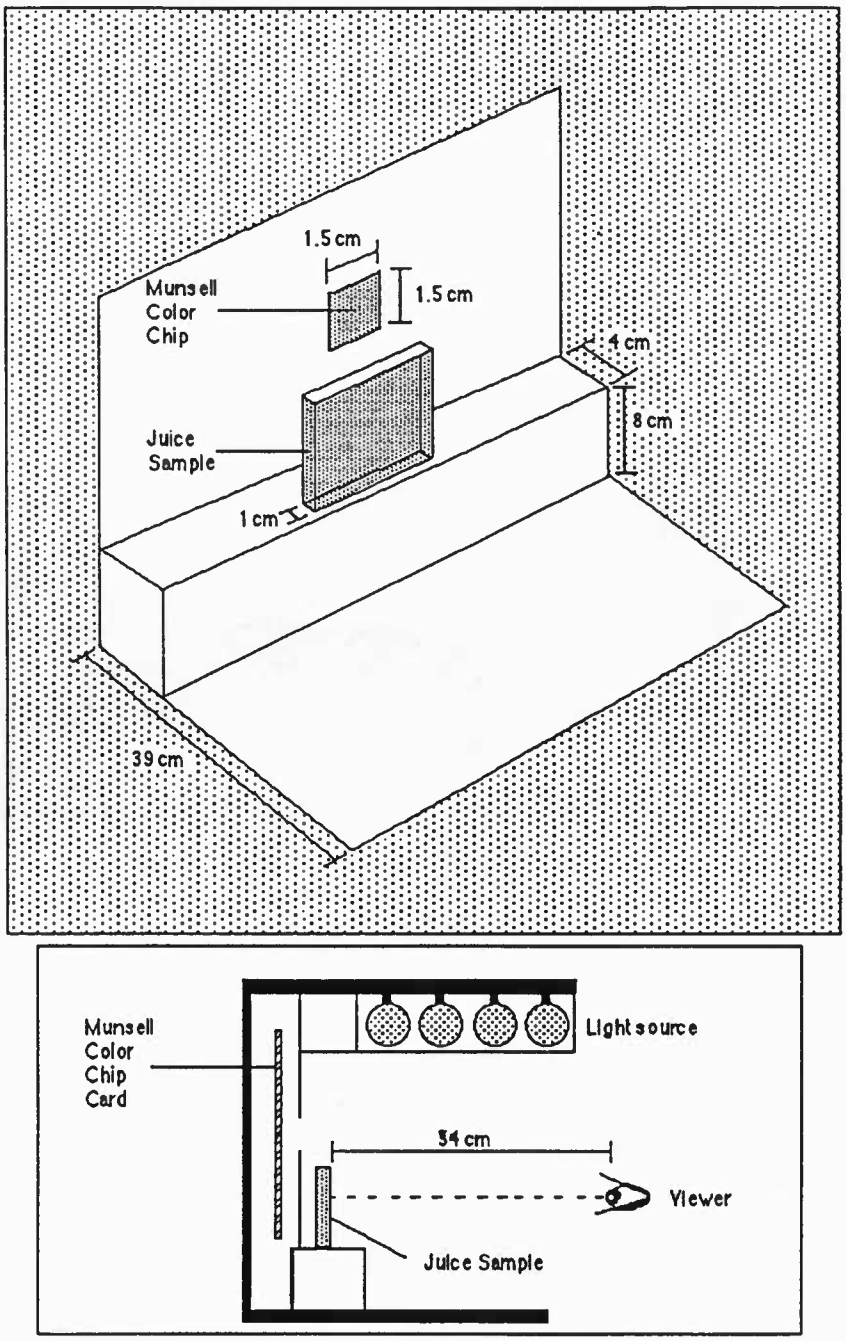


Figure 4.1. Diagram of the booth for evaluation of color differences. Panelists (viewer) match Munsel color chips (displayed on a color card) to the transmitted color of a sample through a 1 cm path length cell. This viewing apparatus is within a MacBeth Executive viewing hood under incandescent light.

APPENDIX 4

Table 4.3. Definitions of descriptors used for sensory evaluation of strawberry juice and concentrate.

DESCRIPTOR	DEFINITION/REFERENCE[1]
Overall Aroma	Total impact of all aroma.
Pungent Aroma	Aroma intensity which yields an irritating, piercing or reflex response.
Musty/moldy Aroma	Primary aroma of a reference prepared by one drop of industrially produced concentrate (68°Brix) after six months storage at 20°C.
Sweet/jammy Aroma	Primary aroma of a reference prepared by 30 ml of a 1:1 (v/v) solution of Smucker's® strawberry jam (Orrville, OH) and served at 40°C.
Cooked Strawberry Aroma	Primary aroma of a reference prepared by 30 ml whole strawberries, Benton cultivar, heated to liquefaction in a microwave oven (Model RE-800TC, Sansung Electronics Co., Compton, CA).
Caramelized Aroma	Primary aroma of a reference prepared by 30 ml of a 1:1 (v/v) solution of brown sugar (C&H Sugar Kitchen, San Francisco, CA) and served at 40°C.
Fresh Strawberry Aroma	Primary aroma of a reference prepared by two frozen, whole strawberries (Benton variety) thawed to room temperature.
Buttery Aroma	Primary aroma of a reference prepared by 15 ml of 100% butter melted in a microwave oven and then served at 40°C.
Citrus Aroma	Primary aroma of a reference prepared by 30 ml of a 1:1 solution of lemon juice (ReaLemon®, Borden, Inc., Columbus, OH) held at room temperature.
Artificial Strawberry Aroma	Primary aroma of a reference prepared by 1/2 packet (dry) of strawberry flavored KoolAid® (General Foods, Inc., White Plains, N.Y.).

1) All samples were evaluated in standard clear wine glasses with a glass cover plate and served at room temperature (unless specified otherwise).

APPENDIX 5

Table 4.4. Preparation of 15-point scale reference samples for aroma evaluations.

INTENSITY (SCALE VALUE)	REFERENCE AROMA	REFERENCE PREPARATION[1]
Slight (3)	Oil	Total impact of the "oil" aroma from 30 mL of Saffola 100% safflower oil (Westley Foods, Inc., City of Industry, CA).
Moderate (7)	Orange	Total impact of the "orange" aroma from 30 mL of Hi-C® Orange Drink (Coca-Cola Foods, Inc., Plymouth, FL).
Large (11)	Grape	Total impact of the "grape" aroma from 30 mL of Welches® 100% Natural Grape Juice (Welch Foods, Inc., Westfield, N.Y.).
Extreme (15)	Cinnamon	Total impact of the "cinnamon" in Big Red® chewing gum (W.M. Wrigley Jr. Co., Chicago, IL).

1) All reference samples were prepared fresh each day. The oil, orange and grape juices samples were stored until their use in 60 mL glass containers with minimal headspace at -10°C.

APPENDIX 6

STRAWBERRY JUICE BALLOT

NAME: DATE:

DIRECTIONS:

1. Familiarize yourself with the seven references.
2. Use the four standards to anchor your intensity scale.
3. Rate both samples for their first impression on "overall intensity" (make sure you are using the same intensity scale for each sample). You should be able to do this with one smell for each sample. Please indicate the intensity of any other descriptive terms that you may recall...if you cannot, don't worry about it.
4. Next, go back to each sample and rate their second impression. Note that you may write in other desriptors and their intensities.
5. Repeat steps 3 and 4 for taste.

SCALE:

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N	J		S		S		M		M		L		L		E
O	U		L		L.		O		D.		A		G.		X
N	S		I				D				R				T
E	T		G		T		E		T		G		T		R
			H		O		R		O		E		O		E
	D		T				A								M
	E				M		T		L				E		E
	T.				D.		E		G.				X.		

STANDARD		INTENSITY		VALUE
"OIL"	-	SLIGHT	-	3
"ORANGE"	-	MODERATE	-	7
"GRAPE"	-	LARGE	-	11
"CINNAMON"	-	EXTREME	-	15

	FIRST IMPRESSION				SECOND IMPRESSION			
SAMPLE #								
AROMA								
OVERALL INTENSITY:								
STRAWBERRY FRESH:								
STRAWBERRY COOKED:								
STRAWBERRY ARTIF.:								
SWEET:								
BUTTERY:								
CITRUS:								
MOLDY:								
TASTE								
SOUR:								

Figure 4.2. Ballot for the aroma and taste evaluations of strawberry juice.

APPENDIX 7

STRAWBERRY JUICE BALLOT

NAME: DATE:

DIRECTIONS:
1. Familiarize yourself with the aroma references.
2. Procede to the aroma evaluation booths.
3. Evaluate aromas using the four aroma standards to anchor your scale.

SCALE:

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N	J		S		S		M		M		L		L		E
O	U		L		L.		O		D.		A		G.		X
N	S		I				D				R				T
E	T		G		T		E		T		G		T		R
			H		O		R		O		E		O		E
	D		T				A								M
	E				M		T		L				E		E
	T.				D.		E		G.				X.		

AROMA STANDARD		INTENSITY		VALUE
"OIL"	-	SLIGHT	-	3
"ORANGE"	-	MODERATE	-	7
"GRAPE"	-	LARGE	-	11
"CINNAMON"	-	EXTREME	-	15

SAMPLE ___ ___ ___ ___ ___ ___

AROMA		
overall	___ ___ ___ ___ ___ ___	The total impact of all aroma.
pungent	___ ___ ___ ___ ___ ___	Irritating, piercing, reflex sensation.
musty/moldy	___ ___ ___ ___ ___ ___	Musty/moldy reference.
sweet/jammy	___ ___ ___ ___ ___ ___	Sweet/jammy reference.
cooked str.	___ ___ ___ ___ ___ ___	Cooked strawberry reference.
caramelized	___ ___ ___ ___ ___ ___	Brown sugar reference.
fresh strawberry	___ ___ ___ ___ ___ ___	fresh strawberry ref.
buttery	___ ___ ___ ___ ___ ___	Butter reference.
citrus	___ ___ ___ ___ ___ ___	Lemon juice reference.
artif. str.	___ ___ ___ ___ ___ ___	Artificial strawberry ref.

4. Return samples and ballot to sensory attendent and procede to the taste evaluation booths.

Figure 4.3. Ballot for the sensory evaluations of reconstituted stored strawberry juice concentrate samples: aroma evaluations (page 1 of 3).

APPENDIX 7 (continued)

Page 2

5. First warm-up by evaluating the time-intensity relationship of the control sample for only the attribute noted on the screen. Then evaluate the two samples with the three digit code.

SCALE:

.0.	.1.	.2.	.3.	.4.	.5.	.6.	.7.	.8.	.9.	.10.	.11.	.12.	.13.	.14.	.15.
N	J		S		S		M		M		L		L		E
O	U		L		L.		O		D.		A		G.		X
N	S		I				D				R				T
E	T		G		T		E		T		G		T		R
			H		O		R		O		E		O		E
	D		T				A								M
	E				M		T		L				E		E
	T.				D.		E		G.				X.		

SAMPLE # CONTROL _____ _____

Time-int.				
sweet	_____	_____	_____	As the reference control.
sour	_____	_____	_____	As the reference control.
astringent	_____	_____	_____	As the reference control.
bitter	_____	_____	_____	As the reference control.

6. Return all samples to the sensory attendent and procede to the color evaluation booth.

Figure 4.4. Ballot for the sensory evaluations of reconstituted stored strawberry juice concentrate samples: taste evaluations (page 2 of 3).

APPENDIX 7 (continued)

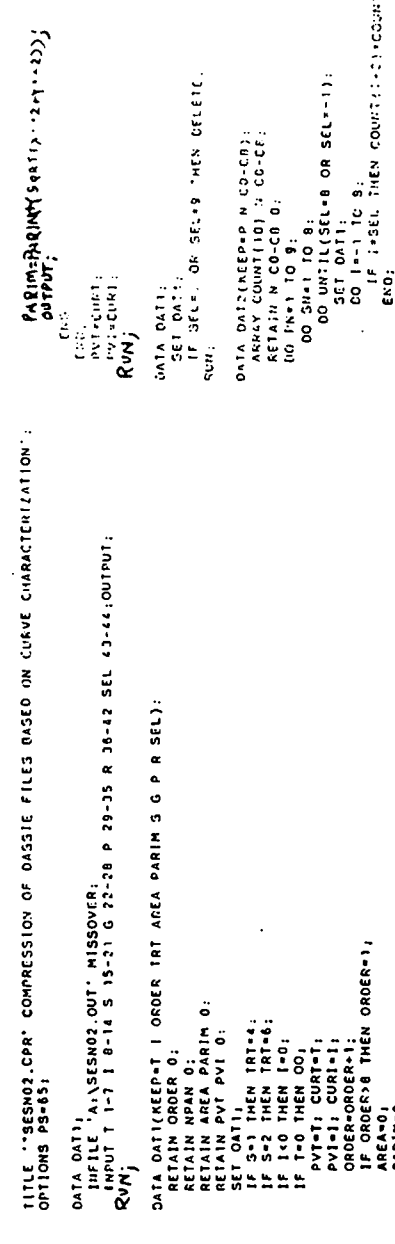
7. Evaluate the two samples for color differences. Pick the closest three hue cards by matching the transmitted color in the sample with color chips. Then extrapolate the matched colors to the best guess for hue, value and chroma.

SAMPLE	_____	_____	
hue	_____	_____	The color of the sample.
value	_____	_____	The lightness/darkness of the sample.
chroma	_____	_____	The intensity of color of the sample.

THANK-YOU for these evaluations. Now please procede to the TREAT STATION.

Figure 4.5. Ballot for the sensory evaluations of reconstituted stored strawberry juice concentrate samples: color evaluations (page 3 of 3).

APPENDIX 8



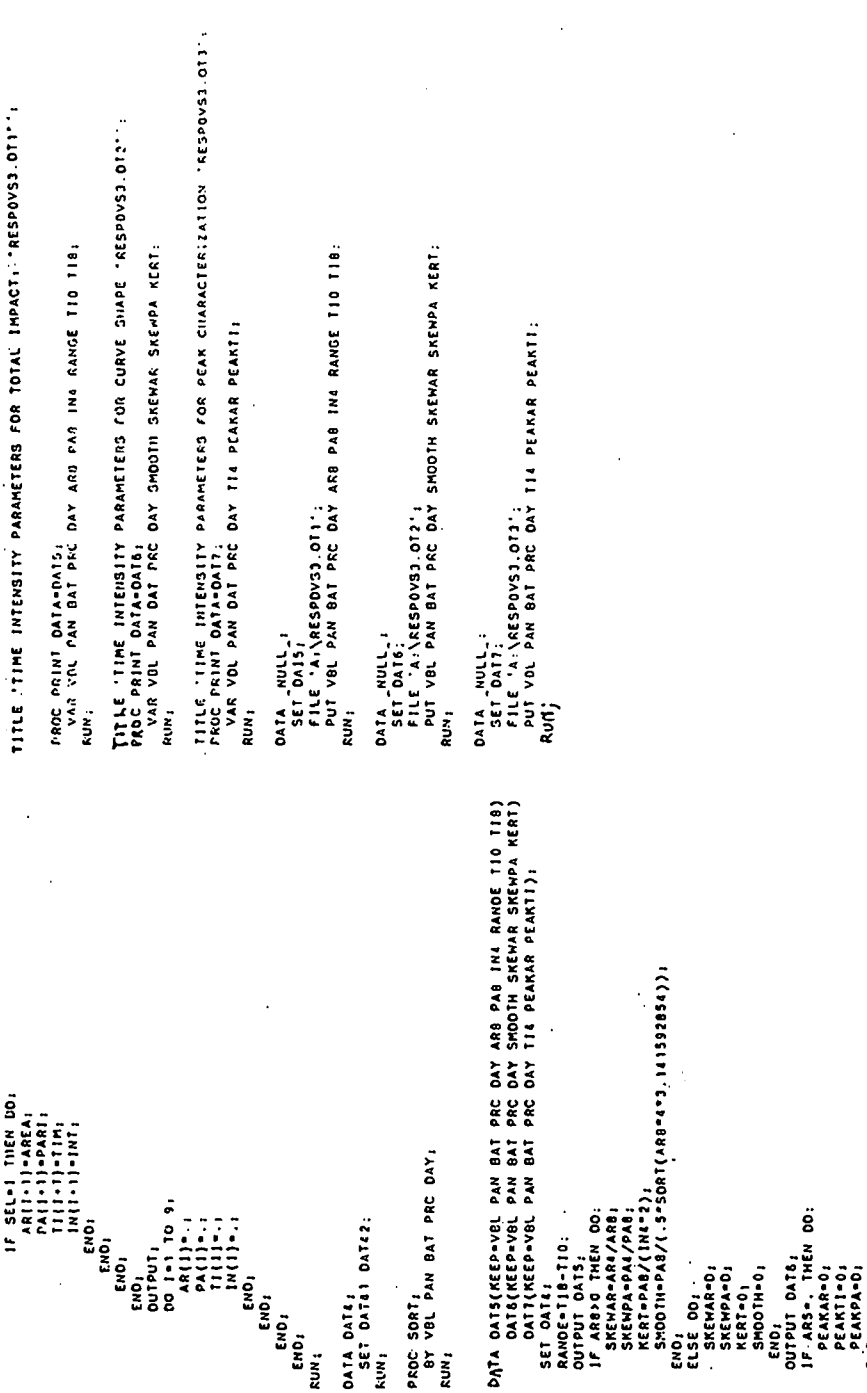
```
TITLE 'SESN02.CPR' COMPRESSION OF DASSIE FILES BASED ON CURVE CHARACTERIZATION';
OPTIONS PS=65;

DATA DAT1;
  INFILE 'A:\SESN02.OUT' MISSOVER;
  INPUT T 1-7 I 8-14 S 15-21 G 22-28 P 29-35 R 36-42 SEL 43-44;OUTPUT;
RUN;

DATA DAT1(KEEP=T I ORDER TRT AREA PARIM S G P R SEL);
   RETAIN ORDER 0;
   RETAIN NPAN 0;
   RETAIN AREA PARIM 0;
   RETAIN PVT PVI 0;
   SET DAT1;
   IF S=1 THEN TRT=4;
   IF S=2 THEN TRT=6;
   IF I<0 THEN I=0;
   IF T=0 THEN DO;
      PVT=T; CURT=T;
      PVI=1; CURI=1;
      ORDER=ORDER+1;
      IF ORDER>8 THEN ORDER=1;
      AREA=0;
      PARIM=0;
      IF SEL=-1 THEN DO;
         OUTPUT;
      END;
      IF SEL=1 THEN DO;
         SEL=0;
         OUTPUT;
      END;
   END;
   IF T<>0 THEN DO;
      CURT=T;CURI=I;
      IF SEL=1 THEN DO;
         STEP1=MIN(.125,.5*(CURT-PVT));
         T=CURT-STEP1;
         I=0;
         SEL=0;
         AREA=0;
         PARIM=0;
         OUTPUT;
         SEL=1;
         T=CURT;
         I=CURI;
         AREA=0.5*CURI*STEP1;
         PARIM=SQRT(STEP1**2+CURI**2);
         OUTPUT;
      END;
      ELSE IF SEL=8 AND CURI=0 THEN DO;
         STEP2=MIN(.125,.5*(CURT-PVT));
         T=PVT+STEP2;
         AREA=AREA+(0.5*PVI*STEP2);
         PARIM=PARIM+(SQRT(STEP2**2+PVI**2));
         OUTPUT;
         T=CURT;
         I=CURI;
         SEL=9;
         OUTPUT;
         SEL=8;
      END;
      ELSE DO;
         X=CURT-PVT;
         Y=CURI-PVI;
         AREA=AREA+((PVI*X)+(0.5*X*Y));
         PARIM=PARIM+(SQRT(X**2+Y**2));
         OUTPUT;
         T=CURT;
         I=CURI;
         SEL=9;
         OUTPUT;
         SEL=8;
      END;
   END;
RUN;

DATA DAT2(KEEP=P N CO-CB);
   ARRAY COUNT(10) N CO-CB;
   RETAIN N CO-CB 0;
   DO P=1 TO 9;
      DO SEL=1 TO 8;
         DO UNTIL(SEL=8 OR SEL=-1);
            SET DAT1;
            DO I=-1 TO 9;
               IF I=SEL THEN COUNT(I+2)=COUNT(I+2)+1;
            END;
         END;
      END;
      OUTPUT;
      DO J=1 TO 10;
         COUNT(J)=0;
      END;
   END;
RUN;

PROC SORT DATA=DAT1;
  BY P R G S SEL;
RUN;

PROC PRINT DATA=DAT1;
   VAR P G TRT ORDER SEL T I AREA PARIM;
RUN;

PROC PRINT DATA=DAT2;
  VAR P N CO-CB;
RUN;

DATA _NULL_;
   SET DAT1;
   FILE 'A:\SESN02.CPR';
   PUT P R G TRT ORDER SEL T I AREA PARIM;
RUN;
```

Figure 4.6. SAS® program for the reduction of each time-intensity curve to eight points: including initial time, time to peak intensity, end of peak intensity and final time. At each point, the area and perimeter is calculated (page 1 of 3).

```
TITLE 'SAS ANALYSIS OF TIME INTENSITY PROGRAM "TIMINT01.SAS"';
OPTIONS PS=60;

DATA DAT11;
  INFILE 'A:\SESN10.CPR';
  INPUT PAN SES VBL TRT ORD SEL TIM INT AREA PARI@@;OUTPUT;
RUN;

DATA DAT21;
  INFILE 'C:\SESN05.CPR';
  INPUT PAN SES VBL TRT ORD SEL TIM INT AREA PARI@@;OUTPUT;
RUN;

DATA DAT31(DROP=TRT SES);
  SET DAT11 DAT21;
  IF SES=10 THEN BAT=1;
  ELSE BAT=2;
  IF TRT=4 THEN DO;
    PRC=2; DAY=1;
  END;
  ELSE DO;
    PRC=2; DAY=2;
  END;
RUN;

DATA DAT12;
  INFILE 'A:\SESN07.CPR';
  INPUT PAN SES VBL TRT ORD SEL TIM INT AREA PARI@@;OUTPUT;
RUN;

DATA DAT22;
  INFILE 'C:\SESN04.CPR';
  INPUT PAN SES VBL TRT ORD SEL TIM INT AREA PARI@@;OUTPUT;
RUN;

DATA DAT32(DROP=TRT SES);
  SET DAT12 DAT22;
  IF SES=7 THEN BAT=1;
  ELSE BAT=2;
  IF TRT=1 THEN DO;
    PRC=1; DAY=1;
  END;
  ELSE DO;
    PRC=1; DAY=2;
  END;
RUN;

PROC SORT DATA=DAT31;
  BY VBL PAN BAT PRC DAY;
RUN;

DATA DAT41(KEEP=VBL PAN BAT PRC DAY TI0-TI8 IN0-IN8 AR0-AR8 PA0-PA8);
  ARRAY AR(9) AR0-AR8;

  ARRAY PA(9) PA0-PA8;
  ARRAY TI(9) TI0-TI8;
  ARRAY IN(9) IN0-IN8;
  RETAIN AR0-AR8 PA0-PA8 TI0-TI8 IN0-IN8;
  DO V=1 TO 4;
    DO P=1 TO 9;
      DO T=1 TO 8;
        DO UNTIL(SEL=8 OR SEL=-1);
          SET DAT31;
          IF SEL=-1 THEN DO;
            DO I=1,5,9;
              AR(I)=0;
              PA(I)=0;
              TI(I)=0;
              IN(I)=0;
            END;
          END;
          ELSE DO;
            DO I=0 TO 8;
              IF SEL=I THEN DO;
                AR(I+1)=AREA;
                PA(I+1)=PARI;
                TI(I+1)=TIM;
                IN(I+1)=INT;
              END;
            END;
          END;
        END;
        OUTPUT;
        DO I=1 TO 9;
          AR(I)=.;
          PA(I)=.;
          TI(I)=.;
          IN(I)=.;
        END;
      END;
    END;
  END;
RUN;

PROC SORT DATA=DAT32;
  BY VBL PAN BAT PRC DAY;
RUN;

DATA DAT42(KEEP=VBL PAN BAT PRC DAY TI0-TI8 IN0-IN8 AR0-AR8 PA0-PA8);
  ARRAY AR(9) AR0-AR8;
  ARRAY PA(9) PA0-PA8;
  ARRAY TI(9) TI0-TI8;
  ARRAY IN(9) IN0-IN8;
  RETAIN AR0-AR8 PA0-PA8 TI0-TI8 IN0-IN8;
  DO V=1 TO 4;
    DO P=1 TO 9;
      DO T=1 TO 8;
        DO UNTIL(SEL=8 OR SEL=-1);
          SET DAT32;
          IF SEL=-1 THEN DO;
            DO I=1,5,9;
              AR(I)=0;
              PA(I)=0;
              TI(I)=0;
              IN(I)=0;
            END;
          END;
          ELSE DO;
            DO I=0 TO 8;
```

Figure 4.6. SAS® program for the reduction of each time-intensity curve to eight points: including initial time, time to peak intensity, end of peak intensity and final time. At each point, the area and perimeter is calculated (page 2 of 3).

APPENDIX 8 (continued)



```
TITLE 'TIME INTENSITY PARAMETERS FOR TOTAL IMPACT: 'RESPOVS3.OT1';

PROC PRINT DATA=DAT5;
  VAR VBL PAN BAT PRC DAY ARB PAB IN4 RANGE T10 T18;
RUN;

TITLE 'TIME INTENSITY PARAMETERS FOR CURVE SHAPE 'RESPOVS3.OT2';
PROC PRINT DATA=DAT6;
  VAR VBL PAN BAT PRC DAY SMOOTH SKEWAR SKEWPA KERT;
RUN;

TITLE 'TIME INTENSITY PARAMETERS FOR PEAK CHARACTERIZATION 'RESPOVS3.OT3';
PROC PRINT DATA=DAT7;
  VAR VBL PAN BAT PRC DAY T14 PEAKAR PEAKTI;
RUN;

DATA _NULL_;
  SET DAT5;
  FILE 'A:\RESPOVS3.OT1';
  PUT VBL PAN BAT PRC DAY ARB PAB IN4 RANGE T10 T18;
RUN;

DATA _NULL_;
  SET DAT6;
  FILE 'A:\RESPOVS3.OT2';
  PUT VBL PAN BAT PRC DAY SMOOTH SKEWAR SKEWPA KERT;
RUN;

DATA _NULL_;
  SET DAT7;
  FILE 'A:\RESPOVS3.OT3';
  PUT VBL PAN BAT PRC DAY T14 PEAKAR PEAKTI;
RUN;
```

```
    IF SEL=1 THEN DO;
        AR(I-1)=AREA;
        PA(I-1)=PAR;
        TI(I-1)=TIM;
        IN(I-1)=INT;
      END;
    END;
  END;
  OUTPUT;
  DO I=1 TO 9;
    AR(I)=.;
    PA(I)=.;
    TI(I)=.;
    IN(I)=.;
  END;
 END;
END;
RUN;

DATA DAT1;
  SET DAT1 DAT2;
RUN;

PROC SORT;
  BY VBL PAN BAT PRC DAY;
RUN;

DATA DAT5(KEEP=VBL PAN BAT PRC DAY ARB PAB IN4 RANGE T10 T18)
     DAT6(KEEP=VBL PAN BAT PRC DAY SMOOTH SKEWAR SKEWPA KERT)
     DAT7(KEEP=VBL PAN BAT PRC DAY T14 PEAKAR PEAKTI);
  SET DAT1;
  RANGE=T18-T10;
  OUTPUT DAT5;
  IF ARB>0 THEN DO;
     SKEWAR=AR4/ARB;
     SKEWPA=PA4/PAB;
     KERT=PAB/(IN4**2);
     SMOOTH=PAB/(.5*SQRT(ARB**4*3.1415926854));
  END;
  ELSE DO;
     SKEWAR=0;
     SKEWPA=0;
     KERT=0;
     SMOOTH=0;
  END;
  OUTPUT DAT6;
  IF ARS=. THEN DO;
     PEAKAR=0;
     PEAKTI=0;
     PEAKPA=0;
  END;
  ELSE DO;
     PEAKAR=ARS-AR4;
     PEAKTI=T15-T14;
  END;
  OUTPUT DAT7;
RUN;
```

Figure 4.6. SAS® program for the reduction of each time-intensity curve to eight points: including initial time, time to peak intensity, end of peak intensity and final time. At each point, the area and perimeter is calculated (page 3 of 3).

APPENDIX 8 (continued)

```
TITLE 'SAS ANALYSIS OF TIME INTENSITY PROGRAM TIMINTOS.SAS';
OPTIONS PS=65;

DATA DAT1;
  INFILE 'A:\RESPOVS6.OT1';
  INPUT VBL PAN BAT PRC DAY AR8 PA8 IN4 RANGE T10 T18@@;
  IF DAY=2 THEN DAY=3;
  OUTPUT;
RUN;

DATA DAT2;
  INFILE 'A:\RESPOVS3.OT1';
  INPUT VBL PAN BAT PRC DAY AR8 PA8 IN4 RANGE T10 T18@@;
  OUTPUT;
RUN;

DATA DAT3;
  INFILE 'A:\RESPOVSH.OT1';
  INPUT VBL PAN BAT PRC DAY AR8 PA8 IN4 RANGE T10 T18@@;
  OUTPUT;
RUN;

DATA DAT4;
  SET DAT1 DAT2 DAT3;
  IF AR8<1 THEN LAR8=0;
  ELSE LAR8=LOG(AR8);
  IF PA8<1 THEN LPA8=0;
  ELSE LPA8=LOG(PA8);
RUN;

PROC SORT DATA=DAT4;
  BY VBL PAN BAT PRC DAY;
RUN;

TITLE 'TIME INTENSITY RESPONSE DATA (MAGNITUDE)';
PROC PRINT DATA=DAT4;
  VAR VBL PAN BAT PRC DAY AR8 PA8 IN4 RANGE T10 T18 LAR8 LPA8;
RUN;

TITLE 'ANOVA - TIME INTENSITY RESPONSE DATA (MAGNITUDE)';
PROC ANOVA DATA=DAT4;
  BY VBL;
  CLASS PAN BAT PRC DAY;
  MODEL AR8 PA8 IN4 RANGE T10 T18 LAR8 LPA8=PAN BAT PAN*BAT
        PRC PAN*PRC BAT*PRC PAN*BAT*PRC
        DAY(PRC) PAN*DAY(PRC) BAT*DAY(PRC);
  TEST H=PAN BAT E=PAN*BAT;
  TEST H=PAN*PRC BAT*PRC E=PAN*BAT*PRC;
  MEANS BAT*PRC/LSD E=PAN*BAT*PRC;
  MEANS BAT PRC BAT*PRC DAY(PRC);
RUN;

PROC SORT DATA=DAT4;
  BY VBL PRC PAN BAT DAY;
RUN;

TITLE 'WITHIN PRC ANOVA - TIME INTENSITY RESPONSE DATA (MAGNITUDE)';
PROC ANOVA DATA=DAT4;
  BY VBL PRC;
  CLASS PAN BAT DAY;
  MODEL AR8 PA8 IN4 RANGE T10 T18 LAR8 LPA8=PAN BAT PAN*BAT
        DAY PAN*DAY BAT*DAY;
RUN;
```

Figure 4.7. SAS® program for the analysis of variance of time intensity data.

```
TITLE 'SJC812C: SATTERTHWAITE APPROXIMATION AND COMPOUND F-VALUES';
OPTIONS PS=65;

DATA DATPRC;
  ARRAY
  INFILE 'A:\SJC812C1.PRN';
  INPUT OF1-OF4??;
  OUTPUT;
  DO VBL=1 TO NVBL;
    INPUT MS1-MS4??;
    OUTPUT;
  END;
RUN;

DATA OATSTO(KEEP=OF5-OF10 MS5-MS10);
  NVBL=1;
  INFILE 'A:\SJC812C2.PRN';
  INPUT OF5-OF10??;
  OUTPUT;
  DO VBL=1 TO NVBL;
    INPUT MS5-MS10??;
    OUTPUT;
  END;
RUN;

DATA DAT1(KEEP=VBL OF1-OF10 MS1-MS10);
  MERGE DATPRC OATSTO;
  IF VBL=. THEN DELETE;
RUN;

PROC PRINT DATA=DAT1;
  VAR VBL MS1-MS10 OF1-OF10;
RUN;

DATA DAT1;
  ARRAY MS(10) MS1-MS10; ARRAY OF(10) OF1-OF10;
  SET DAT1; NREP1=90; NREP1A=54; NREP1B=18;
  FP1=MS(2)/MS(4);
  FB1=MS(3)/MS(4);
  DFN1=((MS(1)+MS(4))**2)/(MS(1)**2/OF(1)+MS(4)**2/OF(4));
  DFD1=((MS(2)+MS(3))**2)/(MS(2)**2/OF(2)+MS(3)**2/OF(3));
  F1=((MS(1)+MS(4))/MS(2)+MS(3));
  MSLSO1=MS(2)+MS(3)-MS(4);
  IF MSLSO1>0 THEN DO;
    DFLSO1=MSLSO1**2/((MS(2)**2/OF(2))+MS(3)**2/OF(3))+MS(4)**2/OF(4));
    LSO1=TINV(.925,DFLSO1)*SQRT(2*MSLSO1/NREP1);
  END;
  ELSE DO; LSO1=.; DFLSO1=.; END;
  OFPOOL1=OF(2)+OF(3)+OF(4);
  MSPOOL1=(OF(2)*MS(2)+OF(3)*MS(3)+OF(4)*MS(4))/OFPOOL1;
  FPOOL1=MS(1)/MSPOOL1;
  LSOPOOL1=TINV(.925,OFPOOL1)*(SQRT(2*MSPOOL1/NREP1));
  FP2=MS(8)/MS(10);
  FB2=MS(9)/MS(10);
  DFN2=((MS(5)+MS(10))**2)/((MS(5)**2/OF(5))+(MS(10)**2/OF(10)));
  DFD2=((MS(8)+MS(9))**2)/((MS(8)**2/OF(8))+(MS(9)**2/OF(9)));
  F2=(MS(5)+MS(10))/MS(8)+MS(9));
  MSLSO2=MS(8)+MS(9)-MS(10);
  IF MSLSO2>0 THEN DO;
    DFLSO2=MSLSO2**2/((MS(8)**2/DF(8))+(MS(9)**2/OF(9))+(MS(10)**2/OF(10)));
    LSO2A=TINV(.975,OFLSO2)*SQRT(2*MSLSO2/NREP2A);
    LSO2AB=TINV(.975,OFLSO2)*(SQRT((NREP2A+NREP2B)*MSLSO2/(NREP2A*NREP2B)));
    LSO2B=TINV(.975,OFLSO2)*(SQRT(2*MSLSO2/NREP2B));
  END;

  ELSE DO; LSO2A=.; LSO2AB=.; LSO2B=.; OFLSO1=.; END;
  OFPOOL2=OF(8)+OF(9)+OF(10);
  MSPOOL2=(OF(8)*MS(8)+OF(9)*MS(9)+OF(10)*MS(10))/OFPOOL2;
  FPOOL2=MS(5)/MSPOOL2;
  FPOOL3=MS(6)/MSPOOL2;
  FPOOL4=MS(7)/MSPOOL2;
  LSOPOL2A=TINV(.925,OFPOOL2)*(SQRT(2*MSPOOL2/NREP2A));
  LSOPL2AB=TINV(.975,OFPOOL2)*(SQRT((NREP2A*BREP2B)*MSPOOL2/(NREP2A*NREP2B)));
  LSOPOL2B=TINV(.975,OFPOOL2)*(SQRT(2*MSPOOL2/NBEP2B));
  OFN3=((MS(6)+MS(10))**2)/((MS(6)**2/OF(6))+(MS(10)**2/OF(10)));
  OFD3=((MS(8)+MS(9))**2)/((MS(8)**2/OF(8))+(MS(9)**2/OF(9)));
  F3=(MS(6)+MS(10))/(MS(8)+MS(9));
  OFN4=((MS(7)+MS(10))**2)/((MS(7)**2/OF(7))+(MS(10)**2/OF(10)));
  OFO4=((MS(8)+MS(9))**2)/((MS(8)**2/OF(8))+(MS(9)**2/OF(9)));
  F4=(MS(7)+MS(10))/MS(8)+MS(9));
  P1=1-PROBF(F1,OFN1,OFO1);
  P2=1-PROBF(F2,OFN2,OFO2);
  P3=1-PROBF(F3,OFN3,OFO3);
  P4=1-PROBF(F4,OFN4,OFO4);
  PPOOL1=1-PROBF(FPOOL1,OF1,OFPOOL1);
  PPOOL2=1-PROBF(FPOOL2,OF5,OFPOOL2);
  PPOOL3=1-PROBF(FPOOL3,OF6,OFPOOL2);
  PPOOL4=1-PROBF(FPOOL4,OF7,OFPOOL2);
  PP1=PROBF(FP1,OF2,OF4);
  PB1=PROBF(FB1,OF3,OF4);
  PP2=PROBF(FP2,OF8,OF10);
  PB2=PROBF(FB2,OF9,OF10);
RUN;

TITLE 'P-VALUES TO TEST PRC MODEL';
PROC PRINT;
  VAR FP1 PP1 FB1 PB1;
ROB;

TITLE 'P-VALUES AND LSD FOR PROCESS';
PROC PRINT;
  VAR F1 OFN1 OFO1 P1 FPOOL1 OF1 OFPOOL1 PPOOL1;
ROW;

TITLE 'F-VALUES TO TEST STORAGE(PROCESS) MODEL';
PROC PRINT;
  VAR FP2 PP2 FB2 PB2;
RUN;

TITLE 'P-VALUES AND LSD FOR STORAGE(PROCESS)';
PROC PRINT;
  VAR F2 OFN2 OFO2 P2 FPOOL2 OF5 OFPOOL2 PPOOL2;
ROW;

TITLE 'P-VALUES ARO LSO FOR STORAGE(CONTROL)';
PROC PRINT;
  VAR F3 OFN3 OFD3 P3 FPOOL3 OF6 OFPOOL2 PPOOL3;
RUN;

TITLE 'P-VALUES AND LSO FOR STORAGE(BEAT)';
PROC PRINT;
  VAR F4 OFN4 OFO4 P4 FPOOL4 OF7 OFPOOL2 PPOOL4;
RUN;

TITLE 'LSO VALUES FOR PAIRED COMPARISONS';
PROC PRINT;
  VAR LSO1 LSOPOOL1 LSO2A LSO2AB LSO2B LSOPOL2A
      LSOPL2AB LSOPOL2B;
  RUN;
```

Figure 4.8. SAS® program for the analysis of variance for the process and storage within process effects using Satterthwaite approximation.

```
TITLE 'S.J.C. TIME INTENSITY MEANS "PCADD6.SAS"';
OPTIONS PS=65;

DATA DAT1;
  INFILE 'A:\RESPDVS6.OTI';
  INPUT VDL PAN DAT PRC DAY AR8 PA8 IN4 RANGE TID TI800;
  IF DAY=2 THEN DAY=3;
  OUTPUT;
RUN;

DATA DAT2;
  INFILE 'A:\RESPDVS3.OTI';
  INPUT VBL PAN DAT PRC DAY AR8 PA8 IN4 RANGE TID TI800;
  OUTPUT;
RUN;

DATA DAT3;
  INFILE 'A:\RESPCVSH.OTI';
  INPUT VBL PAN DAT PRC DAY AR8 PA8 IN4 RANGE TIO TI800;
  OUTPUT;
RUN;

DATA DAT4;
  SET DAT1 DAT2 DAT3;
  IF AR8<1 THEN LAR8=0;
  ELSE LAR8=LOG(AR8);
  IF PA8<1 THEN LPA8=0;
  ELSE LPA8=LOG(PA8);
RUN;

PROC SORT DATA=DAT4;
  BY VDL PAN BAT PRC DAY;
RUN;

DATA DAT5 DAT6 DAT7 DAT8;
  SET DAT4;
  IF VBL=1 THEN OUTPUT DAT5;
  ELSE IF VBL=2 THEN OUTPUT DAT6;
  ELSE IF VBL=3 THEN OUTPUT DAT7;
  ELSE OUTPUT DAT8;
RUN;

DATA DAT5(DROP=VDL AR8 PA8 IN4 RANGE TIO TI8 LAR8 LPA8);
  SET DAT5;
  Y11=AR8; Y12=PA8; Y13=IN4; Y14=RANGE; Y15=TIO; Y16=TI8;
RUN;

DATA DAT6(DROP=VDL BAT PRC DAY PAN AR8 PA8 IN4 RANGE TIO TI8 LAR8 LPA8);
  SET DAT6;
  Y21=AR8; Y22=PA8; Y23=IN4; Y24=RANGE; Y25=TIO; Y26=TI8;
RUN;

DATA DAT7(DROP=VDL BAT PRC DAY PAN AR8 PA8 IN4 RANGE TIO TI8 LAR8 LPA8);
  SET DAT7;
  Y31=AR8; Y32=PA8; Y33=IN4; Y34=RANGE; Y35=TIO; Y36=TI8;
RUN;

DATA DAT8(DROP=VDL DAT PRC DAY PAN AR8 PA8 IN4 RANGE TIO TI8 LAR8 LPA8);
  SET DAT8;
  Y41=AR8; Y42=PA8; Y43=IN4; Y44=RANGE; Y45=TIO; Y46=TI8;
RUN;

DATA DAT11;
  INFILE 'A:\RESPDVS6.OT3';
  INPUT V8L PAN DAT PRC DAY TI4 PDA PDT@@;
  IF DAY=2 THEN DAY=3;
  OUTPUT;
RUN;

DATA DAT12;
  INFILE 'A:\RESPDVS3.DT3';
  INPUT VDL PAN DAT PRC DAY TI4 PDA PDT@@;
  OUTPUT;
RUN;

DATA DAT13;
  INFILE 'A:\RESPCVSH.OT3';
  INPUT V8L PAN 8AT PRC DAY TI4 PDA PDT@@;
  OUTPUT;
RUN;

DATA DATI4;
  SET DAT11 DAT12 DAT13;
RUN;

PROC SORT DATA=DATI4;
  8Y V8L PAN 8AT PRC DAY;
RUN;

DAT' DAT15 DATI6 DATI7 DATI8;
  S.. DATI4;
  IF VDL=1 TNEN OUTPUT DAT15;
  ELSE IF V8L=2 TNEN OUTPUT DATI6;
  ELSE IF VBL=3 TNEN DUTPUT DATI7;
  ELSE OUTPUT DATI8;
RUN;

DATA DATI5(DRDP=V8L BAT PRC DAY PAN TI4 PDA PDT);
  SET DAT15;
  YI10=TI4; YIII=PDA; YII2=PDT;
RUN;

DATA DAT16(DRDP=VDL DAT PRC DAY PAN T14 PDA PDT);
  SET DATI6;
  Y210=TI4; Y211=PDA; Y212=PDT;
RUN;

DATA DATI7(DROP=VDL 8AT PRC DAY PAN TI4 PDA PDT);
  SET DAT17;
  Y310=TI4; Y311=PDA; Y312=PDT;
RUN;

DATA DAT18(DRDP=V8L DAT PRC DAY PAN TI4 PDA PDT);
  SET DATI8;
  Y410=T14; Y411=PDA; Y412=PDT;
RUN;

DATA ALLTIDAT;
  HERGE DAT5 DAT6 DAT7 DAT8 DAT15 DAT16 DAT17 DAT18;
RUN;
```

Figure 4.9. SAS® program for the merging and analyses of time intensity data by principle components analysis and analysis of variance (page 1 of 2).

APPENDIX 9 (continued)

```
TITLE 'PCA ALL DATA FROM SW/SO TI EVALUATIONS';
PROC PRINCOMP DATA=ALLTIDAT OUT=SWSOOUT1 N=6;
  VAR Y11-Y16 Y21-Y26 Y110-Y112 Y210-Y212;
RU

PROC CORR DATA=SWSOOUT1 OUTP=SWSOCOR1 NOPRINT;
  VAR Y11-Y16 Y21-Y26 Y110-Y112 Y210-Y212 PRIN1-PRIN6;
RUN;

DATA SWSOCOR1;
  SET SWSOCOR1;
  IF _TYPE_="CORR" THEN OUTPUT;
RUN;

TITLE 'CORRELATION ANALYSIS OF PC1-PC6 VS. SW/SO TI VARIABLES';
PROC PRINT;
  VAR _NAME_ PRIN1-PRIN6;
RUN;

TITLE 'ANOVA OF SW/SO TI PC1-PC6';
PROC ANOVA DATA=SWSOOUT1;
  CLASS PAN BAT PRC DAY;
  MODEL PRIN1-PRIN6=PAN BAT PAN*BAT PRC PAN*PRC BAT*PRC PAN*BAT*PRC
                    DAY(PRC) PAN*DAY(PRC) BAT*DAY(PRC);
  TEST H=PAN BAT E=PAN*BAT;
  TEST H=PAN*PRC BAT*PRC E=PAN*BAT*PRC;
  MEANS BAT PRC BAT*PRC DAY(PRC);
RUN;

PRO  SORT DATA=SWSOOUT1;
  BY PRC PAN BAT DAY;
RUN;

PROC ANOVA DATA=SWSOOUT1;
  BY PRC;
  CLASS PAN BAT DAY;
  MODEL PRIN1-PRIN6=PAN BAT PAN*BAT DAY PAN*DAY BAT*DAY;
RUN;
```

Figure 4.9. SAS® program for the merging and analyses of time intensity data by principle components analysis and analysis of variance (page 2 of 2).

APPENDIX 10A

Table 4.5. F-values to test for the detection of color differences by sensory evaluation in strawberry juice samples.

Source of Variation	D.F.	Hue	Value	Chroma
Panelist (PAN)	14	18.14^{***}	8.73^{***}	5.82^{**}
Batch (BAT)	1	1.07^{NS}	1.86^{NS}	1.67^{NS}
PAN*BAT	14	1.01^{NS}	1.09^{NS}	1.81^{NS}
Process (PRC)	1	0.94^{NS}	0.421^{NS}	1.027^{NS}
PAN*PRC	14	1.25^{NS}	1.54^{NS}	0.62^{NS}
BAT*PRC	1	4.61^{*}	1.18^{NS}	0.41^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 10B

Table 4.6. Process and batch cross classification means and standard deviations (in parentheses) for sensory evaluations of strawberry juice color differences.

Variable	BAT*PRC Sig. Level	Batch 1 Process control	Batch 1 Process blanch	Batch 2 Process control	Batch 2 Process blanch
Hue[1]	*	9.78R[b]	9.78R[b]	10.36R[a]	9.58R[b]
		(1.76)	(1.46)	(1.57)	(1.69)
Value	NS	5.92	5.96	5.90	5.81
		(0.31)	(0.42)	(0.42)	(0.51)
Chroma	NS	11.92	12.12	12.48	12.38
		(1.12)	(1.45)	(1.96)	(2.08)

NS - not significant ($p>0.05$)
* - significant ($p\leq 0.05$)

Note: means with the same letter are not significantly different at the 0.05 significance level.

1) Scale in Munsell notation R="red hue" (11R=1YR)

APPENDIX 11A

Table 4.7. F-values for testing Hunter L-a-b indices for strawberry juice color measurements.

Source of Variation	D.F.	L	a	b	Hue angle
Batch (BAT)	1	9.07^{NS}	10.45^{NS}	10.50^{NS}	17.09^{NS}
Process (PRC)	1	5.18^{NS}	5.68^{NS}	4.29^{NS}	10.75^{NS}
BAT*PRC	1	0.78^{NS}	0.69^{NS}	0.47^{NS}	0.45^{NS}

NS - not significant ($p>0.05$)

APPENDIX 11B

Table 4.8. Means, standard deviations (in parentheses) and least significant difference (LSD) for Hunter L-a-b data for evaluation of batch and processing effects on strawberry juice color.

Variable	BAT Sig. Level	Batch			PRC Sig. Level	Process		
		1	2	LSD		control	blanch	LSD
L	NS	61.69 (3.10)	65.62 (1.79)	12.40	NS	64.14 (2.58)	62.16 (3.25)	12.40
a	NS	44.52 (4.11)	39.07 (2.62)	15.33	NS	39.78 (3.68)	43.81 (4.39)	15.33
b	NS	33.55 (1.00)	32.13 (0.86)	9.88	NS	32.39 (1.10)	33.29 (1.15)	9.88
Hue angle	NS	0.647 (0.03)	0.689 (0.02)	0.22	NS	0.685 (0.03)	0.652 (0.03)	0.22

NS - not significant ($p>0.05$)

APPENDIX 12A

Table 4.9. F-values for the detection of color differences among strawberry juice concentrate samples by sensory evaluation.

Source of Variation	D.F.	Hue	Value	Chroma
Panelist (PAN)	8	41.38^{***}	35.55^{***}	37.24^{***}
Batch (BAT)	1	0.84^{NS}	0.70^{NS}	1.43^{NS}
PAN*BAT	8	1.04^{NS}	0.55^{NS}	1.52^{NS}
Process (PRC)[1]	1	0.38^{NS}	0.63^{NS}	2.70^{NS}
PAN*PRC	8	0.24^{NS}	1.39^{NS}	0.60^{NS}
BAT*PRC	1	0.53^{NS}	0.30^{NS}	0.00^{NS}
PAN*BAT*PRC	8	2.08^{*}	0.54^{NS}	1.66^{NS}
Storage within PRC[2] (STO/PRC)	4	32.01^{***}	6.01^{***}	4.95^{**}
STO/CON (control)	2	32.91^{***}	5.98^{**}	6.10^{**}
STO/BLN (blanch)	2	31.11^{***}	6.04^{**}	1.31^{NS}
PAN*STO/PRC	32	2.00^{**}	0.58^{NS}	1.62^{**}
PAN*STO/CON	16	1.94^{*}	0.45^{NS}	1.35^{NS}
PAN*STO/BLN	16	2.08^{*}	0.96^{NS}	2.15^{*}
BAT*STO/PRC	4	3.31^{*}	0.94^{NS}	0.84^{NS}
BAT*STO/CON	2	3.38^{*}	0.37^{NS}	0.64^{NS}
BAT*STO/BLN	2	3.22^{*}	2.66^{NS}	1.23^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

1) F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)] and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)] and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 12B

Table 4.10. Means and standard deviations (in parentheses) of color parameters of reconstistuted strawberry juice concentrate under different processing and storage treatments as rated by the sensory panel.

Variable	PRC Sig. Level	Control 0 Days	Control 3 Days	Control 6 Days	Blanch 0 Days	Blanch 3 Days	Blanch 6 Days
Hue	***	10.70^{b}	13.78^{a}	15.01^{a}	10.66^{b}	13.48^{a}	14.94^{a}
		(1.79)	(1.36)	(1.68)	(1.61)	(1.95)	(1.53)
Value	***	6.13^{b}	6.64^{a}	6.67^{a}	6.18^{b}	6.58^{a}	6.75^{a}
		(1.22)	(0.65)	(0.66)	(0.71)	(0.95)	(0.65)
Chroma	**	11.72^{a}	10.58^{c}	10.39^{c}	11.42^{ab}	10.75^{bc}	10.28^{c}
		(2.28)	(1.73)	(1.88)	(1.94)	(2.33)	(2.24)

Note: means with the same letter are not significantly different at the 0.05 significance level.

* - significant ($p \leq 0.05$)
** - significant ($p \leq 0.01$)
*** - significant ($p \leq 0.001$)

APPENDIX 13A

Table 4.11. F-values from ANOVA of color parameters for strawberry juice concentrate samples by Hunter L-a-b.

Source of Variation	D.F.	L	a	b	Hue angle ($tan^{-1}b/a$)
Batch (BAT)	1	2.78^{NS}	0.20^{NS}	1.36^{NS}	0.03^{NS}
Process (PRC)	1	0.62^{NS}	1.05^{NS}	1.04^{NS}	0.92^{NS}
BAT*PRC	1	1.54^{NS}	0.94^{NS}	1.26^{NS}	0.50^{NS}
Storage within PRC (STO/PRC)	4	10.39^{*}	48.88^{**}	4.86^{NS}	45.52^{**}
STO/CON (control)	2	7.09^{*}	40.05^{**}	6.26^{NS}	35.17^{**}
STO/BLN (blanch)	2	13.70^{*}	57.72^{**}	3.47^{NS}	55.87^{**}
BAT*STO/PRC	4	1.62^{NS}	1.06^{NS}	0.70^{NS}	1.05^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 13B

Table 4.12. Hunter L-a-b means and standard deviations (in parentheses) from reconstituted strawberry juice concentrate samples after processing and storage.

Variable	PRC Sig. Level	Control 0 Days	Control 3 Days	Control 6 Days	Blanch 0 Days	Blanch 3 Days	Blanch 6 Days
L	**	66.69^{b}	72.89^{a}	71.60^{a}	65.96^{b}	73.12^{a}	74.39^{a}
		(2.90)	(1.34)	(6.63)	(2.49)	(0.98)	(0.93)
a	**	37.60^{a}	21.96^{b}	19.21^{bc}	38.42^{a}	21.00^{bc}	15.64^{c}
		(7.54)	(2.79)	(7.51)	(2.56)	(2.53)	(1.93)
b	NS	33.08	33.54	36.37	32.35	33.30	34.97
		(0.76)	(0.61)	(6.36)	(0.96)	(0.51)	(0.64)
Hue Angle	**	0.733^{c}	0.993^{b}	1.09^{b}	0.701^{c}	1.010^{b}	1.151^{a}
		(0.14)	(0.06)	(0.15)	(0.02)	(0.05)	(0.04)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)

Tabla 4.13. F-valuas for tasting tha aroma and tasta diffarancas among strawberry juica samplas.

SOURCE OF VARIATION	D.F.	Ovarall Aroma	Frash Strawbarry	Cooked Strawberry	Artificial Strawbarry	Swaat/ Jammy	Buttery	Citrus	Moldy	Sour Tasta
Panalist (PAN)	10	5.79^{**}	20.06^{***}	12.34^{***}	4.25^{*}	34.41^{***}	2.58^{NS}	10.20^{***}	8.49^{**}	17.25^{***}
Batch (BAT)	1	6.30^{*}	0.92^{NS}	8.70^{*}	1.10^{NS}	0.35^{NS}	0.04^{NS}	0.01^{NS}	0.01^{NS}	1.29^{NS}
PAN*BAT	10	2.02^{NS}	0.98^{NS}	2.77^{NS}	1.18^{NS}	1.18^{NS}	8.26^{**}	1.10^{NS}	0.49^{NS}	0.76^{NS}
Procass (PRC)[1]	1	0.95^{NS}	0.69^{NS}	0.16^{NS}	0.38^{NS}	0.81^{NS}	0.24^{NS}	1.38^{NS}	2.79^{NS}	15.09^{**}
PAN*PRC	10	0.63^{NS}	1.57^{NS}	2.01^{NS}	0.72^{NS}	0.73^{NS}	0.90^{NS}	0.40^{NS}	0.47^{NS}	0.41^{NS}
BAT*PRC	1	0.79^{NS}	0.90^{NS}	4.67^{NS}	2.84^{NS}	0.59^{NS}	3.23^{NS}	0.01^{NS}	0.18^{NS}	0.05^{NS}

NS - not significant ($p>0.05$)

* - significant ($p\leq0.05$)

** - significant ($p\leq0.01$)

*** - significant ($p\leq0.001$)

1) $F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)]$ end degraes of freadom astimatad by Setterthwaita approximation (Andarson and Bancroft, 1952)

APPENDIX 14B

Table 4.14. Process and batch means and standard deviations (in parentheses) from sensory evaluations of taste and aroma of strawberry juice.

Variable	Sig. Level (BAT)	Batch 1	Batch 2	Sig. Level (PRC)	Process control	Process blanch
Aromas						
Overall	*	7.77 (0.95)	8.32 (0.99)	NS	8.00 (0.91)	8.09 (1.10)
Fresh Strawberry	NS	3.46 (1.72)	3.67 (1.66)	NS	3.48 (1.95)	3.66 (1.38)
Cooked Strawberry	*	2.98 (1.73)	3.83 (1.84)	NS	3.38 (1.92)	3.42 (1.75)
Artificial Strawberry	NS	0.90 (1.12)	0.66 (0.79)	NS	0.84 (1.13)	0.72 (0.78)
Sweet/ jammy	NS	3.02 (1.84)	3.14 (1.96)	NS	3.06 (2.00)	3.10 (1.79)
Buttery	NS	2.28 (1.39)	2.38 (1.61)	NS	2.33 (1.57)	2.33 (1.43)
Citrus	NS	0.56 (0.83)	5.57 (0.73)	NS	0.64 (0.77)	0.51 (0.78)
Moldy	NS	0.43 (0.66)	0.42 (0.82)	NS	0.34 (0.72)	0.51 (0.75)
Taste						
Sour	NS	9.59 (1.18)	9.39 (1.46)	**	9.24 (1.39)	9.74 (1.22)

NS - not significant ($p>0.05$)
* - significant ($p\leq 0.05$)

Table 4.15. F-values for testing aroma differences among strawberry juice concentrate samples evaluated by 11 panelists (PAN). Samples include two process batches (BAT), two process (PRC) treatments (C=control, B=blanch) and three storage times (STO).

Source of Variation	D.F.	Overall	Pungent	Musty/ Moldy	Sweet/ Jammy	Cooked Strawberry	Caramel	Fresh Strawberry	Buttery	Citrus	Artificial Strawberry
PAN	8	14.87^{***}	68.05^{***}	132.87^{***}	15.22^{***}	26.03^{***}	84.31^{***}	32.89^{***}	16.38^{***}	51.16^{***}	329.83^{***}
BAT	1	0.16^{NS}	1.20^{NS}	0.72^{NS}	0.97^{NS}	0.39^{NS}	0.73^{NS}	2.80^{NS}	0.50^{NS}	2.06^{NS}	5.74^{*}
PAN*BAT	8	2.87^{**}	0.63^{NS}	0.31^{NS}	2.36^{**}	0.49^{NS}	1.28^{NS}	2.02^{NS}	2.09^{NS}	0.78^{NS}	0.41^{NS}
PRC[1]	1	0.06^{NS}	1.05^{NS}	0.52^{NS}	0.89^{NS}	0.01^{NS}	1.98^{NS}	1.22^{NS}	0.22^{NS}	1.89^{NS}	0.02^{NS}
PAN*PRC	8	5.30^{**}	0.70^{NS}	0.64^{NS}	2.61^{NS}	0.94^{NS}	0.61^{NS}	0.44^{NS}	3.18^{NS}	0.53^{NS}	0.28^{NS}
BAT*PRC	1	13.07^{**}	0.51^{NS}	2.17^{NS}	0.60^{NS}	0.00^{NS}	0.04^{NS}	1.37^{NS}	1.41^{NS}	0.04^{NS}	0.71^{NS}
PAN*BAT*PRC	8	0.15^{NS}	1.02^{NS}	0.96^{NS}	0.56^{NS}	0.48^{NS}	3.07^{*}	1.45^{NS}	0.46^{NS}	1.56^{NS}	3.95^{**}
STO(PRC)[2]	4	1.76^{NS}	2.69^{**}	5.00^{**}	1.51^{NS}	0.70^{NS}	0.86^{NS}	0.95^{NS}	5.81^{***}	0.72^{NS}	0.51^{NS}
STO(C)	2	0.92^{NS}	1.32^{NS}	4.46^{**}	0.44^{NS}	0.79^{NS}	0.53^{NS}	1.22^{NS}	3.38^{**}	1.06^{NS}	0.27^{NS}
STO(B)	2	2.60^{NS}	4.05^{**}	5.54^{**}	2.53^{NS}	0.61^{NS}	1.18^{NS}	0.68^{NS}	8.25^{***}	0.37^{NS}	0.75^{NS}
PAN*STO(PRC)	32	2.87^{**}	4.72^{***}	4.76^{***}	2.00^{*}	1.18^{NS}	2.11^{*}	1.51^{NS}	2.09^{*}	1.27^{NS}	1.53^{NS}
PAN*STO(C)	16	1.95^{NS}	4.70^{**}	3.31^{**}	3.48^{**}	1.38^{NS}	2.06^{NS}	1.38^{NS}	1.01^{NS}	2.35^{*}	2.75^{*}
PAN*STO(B)	16	3.78^{**}	4.74^{**}	7.25^{***}	1.27^{NS}	1.06^{NS}	2.17^{NS}	1.65^{NS}	4.13^{**}	0.77^{NS}	0.73^{NS}
BAT*STO(PRC)	4	0.64^{NS}	3.48^{*}	3.91^{*}	0.89^{NS}	1.89^{NS}	0.39^{NS}	0.75^{NS}	0.34^{NS}	2.02^{NS}	3.06^{*}
BAT*STO(C)	2	0.73^{NS}	6.42^{**}	4.84^{**}	2.23^{NS}	0.69^{NS}	0.64^{NS}	1.07^{NS}	0.12^{NS}	1.26^{NS}	2.04^{NS}
BAT*STO(B)	2	0.55^{NS}	1.34^{NS}	2.30^{NS}	0.22^{NS}	2.32^{NS}	0.12^{NS}	0.41^{NS}	0.76^{NS}	2.37^{NS}	3.73^{*}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

1) $F=(MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC))$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) STO/PRC implies storage within process source of variation.
$F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 15B

Table 4.16. Means and standard deviations (in parentheses) from the sensory evaluation of aroma from reconstituted strawberry juice concentrate after processing and storage treatments.

AROMA	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
Overall	NS	7.06 (1.22)	7.37 (1.08)	7.32 (0.87)	6.96 (1.21)	7.22 (0.94)	7.60 (0.99)
Pungent	**	1.19^{bc} (1.46)	2.06^{ab} (1.50)	2.02^{ab} (1.64)	0.97^{c} (1.54)	1.77^{bc} (1.36)	2.75^{a} (1.80)
Musty/ Moldy	***	0.80^{c} (1.26)	2.66^{ab} (1.81)	2.60^{ab} (1.84)	0.88^{c} (1.41)	2.22^{b} (1.23)	3.24^{a} (2.35)
Sweet/ Jammy	**	3.24^{ab} (1.26)	3.24^{ab} (1.34)	3.03^{ab} (2.02)	3.54^{a} (1.50)	2.96^{ab} (1.63)	2.63^{b} (1.64)
Cooked Straw.	NS	3.36 (1.12)	2.78 (1.81)	3.10 (1.38)	3.18 (1.49)	3.21 (1.33)	2.80 (1.79)
Carmel-ized	NS	2.30 (1.97)	2.15 (1.98)	2.21 (1.80)	1.96 (1.54)	2.31 (1.63)	2.10 (1.71)
Fresh Straw.	NS	2.40 (1.74)	2.87 (2.01)	2.56 (1.82)	2.54 (2.19)	2.43 (1.91)	2.28 (1.73)
Buttery	***	2.56^{a} (1.56)	1.72^{b} (1.42)	1.83^{b} (1.38)	2.88^{a} (1.31)	1.70^{b} (1.27)	1.53^{b} (1.59)
Citrus	NS	1.9 (1.52)	2.16 (1.38)	1.60 (1.60)	2.01 (1.79)	1.85 (1.40)	1.96 (1.38)
Artif. Straw.	NS	1.60 (1.51)	1.61 (1.70)	1.51 (1.75)	1.76 (1.71)	1.45 (1.70)	1.45 (1.52)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 16

Table 4.17. Correlation coefficients for linear associations of aroma variables and principle components for strawberry juice concentrate.

TIME-INTENSITY VARIABLE	PRINCIPLE COMPONENT PC1	PC2	PC3	PC4
Overall	0.735*	0.247*	-0.246*	-0.044
Pungent	0.006	0.887*	-0.092	0.284*
Musty/moldy	-0.228*	0.875*	0.157	-0.094
Sweet/jammy	0.533*	-0.218*	-0.411*	0.572*
Cooked Strawberry	0.553*	-0.095	0.612*	-0.232*
Carmelized	0.794*	0.147	0.031	-0.226*
Fresh Strawberry	0.838*	-0.027	-0.027	-0.120
Buttery	0.222*	-0.036	0.773*	0.532*
Citrus	0.843*	0.131	-0.038	-0.045
Artificial Strawberry	0.918*	-0.018	-0.046	0.036
Descriptor for Principle Component	straw. juice aroma vs musty/ moldy	off-aromas	cooked & buttery vs sweet/ jammy aromas	caramelized & cooked vs pungent & buttery aromas

* reject the hypothesis ($p \leq 0.05$) of no correlation, $r=0$, between principle components and time-intensity variables.

APPENDIX 17A

Table 4.18. F-values for testing aroma principle components for differences among strawberry juice concentrate samples.

Source of Variation	D.F.	PC1	PC2	PC3	PC4
Panelist (PAN)	8	97.43^{***}	55.19^{***}	42.99^{***}	11.41^{**}
Batch (BAT)	1	3.11^{NS}	0.74^{NS}	0.21^{NS}	0.47^{NS}
PAN*BAT	8	1.86^{NS}	0.77^{NS}	0.83^{NS}	1.64^{NS}
Process (PRC)[1]	1	0.90^{NS}	0.66^{NS}	0.16^{NS}	2.09^{NS}
PAN*PRC	8	2.35^{NS}	0.40^{NS}	5.42^{*}	0.44^{NS}
BAT*PRC	1	0.09^{NS}	2.65^{NS}	2.05^{NS}	0.04^{NS}
PAN*BAT*PRC	8	0.54^{NS}	0.70^{NS}	0.33^{NS}	0.72^{NS}
Storage within PRC[2]					
(STO/PRC)	4	1.27^{NS}	3.98^{*}	1.74^{NS}	3.81^{*}
STO/CON (control)	2	1.04^{NS}	2.56^{NS}	1.72^{NS}	1.41^{NS}
STO/BLN (blanch)	2	1.50^{NS}	5.40^{*}	1.76^{NS}	6.21^{**}
PAN*STO/PRC	32	1.46^{NS}	7.60^{***}	2.28^{*}	0.78^{NS}
PAN*STO/CON	16	1.49^{NS}	5.98^{***}	1.67^{NS}	1.19^{NS}
PAN*STO/BLN	16	1.43^{NS}	9.22^{***}	2.89^{*}	0.37^{NS}
BAT*STO/PRC	4	0.67^{NS}	5.86^{**}	1.37^{NS}	0.60^{NS}
BAT*STO/CON	2	0.27^{NS}	8.68^{**}	0.59^{NS}	1.19^{NS}
BAT*STO/BLN	2	1.07^{NS}	3.04^{**}	2.14^{NS}	0.01^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

1) $F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) $F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 17B

Table 4.19. Means and standard deviations (in parentheses) of aroma principle components from reconstituted strawberry juice concentrate after processing and storage treatments.

TI curve param.	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
PC1	NS	0.13 (1.98)	0.10 (2.25)	-0.12 (2.11)	0.16 (2.09)	-0.08 (2.05)	-0.20 (1.95)
PC2	*	-0.76^{b} (1.12)	0.36^{ab} (1.05)	0.29^{ab} (1.19)	-0.89^{c} (1.13)	0.06^{abc} (0.79)	-0.95^{ab} (1.57)
PC3	NS	0.30 (1.14)	-0.29 (1.12)	-0.04 (1.05)	0.34 (1.08)	-0.04 (1.05)	-0.26 (1.22)
PC4	*	0.16^{a} (0.74)	-0.04^{ab} (0.93)	-0.10^{ab} (1.11)	0.44^{a} (0.94)	-0.24^{b} (0.74)	-0.22^{b} (0.87)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)
* - significant ($p\leq 0.05$)

APPENDIX 18A

Table 4.20. F-values for testing taste differences among strawberry juice concentrate samples.

Source of Variation	DF	SWEET	SOUR	ASTRINGENT	BITTER
Panelist (PAN)	8	43.39^{***}	11.02^{**}	16.26^{***}	28.85^{***}
Batch (BAT)	1	0.00^{NS}	0.43^{NS}	2.91^{NS}	0.42^{NS}
PAN*BAT	8	1.01^{NS}	1.05^{NS}	1.29^{NS}	0.50^{NS}
Process (PRC)[1]	1	0.43^{NS}	1.40^{NS}	5.20^{*}	0.02^{NS}
PAN*PRC	8	0.54^{NS}	0.29^{NS}	0.45^{NS}	0.12^{NS}
BAT*PRC	1	1.84^{NS}	3.42^{NS}	0.13^{NS}	0.84^{NS}
PAN*BAT*PRC	8	1.68^{NS}	1.31^{NS}	1.82^{NS}	2.28^{*}
Storage within PRC[2]					
(STO/PRC)	4	2.31^{*}	1.34^{NS}	0.31^{NS}	1.14^{NS}
STO/CON (Control)	2	3.54^{*}	1.20^{NS}	0.36^{NS}	1.08^{NS}
STO/BLN (blanch)	2	1.08^{NS}	1.47^{NS}	0.25^{NS}	1.20^{NS}
PAN*STO/PRC	32	1.06^{NS}	0.68^{NS}	1.25^{NS}	0.72^{NS}
PAN*STO/CON	16	2.22^{*}	0.34^{NS}	1.16^{NS}	1.17^{NS}
PAN*STO/BLN	16	0.61^{NS}	1.10^{NS}	1.34^{NS}	0.54^{NS}
BAT*STO/PRC	4	0.30^{NS}	0.59^{NS}	2.80^{*}	0.17^{NS}
BAT*STO/CON	2	0.31^{NS}	0.17^{NS}	5.36^{**}	0.16^{NS}
BAT*STO/BLN	2	0.29^{NS}	1.12^{NS}	0.16^{NS}	0.18^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

1) F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)] and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)] and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 18B

Table 4.21. Means and standard deviations (in parentheses) for sensory evaluation for taste of reconstituted strawberry juice concentrate after processing and storage treatments.

TASTE	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
Sweet	*	4.69^{a} (2.34)	4.56^{ab} (3.11)	3.53^{b} (2.63)	4.33^{ab} (2.81)	4.72^{a} (3.00)	4.56^{ab} (2.85)
Sour	NS	7.83 (2.07)	7.39 (1.72)	7.61 (1.72)	8.07 (1.99)	7.56 (1.72)	8.22 (2.32)
Astrgt.	NS	6.98 (2.28)	6.67 (2.17)	6.61 (2.59)	7.30 (2.34)	7.39 (2.25)	7.33 (2.83)
Bitter	NS	2.83 (2.25)	3.56 (2.62)	3.17 (2.09)	2.89 (2.59)	3.11 (2.35)	3.67 (2.50)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)
* - significant ($p\leq 0.05$)

Table 4.22. F-values for testing for differences in the sweetness time-intensity perception among samples of strawberry juice concentrate.

Source of Variation	DF	Duration Area	Duration Perimeter	Maximum Intensity	Duration Time	Initial Time	Final Time	Time to Peak Int.	Peak Area	Peak Duration
Panelist (PAN)	8	68.59^{***}	44.20^{***}	63.84^{***}	51.38^{***}	1.38^{NS}	51.78^{***}	7.54^{**}	21.95^{***}	14.82^{***}
Batch (BAT)	1	0.85^{NS}	0.04^{NS}	0.15^{NS}	0.02^{NS}	0.01^{NS}	1.10^{NS}	0.22^{NS}	0.44^{NS}	2.19^{NS}
PAN*BAT	8	1.67^{NS}	1.39^{NS}	0.75^{NS}	1.53^{NS}	3.71^{***}	1.39^{NS}	3.34^{NS}	1.19^{NS}	0.66^{NS}
Process (PRC)[1]	1	0.55^{NS}	0.29^{NS}	0.47^{NS}	0.69^{NS}	3.49^{*}	0.63^{NS}	0.58^{NS}	1.16^{NS}	4.66^{*}
PAN*PRC	8	0.30^{NS}	0.50^{NS}	0.34^{NS}	0.45^{NS}	0.32^{NS}	0.48^{NS}	0.37^{NS}	0.22^{NS}	0.23^{NS}
BAT*PRC	1	1.56^{NS}	3.33^{NS}	1.83^{NS}	1.07^{NS}	0.01^{NS}	1.10^{NS}	0.36^{NS}	1.66^{NS}	1.82^{NS}
PAN*BAT*PRC	8	1.45^{NS}	1.55^{NS}	1.92^{NS}	1.04^{NS}	1.23^{NS}	1.05^{NS}	1.40^{NS}	2.31^{*}	1.39^{NS}
Storage within PRC[2]										
(STO/PRC)	4	2.12^{NS}	1.68^{NS}	1.98^{NS}	2.18^{NS}	0.98^{NS}	1.88^{NS}	2.61^{*}	0.33^{NS}	0.57^{NS}
STO/CON(control)	2	2.52^{NS}	2.47^{NS}	3.13^{*}	2.31^{NS}	0.98^{NS}	2.60^{NS}	3.72^{*}	0.32^{NS}	0.51^{NS}
STO/BLN (blanch)	2	1.72^{NS}	0.90^{NS}	0.85^{NS}	1.61^{NS}	0.97^{NS}	1.16^{NS}	2.07^{NS}	0.35^{NS}	0.63^{NS}
PAN*STO/PRC	32	0.68^{NS}	0.99^{NS}	0.93^{NS}	0.65^{NS}	0.82^{NS}	0.53^{NS}	0.81^{NS}	1.05^{NS}	0.77^{NS}
PAN*STO/CON	16	0.48^{NS}	1.49^{NS}	1.90^{NS}	0.36^{NS}	0.29^{NS}	0.30^{NS}	0.27^{NS}	0.62^{NS}	0.57^{NS}
PAN*STO/BLN	16	0.86^{NS}	0.75^{NS}	0.53^{NS}	1.19^{NS}	1.50^{NS}	1.00^{NS}	1.35^{NS}	1.48^{NS}	0.97^{NS}
BAT*STO/PRC	4	0.62^{NS}	0.85^{NS}	0.60^{NS}	0.49^{NS}	1.03^{NS}	0.25^{NS}	0.32^{NS}	2.50^{*}	1.31^{NS}
BAT*STO/CON	2	0.69^{NS}	0.43^{NS}	0.51^{NS}	0.28^{NS}	0.49^{NS}	0.25^{NS}	0.41^{NS}	0.96^{NS}	0.22^{NS}
BAT*STO/BLN	2	0.53^{NS}	1.05^{NS}	0.63^{NS}	0.99^{NS}	1.73^{NS}	0.27^{NS}	0.24^{NS}	4.15^{**}	2.40^{*}

NS - not significant ($p>0.05$)

* - significant ($p\leq0.05$)

** - significant ($p\leq0.01$)

*** - significant ($p\leq0.001$)

1) $F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) $F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 19B

Table 4.23. Means and standard deviations (in parentheses) of time-intensity (TI) curve parameters for sweetness perception from reconstituted strawberry juice concentrate after processing and storage treatments.

TI curve param.	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
A_{tot}	NS	405.3 (505.2)	378.8 (495.5)	294.0 (391.0)	345.8 (425.9)	398.7 (544.9)	419.8 (505.2)
P_{tot}	NS	71.1 (47.5)	65.2 (46.3)	53.4 (49.1)	66.0 (45.8)	68.3 (49.8)	73.7 (55.0)
I_{peak}	NS[1]	29.0^{a} (19.1)	27.1^{ab} (20.0)	20.6^{b} (17.3)	26.6 (20.7)	28.6 (22.3)	28.3 (20.5)
D_{tot}	NS	17.0 (14.2)	16.0 (14.0)	14.0 (13.3)	15.4 (11.1)	15.8 (12.2)	18.1 (16.2)
T_i	NS	2.7 (2.18)	2.1 (1.98)	2.2 (1.64)	2.5 (1.91)	3.0 (3.20)	2.2 (2.31)
T_f	NS	19.7 (13.8)	18.1 (13.6)	16.1 (13.0)	17.9 (10.6)	18.8 (11.8)	20.3 (15.5)
T_{peak}	*	7.4^{a} (4.29)	6.2^{ab} (3.92)	5.6^{b} (4.00)	6.7^{ab} (3.35)	7.2^{ab} (3.78)	7.6^{a} (6.00)
A_{peak}	NS	82.4 (93.7)	85.7 (106.2)	74.7 (92.4)	94.1 (112.9)	104.2 (112.7)	91.2 (91.2)
D_{peak}	NS	2.4 (1.86)	2.6 (2.60)	2.3 (2.26)	3.2 (2.26)	2.9 (2.63)	2.8 (2.22)

Note: means with the same letter are not significantly different at the 0.05 significance level.

1) Since the storage variation was significant for only the control samples, the LSD test was conducted for only the control means.

NS - not significant ($p>0.05$)
* - significant ($p\leq 0.05$)

Table 4.24. F-values for testing for differences in the sourness time-intensity perception among samples of strawberry juice concentrate.

Source of Variation	DF	Duration Area	Duration Perimeter	Maximum Intensity	Duration Time	Initial Time	Final Time	Time to Peak Int.	Peak Area	Peak Duration
Panelist (PAN)	8	41.42^{***}	18.80^{***}	11.24^{**}	48.26^{***}	7.34^{**}	55.20^{***}	20.87^{***}	7.19^{**}	11.44^{**}
Batch (BAT)	1	7.84^{*}	1.55^{NS}	0.85^{NS}	1.28^{NS}	0.51^{NS}	2.00^{NS}	0.86^{NS}	1.34^{NS}	1.06^{NS}
PAN*BAT	8	0.64^{NS}	1.01^{NS}	1.21^{NS}	1.24^{NS}	1.42^{NS}	1.09^{NS}	0.75^{NS}	0.90^{NS}	0.64^{NS}
Process (PRC)[1]	1	4.69^{*}	4.36^{*}	1.86^{NS}	1.29^{NS}	0.42^{NS}	1.20^{NS}	0.29^{NS}	6.07^{*}	4.28^{NS}
PAN*PRC	8	1.01^{NS}	0.64^{NS}	0.24^{NS}	2.60^{NS}	1.61^{NS}	2.31^{NS}	3.84^{*}	1.13^{NS}	1.26^{NS}
BAT*PRC	1	0.11^{NS}	0.13^{NS}	0.74^{NS}	2.51^{NS}	0.83^{NS}	3.98^{NS}	2.38^{NS}	0.08^{NS}	0.05^{NS}
PAN*BAT*PRC	8	1.08^{NS}	1.71^{NS}	1.61^{NS}	0.78^{NS}	2.42^{*}	0.75^{NS}	0.49^{NS}	1.32^{NS}	1.15^{NS}
Storage within PRC[2]										
(STO/PRC)	4	1.16^{NS}	1.31^{NS}	0.39^{NS}	1.80^{NS}	0.67^{NS}	1.38^{NS}	0.97^{NS}	0.36^{NS}	0.35^{NS}
STO/CON(control)	2	0.29^{NS}	1.42^{NS}	0.16^{NS}	0.85^{NS}	0.87^{NS}	0.76^{NS}	1.11^{NS}	0.56^{NS}	0.51^{NS}
STO/BLN (blanch)	2	2.03^{NS}	2.00^{NS}	0.61^{NS}	2.66^{*}	0.67^{NS}	1.99^{NS}	0.84^{NS}	0.15^{NS}	0.18^{NS}
PAN*STO/PRC	32	0.37^{NS}	0.62^{NS}	0.52^{NS}	1.00^{NS}	1.22^{NS}	1.25^{NS}	0.75^{NS}	0.58^{NS}	0.66^{NS}
PAN*STO/CON	18	0.38^{NS}	0.75^{NS}	0.38^{NS}	1.16^{NS}	1.46^{NS}	1.66^{NS}	0.67^{NS}	0.28^{NS}	0.41^{NS}
PAN*STO/BLN	16	0.37^{NS}	0.50^{NS}	0.68^{NS}	0.88^{NS}	0.87^{NS}	0.95^{NS}	0.83^{NS}	0.90^{NS}	0.80^{NS}
BAT*STO/PRC	4	0.32^{NS}	0.34^{NS}	0.48^{NS}	0.18^{NS}	1.44^{NS}	0.18^{NS}	0.17^{NS}	0.25^{NS}	0.10^{NS}
BAT*STO/CON	2	0.37^{NS}	0.04^{NS}	0.12^{NS}	0.17^{NS}	1.55^{NS}	0.38^{NS}	0.24^{NS}	0.28^{NS}	0.12^{NS}
BAT*STO/BLN	2	0.29^{NS}	0.60^{NS}	0.88^{NS}	0.21^{NS}	1.30^{NS}	0.08^{NS}	0.08^{NS}	0.24^{NS}	0.08^{NS}

NS - not significant ($p>0.05$)

* - significant ($p\leq0.05$)

** - significant ($p\leq0.01$)

*** - significant ($p\leq0.001$)

1) $F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) $F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 20B

Table 4.25. Means and standard deviations of time-intensity (TI) curve parameters of sourness perception from reconstituted strawberry juice concentrate after processing and storage treatments.

TI curve param.	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
A_{tot}	NS	718.1 (344.2)	669.4 (397.5)	685.4 (381.6)	824.6 (475.1)	684.5 (378.6)	799.5 (355.9)
P_{tot}	NS	118.0 (31.5)	118.6 (28.4)	112.4 (34.4)	124.8 (35.8)	122.4 (43.0)	127.0 (35.9)
I_{peak}	NS	49.8 (14.6)	48.7 (11.7)	48.4 (11.6)	51.7 (14.1)	49.6 (11.3)	53.4 (16.0)
D_{tot}	NS	24.2 (9.8)	24.0 (10.2)	23.4 (12.5)	26.8 (14.00	23.5 (10.7)	25.3 (9.5)
T_i	NS	1.9 (1.2)	1.7 (1.0)	2.2 (1.9)	1.9 (1.3)	2.3 (2.6)	2.0 (1.1)
T_f	NS	26.1 (9.4)	25.7 (10.0)	25.5 (13.1)	28.7 (13.4)	25.8 (10.0)	27.3 (8.9)
T_{peak}	NS	8.2 (3.2)	7.2 (2.3)	8.1 (2.7)	8.3 (3.4)	7.6 (3.4)	8.6 (3.5)
A_{peak}	NS	125.9 (76.1)	148.9 (82.3)	121.9 (87.5)	173.2 (120.6)	168.9 (91.4)	160.2 (132.2)
D_{peak}	NS	2.6 (1.5)	3.1 (1.6)	2.7 (1.8)	3.3 (2.3)	3.6 (2.1)	3.2 (2.8)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)

APPENDIX 21

Table 4.26. Correlation coefficients for linear associations of time-intensity variables and principle components from those time-intensity variables.

TIME-INTENSITY VARIABLE	PRINCIPLE COMPONENT PCS1	PCS2	PCS3	PCS4
Sweetness				
Duration Area	0.902*	0.268*	-0.088	-0.157
Duration Perimeter	0.815*	0.444*	-0.180	-0.169
Intensity Maximum	0.720*	0.456*	-0.240*	-0.194*
Duration Time	0.879*	0.337*	0.000	-0.051
Initial Time	-0.355*	0.352*	0.124	0.647*
Final Time	0.848*	0.408*	0.022	0.057
Time to Peak	0.030	0.691*	0.211*	0.367*
Peak Area	0.803*	0.135	-0.250*	0.013
Peak Duration Time	0.538*	0.010	-0.223*	0.238*
Sourness				
Duration Area	0.766*	-0.412*	0.398*	0.106
Duration Perimeter	0.575*	-0.492*	0.553*	0.090
Intensity Maximum	0.317*	-0.468*	0.658*	0.037
Duration Time	0.847*	-0.188*	0.206*	0.112
Initial Time	-0.332*	0.494*	-0.012	0.424*
Final Time	0.834*	-0.130	0.212*	0.171
Time to Peak	-0.128	0.446*	0.659*	0.182*
Peak Area	0.404*	-0.586*	-0.451*	0.427*
Peak Duration Time	0.255*	-0.435*	-0.709*	0.412*

Descriptor for Principle Component	Sweet and Sour Intensity	Sweet vs. Sour Intensity	Sharpness of Sour Peak	Reaction Time

* reject the hypothesis ($p \leq 0.05$) of no correlation, $r=0$, between principle components and time-intensity variables.

APPENDIX 22A

Table 4.27. F-values for testing sweet/sour time-intensity principle component differences among strawberry juice concentrate samples.

Source of Variation	D.F.	PCS1	PCS2	PCS3	PCS4
Panelist (PAN)	8	109.87^{***}	15.40^{***}	22.65^{***}	1.40^{NS}
Batch (BAT)	1	1.48^{NS}	0.46^{NS}	0.68^{NS}	1.19^{NS}
PAN*BAT	8	0.76^{NS}	1.48^{NS}	0.76^{NS}	3.21^{**}
Process (PRC)[1]	1	1.94^{NS}	2.53^{NS}	0.65^{NS}	6.72^{*}
PAN*PRC	8	1.45^{NS}	1.14^{NS}	0.94^{NS}	0.12^{NS}
BAT*PRC	1	1.94^{NS}	0.02^{NS}	0.64^{NS}	0.33^{NS}
PAN*BAT*PRC	8	0.84^{NS}	1.63^{NS}	0.75^{NS}	2.42^{*}
Storage within PRC[2] (STO/PRC)	4	1.47^{NS}	1.31^{NS}	1.59^{NS}	1.18^{NS}
STO/CON (control)	2	1.92^{NS}	1.69^{NS}	1.53^{NS}	1.13^{NS}
STO/BLN (blanch)	2	1.02^{NS}	0.92^{NS}	1.65^{NS}	1.23^{NS}
PAN*STO/PRC	32	0.60^{NS}	0.52^{NS}	0.82^{NS}	0.62^{NS}
PAN*STO/CON	16	0.52^{NS}	0.38^{NS}	0.88^{NS}	0.50^{NS}
PAN*STO/BLN	16	0.68^{NS}	0.66^{NS}	0.76^{NS}	0.74^{NS}
BAT*STO/PRC	4	0.74^{NS}	0.25^{NS}	0.36^{NS}	0.43^{NS}
BAT*STO/CON	2	0.18^{NS}	0.28^{NS}	0.10^{NS}	0.33^{NS}
BAT*STO/BLN	2	1.30^{NS}	0.22^{NS}	0.62^{NS}	0.53^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

1) $F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) $F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 22B

Table 4.28. Means and standard deviations (in parentheses) of time-intensity (TI) curve parameters of sweet/sour time-intensity principle components from reconstituted strawberry juice concentrate after processing and storage treatments.

TI curve param.	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
PCS1	NS	-0.27 (2.50)	-0.13 (2.71)	-0.67 (2.76)	0.22 (2.86)	-0.01 (3.03)	0.35 (2.71)
PCS2	NS	0.35 (1.69)	-0.14 (1.56)	-0.08 (1.59)	-0.30 (1.85)	0.08 (1.91)	-0.00 (1.77)
PCS3	NS	0.12 (1.48)	-0.30 (1.22)	0.02 (1.45)	0.04 (1.59)	-0.35 (1.46)	0.16 (2.12)
PCS4	NS	-0.18 (1.05)	-0.32 (1.01)	-0.29 (1.03)	0.25 (1.15)	0.32 (1.66)	0.07 (1.02)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)

Table 4.29. F-values for testing for differences in the astringency time-intenaity perception among samplea of atrawberry juice concentrate.

Source of Variation	DF	Duration Area	Duration Perimeter	Maximum Intensity	Duration Time	Initial Time	Final Time	Time to Peak Int.	Peak Area	Peak Duration
Panalist (PAN)	8	16.36^{***}	18.15^{***}	27.92^{***}	24.89^{***}	16.52^{***}	25.27^{***}	12.23^{***}	12.31^{***}	11.03^{**}
Batch (BAT)	1	4.19^{NS}	3.26^{NS}	7.94^{*}	3.93^{NS}	0.27^{NS}	3.44^{NS}	0.00^{NS}	2.35^{NS}	1.77^{NS}
PAN*BAT	8	2.32^{NS}	1.79^{NS}	0.70^{NS}	2.41^{*}	1.53^{NS}	2.54^{NS}	2.24^{NS}	1.29^{NS}	1.54^{NS}
Process (PRC)[1]	1	2.65^{NS}	0.47^{NS}	2.22^{NS}	1.31^{NS}	0.72^{NS}	1.32^{NS}	0.67^{NS}	2.34^{NS}	4.16^{NS}
PAN*PRC	8	0.82^{NS}	0.29^{NS}	0.58^{NS}	0.28^{NS}	1.66^{NS}	0.35^{NS}	2.17^{NS}	0.15^{NS}	0.49^{NS}
BAT*PRC	1	1.05^{NS}	1.10^{NS}	0.25^{NS}	1.12^{NS}	0.02^{NS}	1.22^{NS}	1.53^{NS}	0.22^{NS}	0.18^{NS}
PAN*BAT*PRC	8	1.09^{NS}	1.86^{NS}	2.44^{*}	1.75^{NS}	0.91^{NS}	1.52^{NS}	0.31^{NS}	0.11^{NS}	0.32^{NS}
Storage within PRC[2]										
(STO/PRC)	4	1.09^{NS}	0.61^{NS}	0.43^{NS}	1.01^{NS}	0.96^{NS}	1.09^{NS}	0.79^{NS}	1.37^{NS}	1.38^{NS}
STO/CON(control)	2	0.94^{NS}	0.49^{NS}	0.48^{NS}	0.66^{NS}	1.31^{NS}	0.74^{NS}	0.64^{NS}	1.22^{NS}	0.92^{NS}
STO/BLN (blanch)	2	1.24^{NS}	0.76^{NS}	0.38^{NS}	1.37^{NS}	0.60^{NS}	1.44^{NS}	0.94^{NS}	1.51^{NS}	1.84^{NS}
PAN*STO/PRC	32	0.75^{NS}	0.93^{NS}	1.23^{NS}	0.90^{NS}	1.07^{NS}	0.81^{NS}	0.95^{NS}	1.90^{*}	1.39^{NS}
PAN*STO/CON	16	1.49^{NS}	0.75^{NS}	0.74^{NS}	0.91^{NS}	0.99^{NS}	0.79^{NS}	0.35^{NS}	1.27^{**}	1.71^{NS}
PAN*STO/BLN	16	0.41^{NS}	0.89^{NS}	1.90^{NS}	0.88^{NS}	1.42^{NS}	0.82^{NS}	1.35^{NS}	1.32^{NS}	1.07^{NS}
BAT*STO/PRC	4	1.09^{NS}	2.51^{*}	2.27^{NS}	1.60^{NS}	0.68^{NS}	1.49^{NS}	0.79^{NS}	0.69^{NS}	0.84^{NS}
BAT*STO/CON	2	2.73^{NS}	3.59^{*}	3.68^{*}	2.64^{NS}	0.55^{NS}	2.21^{NS}	0.19^{NS}	0.41^{NS}	0.11^{NS}
BAT*STO/BLN	2	0.31^{NS}	1.92^{NS}	0.67^{NS}	0.99^{NS}	0.92^{NS}	1.00^{NS}	1.38^{NS}	0.95^{NS}	1.57^{NS}

NS - not significant ($p>0.05$)

* - significant ($p\leq0.05$)

** - significant ($p\leq0.01$)

*** - significant ($p\leq0.001$)

1) $F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) $F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 23B

Table 4.30. Means and standard deviations (in parentheses) of time-intensity (TI) curve parameters of astringency perception from reconstituted strawberry juice concentrate after processing and storage treatments.

TI curve param.	STO/PRC Sig. Level	Control 0 Days	Control 3 Days	Control 6 Days	Blanch 0 Days	Blanch 3 Days	Blanch 6 Days
A_{tot}	NS	1255.6 (1141.4)	1062.4 (1077.5)	1369.2 (1256.0)	1442.4 (1427.1)	1340.0 (1160.1)	1730.7 (1625.0)
P_{tot}	NS	136.4 (65.9)	127.3 (52.9)	141.6 (66.0)	137.6 (66.9)	133.8 (62.4)	156.0 (90.4)
I_{peak}	NS	44.0 (13.9)	42.4 (13.7)	46.4 (12.6)	45.7 (14.5)	46.8 (14.0)	47.9 (19.5)
D_{tot}	NS	46.9 (34.5)	41.7 (29.7)	47.0 (34.2)	48.2 (34.8)	44.4 (28.0)	56.9 (45.5)
T_i	NS	3.5 (2.6)	3.4 (2.7)	4.3 (3.1)	3.7 (2.7)	3.9 (3.9)	3.8 (3.0)
T_f	NS	50.4 (35.6)	45.0 (30.8)	51.3 (35.3)	51.9 (36.4)	48.3 (29.6)	60.6 (47.6)
T_{peak}	NS	14.4 (7.5)	14.1 (7.1)	14.6 (6.2)	13.5 (6.4)	13.9 (6.3)	14.9 (10.4)
A_{peak}	NS	266.9 (384.1)	200.9 (159.7)	408.4 (736.2)	280.5 (336.1)	281.0 (325.6)	478.8 (617.7)
D_{peak}	NS	5.7 (7.4)	4.8 (3.7)	7.5 (12.1)	5.8 (6.2)	5.5 (5.7)	9.5 (11.1)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)

Table 4.31. F-values for testing for differences in the bitterness time-intensity perception among samples of strawberry juice concentrate.

Source of Variation	DF	Duration Area	Duration Perimeter	Maximum Intensity	Duration Time	Initial Time	Final Time	Time to Peak Int.	Peak Area	Peak Duration
Panelist (PAN)	8	23.24^{***}	26.92^{***}	36.98^{***}	33.51^{***}	6.18^{**}	31.50^{***}	18.15^{***}	3.89^{*}	2.14^{NS}
Batch (BAT)	1	1.07^{NS}	0.44^{NS}	0.01^{NS}	0.00^{NS}	0.09^{NS}	0.01^{NS}	0.00^{NS}	1.15^{NS}	0.59^{NS}
PAN*BAT	8	0.62^{NS}	0.51^{NS}	0.53^{NS}	0.87^{NS}	0.62^{NS}	0.73^{NS}	0.89^{NS}	2.07^{*}	1.90^{NS}
Process (PRC)[1]	1	0.87^{NS}	0.22^{NS}	0.01^{NS}	0.80^{NS}	0.29^{NS}	0.39^{NS}	0.24^{NS}	0.99^{NS}	0.66^{NS}
PAN*PRC	8	0.20^{NS}	0.10^{NS}	0.16^{NS}	0.32^{NS}	1.72^{NS}	0.41^{NS}	1.32^{NS}	0.91^{NS}	0.84^{NS}
BAT*PRC	1	0.12^{NS}	0.28^{NS}	0.73^{NS}	0.92^{NS}	1.71^{NS}	2.36^{NS}	7.53^{*}	0.91^{NS}	1.21^{NS}
PAN*BAT*PRC	8	2.68^{*}	1.84^{NS}	1.84^{NS}	1.87^{NS}	0.75^{NS}	1.50^{NS}	0.99^{NS}	2.73^{**}	1.59^{NS}
Storage within PRC[2] (STO/PRC)	4	1.36^{NS}	1.50^{NS}	1.34^{NS}	1.70^{NS}	1.43^{NS}	1.35^{NS}	0.44^{NS}	1.33^{NS}	1.06^{NS}
STO/CON(control)	2	0.58^{NS}	1.24^{NS}	0.53^{NS}	1.50^{NS}	1.24^{NS}	1.25^{NS}	0.00^{NS}	0.34^{NS}	0.74^{NS}
STO/BLN (blanch)	2	2.30^{NS}	1.75^{NS}	2.15^{NS}	1.88^{NS}	1.61^{NS}	1.46^{NS}	0.88^{NS}	2.33^{NS}	1.39^{NS}
PAN*STO/PRC	32	2.32^{***}	1.31^{NS}	0.58^{NS}	1.61^{*}	0.87^{NS}	1.79^{*}	1.88^{NS}	2.47^{***}	1.37^{NS}
PAN*STO/CON	16	0.28^{NS}	0.57^{NS}	0.66^{NS}	0.48^{NS}	0.35^{NS}	0.41^{NS}	0.79^{NS}	0.12^{NS}	0.47^{NS}
PAN*STO/BLN	16	2.84^{**}	1.58^{NS}	0.53^{NS}	2.14^{*}	1.45^{NS}	3.01^{NS}	2.87^{NS}	4.82^{***}	2.27^{**}
BAT*STO/PRC	4	0.39^{NS}	0.80^{NS}	0.20^{NS}	0.24^{NS}	0.38^{NS}	0.08^{NS}	0.17^{NS}	1.09^{NS}	1.10^{NS}
BAT*STO/CON	2	0.05^{NS}	1.44^{NS}	0.29^{NS}	0.14^{NS}	0.32^{NS}	0.05^{NS}	0.31^{NS}	0.18^{NS}	1.67^{NS}
BAT*STO/BLN	2	0.50^{NS}	0.70^{NS}	0.14^{NS}	0.28^{NS}	0.44^{NS}	0.11^{NS}	0.03^{NS}	1.99^{NS}	0.54^{NS}

NS - not significant ($p>0.05$)

* - significant ($p\leq 0.05$)

** - significant ($p\leq 0.01$)

*** - significant ($p\leq 0.001$)

1) $F=[MS(PRC)+MS(PAN*BAT*PRC)]/[MS(PAN*PRC)+MS(BAT*PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

2) $F=[MS(STO/PRC)+MS(PAN*BAT*STO/PRC)]/[MS(PAN*STO/PRC)+MS(BAT*STO/PRC)]$ and degrees of freedom estimated by Satterthwaite approximation (Anderson and Bancroft, 1952)

APPENDIX 24B

Table 4.32. Means and standard deviations (in parentheses) of time-intensity (TI) curve parameters of bitterness perception from reconstituted strawberry juice concentrate after processing and storage treatments.

TI curve param.	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
A_{tot}	NS	203.2 (199.7)	246.6 (191.3)	176.0 (192.5)	188.2 (223.2)	346.1 (568.2)	303.1 (307.1)
P_{tot}	NS	49.8 (33.6)	65.3 (34.9)	47.9 (35.0)	48.5 (36.8)	59.9 (72.4)	68.7 (45.8)
I_{peak}	NS	18.0 (14.7)	21.0 (16.0)	18.2 (15.2)	17.2 (16.2)	19.2 (15.6)	23.5 (17.2)
D_{tot}	NS	14.0 (8.2)	16.9 (8.4)	13.4 (7.9)	13.6 (8.5)	16.6 (13.3)	16.8 (10.9)
T_i	NS	4.4 (3.9)	3.6 (2.7)	3.7 (2.5)	4.3 (3.5)	3.0 (2.7)	4.3 (4.6)
T_f	NS	18.4 (9.0)	20.5 (8.9)	17.1 (7.2)	18.0 (9.1)	19.6 (13.4)	21.1 (9.7)
T_{peak}	NS	9.8 (6.1)	9.7 (4.4)	9.7 (4.7)	9.6 (5.9)	8.1 (4.4)	8.7 (5.1)
A_{peak}	NS	62.4 (65.3)	63.2 (54.3)	41.3 (59.2)	56.8 (134.8)	191.2 (478.2)	74.4 (99.1)
D_{peak}	NS	3.4 (3.2)	3.5 (3.0)	2.2 (2.2)	3.1 (4.1)	5.3 (8.3)	3.2 (3.4)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)

APPENDIX 25A

Table 4.33. F-values to test for differences in anthocyanin concentration ([ACN]), browning index (BI), degradation index (DI), polymeric color (PC) and the percent contribution of polymeric color to color density (%PC:CD) among strawberry juice samples.

Source of Variation	DF	[ACN]	BI	DI	CD	PC	%PC:CD
Batch (BAT)	1	8.60^{NS}	1.08^{NS}	0.03^{NS}	11.48^{NS}	14.51^{NS}	15.46^{NS}
Process (PRC)	1	0.28^{NS}	0.43^{NS}	0.00^{NS}	2.52^{NS}	0.01^{NS}	0.27^{NS}
BAT*PRC	1	1.03^{NS}	11.71^{*}	5.48^{NS}	1.25^{NS}	0.32^{NS}	0.18^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 25B

Table 4.34. Process and batch cross classification means and standard devaitions (in parentheses) for spectrophotometric evaluations of strawberry juice color.

Variable	BAT*PRC Sig. Level	Batch 1 Process control	Batch 1 Process blanch	Batch 2 Process control	Batch 2 Process blanch
[ACN]	NS	4.17 (0.07)	4.20 (0.05)	4.43 (0.05)	4.33 (0.15)
BI	*	1.58[a] (0.01)	1.54[a] (0.07)	1.36[b] (0.06)	1.54[a] (0.01)
DI	NS	1.28 (0.00)	1.31 (0.03)	1.30 (0.01)	1.28 (0.00)
CD	NS	3.47 (0.06)	3.51 (0.12)	3.12 (0.14)	3.32 (0.03)
PC	NS	0.39 (0.00)	0.36 (0.04)	0.27 (0.04)	0.29 (0.11)
%PC:CD	NS	11.17 (0.19)	10.36 (0.78)	8.53 (0.97)	8.79 (3.29)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)
* - significant ($p\leq 0.05$)

APPENDIX 26A

Table 4.35. F-values to test for differences in anthocyanin concentration ([ACN]), browning index (BI), degradation index (DI), polymeric color (PC) and the percent contribution of polymeric color to color density (%PC:CD) among strawberry juice concentrate samples.

Source of Variation	DF	[ACN]	BI	DI	CD	PC	%PC:CD
Batch (BAT)	1	0.33^{NS}	2.25^{NS}	8.83^{NS}	1.84^{NS}	136.89^{NS}	139.51^{NS}
Process (PRC)	1	14.93^{NS}	1.31^{NS}	0.64^{NS}	0.88^{NS}	62.49^{NS}	1138.70^{*}
BAT*PRC	1	0.74^{NS}	0.77^{NS}	0.11^{NS}	0.87^{NS}	0.62^{NS}	0.00^{NS}
Storage within PRC							
(STO/PRC)	4	44.70^{**}	1.42^{NS}	762.92^{***}	0.56^{NS}	440.70^{***}	19.98^{**}
STO/CON(control)	2	55.26^{**}	2.00^{NS}	120.30^{***}	0.36^{NS}	71.89^{**}	26.26^{**}
STO/BLN (blanch)	2	34.14^{**}	0.84^{NS}	1405.54^{***}	0.76^{NS}	809.51^{***}	13.70^{**}
BAT*STO/PRC	2	0.87^{NS}	1.29^{NS}	0.17^{NS}	1.04^{NS}	0.15^{NS}	1.40^{NS}
BAT*STO/CON	1	1.63^{NS}	0.89^{NS}	0.00^{NS}	0.96^{NS}	0.26^{NS}	0.04^{NS}
BAT*STO/BLN	1	0.11^{NS}	0.40^{NS}	0.34^{NS}	1.12^{NS}	0.04^{NS}	2.76^{NS}

NS - not significant ($p>0.05$)

* - significant ($p\leq0.05$)

** - significant ($p\leq0.01$)

*** - significant ($p\leq0.001$)

APPENDIX 26B

Table 4.36. Means and standard deviations (in parentheses) from spectrophotometric determinations of pigments from reconstituted strawberry juice concentrate samples after processing and storage.

Variable	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
[ACN]	**	4.87^{c} (0.15)	5.03^{c} (0.04)	4.18^{a} (0.21)	4.92^{c} (0.03)	4.93^{c} (0.05)	4.43^{b} (0.06)
BI	NS	1.05 (0.32)	1.20 (0.15)	1.35 (0.06)	0.99 (0.21)	1.09 (0.19)	1.26 (0.29)
DI	***	1.14^{a} (0.02)	0.69^{b} (0.01)	0.52^{c} (0.01)	1.16^{a} (0.12)	0.66^{b} (0.02)	0.51^{c} (0.02)
CD	NS	2.23 (0.67)	2.00 (0.27)	2.02 (0.08)	2.14 (0.51)	1.77 (0.33)	1.89 (0.46)
PC	***	0.23^{c} (0.07)	0.71^{b} (0.10)	1.03^{a} (0.13)	0.28^{c} (0.06)	0.77^{b} (0.06)	1.01^{a} (0.04)
%PC:CD	**	10.55^{c} (2.22)	36.02^{b} (5.96)	51.03^{a} (5.33)	14.28^{c} (4.95)	44.22^{a} (6.69)	56.60^{a} (15.64)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 27A

Table 4.37. F-values for detection of significant differences in free sugars among strawberry juice samples.

Source of Variation	D.F.	SUC	GLU	FRU	SOR
Batch (BAT)	1	13.19^{NS}	0.15^{NS}	0.03^{NS}	1.00^{NS}
Process (PRC)	1	17.29^{NS}	1.93^{NS}	3.54^{NS}	9.00^{NS}
BAT*PRC	1	1.15^{NS}	7.62^{NS}	1.70^{NS}	0.01^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 27B

Table 4.38. Means, standard deviations (in parentheses) and least significant difference (LSD) for free sugar evaluation of batch and processing effects on strawberry juice color.

Variable	BAT Sig. Level	Batch			PRC Sig. Level	Process		
		1	2	LSD		control	blanch	LSD
Sucrose	NS	1.41 (0.06)	1.32 (0.07)	0.302	NS	1.42 (0.04)	1.32 (0.07)	0.302
Glucose	NS	1.30 (0.07)	1.29 (0.02)	0.572	NS	1.33 (0.02)	1.26 (0.04)	0.572
Fructose	NS	1.52 (0.08)	1.51 (0.04)	0.540	NS	1.56 (0.03)	1.48 (0.06)	0.540
Sorbitol	NS	0.03 (0.02)	0.03 (0.01)	0.016	NS	0.03 (0.01)	0.02 (0.01)	0.016

NS - not significant ($p>0.05$)

APPENDIX 28

Table 4.39. F-values for testing for differences in free sugars among strawberry juice concentrate samples.

Source of Variation	D.F.	SUC	GLU	FRU	SOR
Batch (BAT)	1	0.01^{NS}	0.67^{NS}	1.26^{NS}	3.55^{NS}
Process (PRC)	1	0.64^{NS}	8.64^{NS}	7.47^{NS}	2.85^{NS}
BAT*PRC	1	5.01^{NS}	0.41^{NS}	0.42^{NS}	0.14^{NS}
Storage within PRC (STO/PRC)	4	0.38^{NS}	4.30^{NS}	4.28^{NS}	0.05^{NS}
STO/CON (control)	2	0.72^{NS}	6.97^{NS}	7.19^{NS}	0.09^{NS}
STO/BLN (blanch)	2	0.05^{NS}	2.63^{NS}	1.37^{NS}	0.01^{NS}
BAT*STO/PRC	4	0.71^{NS}	0.33^{NS}	0.20^{NS}	2.09^{NS}
BAT*STO/CON	2	1.12^{NS}	0.24^{NS}	0.15^{NS}	0.03^{NS}
BAT*STO/BLN	2	0.31^{NS}	0.42^{NS}	0.26^{NS}	4.14^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 29A

Table 4.40. F-values for testing for differences in pH, titratable acidity (TA) or free amino acids by the formal number (FN) in strawberry juice samples.

Source of Variation	D.F.	pH	TA	FN
Batch (BAT)	1	0.04^{NS}	1.00^{NS}	0.43^{NS}
Process (PRC)	1	0.04^{NS}	1.00^{NS}	0.59^{NS}
BAT*PRC	1	0.24^{NS}	0.11^{NS}	1.00^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$)
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 29B

Table 4.41. Means, standard deviations (in parentheses) and least significant difference (LSD) for pH, titratable acidity (TA) and free α-amino acids by formal number (FN) from batch and processing effects on strawberry juice.

Variable	BAT Sig. Level	Batch		PRC Sig. Level	Process	
		1	2		control	blanch
pH	NS	3.28 (0.02)	3.28 (0.01)	NS	3.28 (0.02)	3.28 (0.02)
TA	NS	2.30 (0.00)	2.30 (0.00)	NS	2.30 (0.00)	2.30 (0.00)
FN	NS	5.18 (1.61)	5.76 (0.64)	NS	5.82 (1.34)	5.12 (1.06)

NS - not significant ($p>0.05$)

APPENDIX 30

Table 4.42. F-values for testing differences in pH, titratable acidity (TA) and free amino acids as measured by the formal number (FN) among samples of strawberry juice concentrate.

Source of Variation	D.F.	pH[1]	TA	FN
Batch (BAT)	1	1.00^{NS}	0.26^{NS}	0.76^{NS}
Process (PRC)	1	9.00^{NS}	1.03^{NS}	0.01^{NS}
BAT*PRC	1	0.00^{NS}	0.16^{NS}	0.50^{NS}
Storage within PRC (STO/PRC)	4	0.28^{NS}	1.10^{NS}	3.47^{NS}
STO/CON (control)	2	0.24^{NS}	1.52^{NS}	1.82^{NS}
STO/BLN (blanch)	2	0.32^{NS}	0.68^{NS}	5.10^{NS}
BAT*STO/PRC	4	0.00^{NS}	1.15^{NS}	0.49^{NS}
BAT*STO/CON	2	0.01^{NS}	1.26^{NS}	0.81^{NS}
BAT*STO/BLN	2	0.00^{NS}	1.04^{NS}	0.17^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

1) F-values for testing Storage (PRC) source of variation using a mean square error by pooling over the mean square Bat*Sto (PRC) and experimental error sources. This was done since the Bat*Sto (PRC) variation was much lower than expected ($p>0.95$) in comparison to the experimental error variation.

APPENDIX 31A

Table 4.43. F-values for testing differences in the headspace CO_2 and O_2 gasses among samples of strawberry juice concentrate.

Source of Variation	D.F.	PCO2	PO2
Batch (BAT)	1	0.06^{NS}	187.83^{*}
Process (PRC)	1	1.13^{NS}	9.40^{NS}
BAT*PRC	1	2.58^{NS}	0.01^{NS}
Storage within PRC (STO/PRC)	4	53.39^{***}	0.59^{NS}
STO/CON (control)	2	45.53^{**}	4.64^{NS}
STO/BLN (blanch)	2	64.54^{***}	0.31^{NS}
BAT*STO/PRC	4	0.64^{NS}	0.98^{NS}
BAT*STO/CON	2	0.47^{NS}	2.08^{NS}
BAT*STO/BLN	2	1.02^{NS}	0.65^{NS}

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)

APPENDIX 31B

Table 4.44. Means and standard deviations (in parentheses) from headspace CO_2 and O_2 gas determinations strawberry juice concentrate samples after processing and storage.

Variable	STO/PRC Sig. Level	Control			Blanch		
		0 Days	3 Days	6 Days	0 Days	3 Days	6 Days
$\%CO_2$	***	0.26^c (0.10)	3.82^b (0.72)	7.47^a (2.05)	0.36^c (0.12)	3.03^b (0.83)	5.86^a (1.23)
$\%O_2$	NS	20.20 (0.56)	20.21 (0.08)	19.73 (0.22)	19.97 (1.05)	20.00 (0.31)	19.95 (0.29)

Note: means with the same letter are not significantly different at the 0.05 significance level.

NS - not significant ($p>0.05$)
* - significant ($p\leq0.05$
** - significant ($p\leq0.01$)
*** - significant ($p\leq0.001$)