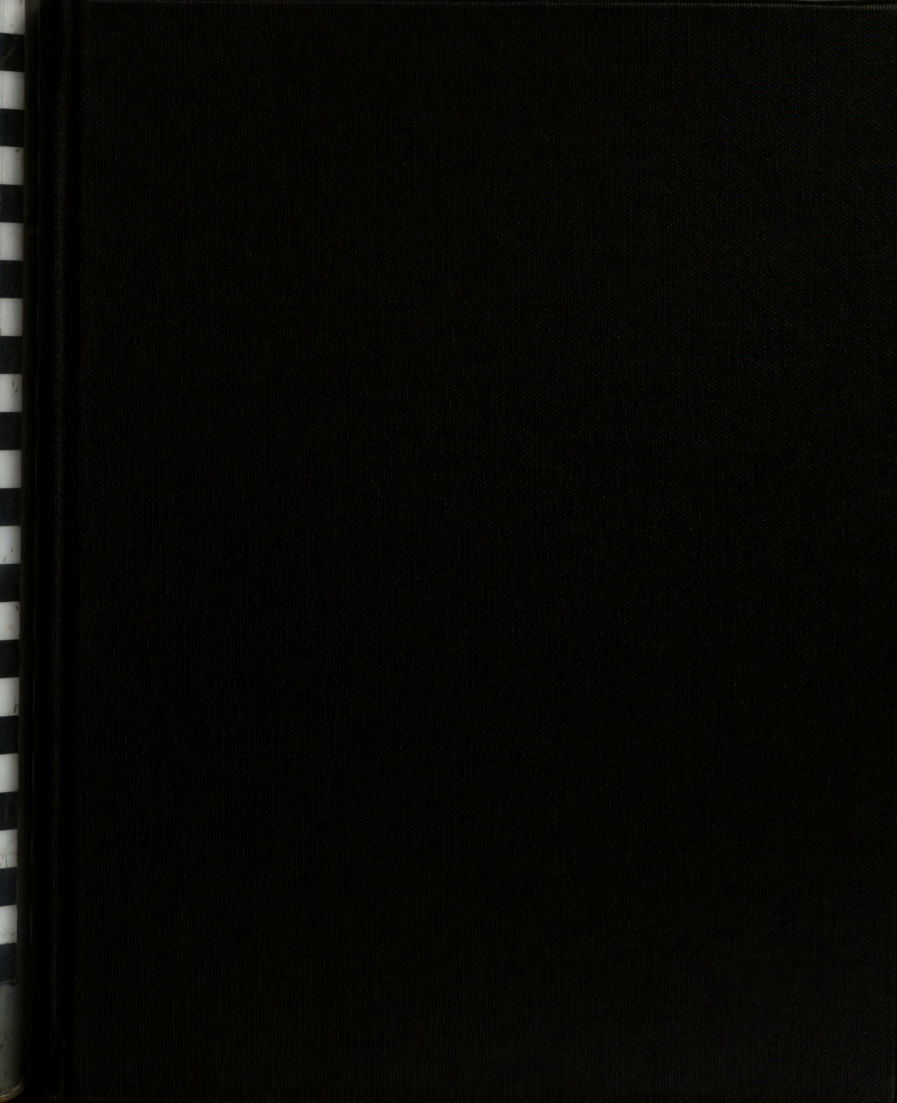






3 1293 01686 0847

This is to certify that the

thesis entitled

EVALUATION OF PROCESSING QUALITY OF SELECTED
APPLE CULTIVARS GROWN IN MICHIGAN

presented by

Korada Sunthanont

has been accepted towards fulfillment
of the requirements for

M.S. degree in Food Science

Major professor

Date 12/04/97

LIBRARY
Michigan State
University

PLACE IN RETURN BOX
to remove this checkout from your record.
TO AVOID FINES return on or before date due.

DATE DUE	DATE DUE	DATE DUE

**EVALUATION OF PROCESSING QUALITY OF SELECTED APPLE
CULTIVARS GROWN IN MICHIGAN**

By

Korada Sunthanont

A THESIS

**Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of**

MASTER OF SCIENCE

Department of Food Science and Human Nutrition

1997

ABSTRACT

EVALUATION OF PROCESSING QUALITY OF SELECTED APPLE CULTIVARS GROWN IN MICHIGAN

By

Korada Sunthanont

Fifteen apple selections were processed into applesauce, apple puree, and frozen apple slices after harvest and after 2-month storage (1.1 °C) for a processing potential study. The chemical-physical measurements, subjective measurements, and sensory evaluations, which were conducted only in applesauce, were analyzed. Influences of cultivar, and storage were found for all characteristics of applesauce and frozen apple, except influence of storage on frozen apple color ($-a_L$). USDA grading specification of processed products were reported. Sensory evaluations determined that Golden Delicious, Mutsu, Empires, and Honeycrisp were the most acceptable varieties tested.

Jonagold apples with 9 different maturities were used for a controlled atmosphere(CA) storage study. One-half of the apples for each maturity was sprayed one month pre-harvest with 200 ppm aminoethoxyvinylglycine(AVG). The apples were stored in CA for 6 months before processed into applesauce. The objective measurements were evaluated. Influences of AVG treatment and maturity were detected on all characteristics of applesauce except consistency.

To my parents
Mr. and Mrs. Sunthanont

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisor, Dr. Mark A. Uebersax, for his encouragement, advice, and thoughtful guidance throughout my graduate program. Appreciation is also extended to Dr. Randolph Beaudry, Dr. Jerry Cash, and Dr. Robert Herner, for serving the committee guidance and for critically reviewing the thesis.

I would like to acknowledge Mr. Phil Schwallier from Michigan State University Clarksville Research Station, Clarksville, Michigan for his help with the processing of the research samples.

I would like to thank Mr. Yong-joo Chung, Ms. Stephanie Davis, Ms. Jose Jackson, and Mr. John Roger for apple processing assistance and their encouragement and especially Dr. Yong-soo Chung for his valuable advice. I also would like to thank to all my friends for their support and encouragement.

A very special thank you goes to my dear parents, Mr. Kampol Sunthanont and Mrs. Suchada Sunthanont in Thailand, and my sister, Ms. Korakoch Sunthanont in Wisconsin for their love and support throughout my life.

TABLE OF CONTENTS

	page
LIST OF TABLES	x
LIST OF FIGURES.	xiv
REVIEW OF LITERATURE	
Apple as a food source.	1
Apple varieties.	2
Compositions of apples and their changes due to the ripening processes. . . .	2
Carbohydrates	2
Organic acids	9
Proteins.	9
Minerals and vitamins	10
Pigments.	11
Flavor volatiles.	12
Maturation.	13
Ethylene and apple fruit ripening	14
Ethylene biosynthesis.	15
Control of ethylene.	17
Aminoethoxyvinylglycine (AVG) effects on ethylene biosynthesis.	17
Storage of apples	18
Cold storage	19
Controlled atmosphere (CA) storage	20

Browning reactions	24
Enzymatic browning.	24
Nonenzymatic browning	24
Thermal processing of apples	26
Blanching	26
Apple processing and processed apple products. . .	28
Applesauce and apple puree.	29
Frozen apple slices	32
Individually Quick Frozen (IQF).	34
Processed apple product quality.	34
Color	34
Soluble solids/acid ratio	35
Texture/consistency	36
Sensory evaluation.	37
STUDY I: ASSESSING THE COMMERCIAL PROCESSING POTENTIAL OF NEW CULTIVARS AND ADVANCED SELECTIONS OF APPLES SUITABLE FOR THE STATE OF MICHIGAN	
INTRODUCTION.	40
MATERIALS AND METHODS	
Sources of Materials and Sample Preparations. . .	43
Apples	43
Experimental conditions.	43
Apple processing	44
Adult applesauce.	44
Frozen apple Slices	45
Product Quality Evaluations	47

Adult applesauces	47
Chemical-physical analyses (objective measurements)	47
Soluble solids.	47
Acidity/pH.	47
Color	49
Consistency	51
Subjective measurements.	51
Sensory evaluations	52
Triangle test	52
Scaling tests	53
Acceptance tests.	56
Frozen apple slices	56
Chemical-physical analyses (objective measurements)	56
Soluble solids.	58
Acidity/pH.	58
Shear resistance.	58
Drained weight.	58
Color	60
Subjective measurements.	60
Statistical Analyses	60
RESULTS AND DISCUSSION	
Chemical-physical processing quality (objective measurements) of apple processed products.	63
Adult applesauce.	63

Frozen apple Slices.	75
Subjective measurements	90
Adult applesauces.	93
Frozen apple slices	97
Sensory evaluations of adult applesauces.	102
Triangle test.	102
Scaling tests.	102
Acceptance tests	109
SUMMARY AND CONCLUSIONS.	120
STUDY II: ASSESSING THE INFLUENCE OF AMINOETHOXYVINYL- GLYCINE (AVG) ON PROCESSING QUALITY OF ADULT APPLESAUCE FROM CONTROLLED ATMOSPHERE STORAGE	
INTRODUCTION	124
MATERIALS AND METHODS	
Sources of Materials and Sample Preparations.	126
Apples	126
Experimental conditions.	126
Apple processing	127
Product Quality Evaluations	127
Statistical Analyses.	127
RESULTS AND DISCUSSION	
Chemical-physical processing quality (objective measurements) of apple processed products	129
SUMMARY AND CONCLUSIONS.	147
APPENDIX I	
Apple production by cultivar in the United States (1986-1987).	149

Commercial U.S. production by cultivars.	150
Production figures for 1992-1993 from USDA figures and estimates.	151
Top 10 states by apple production.	152
Analysis of major sources of supply and major uses of apples by country and region, 1989-1990.	153
Importance of various quality factors to different processed products	155
APPENDIX II	
Fresh maturity test for selected apples.	156
Comparison of yield of applesauces processed from traditional, recent, and new varieties.	157
Comparison of yield of frozen apple slices processed from traditional, recent, and new varieties.	158
Comparison of yield of apple puree processed from traditional, recent, and new varieties (control, 2 month storage) . . .	159
Flow diagram for baby puree process.	160
Chemical-physical processing qualities (Objective measurement) of baby apple puree processed from traditional, recent, and new varieties (control vs 2 month storage) . .	161
USDA grading specification of adult applesauce	163
USDA grading specification of frozen apple slices	164
Approval for human subject application from University Committee on Research Involving Human Subjects (UCRIHS).	165
Fresh maturity test for Jonagold apples on sequential harvest dates (UTC vs AVG)	166
LIST OF REFERENCES.	167

LIST OF TABLES

Table	page
1. Comparison of specific characteristics of superior commercial U.S. apple cultivars and their characteristics	3
2. Assumed score range for each chemical-physical characteristic of processed applesauce.	62
3. Assumed score range for each chemical-physical characteristic of processed frozen apple slices	62
4. Comparison of sugar/acid ratio mean values of applesauces processed from traditional, recent, and new varieties	64
5. Comparison of consistency mean values of applesauces processed from traditional, recent, and new varieties	66
6. Comparison of lightness (L) mean values of applesauces processed from traditional, recent, and new varieties	68
7. Comparison of greenness ($-a_L$) mean values of applesauces processed from traditional, recent, and new varieties	70
8. Comparison of yellowness (b_L) mean values of applesauces processed from traditional, recent, and new varieties	72
9. Descending order for sugar/acid ratios and consistencies of applesauce processed from 15 apple selection.	73
10. Descending order for lightness (L), greenness ($-a_L$) and yellowness (b_L) values of applesauces processed from 15 apple selection	74

11. Analysis of variance for chemical-physical processing quality of applesauce from 15 apple selections.	76
12. Comparison of sugar/acid ratio mean values of frozen apple slices processed from traditional, recent, and new varieties	77
13. Comparison of shear resistance mean values of frozen apple slices from traditional, recent, and new varieties	79
14. Comparison of drained weight mean values of frozen apple slices processed from traditional, recent, and new varieties	81
15. Comparison of lightness (L) mean values of frozen apple slices processed from traditional, recent, and new varieties.	83
16. Comparison of greenness ($-a_L$) mean values of frozen apple slices from traditional, recent, and new varieties	85
17. Comparison of yellowness (b_L) mean values of frozen apple slices processed from traditional, recent, and new varieties	87
18. Descending order for sugar/acid ratios, shear resistance, and drained weights of frozen apple slices processed from 14 apple selection	88
19. Descending order for lightness (L), greenness ($-a_L$) and yellowness values of frozen apple slices processed from 14 apple selection.	89
20. Analysis of variance for chemical-physical processing quality of frozen apple slices from 14 apple selections.	91
21. Comparison of quality evaluations of applesauces using subjective measurements	92
22. Comparison of quality evaluation of applesauces using subjective measurements	94
23. Comparison of quality evaluation of frozen apple slices using subjective measurements.	95
24. Comparison of quality evaluation of frozen apple slices using subjective measurements.	96

25. Descending rank order for quality score of applesauces and frozen apple slices processed from 15 apple selections after fresh harvest and after 2 month storage	99
26. Comparison of detectable differences of applesauce between control and two month storage from traditional, recent, new varieties in triangle	103
27. Comparison of color perception mean values for applesauce sensory evaluation from traditional, recent, and new varieties in scaling tests	104
28. Comparison of flavor perception mean values for applesauce sensory evaluation from traditional, recent, and new varieties in scaling tests	106
29. Comparison of texture perception mean values for applesauce sensory evaluation from traditional, recent, and new varieties in scaling tests.	107
30. Analysis of variance for sensory evaluation (scaling tests) of applesauces from 15 apple selections.	108
31. Comparison of color perception mean values for applesauce sensory evaluation from traditional, recent, and new varieties in acceptance tests	110
32. Comparison of texture perception mean values for applesauce sensory evaluation from traditional, recent, and new varieties in acceptance tests	111
33. Comparison of sweetness perception mean values for applesauce sensory valuation from traditional, recent, and new varieties in acceptance tests	112
34. Comparison of general acceptance mean values for applesauce sensory evaluation from traditional, recent, and new varieties in acceptance tests	113
35. Analysis of variance for sensory evaluation (acceptance tests) of applesauces from 15 apple selections.	114

36. Comparison of sugar/acid ratio mean values for applesauces processed from Jonagold apples on different harvest dates (AVG vs UTC). . .	130
37. Comparison of consistency mean values for applesauces processed from Jonagold apples on different harvest date (AVG vs UTC).	135
38. Comparison of lightness (L) mean values for applesauces processed from Jonagold apples on different harvest date (AVG vs UTC).	136
39. Comparison of greenness ($-a_L$) mean values for applesauces processed from Jonagold apples on different harvest date (AVG vs UTC)	138
40. Comparison of yellowness (b_L) mean values for applesauces processed from Jonagold apples on different harvest date (AVG vs UTC).	142
41. Analysis of variance for chemical-physical processing quality of applesauces processed from Jonagold apples (control vs AVG)	144

LIST OF FIGURES

Figure	page
1. Ethylene synthesis path way	16
2. Mechanism of ethylene action	23
3. Formation path way of melanin pigments.	25
4. Decomposition pathways of amadori compounds to produce melanoidin pigments.	27
5. Flow diagram for adult applesauce process	46
6. Flow diagram for frozen apple slices.	48
7. Score sheet for applesauce sensory evaluations used triangle test.	54
8. Score sheet for applesauce sensory evaluations used scaling test	55
9. Score sheet for applesauce sensory evaluations used acceptance test.	57
10. Standard shear compression cell (CS-1) with 10 multiple blades.	59
11. Color quality of applesauces processed from fresh harvest apples	100
12. Color quality of applesauces processed from 2-month stored apples.	101
13. Comparison of color preference score means values (scale from 1 to 9) for applesauce from 15 apple selections processed after fresh harvest in acceptance tests	115
14. Comparison of texture preference score means values (scale from 1 to 9) for applesauce from 15 apple selections processed after fresh harvest in acceptance tests	116

15. Comparison of sweetness preference score means values (scale from 1 to 9) for applesauce from 15 apple selections processed after fresh harvest in acceptance tests	117
16. Comparison of general acceptance score means values (scale from 1 to 9) for applesauce from 15 apple selections processed after fresh harvest in acceptance tests	118
17. Comparison for sugar/acid ratios of UTC and AVG applesauces on different harvest dates.	131
18. Linear relationship between sugar content (°Brix) of fresh apples and sugar/acid ratio of applesauces processed from untreated control apples and AVG treated apples	132
19. Comparison for total acidity between applesauces processed from untreated control and AVG treated apples.	134
20. Linear relationship between %red of surface color of fresh apples and greenness value of applesauces processed from UTC and AVG apples . . .	139
21. Comparison for total greenness value ($-a_L$) between applesauces processed from untreated control and AVG treated apples.	140
22. Comparison for yellowness value (b_L) between applesauces processed from untreated control and AVG treated apples.	143

REVIEW OF LITERATURE

APPLE AS A FOOD RESOURCE

Most of the world's supply of apples come from the temperate zone of the Northern and Southern hemispheres between latitudes 40° and 50° north in Europe and North America, between 30° and 40° north in Asia and between 20° and 40° south in the southern hemisphere. The European continent has been the dominant supplier of apples. The outlook for production in the 1990s reflected a stagnation of European apple production, while growth was expected in the US., Mexico, selected countries of south and east Asia, and among leading producers in the Southern hemisphere such as Chile, Brazil, South Africa, Australia, and New Zealand (O'Rourke, 1994). Apples have been a popular fruit from the earliest times, especially for fresh consumption, and no other fruit can be used in as many ways as apples. Fresh apples are considered a food of moderate energy value, comparable in this respect to many other fruits. Processed apple products are either comparable to fresh apples in energy value or higher because of concentration (dehydration) or the addition of sugars during processing (Lee and Mattick, 1989).

Apple Varieties

There are hundreds of apple cultivars, many of them shown with color plates in *The Apples of New York* (Beach, 1903). Only about twenty cultivars are now grown commercially in the United States. Table 1 presents superior commercial U.S. apple cultivars and their characteristics (Manhart, 1995).

Compositions of Apples and Their Changes due to the Ripening Processes

Carbohydrates

Carbohydrate are the principal food constituents in apple, with starch and sugars the available carbohydrates and pectin, cellulose, and hemicellulose the unavailable fraction (Lal Kaushal and Sharma 1995). Apple fruit cell walls consist mainly of cellulose and pectin, with some hemicellulose and a very small amount of extensin (Knee and Bartley, 1981). Total carbohydrate in fresh apples is approximately 15%. The most common sugars are fructose (3-11.76%), sucrose (0.88-5.62%), and glucose (0.89-5.58%) (Lee and Mattick, 1989).

Immature apples contain a relatively large amount of starch , 3-4%, but as the fruit ripens the starch is converted into sugars remaining very little in quantity (Lee and Mattick, 1989). Starch hydrolysis usually begin in the latter stages of fruits growth but before the onset of climacteric; this contributes to a further increase in free

Table 1. Comparison of specific characteristics of superior commercial apple cultivars in the United States (Way and McLellan, 1989; Manhart, 1995)

Name	Size	Skin color	Flesh color	Texture	Flavor	Storage	Note
Braeburn	medium	red blush over green	greenish to white	firm, slightly coarse	high	up to 5 months at 0 °C	superior for all uses
Cortland	medium	red stripes over yellow green	white	coarse, juicy	sweet tart but not intense	up to 2 months at 0 °C	good for salad, but makes a poorly color sauce
Cox's Orange	medium	bright orange-red to reddish brown	-	-	high	up to 2-3 months at 0 °C	-
Jonagold	large to very large	pinkish-red blush over yellow	light yellow	-	sweet-tart	medium to short	-
Empire	medium to small	-	-	crisp, breaking	sweet	up to 2-3 months in cold storage	best for fresh, fair for sauce and drying

Table 1. Comparison of specific characteristics of superior commercial apple cultivars in the United States (Way and McLellan, 1989; Manhart, 1995)

Name	Size	Skin color	Flesh color	Texture	Flavor	Storage	Note
Fuji	medium	light pink or purple stripes over green	-	crisp	sweet, appealing if sugar is high enough; otherwise, flat, unappealing	long shelf life at room temperature	good for eating fresh
Golden Delicious	medium to medium -large	golden yellow (often russet due to cool weather)	bright light yellow (resists oxidative browning)	juicy, firm	sweet and sprightly	2-3 months at 0°C	all purposes prefer for processing because the russet makes unpleasant appearance
Stayman	medium to medium -large	light red with darker stripes over yellow-green	yellow to yellow-green	firm, crisp, fairly fine grained	sweet, sprightly	up to 3-5 months at 0°C	a processing apple

Table 1. Comparison of specific characteristics of superior commercial apple cultivars in the United States (Way and McLellan, 1989; Manhart, 1995)

Name	Size	Skin color	Flesh color	Texture	Flavor	Storage	Note
Jonathan	medium	red with yellow-green ground color	white, yellow-white, streaked pink	firm, tender, crisp	tart and aromatic	stored well in CA, can be stored at $\geq 2.2^{\circ}\text{C}$ in regular storage	a multi-purpose apple
McIntosh	medium to medium-large	bright red, striped carmine, often dark purple-red	dull	soft, juicy become so soft after 2 month storage	acidic, perfumey aroma	long in CA, rather short in common storage (0°C)	poor for slice, good for fresh eating, pie, sauce, salad
Rhode Island Greening	medium to large	green, sometimes reddish blush	yellow	firm, juicy	rich, somewhat tart	up to one month at 0°C	a processing apple
Mutsu	large to very large	green, light yellow	-	coarse, firm	balanced of sugar and acid, excellent flavor	long, an out-standing keeper in common storage	all purpose: fresh. juice, sauce, pie

Table 1. Comparison of specific characteristics of superior commercial apple cultivars in the United States (Way and McLellan, 1989; Manhart, 1995)

Name	Size	Skin color	Flesh color	Texture	Flavor	Storage	Note
Northern Spy	medium -large	red and red-stripes over yellow	yellowish, bright	fine, tender, juicy, crisp	sharp, and high, sweet	keep well at 0°C	excellent for slices, sauce, juice, salad but fair for drying
York	medium - large to large	red to pinkish red	yellowish	firm, crisp, slightly coarse	tart-sweet, low volatile	well above average at 0°C	a fresh-eating apple, makes excellent yellow sauce
Winesap	medium to medium -large	glossy red with stripes of purple red over yellow	yellowish white, often with red veins	firm, crisp, coarse	tart	-	desirable for apple juice, a processing cultivar
Idared	medium - large	bright, light red over green	white, or tinged green	fine, crisp	tart, lack of aromatic flavor	long keeper in cold storage, and CA	good for canned, frozen, and dehydrofrozen, but fair for sauce

Table 1. Comparison of specific characteristics of superior commercial apple cultivars in United States (Way and McLellan, 1989; Manhart, 1995)

Name	Size	Skin color	Flesh color	Texture	Flavor	Storage	Note
Newtown	small-medium to medium-large	green	-	-	unusual, piney, delightful	long even under garage condition	all purposes except salad
Gravenstein	medium to large	light green to striped red over yellow	white to ivory	tender, crisp, juicy	appealing tart	-	good for both cooking and fresh eating
Red Delicious	small to large	solid red	white to cream white	firm, starchy from early picking	sweet to rather bland	10 months in CA, 3-5 months in cold storage	good for eating-fresh, dehydrofrozen slices and juice, but not good for sauce
Grainny Smith	medium to medium-large	bright green with brownish-red flush	white, tinged green	firm, juicy	tart at first picked but gain sweetness after storage	4-6 months in cold storage, longer in C.A.	-

sugars (Beruter et al. 1985; Knee et al. 1989). Later, sucrose is slowly hydrolyzed to form more glucose and fructose (Whiting, 1970). Sorbitol dehydrogenase is predominant in more mature apples to allow the utilization of the major translocated carbohydrate, sorbitol, for synthesis of the major accumulated sugar, fructose (Beruter, 1985; Yamaki and Ishikawa, 1986).

Apples, a good source of fiber, with skin contain more than 0.7-0.8% fiber than that in oranges, bananas, apricots, grape fruit, or peaches (Lee and Mattick, 1989).

Pectin consists of two separate polymers, a rhamnogalacturonan and a homogalacturonan, and these are both at least 70% methyl-esterified. The rhamnogalacturonan carries side chains of arabinose and galactose residues and may constitute much of the primary wall matrix; the homogalacturonan may form the middle lamella (Knee and Bartley, 1981).

Cell wall compositional changes during ripening are restricted to the pectic polymers. There is no evidence of changes in the cellulose or hemicellulose (Nelmes and Preston, 1968; Bartley, 1976). Kertesz et al. (1959) reported that a higher cellulose content distinguished firmer apples from soft ones, but that the softening that accompanied ripening could not be accounted for on the basis of changes in the cellulose of the fruit. Wiley and Stembridge (1961) presented evidence that a decrease in starch was associated with softening of apples as they

ripened. The galactose side chains of the rhamnogalacturonan are lost (Knee, 1973) and homogalacturonan is solubilized by removal of calcium ions from the wall into the cell during ripening process (Knee, 1978), allowing softening of the apples.

Organic acid

Organic acids are among the most important constituents in apples. The primary acid in this fruit is malic acid, although others such as citric, lactic, and oxalic are also present. The acidity in the fruit is of interest because it affects eating and cooking quality (Lal Kaushal and Sharma 1995). Malic acid is metabolized to a greater extent than the others and may fall by 50% during the life of the fruit. It is a major substrate of respiration and this accounts for the respiratory quotient of 1.1 or higher (Fidler and North, 1967).

Proteins

Fresh apples with skin contain about 0.19% protein, thus being a poor source of this important nutrient (Lee and Mattick 1989; Lal Kaushal and Sharma 1995). Aspartic and glutamic acid are the predominant amino acids in apples, followed by lysine and leucine (Gebhardt et al. 1982).

Protein synthesis that has been found to increase during the climacteric phase in apples provide the enzymes involved in the ripening processes (Frenkel et al. 1968). This coupled with numerous reports (Looney and Patterson, 1967; Rhodes and Woollorton, 1967; Hartmann, 1963; Dilley,

1962; Hulme and Woollorton, 1962) of increased activity of several enzymes during ripening of climacteric fruits. Ethylene synthesis is dependent on protein synthesis at the early-climacteric stage (Frenkel et al., 1968).

Minerals and vitamins

The vitamin contained highest in apples is vitamin C (ascorbic acid). The average ascorbic acid content is about 5 mg/100 g of apple, depending on cultivar, maturity stage, and growing condition (Gebhardt et al., 1982). It has been shown that the peel contains up to three to five times more vitamin C than the pulp (Young, 1975). Among the popular apple cultivars, McIntosh contains very low amounts of vitamin C (Lee and Mattick, 1989).

The average ash (mineral) content of fresh apples with skin is 0.26%. Potassium constitutes the main portion of the total mineral content of apples, and it accounts for more than 40% of the total ash (Gebhardt et al. 1982). Its content in fresh apples with and without skin is 115 mg/100 g and 113 mg/100 g, respectively. Phosphorus (7 mg/100 g with skin, 7 mg/100 g without skin) and calcium (7 mg/100 g with skin, 4 mg/100 g without skin) are the second and third most prevalent minerals, which are varied within a cultivar from season to season (Gebhardt et al., 1982). Calcium ions may aid the packing of polygalacturonate chains fitting into a microcrystalline structure and neutralizing mutually repulsive charges (Ree, 1972). Processing caused no change in the content of chromium, cobalt, copper, iodine,

magnesium, manganese, molybdenum, or selenium but resulted in an increase in chloride and sodium. This was attributed to dipping of the peeled apples in 3% NaCl to inhibit enzymatic browning (Upshaw et al., 1978).

Pigments

The pigments of apples consist of anthocyanins, chlorophylls and carotenoids. Chlorophyll is held tightly bound to the thylakoid membranes within the chloroplast (Tucker 1993). Anthocyanins are a very diverse range of pigments localized within the vacuole of the plant cell (Timberlake 1981). The main anthocyanin in apples is idaein (cyanidin-3-galactoside) (Timberlake, 1981). Carotenoid pigments are localized within the chloroplast (Tucker 1993). Carotenoids like other photosynthetic higher plant tissues are principally β -carotene, lutein, violaxanthin, neoxanthin and cryptoxanthin (Knee, 1972; Gross et al., 1978).

The regulation of color pigment synthesis pathway during ripening is unclear, but may involve enzymatic and chemical reactions (Tucker 1993). The color changes during ripening of apples depend mainly on the simultaneous disappearance of chlorophylls a and b (Knee, 1972, 1980). 75% of chlorophyll content degraded during ripening of Golden Delicious apple, with fivefold increase in xanthophyll contents (Workman 1963). Among the carotenoids, β -carotene decrease, whereas xanthophylls, particularly

lutein and violaxanthin increase substantially (Knee, 1972; Gross et al., 1978).

Flavor volatiles

Apple flavors depend upon complex mixtures of organic compounds, many of which are synthesized during the climacteric phase. Analysis of the volatiles present in apple indicated at least 230 different compounds (Van Straten 1977). Typical constituent aliphatic esters are butyl ethanoate, 2-methyl butyl ethanoate and hexyl ethanoate (Dimick and Hoskin, 1983). Furthermore, Drawert et al. (1983) also detected 2-freexanol and freexanol of aldehyde and ethyl-2-methyl butyrate as important compounds contributing to apple flavor. The saturated aliphatic esters usually contribute a generic fruity aroma. Other kinds of volatile compound occur in trace amount or in a restricted range of cultivars. 4-methoxy(propenyl benzene) gives a spicy flavor to some apple cultivars (Williams et al., 1977). Terpenoid compounds are represented among apple volatiles by linalool and its epoxide, as well as farnesene (Dimick and Hoskin, 1983). Flath et al. (1967) has reported that acetaldehyde is generated by senescent apples, likewise hexanal and trans-2-hexenal are formed on tissue disruption, these can be dominant compounds giving a green flavor to immature fruits.

MATURATION

Horticultural maturity is "The stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose" (Herner et al. 1984). Physiological maturity is "The stage of development when a plant or plant part will continue ontogeny even if detached" (Herner et al. 1984).

Harvesting at the appropriate maturity is a critical factor in determining quality of the fruits. Wiley and Thompson (1960) have reported that apple maturity at harvest time has an important effect on canned apple slice quality. Color, flavor, and overall canned grade were observed to be improved with increasing apple maturity, but early-harvest apples gave firmer canned slices. Fully mature apples also produce the best-quality sauce (Way and McLellan, 1989). Harvested before optimum maturity, apples are more susceptible to superficial scald, incomplete development, and decreased in storage life. Harvested after optimum maturity, apples may decrease storage life and increase physiological disorders, such as softening, internal breakdown, mealiness, and are more susceptible to bruising and decay. Apples are commonly harvested just as they begin to ripen or in the preclimacteric stage (Knee, 1993). Predicting harvest date is not only important for quality of the fruits but it is useful in scheduling harvest of processed crops. This allows an even flow of produce through the processing plant which helps increase efficiency.

Indices of harvest maturity of apples are based largely on color (external and internal), flesh firmness, composition (starch, sugar, and acid), mechanical properties (rupture force, modules of elasticity), ease of separation from spurs, and days from full bloom to harvest (Salunkhe and Desai 1984). Measurement of fruit firmness, respiration rate, ethylene production, starch hydrolysis, soluble solids, titratable acidity, color of skin, and cortical tissue are included to monitor the changes in fruit maturity (Fidler 1973). The sorbitol/total sugar ratio, or fructose/glucose ratio has been used to detect the adulteration (Lee and Mattick, 1989). However, the most reliable index of harvest maturity for several cultivars is a standard calendar date, i.e., the number of days from full bloom (DAFB) to harvest (Salunkhe and Desai 1984; Mitra 1991)

Ethylene and Apple Fruit Ripening

Ethylene is a natural product of plant metabolism and is produced by all tissues of higher plants and by some microorganisms. Because of its marked effect on growth and ripening, ethylene is considered to be a plant growth hormone (Pratt and Goeschl, 1969).

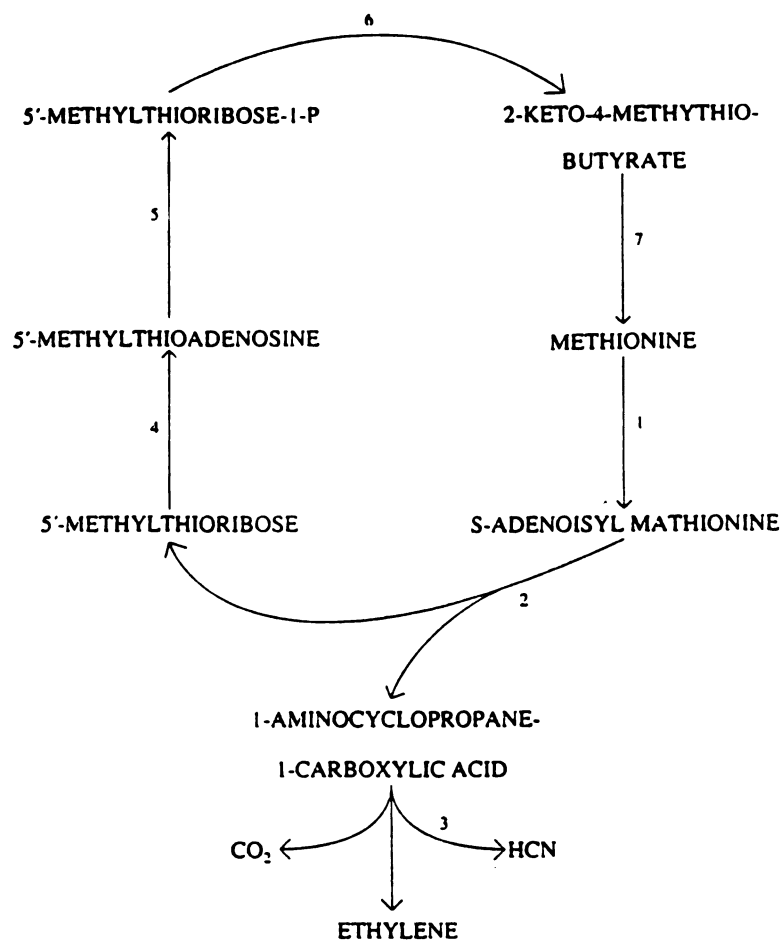
Fruits can be divided into climacteric and nonclimacteric types. Climacteric fruits are those in which ripening is associated with a distinct increase in respiration and ethylene production such as apples, bananas,

avocados, pears, mango, fig, and tomato. In nonclimacteric fruits such as oranges, lemon, strawberry, cherry, pineapple, grape, ripening is protracted and the attainment of the ripe stage is not associated with a marked increase in respiration or ethylene production (Hultin and Milner 1978).

It is the effect of ethylene as a self-generating regulator that is important in post-harvest handling of fruit, particularly the fleshy fruits such as apples. A very small quantity of ethylene within the tissues of the fruit is required to bring about the ripening response, probably 1.0 ppm or less (pratt and Goeschl, 1969). The ethylene is produced in sufficiently high concentrations during the preclimacteric stage to induce the rise in respiration and the ripening process (McGlasson 1970; Pratt and Goeschl et al. 1969; Burg and Burg et al. 1965). It has been reported that Ethylene stimulates the synthesis of protein which is necessary for the ripening process (Ness et al. 1980; Frenkel et al., 1968).

Ethylene biosynthesis

Methionine is the principal substrate for ethylene production and a cycle for the synthesis of methionine and its conversion to ethylene has been described (Yang and Hoffman et al. 1984; Yang 1975; Beyer 1985). Figure 1 shows ethylene synthesis path way by Adams and Yang (1979). The conversion of ACC to ethylene has been reported to be oxygen



- 1 Methionine adenosyl transferase (EC 2.5.1.6)
- 2 ACC synthase (EC 4.4.1.14)
- 3 ACC oxidase
- 4 5'-methylthioadenosine nucleosidase
- 5 5'-methylthioribose kinase (EC 2.7.1.100)
- 6 This step is catalysed by at least three enzymes.
- 7 This step represents a transamination reaction with glutamine as the most efficient amino donor.

Figure 1. Ethylene synthesis pathway (Adams and Yang, 1979)

dependent (Adams and Yang, 1979) and heat sensitive process (Field, 1981; Yu et al., 1980).

Control of Ethylene

The two key control enzymes for the biosynthesis of ethylene are aminocyclopropane carboxylic acid (ACC) synthase and the ethylene forming enzyme or ACC oxidase (Tucker 1993). The levels of ACC are low in green fruit and accumulate rapidly and coincident with ethylene synthesis (Hoffman and Yang 1980). In post-climacteric fruit, levels of ACC remain high while ethylene production declines (Hoffman and Yang 1980). These incidents could indicate roles of ACC synthase and ACC oxidase, respectively (Tucker 1993).

Aminoethoxyvinylglycine (AVG) effects on ethylene biosynthesis

A number of papers have shown that AVG [$\text{NH}_2\text{-CH}_2\text{-CH}_2\text{-O-CH:CH-CH(NH}_2\text{)-COOH}$], a derivative of the antibiotic rhizobitoxine, inhibited ethylene biosynthesis, resulting in delaying of ripening, respiration, and pre-harvest drop in apples (Bufler et al. 1984; Child et al. 1984; Bramlage et al. 1980; Ness et al. 1980; Bangerth et al. 1978; Liebermann et al. 1974). Adams and Yang et al. (1979) have reported that AVG, a potent inhibitor that blocks conversion of methionine to ethylene, inhibited the conversion of S-adenosylmethionine (SAM) to 1-Aminocyclopropanecarboxylic acid (ACC). The soluble and strongly enzyme that can be

inhibited by AVG was ACC synthase (Boller et al. 1979). Additional studies suggested that AVG may interfere with other pyridoxal phosphate-dependent reactions (Giovannelli et al. 1971; Owens et al. 1971). It may also inhibit tRNA charging, suppressing protein synthesis in plant tissue which is necessary for the ripening of harvested fruits (Ness et al. 1980; Anderson et al. 1978). The application of AVG in reducing ethylene production could be a pre-harvest spray or as a post-harvest dip (Child et al. 1984). Bramlage et al. (1980) observed that preharvest spray of AVG at 500 ppm delayed ripening and ethylene production in McIntosh apples (after 30 days, ethylene was 10% of that in untreated controls) and inhibited ripening. The effective use of AVG is dependent on cultivars, time of application, and stage of maturity (Child et al. 1984). The greater benefit of AVG toward less mature fruits has been reported, where the strongest inhibition of ethylene production is in green stage (Baker et al. 1978).

Inhibition of ethylene forming enzyme or ACC oxidase was discussed later in controlled-atmosphere storage.

Storage of Apples

Apples for processing are rarely utilized immediately following removal from the tree for many reasons: the wish to permit further ripening of the fruit to make them more suitable for manufacturing of a particular finished product, the necessity of using up previously harvested fruit to

avoid excessive spoilage, or simply the need to lengthen the processing season (Massey, 1989). Shelf life of a fruit during storage is dependent on its initial quality, its storage stability, the external conditions, and the handling methods (Shewfelt, 1986). The practical storage situations benefits can be obtained by maintaining ethylene at low levels in produce (Hultin and Milner 1978).

Cold storage

The most frequently utilized holding environment for intermediate to long-term holding of apples is low-temperature refrigerated storage (Patchen, 1971). For optimum benefits for CA storage, the fruit should be harvested very early, often 2-3 weeks before conventional harvest dates for ordinary cold storage (Massey 1989). Apple fruit tissue showed increases or decreases of at least 30% for divergencies of 5°C (41°F) from the reference temperature of 20°C (68°F) (Burg and Thimann 1959). The mean percentage increase for a rise in temperature from 38°F -45°F (3.3-7.2 °C) was 40% for CO₂ output and 60% for O₂ uptake, for apples in air. However, Cox's Orange Pippin, Tydeman's Late Orange, and Blenheim Orange apples were susceptible to low temperature injury, the rates of CO₂ output and O₂ uptake, at temperature below 2.8-3.3°C (37-38°F), increased with time and with onset of injury (Fidler and North 1967). Additionally, heating Spartan and Golden

Delicious apples to 38°C (100.4°F) for 4-6 days after harvest maintained fruit firmness in storage but also significantly decreased titratable acidity (Lidster, 1979). Increased firmness resulting from heat treatments was associated with a decrease in pectin solubility and esterification (Van Buren, 1967; Hoogzand and Doesburg, 1961).

Controlled atmosphere (CA) storage

Controlled-atmosphere (CA) storage is a system for holding produce in an atmosphere that differs substantially from normal air in respect to the proportion of nitrogen (N₂), oxygen (O₂), or carbon dioxide (CO₂) (Ryall and Lipton, 1972). The principle of using a CA storage, most effective means of extending storage life, is to slow down respiration, therefore extending the shelf life of respiring fruits (Dalrymple, 1967). A typical storage atmosphere could be composed of 3% O₂ and 3-5% CO₂ at 0 °C (Blanpied and Smock 1983; Meheriuk 1985; Patchen 1971; Ryall and Penzer 1981; Smock and Neubert 1950). The combination of 1.25% O₂ and 0.75% CO₂ for CA storage of apples has been reported by Hutin and Milner 1978). Effectiveness of CA storage varies considerably with cultivar (Meheriuk 1985).

The effects of O₂ and CO₂ are basic factors in which a lower concentration of O₂ limits the oxidation process of respiration and CO₂ and also plays a role in carboxylation and decarboxylation activities. With reduced respiration rates, the energy available for the ripening process is

limited (Ryall and Pentzer 1974). The benefits of low O₂ storage on fruit firmness and titratable acids, depended on fruit maturity, have been confirmed for Turley (Workman 1963), Delicious (Anderson 1967; Lau and Looney 1982), Cox's Orange Pippin' (North et al. 1976), and McIntosh (Sharples et al. 1978; Lidster et al. 1980; Lau et al. 1986). Lowering O₂ and elevated CO₂ reduce respiration rate of fresh fruits and vegetables (Kader 1986). Shipway and Bramlage (1973) found that CO₂ levels above 6% simulated malate oxidation and suppressed oxidation of citrate, α -ketoglutarate, succinate, fumarate, and pyruvate in mitochondria isolated from apples.

The conversion of ACC, as an intermediate in ethylene synthesis cycle, to ethylene is oxygen-dependent (Yang and Hoffman 1984). Low oxygen concentration has been found to inhibit the final step in the ethylene synthesis pathway (Reid 1992). Fidler and North (1967); and Smock (1942) agreed that the effect of very low O₂ storage would be additional to the inhibitory effects on C₂H₄ production and fruit respiration. Reduced O₂ levels below 8% decrease ethylene production by fresh fruits and vegetables and reduce their sensitivity to ethylene (Kader 1986). Burg and Burg (1967; 1969) confirmed that O₂ is required for ethylene production and action. At 2.5% O₂, ethylene production was halved and fruit ripening was retarded. At 3%O₂, the binding of ethylene was reduced to about 50% of that in air (Burg and Burg 1967).

Figure 2 shows the mechanism of ethylene action. The produced ethylene binds to a protein, called binding site, passing through protein synthesis process. The formed proteins are enzymes that cause the actual ethylene response (Reid 1992).

A number of studies reported the means that try to minimize ethylene response by lowering ethylene concentration in CA storage system. Forsyth et al. (1969), Loughheed et al. (1973) and Liu (1979) concluded that removal of C_2H_4 from CA storage retained fruit firmness in McIntosh apples in conventional atmosphere. Scrubbing C_2H_4 (0.304 ml/l) from conventional CA atmosphere (5.0% CO_2 + 3.0% O_2) resulted in significantly firmer fruit than in storages which had no C_2H_4 removal or high C_2H_4 levels (Lidster et al. 1983). Potassium permanganate delayed ethylene accumulation in the storage atmosphere for 40 days with Golden Delicious and 200 days with Bramley's seedling apples stored at 4 °C in 5% CO_2 and 3% O_2 . Knee and Hatfield (1981) found that removal of ethylene retarded softening.

Subatmospheric pressure, a form of controlled atmosphere with reduced atmospheric pressure, at 1% level significantly extended storage life of both Red Kink apples for 3.5 months and Golden Delicious apples for 2.5 months based on delayed losses of sugars and decreases in titratable acidity (Salunkhe and Wu 1973). Jonathan apples stored best at 0.13 atm (Kim et al. 1969). The effects of

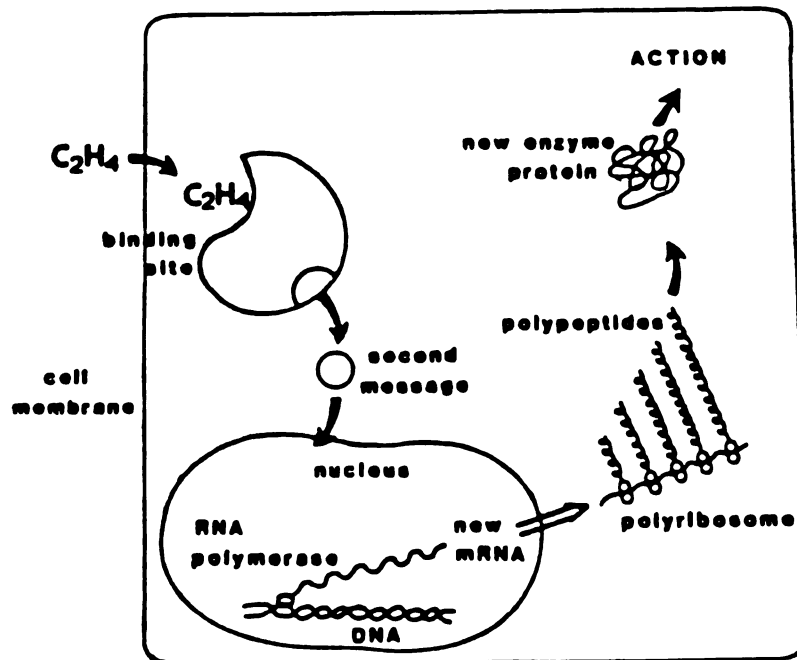


Figure 2. Mechanism of ethylene action (Reid, 1992)

hypobaric (low-pressure) storage on horticultural crops were summarized (Lougheed et al. 1978; Jamison 1980).

CA storage gave the most striking results with apples such as McIntosh, Newtown, and Cortland, which do not keep well at $-1.1-0^{\circ}\text{C}$ ($30.0-32^{\circ}\text{F}$). However it is also used for other apples that do keep well at -1.1°C (30.0°F), such as Delicious, Golden Delicious, Rome Beauty, and stayman, to extend the storage life (Lutz and Hardenberg, 1968).

Browning Reactions

Enzymatic browning

The oxidative, or enzymatic, browning is a reaction between oxygen and a phenolic substrate catalyzed by polyphenol oxidase (Whistler and Daniel 1985). Exposure of the cut surface to air results in rapid browning due to the enzymic oxidation of phenols to orthoquinones, which in turn rapidly polymerize to form brown pigments or melanins (Richardson and Hyslop 1985). Figure 3 shows the formation path way of melanin pigments resulting from the oxidation of tyrosine, a major substrate, by phenolase (Richardson and Hyslop 1985).

Nonenzymatic browning

Nonoxidative, or nonenzymatic, browning includes caramelization and Maillard reaction. Caramelization is a complex group of reactions occurs by direct heating of carbohydrates, particularly sugars and sugar syrups (Whistler and Daniel 1985). Maillard reaction requires the

**Figure 3. Formation pathway of melanin pigments resulting from the oxidation of tyrosine by phenolase.
(Lerner and Fitzpatrick, 1950)**

presence of an amino-bearing compound (usually a protein), a reducing sugar, and some water for minimum reactants. Figure 4 shows decomposition pathways of amadori compounds to produce melanoidin pigments, colloidal and insoluble compounds in Maillard reaction (Whistler and Daniel 1985). Maillard browning can be inhibited by decreasing moisture to very low levels, lowering pH, or lowering temperature (Whistler and Daniel 1985).

Thermal Processing of Apples

An efficient thermal process could be used to inactivate enzymes without the use of enzyme inhibitor such as SO₂. Control of thermal softening in the apple tissue is vital to produce a good quality product. The effect of heating on fruits have been reviewed by Holdsworth (1979).

Blanching

Blanching is a kind of pasteurization generally applied to fruits and vegetables primarily to inactivate natural food enzymes, such as lipase, phenolase, lipoxygenase, chlorophyllase, catalase, peroxidase, and ascorbic acidoxidase, which cause undesirable flavor, color, and aroma changes in the finished product during storage (Potter, 1986; Foley and Buckley, 1977). Blanching is regarded as adequate when the relatively heat resistant enzyme, peroxidase, is no longer active (Richardson and Hyslop 1985). Blanching is essential for vegetables that are to be frozen because freezing process only slows enzyme

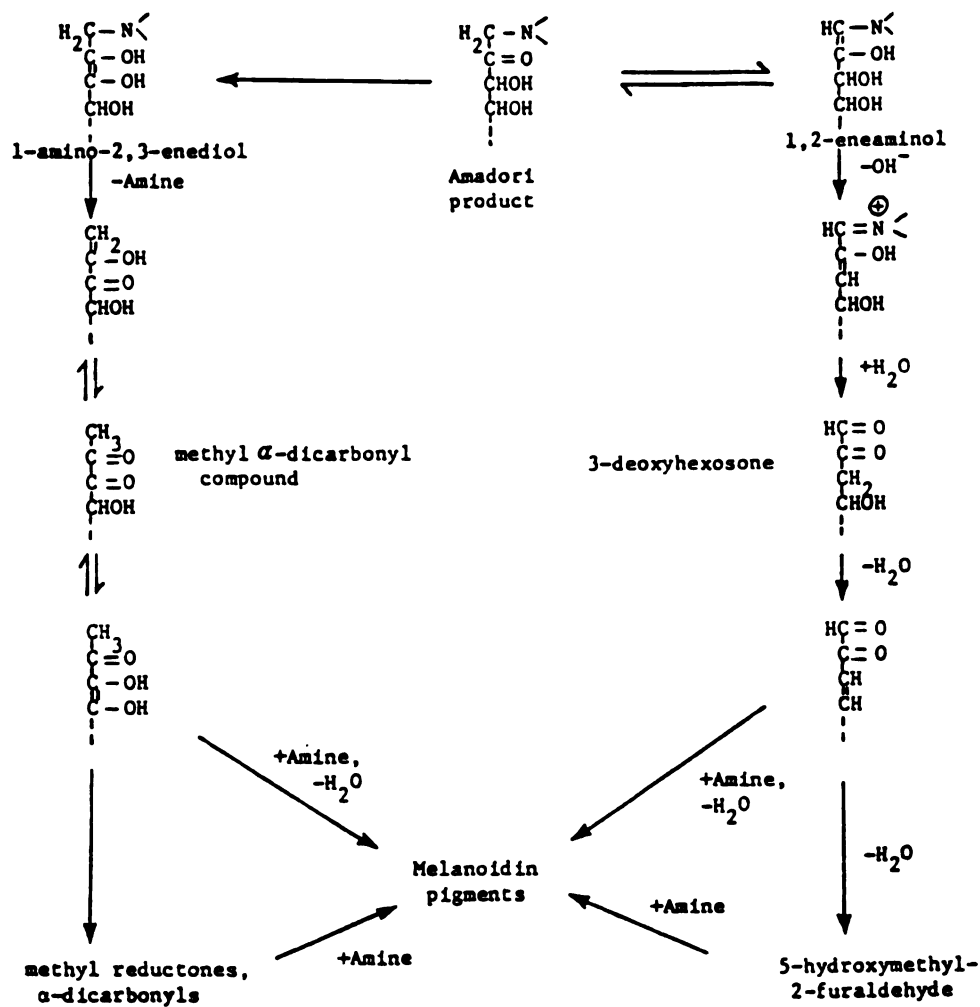


Figure 4. Decomposition pathways of amadori compounds to produce melanoidin pigments (Whistler and Daniel, 1985)

activities (Potter, 1986). However, blanching leads to the most important nutrient (Tannenbaum and Young 1985; Foley and Buckley, 1977) and flavor losses (Foley and Buckley, 1977). Surveys of individual unit operations indicated that blanching contributed significantly to overall plant effluent. In most cases over 50% of the plant biochemical oxygen demand (BOD) was due to blanching and cooling (Lee, 1975). It has been reported that the leaching of valuable soluble material during the prolonged stay in heated water can be inhibited by the application of short-high steam treatments or saturated blanching water (Steinbuch, 1976). High temperature blanching also effects texture changes of frozen fruits and vegetables. However, it has been reported that the LT-LT (Low Temperature Long Time) blanching can maintain desired texture of frozen vegetables (Steinbuch, 1976). Van Buren et al. (1960) reported a relationship between the blanching conditions and the firmness of canned vegetables. The firming effects of LT-LT blanching is considered to be related to activation of pectinesterase.

APPLE PROCESSINGS AND PROCESSED APPLE PRODUCTS EVALUATIONS

The era of most rapid growth in apple processing in the United States was the period from the end of World War II in 1945 to the early 1970s. An increasing number of women were working outside the home. House wives were finding many more valuable uses of their time than cooking or preparing popular foods such as apple juice, applesauce, or apple

pies. Processors rushed to meet consumers' needs for familiar products minus the drudgery of cleaning, preparation, or cooking (O' Rourke, 1994). Processing quality can be affected by decay, damage, maturity, firmness, color, soluble solids, acids, and other chemical compounds such as tannins contained in the fruit (Downing, 1989).

Americans consume an average of 47 lb per capita of apples and apple products per year. Over 27 lb of apples per capita are processed apple products (Diane, 1996). Apples may be grown especially for processing, a practice common among orchards in the eastern United States, but most apples sold to the processor are redeemed from fruit grown for the fresh market (Childers, 1983). Canned applesauce rank the second to apple juice in importance processed apple products. Of the processing apples, an average of 75% are used for applesauce (Root, 1996). Refrigerated, frozen, or dehydrofrozen apple slices represents about 15% of the apple processed (Root 1996).

Applesauce and Apple Puree

Quality attributes in raw apples that produce a high-quality finished product are described by LaBelle (1981). The quality of canned applesauce has been shown to be affected by the varietal characteristics, maturity of the fresh apples, postharvest storage conditions, and storage temperatures of the canned product (LaBelle et al., 1960,

1961; Smock and Neubert, 1950; Wiley and Toldby, 1960; Luh and Kamber, 1963). Desirable characteristics in apples for applesauce include high-sugar solids (usually 11-24 °Brix); high-acid, aromatic, bright golden or white flesh; variable grain or texture; and sufficient water-holding capacity (Root 1996). The brix/acid ratio normally ranges from 25 to 60 (Way and McLellan, 1989). Acid and Tannins, which are responsible for astringency in taste, decreased in the sauce with increased maturation, while sugars and volatile reducing substances increased (Lee, 1965). Desirable characteristics in apples for applesauce and puree include high soluble solid content, high acid, aromatic, bright golden or white flesh, variable grain or texture, and sufficient water-holding capacity (Diane 1996). Water-holding capacity is the single most important yield characteristic for the sauce (LaBelle et al., 1961). It is desirable to combine different varieties of apple for sauce manufacture so that the resulting product is well balanced in acidity and flavor quality. A typical apple blend for applesauce might be primarily York (more than 50%), with Golden Delicious and Rome each contributing a lesser percentage (Way and McLellan, 1989).

In traditional applesauce and puree production, selected apples are washed, peeled, diced, then fed into a stainless steel screw-type cooker. Either live steam injected or steam jacketed provides temperature between 93°C

(199°F) and 98°C (208°F) for about 4-5 minutes is used to soften the fruit tissue and inactivate polyphenoloxidase, which is responsible for enzymatic browning. Sodium hydroxide (NaOH) or potassium hydroxide (KOH) chemical peeler can be used instead of automatic peeling and coring machine to reduce trim waste and time consumed (Diane, 1996; Woodroof, 1975). Sugar, either liquid blend or dry, and other desired ingredients are added into the sauce just before cooking. Liquid sugar is preferred because it imparts a desirable sheen to the finished applesauce. Cooked applesauce is finished with 0.065 to 0.125 in. screens, baby puree with fine 0.033 in. screens; the finished product is then preheated to 90°C (194°F) and piston-filled into glass jars or metal cans immediately. For the last step, containers are cooled to an average of 30-40 °C (95-104 °F) to prevent "stacking cooking" in the warehouse (Diane 1996).

There have been many studies to improve quality of the sauce. Sauce color, flavor and grain improved as harvest was delayed to allow the fruit to tree-ripen, particularly if the apples were processed into sauce directly after harvest (LaBelle, 1960). The flavor of canned applesauce can be improved by fortification with apple essence and citric acid (Buck, et al., 1955; Dyrden and Hills, 1957). Daoud and Luh (1971) reported that higher storage temperatures caused faster corrosion of the tin coating and the formation of hydrogen gas in the head space. The

recommended storage temperature for applesauce is 20 °C (68 °F) or lower. Golden Delicious applesauce yield from CA storage (40.6% weight loss) was less than from cold storage (35.8% weight loss), due to longer cooking time (10 minutes and 5 minutes, respectively) to soften the pulp. However, applesauce from CA apples had a superior yellow color than that from cold stored apples (Drake et al. 1979).

Frozen Apple Slices

Quality of raw fruit is the most important factor in determining the quality of the frozen product. It is influenced by varietal characteristics, climate of the growing area, irrigation, cultural practices, and ripeness level at harvest (Diane, 1996). Ripening of firm-ripe fruit was required to improve product flavor, and to a lesser extent, color (Caldwell et al 1955). Important characteristics for apple slices are firmness, color, and integrity of the flesh when diced. Sweetness is less important in making slices than in sauce (Root 1996). It has been shown that texture attribute may account for about one half of an overall slice grade (Wiley and Thompson 1963). An easily peelable shape and small seed pocket will help to minimize residual peel and carpel that are also undesirable and cause for down-grading under the U.S. Standard. Medium-size wedge slices are preferred because large slices tend to be underbalanced (with brown centers) and also to have excessive residual carpel attached

(LaBelle, 1981). The early harvest apples should be ripened 20 days in common storage, or 30-60 days in cold storage. The late harvest apples gave the best product if processed immediately (Wiley and Thompson, 1959). Generally, processors do not mix cultivars in the production of apple slices (Hall, 1989). Shallenberger et al. (1963) reported that more mature fruit yielded firmer slices. The addition of Ca salts improved firmness of canned vegetable products (Durocher and Roskis 1949; Loconti and Kertesz 1941).

In traditional frozen apple slices processing, the dumping, washing, grading, peeling, and coring steps are similar to those used for sauce production. The slicing operation is usually an integral part of the peeling and coring process, where the apples are sliced into twelve to sixteen pieces in the coring section. Apple slices are inspected for defects, and conveyed over a shaker screen to remove small chips. The slices are passed through vacuum impregnation, in which the slices are placed in a vessel that is sealed and a 27- to 28- Hg vacuum is pulled. The vacuum is broken by the injection of water, salt, ascorbic acid, and/or sugar. The apples pass through an IQF (Individually Quick Frozen) unit where the slices are individually frozen. The freezing air forced upwards through a perforated tray fluidizes the product plus acts as freezing medium. The slices are packaged and stored frozen at -17°C (-1°F) or below (Root, 1996).

IQF (Individually Quick Frozen)

IQF is the term that is applied when the freezing process is accomplished rapidly in order to control moisture loss from food products (Singh and Heldman, 1993; Heldman, 1992). Primarily, a form of IQF is obtained using the combination of low-temperature air with high convective heat-transfer coefficient (high air speed) contact directly with a small product leads to short freezing time or rapid freezing (Singh and. Heldman, 1993). Quick frozen food achieves temperature as low as -45°C in 30 minutes or less. The rapid freezing forms only very small ice crystals that do not rupture the cells, reducing tissue damage (Hsu, 1975). The enzyme activity which causes browning and off-flavors is inhibited by quick freezing (Luh et al., 1975).

Processed Apple Product Quality

Color

One of the most critical factors affecting acceptability for consumers is the color of the products. The color of the products mostly relies upon the raw materials, processing operations, and storage conditions. The preferred color for canned applesauce is uniform and bright golden yellow (Root, 1996; USDA, 1974) and that for frozen apples, internally and externally, is a reasonably uniform bright color characteristic of apples of similar varieties (USDA, 1954).

Heat processing, freezing, and thawing lead to cell disintegration, pigment degradation and isomerization of carotenoids (Simpson, 1985). Discoloration of canned applesauce stored at high temperature above 20°C (68°F) could have been caused by Maillard browning (slow chemical reaction between amino acids and reducing sugars); fragmentation of sugars to furfural and other carbonyl compounds, and formation of hydroxymethyl furfural from hexoses and amino-carbonyl reactions; and reaction of the tannins with iron due to severe can corrosion (Luh and Kamber, 1963).

Soluble solids/acid ratio

The common use of soluble solids to define product quality came about in response to the need for a more reliable and meaningful direction. An estimation of percent soluble solids, mostly sugar, is determined as the equivalent °Brix by a representative drop of juice on refractometer (Belle, 1981).

The acidity and pH, as chemical and flavor factors, are frequently used in the processing plant as well as in research to evaluate product flavor. Acidity is of special important to the flavor of processed apple products in that, like sweetness, it remains substantially unchanged during normal canning, freezing, or drying (LaBelle, 1981).

Since acidity is changing in the opposite direction from soluble solids content during maturation, the ratio of the two, variously referred to as "sugar-acid", "Brix-acid",

or "soluble solids-acid", shifts rapidly and is more useful as a guide to determine the optimum maturity, or optimum level for processed products (LaBelle, 1981).

Texture/consistency

Szczesniak (1963) defined the texture for food as " the composite of the structural elements of food and the manner in which it registers with the physiological senses." Kramer (1973) defined it as "... one of the three primary sensory properties of food that relates entirely to the sense of touch or feel and is, therefore, potentially capable of precise measurement objectively by mechanical means in fundamental units of mass or force."

According to Reiner and Scott Blair (1967), consistency is the property of a material by which it resists permanent change of shape, defined by the complete stress-flow curve. Various types of consistometers have been used basically for testing semi-solid foods such as paste, sauce, and puree. Most empirical consistometers fall into two groups: devices which measure distance of spread and devices which measure resistance to a rotating spindle or paddle. The Adams and the Bostwick consistometers are typical of the first group. The Adams consistometer measures the area to which a given quantity of the test material will spread under a certain set of conditions. The Bostwick consistometer, an official National Canners Association device for catsup, measures the distance a given amount of the semi-solid will travel down a

slanted though upon being released from a container (Szczesniak, 1973)

The most common texture measuring instrument for frozen apple slices (solid foods) probably is the Kramer Shear Press (Kramer et al. 1951). The system is driven hydraulically and the force is measured by a force transducer ranging from 0 to 3000 lb capacity. A metal lid containing a set of ten bars that match the bars in the bottom fits over the box (Bourne 1982). The test samples are placed in the standard test cell and covered with the lid. When the ram is activated, the multi-blades are forced down through the box, first "Compressing" and then "Extruding" the material. The moving blades are propelled downward until they pass between the bars on the bottom of the cell.

Sensory evaluation

Sensory evaluation is a scientific discipline used to evoke, measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the sense of sight, smell, taste, touch, and hearing (IFT, 1975). Sensory evaluation involves the measurement and evaluation of the sensory characteristics of foods. It also involves the interpretation of panelists' responses. Sensory evaluation of food can provide data and important information essential to successful marketing of new products (Stone, 1985).

There are two major classifications of sensory tests, analytical test and affective test. The analytical test involves laboratory evaluation of products for differences or similarities and for identification and quantification of sensory characteristics. The affective test evaluates acceptance and preference of products and require a large number of untrained panelists (IFT, 1981).

Most sensory evaluation techniques Use hedonic scaling. The psychological states of like or dislike are measured on a rating scale. Results are interpreted as relating to the sample population's opinion of the product under test. Discussions on the theory and its applications can be found in Moskowitz (1983), Amerine et al.(1965), and Beebe-Center(1932).

Kramer (1955) classified sensory quality under the three major senses: appearance as sensed by the eye, flavor as sensed by the papillae on the tongue and the olfactory epithelium of the nose, and texture as sensed by the nerve endings that is attached to muscle. Sensory descriptors for applesauce chosen by trained panelists fell into five categories: visual attributes, aroma (by smell only), aroma (during tasting of the product), taste, and mouthfeel (McLellan et al., 1984). McLellan and Massey (1984) used three sensory attributes: color, flavor, and texture for sensory study of applesauce.

A Brix/acid ratio of 48.8 was found ideal for consumers (Dryden and Hills, 1957). Using expert applesauce tasters,

the optimal ratio was in the range of 28-45 in still another U.S. study (LaBelle et al., 1960). The preferences change from place to place and time to time, and ideal sensory attribute , such as Brix/acid ratios, must be established for each market.

Sensory evaluations, consumer test, for frozen slices were conducted by Greig et al. (1962) with pie made from frozen slices. However, consumer exhibited no significant preference for any one cultivar.

**STUDY I: ASSESSING THE COMMERCIAL PROCESSING POTENTIAL OF
NEW CULTIVARS AND ADVANCED SELECTIONS OF APPLES
SUITABLE FOR THE STATE OF MICHIGAN**

Introduction

One of the world's most successful apple producers, the United States commercial apple production accounts for one eighth of the current annual world production. Apple production in the United States is primarily in the states of Washington, New York, Michigan, California, and Pennsylvania. These states produce over three-quarters of the total U.S. production. From the USDA estimation for 1993, Michigan is second only to the state of Washington in apple production. (Manhart, 1995).

The development of exceptional apple cultivars and the improvement and enhancement of production methods make Michigan a key participant in the apple industry world wide. The processing quality of Michigan grown apples could be better evaluated if a consistent state-wide process assessment was used to evaluate products over different seasons. To help alleviate this problem, the Michigan apple industry, apple processors, apple grower, and the Michigan State University research program have joined together to established such procedures. There are many fresh market and processing apple varieties grown in Michigan as well as new dual varieties in experimental stages. Common apple

varieties currently grown in Michigan and their acreage are listed below:

<u>Apple varieties</u>	<u>Acres</u>
Red Delicious	14,100
Jonathan	8,150
Golden Delicious	6,090
Rome	5,130
McIntosh	4,680
Idared	4,630
Spy	3,610
Empire	3,330
Gala	990
Winesap	900
Jonagold	820
Mutsu	650
Greening	640
Cortland	520
Spartan	430
Fuji	330
Jonamac	270

(Michigan Fruit Survey - 1995)

LaBelle (1981) described in detail the quality characteristics of raw apples that are necessary for the manufacture of high-quality apple products. He found that processed product quality is affected by the following characteristics of the raw product: ripeness, damage, decay, fruit size, shape, seed pocket size, specific gravity, skin

color, flesh color, firmness, soluble solids, total acid, pH, organic flavor compounds, tannins, tendency to brown by oxidation, and juiciness. The raw-product factors have differing relative influences depending on the types of final processed products used.

Several researchers have sought for innovative alternatives to improve product quality and increase apple yield. Studies have shown that sauce color, flavor and grain improved as harvest was delayed to allow the fruit to tree-ripen, particularly if the apples were processed into sauce directly after harvest (LaBelle, 1960). The flavor of canned applesauce can be improved by fortification with apple essence and citric acid (Buck, et al., 1955; Dyrden and Hills, 1957). Shallenberger et al. (1963) reported that more mature fruit yielded firmer slices. The addition of Ca salts improved firmness of canned vegetable products (Durocher and Roskis 1949; Loconti and Kertesz 1941).

The objectives of this study was to analyze and evaluate the processing qualities of processed products (applesauce, apple puree, and frozen apple slices) of current standard known and new apple varieties both fresh harvest and following common cold storage

MATERIALS AND METHODS

SOURCES OF MATERIALS AND SAMPLE PREPARATIONS

This experiment was conducted to evaluate processing quality of selected apple cultivars, and the influence of storage of fresh apples on their processing quality changes.

Apples

Fifteen apple selections including; Red Delicious, Golden Delicious, McIntosh, Jonathan, Jonagold, Cortland, Honeycrisp, Rome, Gala, Mutsu, Idared, Northern Spy, and Empire (at early, middle, and late harvest season) were delivered from Michigan State University Clarksville Research Station, Clarksville, Michigan. The apples were harvested at defined stage of maturity by hands in the morning to minimize the loss from mechanical damage and water loss, respectively. The apples were loaded into wood crates providing air circulation and immediately transported to Michigan State University, East Lansing, Michigan.

Experimental conditions

Fifteen apple selections were used. One-half of the apple of each selection, approximately 2 bushels, was manufactured into adult applesauce, baby apple puree, and frozen apple slices after fresh harvest. The other half was

manufactured after 2 months of cold air storage at 1.1°C (34°F), 99.8±0.2% relative humidity, in the department of Plant and Soil Science Building, Michigan State University. The apples were stored in the cold storage on the day they were picked.

Apple Processing

The apples were processed under controlled conditions into unsweetened adult applesauce, baby apple puree, and frozen apple slices in Food Processing Center, at the department of Food Science and Human Nutrition, Michigan State University.

First, selectively uniform fruits were separated for frozen apple slices. The rest was divided into two groups, one for applesauce, the other for apple puree. The selected apples were washed using chlorinated water 15.6 °C (60 °F) to remove dirt, debris, and pesticide residues.

Adult applesauce

The prepared apples were peeled, cored and trimmed using peeler and trimmer (model No. 1035, Goodell Co., Antrim, NH) then dipped into 1% NaCl solution to prevent surface discoloration from enzymatic-browning reaction. Then, the apples were sliced into 1/4" width, using a slicer (model No. 101, Qualheim Inc., Racine, WI). The sliced apples were blanched in steam kettles at 98.9 °C (210 °F) for 5 minutes to soften the tissue and inactivate the

enzyme, polyphenoloxidase, which is responsible for enzymatic browning. Cooked apples were passed through a pulper (model No. P56E3050M-FP, Reeves Pulley Co., CO) with a 0.060" screen, removing defects and defining texture. The applesauce was preheated up to 90.6°C (195°F) and consistency of the sauce was adjusted with condensate using Bostwick consistometer until the optimum level was reached (5-7 cm/5 seconds). Applesauce was hot filled into 303 x 406 (16oz) metal cans at 93.3 °C (200 °F). The closure (model No. 5K213BG228 No. YP, General Electric Induction Motor) for metal cans was used followed by cooling cycle. Figure 5 shows flow diagram of adult applesauce process.

Frozen apple slices

Preselected, and washed apples were peeled , cored, and trimmed using peeler and trimmer (model No. 1035, Goodell Co., Antrim, NH). The apples were sliced into twelve, or sixteen pieces depending on their size to achieve approximately 1.6 cm (5/8") wedges. The sliced apples were submerged into chilled water for maximum 3 minutes. After slicing, the apples were inspected for defects such as blossom or calyx, carpel tissue, skin, and bruises. The slices were handled quickly at this point to avoid enzymatic browning. The apple slices were placed in a vessel that was sealed, and a 27- to 28-in. Hg vacuum was held for 15 seconds. The vacuum impregnation was conducted with a solution; containing 1.0% ascorbic acid, 0.5% citric acid, 0.5% NaCl, and 0.3% CaCl₂. The apples were then spread over

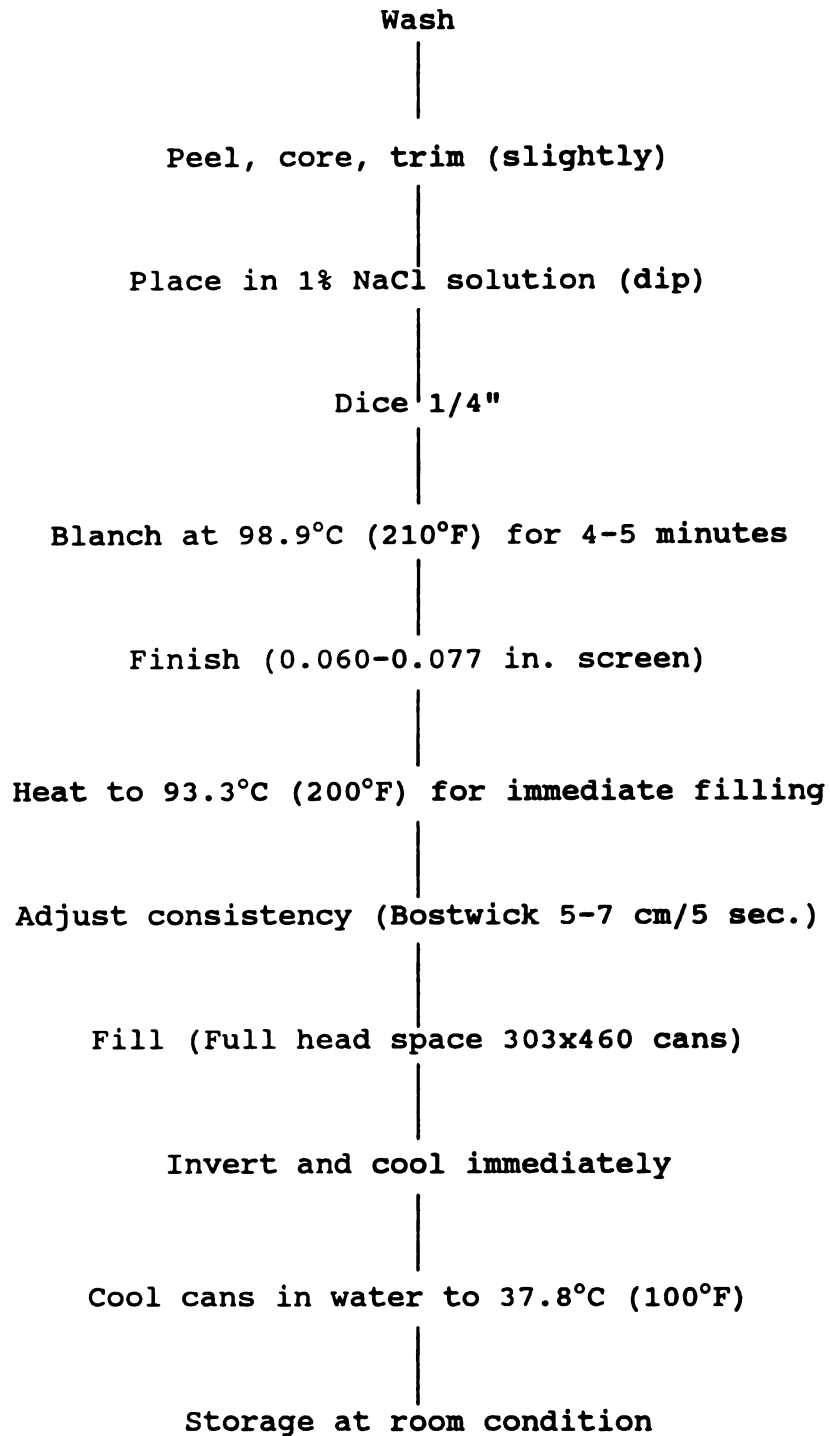


Figure 5. Flow diagram for adult applesauce process

metal screens and stored in freezing room with circulating air flow stimulating IQF (Individually Quick Frozen) unit, where the slices were individually frozen. Finally, the frozen apple slices were packaged in polyethylene sandwich bags and held at -28.9°C (-20°F) until evaluated. Figure 6 shows flow diagram of frozen apple slice process.

PRODUCT QUALITY EVALUATION

Adult Applesauces

Chemical-physical analyses (Objective measurements)

Applesauces were held in 303 x 460 (16oz.) cans and stored at 24°C (75.2°F) prior to analyses. Samples were randomly selected with three replications.

Soluble solids

Soluble solids were measured using refractometer (Baush & Lomb Optical Co., Rochester, NY). One drop of sample juice at approximately 25°C was placed on measuring cell. Refractometric method was prescribed in "Official Methods of the Association of Official Analytical Chemists", 10th edition, page 309. The soluble solid unit was degree brix ($^{\circ}\text{Brix}$).

Acidity/pH

Representative sample (5g @ 25°C) of each selection was diluted with 25 ml deionized water and titrated with 0.10 N NaOH to phenolphthalein end point ($\text{pH} = 8.2$). An automatic

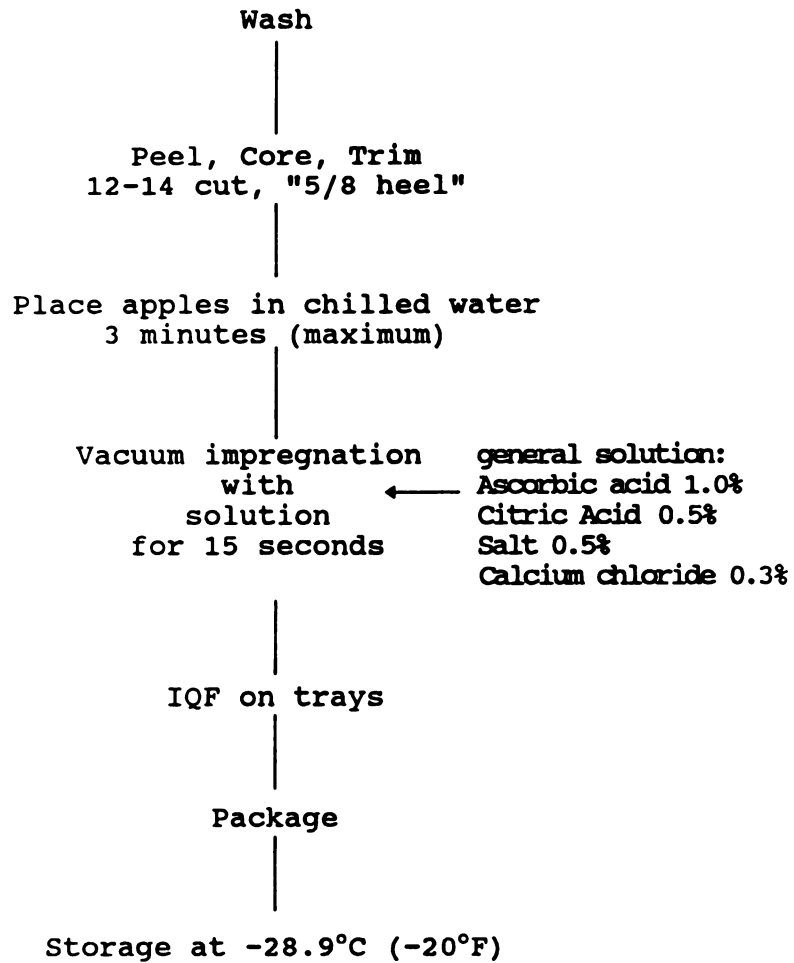


Figure 6. Flow diagram for frozen apple slice process

titrator (Model DL12, Mettler Instrument Co., Hightown, NJ) was used to monitor the end point. Acidity of the sample was calculated in terms of percent concentration of the malic acid, predominant organic acid, occurring in the apple tissue.

$$\% \text{ acidity} = \frac{X \text{ ml} \times 0.1 \text{ meq/ml} \times 67.0 \text{ g/eq} \times 100}{5 \text{ g} \times 1000}$$

Where

X = used ml of 0.10 N NaOH

67.0 = grams of Malic acid per equivalent.

0.1 = concentration of NaOH (N, meq/ml)

Color

The color of product was measured using Hunter Lab Optical sensor (Model D25-PC2Δ, Hunter associates Laboratory, Inc., Reston, Virginia). The color meter measures reflectance on three coordinates labeled L, a_L , and b_L . The L value measures lightness and varies from 100 for perfect white to 0 for black, approximately as the human eye would evaluate it. The a_L value represents redness (positive), gray (zero) and greenness (negative). The b_L value represents yellowness (positive), gray (zero) and blueness (negative). Hue angle was calculated for each sample using the representative L, a_L , and b_L . Step for calculation of hue angle was as followed;

$$Y = L^2 / 100$$

$$X = (a * L + 1.75L^2) / 178.497$$

$$Z = (0.7L^2 - b * L) / 59.270$$

$$L^* = 116 * (Y / 100)^{1/3} - 16$$

$$a^* = 500 * [(X / 98.041)^{1/3} - (Y / 100)^{1/3}]$$

$$b^* = 200 * [(Y / 100)^{1/3} - (Z / 118.103)^{1/3}]$$

$$C^* = (a^{*2} + b^{*2})^{1/2}$$

$$H_a = \text{Arctan} (b^* / a^*)$$

Notes:

L measures lightness and varies from 100 for perfect white to 0 for black, approximately as the human eye would evaluate it.

The chromacity dimensions are represented by a and b which give understandable designation of color as follows:

a measures redness (positive), gray (zero) and greenness (negative). b measures yellowness (positive), gray (zero) and blueness (negative).

L* is the Commission Internationale de l'Eclairage (CIE) 1976 psychometric lightness.

C* is a measure of the CIE 1976 a, b chroma. Chroma is the radius of an arc located on a plane (a*xb* at a height of L*) and expressed as the linear distance between the points A(L*, 0, 0) and B(L*, a*, b*) in a polar coordinate system of (L* a* b*).

H_a is a measure of the CIE 1976 a, b hue angle. Hue angle can be visualized as an angle between the line AB and the a* axis in the above polar coordinate system. The

closer the hue angle is to 90° indicates an increase in yellowness, while the further away it is from 90° indicates an increase in redness.

The Hunter instrument was standardized by a white tile with the coordinate $L = +94.5$, $a_L = -0.6$, and $b_L = +0.4$. Approximately 100 g of sample was placed in an optically pure glass dish, covered to prevent interfering light and readings were recorded.

Consistency

Measurement was measured using USDA flow sheet No.1 (Art and Industrial Lamination Co., Fairfax, VA). Contents of containers were stirred thorough at room temperature, then transferred into plastic cylinder (3-inch inside diameter, $3\frac{1}{4}$ inch high) which was placed exactly over the center of the flow sheet. The cylinder was lifted straight up. The spread of the sauce was recorded after 1 minute by averaging the reading in $\frac{1}{4}$ inch increments at 4 points around the circumference of the plate.

Subjective measurements

The sample preparation for subjective measurements was the same as that for objective measurements. The products were evaluated using the USDA grading specification for applesauces. The considered characteristics included color, consistency, defects, finish, and flavor. Grades of applesauce were divided into U.S. Grade A, U.S. Grade B, and Substandard. USDA grading specification for applesauces (USDA, 1974) is presented in appendix II.

Sensory evaluations

Sensory evaluations were performed for applesauce product. To provide typical consumption, applesauce samples were kept at refrigerated temperature over night (4.4-7.2 °C, 40-45 °F) before conducting the tests. The samples were provided in small white cups with the same amount, and served on a white tray at refrigerated temperature (4.4-7.2 °C, 40-45 °F). All samples were coded with 3-digit random numbers. A complete balanced order of sample presentations were made. The panelists were provided with drinking water to wash their pallet of residual tastes between each sample. This brief instance was also used as rest periods of 30 seconds. The tests were conducted in the morning before lunch time. Three sensory assessment techniques were conducted; including triangle test, scaling test, and acceptance test.

Triangle test

The triangle test (Poste et al., 1991) is use to indicate whether or not a detectable difference exists between two samples. This test was performed to detect significant differences between applesauces processed after fresh harvest and 2 month storage for each variety.

The samples were taken from 15 applesauce samples (13 varieties with 3 different maturities of Empires), of 2 different storage times. One set of harvested apples was stored for 2 months while the other was processed into apple sauce immediately after fresh harvest.

The subjects, untrained panelists, were provided with three coded samples, was told that two of the samples are the same and one was different, and asked to identify the odd samples. The score sheet is presented in Figure 7. To provide controlled conditions, the tests were conducted in separated room. The panelists were seated in fully lighted isolated booths.

Scaling tests

There are two types of scale, structured scale and unstructured scale. The structured, or category, scale provide panelists with an actual scale showing several degrees of intensity or magnitude of a perceived sensory characteristic using number, words, or combination of the two. The detail of structured and unstructured scale has been explained by Poste et al.(1991). This scaling test was performed to detect significant differences between applesauce processed after fresh harvest and 2 month storage for each variety by focusing on specific attributes including color, consistency, and flavor. The samples were the same as those for triangle test.

The subjects were selected from a well-focused group, including professors, and graduate students who were familiar with applesauce processing. The subjects were asked to score the samples at a time based on their sensory perception. The score sheet, 9-point structured scale, is presented in Figure 8. To provide controlled conditions,

Date:

Name:

There are three samples in each of the triangles for you to evaluate. Two samples are duplicates and one is different. Taste the samples in the order indicated and identify the different sample. Circle the number of the different sample.

361

859

427

Figure 7. Score sheet for applesauce sensory evaluations used triangle test

Name:
 Date:
 Sample Code:

Evaluate these samples for physical/sensory character. Indicate the amount of intense in each sample on the scales below.

Color	flavor	Texture
-----not bright	-----extremely undesirable	-----not thick
-----	-----	-----
-----slightly bright	-----slightly undesirable	-----slightly thick
-----	-----	-----
-----moderately bright	-----neither undesirable/desirable	-----moderately thick
-----	-----	-----
-----very bright	-----slightly desirable	-----very thick
-----	-----	-----
-----extremely bright	-----extremely desirable	-----extremely thick

Figure 8. Score sheet for applesauce sensory evaluations used scaling tests

the tests were conducted in separated room. The panelists were seated in fully lighted isolated booths.

Acceptance tests (Hedonic scaling tests)

This is similar to a normal structured scale except that it is not related to any particular physical continuum. Hedonics relates to pleasant and unpleasant state of organism, and in hedonic scaling affective rating of preference or liking and disliking are measured (Piggott, 1988). This test was performed to detect the acceptance among applesauces taken from fifteen samples (13 varieties with 3 different maturities of Empire) which processed after fresh harvest.

The subjects were asked to test the samples through sensory perception using hedonic scale. The score sheet, 9-point structured scale, is presented in Figure 9. To prepare uncontrolled and typically consumed condition, acceptance test was conducted at two different places; in Banquet room of Holiday Inn, Lansing, MI and The Community Center of Spartan Village, Michigan State University.

Frozen Apple Slices

Chemical-physical analyses (Objective measurements)

Frozen apple slices were packaged in polyethylene sandwich bags and stored in freezing room at -28.9°C (-20°F). Before the analyses, frozen apples were thawed at $4.4-7.2^{\circ}\text{C}$ ($40-45^{\circ}\text{F}$) for 2 days. There was an controlled

Michigan Processing Apple Quality Trial 1996-1997
Michigan Food Processors Association

Name (optional): _____ **Age:** _____ **Michigan State University**
Position: _____ **Sex:** _____ **Food Processing Center**

Circle the number that describes your sensory perception
(1=least desirable, 9=most desirable)

Code	Sensory Evaluation			Comment
	Color	Consistency	Sweetness	General Acceptance
	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9
	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9
	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9
	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9

Figure 9. Score sheet for applesauce sensory evaluations used acceptance test

temperature system to keep frozen products temperature approximately 4.4-7.2 °C (40-45 °F) during conducting the analyses. Samples were randomly selected with three replications.

Soluble solid

Soluble solids for frozen apple slices was measured the same manner as that for applesauces.

Acidity/pH

Representative juice of the sample (5g @ 25 °C) selection was used. The acidity/pH for frozen apple slices was measured the same manner as that for applesauce.

Shear resistance

Firmness assessment was proceeded using a Kramer Shear Press (Model TMS-90, Food Technology Corporation, Rockville, Maryland). Thawed and drained samples were placed up to the edge in a Standard Shear-Compression Cell CS-1 (Figure 10 with ten multiple blades). The samples were evenly distributed in the cell and sheared. Results of firmness for the thawed apple slices were presented in N force/100g samples. The firmness was recorded from Kramer Shear resistance as the maximum textural peak force of the thawed apple slices.

Drained weight

After thawing period, thawed apple slices were weighed for the initial weight before draining, and then poured onto a US Standard No. 8 screen (0.24 cm opening). The sample was drained with the screen set at a 15° angle for two

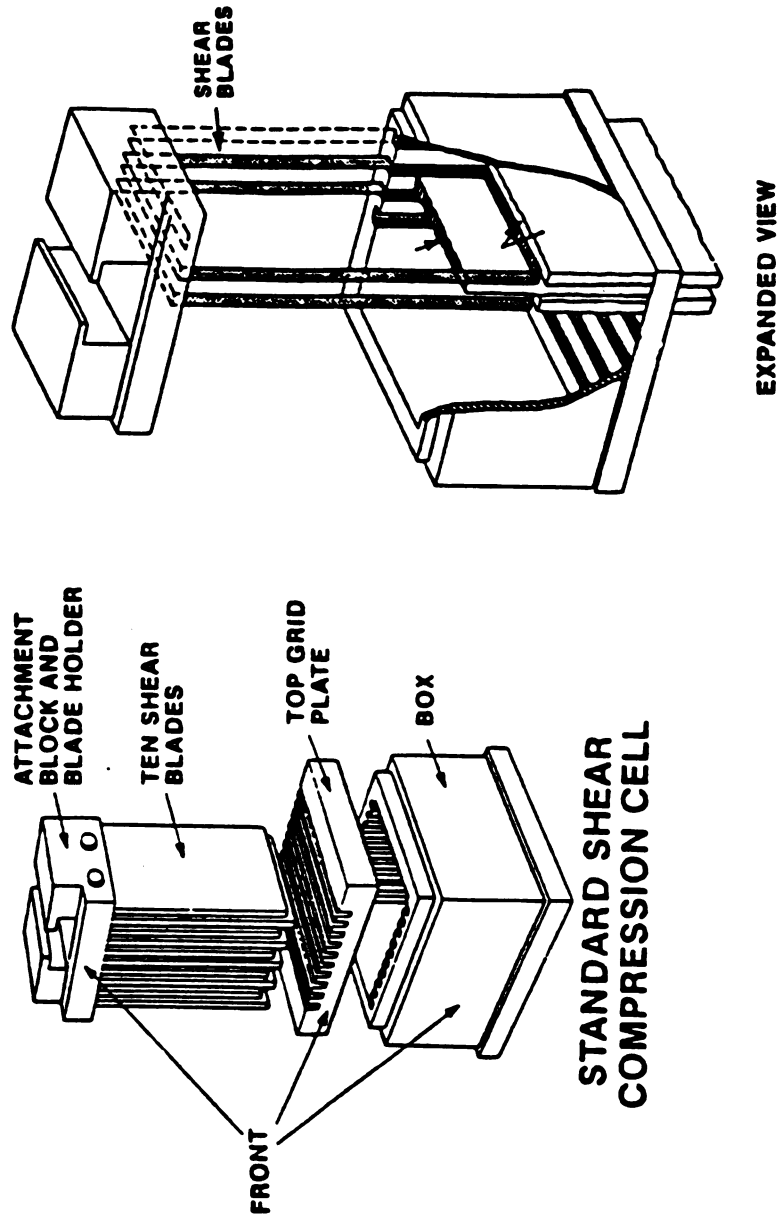


Figure 10. Standard shear compression cell (CS-1) with 10 multiple blades (Uebersax et al., 1988)

minutes prior to weighing. Thaw samples were reweighed and the percent drain weight was calculated.

$$\text{Drained weight \%} = \frac{\text{weight of drained slices (g)}}{\text{initial weight (g)}} \times 100$$

Color

The color measurement for frozen apple slices was measured the same manner as that for applesauces.

Subjective measurements

The sample preparations for subjective measurement were the same as those for objective measurements. The products were evaluated using the USDA grading specification for frozen apple slices. The considered characteristics included color, size, defects, and character. Grades of frozen apple slices were divided into U.S. Grade A or U.S. Fancy, U.S. Grade C or U.S. Standard. USDA grading specification for frozen apple slices (USDA, 1954) is presented in appendix II.

STATISTICAL ANALYSIS

The effects of variety and storage on chemical-physical processing qualities of applesauce and frozen apple slices were analyzed using the analysis of variance (ANOVA) of the statistical program, Stat View for window, version 4.5. The chemical-physical processing qualities were analyzed as a two-way interaction ANOVA, with varieties and storage. F values were reported. The significant level were set at $p \leq 0.05$ (*) and $p \leq 0.01$ (**). Coefficient of variation (%CV)

expresses the standard deviation as a percent of the calculated mean. Least significant difference (LSD) was used for the separation of means. These were used to compare variety differences.

The differences between the chemical-physical processing qualities of each apple variety due to storage were determined using the t-test statistical program (paired two sample for means), Microsoft excel for Window 95 (Ver.7). The two sets of data were evaluated by comparing the calculated t value with tabulated t value. When t (calculated) value is higher than t (tabulated) value, it indicated significant difference. The significant level were set at $p \leq 0.05$ (*), $p \leq 0.01$ (**), $p \leq 0.005$ (***), and $p \leq 0.001$ (****).

The multiple regression equations were used to calculate quality score for both products, applesauces and frozen apple slices. Assumed standards were set up providing range of score for both products shown in Table 2 and Table 3. The chemical-physical characteristics of products were then scored and presented as dependent variable (y) in multiple regression. The multiple regression equations were determined from graph creating program, Microsoft excel for Window 95 (Ver.7). The calculated quality scores of both products were then calculated using derived multiple regression equations.

Table 2. Assumed score range for each chemical-physical characteristic of processed applesauce

Score	Sugar/acid ratio ¹	Consistency ²	Lightness (L)	Hue angle ³ (Ha)
1	13-19	6-5.6	42-47.6	55-62
2	19-25	5.6-5.2	47.6-51.2	62-69
3	25-31	5.2-4.8	51.2-54.8	69-76
4	31-37	4.8-4.4	54.8-58.4	76-83
5	37-43	4.4-4	58.4-62	83-90

1. Brix/malic acid %

2. USDA flow sheet (cm/minute); higher numbers indicate less limited flow (lower consistency)

3. The closer the hue angle is to 90° indicates an increase in yellowness, while the further away it is from 90° indicates an increase in redness.

Table 3. Assumed score range for each chemical-physical characteristic of processed frozen apple slices

Score	Sugar/acid ratio	Shear resistance ¹	Drained weight ²	Lightness (L)
1	12-16.4	150-520	67-76	34-40
2	16.4-20.8	520-890	76-82	40-46
3	20.8-25.2	890-1260	82-88	46-52
4	25.2-29.6	1260-1630	88-94	52-58
5	29.6-34	1630-2000	94-100	58-64

1. N/100g

2. %

RESULTS AND DISCUSSION

Chemical-Physical Processing Quality (Objective Measurement) of Apple Processed Products

Experimental mean values for chemical-physical processing quality of adult applesauces and frozen apple slices processed after fresh harvest and after two months in cold storage are presented in Table 4 to Table 8 and Table 12 to Table 17, respectively. The traditional varieties were Red Delicious, Golden Delicious, McIntosh, Jonathan, Cortland, Northern Spy, Idared, and Rome. The recent varieties were Mutsu, and Empires (with 3 stages of maturity: early, middle, and late harvest season). The new varieties were Honeycrisp, Jonagold, and Gala.

Adult applesauces

Table 4 shows the mean values of the sugar/acid ratio of applesauces, a value related to flavor attributes. Among applesauces from all apple selections, Red Delicious applesauce showed the highest sugar/acid ratio (41.23 and 37.19 °Brix/malic acid % after fresh harvest and storage, respectively), while Northern Spy applesauce showed the lowest sugar/acid ratio (14.53 and 16.25 °Brix/malic acid % after fresh harvest and storage, respectively). Among

Table 4. Comparison of sugar/acid ratio¹ mean values² of applesauces from traditional, recent, and new varieties (control³, 2 month storage⁴)

Category	Selection	Control	2 month	Calculated
Traditional varieties	Red Delicious	41.23	37.19	14.59***
	Rome	25.32	29.10	4.37*
	Golden Delicious	23.96	32.11	5.91*
	Idared	18.27	23.89	13.94**
	McIntosh	18.11	22.50	128.83****
	Cortland	16.94	21.98	31.98****
	Jonathan	16.75	17.36	1.53
	Northern Spy	14.53	16.25	6.69*
Recent varieties	Mutsu	28.64	31.47	3.42
	Empire (Late)	23.35	28.71	8.58*
	Empire (Middle)	22.65	24.86	13.75**
	Empire (Early)	19.64	27.00	21.81***
New varieties	Gala	30.13	33.29	4.06
	Jonagold	24.42	32.92	0.00
	Honeycrisp	20.00	22.50	4.08
LSD _{0.05} ⁵		2.43	2.28	

1. °Brix/malic acid (%)

2. n=3, t-test, * = significant at t calculated value ≥ 4.303 (t_{0.05} tabulated value), ** = significant at t calculated value ≥ 9.93 (t_{0.01} tabulated value), *** = significant at t calculated value ≥ 14.09 (t_{0.005} tabulated value), **** = significant at t calculated value ≥ 31.60 (t_{0.001} tabulated value)

3. Applesauces processed after fresh harvest

4. Applesauces processed after 2 month storage

5. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Empires, both fresh harvested and stored apples harvested at late season, showed the highest sugar/acid ratio, followed by those harvested at middle and early season, respectively. Evaluation of the sugar/acid ratios using a paired t-test for McIntosh ($P \leq 0.001$), Cortland ($P \leq 0.001$), Empire (Early) ($P \leq 0.005$), Empire (Middle) ($P \leq 0.01$), Idared ($P \leq 0.01$), Golden Delicious ($P \leq 0.05$), Empire (Late) ($P \leq 0.05$), Rome ($P \leq 0.05$), and Northern Spy ($P \leq 0.05$) applesauces, showed significantly higher sugar/acid ratios after storage. However, Red Delicious applesauce showed significantly lower sugar/acid ratios ($P \leq 0.005$) after storage. These increases in sugar/acid ratio were attributed due to general ripening processes in the fruits.

Table 5 shows the mean values of consistency of applesauces, a physical property related to viscosity. The lower numbers indicates the limited flow of the applesauces which means higher consistencies. Processing of fresh harvest Mutsu produced applesauce showing the highest consistency (4.47 cm/minute), while Cortland applesauce showed the lowest consistency (5.65 cm/minute). After storage, processed Mutsu applesauce also showed the highest consistency (4.54 cm/minute), while Honeycrisp applesauce showed the lowest consistency (6.00 cm/minute). Among Empires, applesauces produced from fresh harvested apples harvested at late season showed the highest consistency, followed by those harvested at middle and early season,

Table 5. Comparison of consistency¹ mean values² of applesauces from traditional, recent, and new varieties (control³, 2 month storage⁴)

Category	Selection	Control	2 month storage	Calculated
Traditional varieties	Cortland	5.65	5.16	6.90*
	Jonathan	5.44	5.44	0.07
	Northern Spy	5.39	5.33	1.20
	Rome	5.11	4.63	9.55*
	Red Delicious	5.07	5.44	5.20*
	Golden Delicious	4.98	5.63	3.70
	Idared	4.73	5.38	5.55*
	McIntosh	4.59	4.55	0.57
Recent varieties	Empire (Early)	5.53	4.63	10.15**
	Empire (Middle)	5.19	4.94	6.55*
	Empire (Late)	4.52	4.53	0.72
	Mutsu	4.47	4.54	0.50
New varieties	Honeycrisp	5.44	6.00	4.40*
	Gala	4.78	5.71	28.43***
	Jonagold	4.76	4.61	7.20*
LSD _{0.05} ⁵		0.34	0.38	

1. USDA flow sheet (cm/minute); higher numbers indicate less limited flow (lower consistency)

2. n=3, t-test, * = significant at t calculated value ≥ 4.303 (t_{0.05} tabulated value), ** = significant at t calculated value ≥ 9.93 (t_{0.01} tabulated value), *** = significant at t calculated value ≥ 14.09 (t_{0.005} tabulated value), **** = significant at t calculated value ≥ 31.60 (t_{0.001} tabulated value)

3. Applesauces processed after fresh harvest

4. Applesauces processed after 2 month storage

5. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

respectively. However, after storage, applesauce from late season apples showed the highest consistency, followed by those harvested at middle and early season, respectively. Evaluation of consistency using a paired t-test for Empire (Early) ($P \leq 0.001$), Empire (Middle) ($P \leq 0.05$), Jonagold ($P \leq 0.05$), Cortland ($P \leq 0.05$), and Rome ($P \leq 0.05$) showed significantly higher consistencies after storage, while Gala ($P \leq 0.005$), Red Delicious ($P \leq 0.05$), Honeycrisp ($P \leq 0.05$), and Idared ($P \leq 0.05$) showed significantly lower consistencies after storage. The different behaviors of consistency changes due to storage is probably a result of the diversity of pectin molecular architecture in the apple cell wall. Certain cultivars give an increase, rather than the more customary decrease, in sauce particle size with continued fruit storage (Mohr 1989).

Table 6 shows the mean values of lightness (L) of processed applesauces. Processing of fresh harvest Gala produced applesauce showing the highest (61.03), while Rome applesauce showed the lowest lightness value (50.10) among applesauces from all apple selections. After storage, processing of Empire (Early) produced applesauce showing the highest (58.70), while Rome applesauce showed the lowest lightness value (45.37). Among Empires, applesauces produced from fresh harvested apples harvested at late season showed the highest lightness value, followed by those harvested at middle and early season, respectively.

Table 6. Comparison of lightness (L) mean values¹ of applesauces from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage	calculated t
Traditional varieties	Jonathan	58.30	57.33	2.07
	Cortland	58.20	58.00	1.73
	Red Delicious	57.07	55.40	2.87
	Northern Spy	56.17	56.33	0.21
	Idared	54.93	57.57	14.93***
	Golden	54.80	53.67	2.95
	McIntosh	53.53	53.87	3.78
	Rome	50.10	45.37	39.38****
Recent varieties	Mutsu	58.30	56.10	2.06
	Empire (Late)	58.30	58.33	0.07
	Empire (Middle)	54.77	58.13	8.76*
	Empire (Early)	53.03	58.70	170.00****
New varieties	Gala	61.03	55.23	15.32***
	Jonagold	56.63	55.87	4.35*
	Honeycrisp	55.70	53.25	10.69**
LSD _{0.05} ⁴		2.79	2.19	

1. n=3, t-test, * = significant at t calculated value ≥ 4.303 (t_{0.05} tabulated value), ** = significant at t calculated value ≥ 9.93 (t_{0.01} tabulated value), *** = significant at t calculated value ≥ 14.09 (t_{0.005} tabulated value), **** = significant at t calculated value ≥ 31.60 (t_{0.001} tabulated value)

2. Applesauces processed after fresh harvest

3. Applesauces processed after 2 month storage

4. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

However, after storage, applesauce from early season apples showed the highest lightness value, followed by those harvested at late and middle season, respectively. Evaluation of the lightness values using a paired t-test for Empire (Early) ($P \leq 0.001$), Idared ($P \leq 0.005$), Empire (Middle) ($P \leq 0.05$) showed significantly higher, while Rome ($P \leq 0.001$), Gala ($P \leq 0.005$), Honeycrisp ($P \leq 0.01$), and Jonagold ($P \leq 0.05$) showed significantly lower lightness values after storage.

Table 7 shows mean values of greenness ($-a_L$) of applesauces. Honeycrisp applesauce showed the highest (-7.93), while Rome applesauce showed the lowest greenness value (-0.85) among applesauces from all apple selections including both fresh harvest and storage. Among Empires, applesauces produced from fresh harvested apples harvested at late season showed the highest greenness value, followed by those harvested at middle and early season, respectively. However, after storage, applesauce from middle season apples showed the highest consistency, followed by those harvested at late and early season, respectively. Evaluation of the greenness values using a paired t-test for Empire (Early) ($P \leq 0.001$), Empire (Middle) ($P \leq 0.001$), Idared ($P \leq 0.005$), and Empire (Late) ($P \leq 0.05$) showed significantly higher greenness values after storage, while Rome ($P \leq 0.001$), Gala ($P \leq 0.005$), Jonagold ($P \leq 0.005$), Red Delicious ($P \leq 0.01$),

Table 7. Comparison of greenness ($-a_L$) mean values¹ of applesauces from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Northern Spy	-5.47	-6.43	5.48
	Red Delicious	-5.40	-4.20	12.00**
	Golden Delicious	-5.27	-4.73	6.05*
	Jonathan	-5.07	-4.63	6.50*
	McIntosh	-4.07	-3.97	1.73
	Cortland	-3.70	-4.03	3.78
	Idared	-2.10	-6.23	17.71***
	Rome	-0.85	4.83	37.97****
Recent varieties	Empire (Late)	-6.00	-6.53	8.00*
	Empire (Middle)	-5.53	-6.77	37.00****
	Mutsu	-5.20	-4.30	2.94
	Empire (Early)	-3.50	-5.63	64.00****
New varieties	Honeycrisp	-7.93	-7.53	6.93*
	Gala	-7.20	-6.10	19.05***
	Jonagold	-5.10	-4.07	15.50***
LSD _{0.05} ⁴		0.78	0.76	

1. $n=3$, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)
2. Applesauces processed after fresh harvest
3. Applesauces processed after 2 month storage
4. $n=3$, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Golden Delicious ($P \leq 0.05$), Jonathan ($P \leq 0.05$), and Honeycrisp ($P \leq 0.05$) showed significantly lower greenness value after storage. However, it should be obvious that the higher the greenness values, the lower the redness values.

Table 8 shows mean values of yellowness (b_L) of applesauces. Mutsu applesauce showed the highest (24.03), while Cortland applesauce showed the lowest yellowness value (13.20) among applesauces from all apple selections including those processed using fresh harvested and stored apples. Among Empires, processed applesauces from both fresh harvested and stored apples harvested at late season showed the highest yellowness value, followed by those harvested at middle and early season, respectively. Evaluation of the yellowness values using a paired t-test for Empire (Early) ($P \leq 0.001$) and Empire (Middle) ($P \leq 0.05$) showed significantly higher, while Rome ($P \leq 0.001$), Honeycrisp ($P \leq 0.001$), and Jonagold ($P \leq 0.05$) showed significantly lower yellowness values after storage.

Table 9 and Table 10 show the rank of processed applesauces from fresh harvested and stored apples based on chemical-physical processing qualities. Golden Delicious as a typical variety for applesauce is highlighted to indicate the standard generally recognized by industry. Desirable characteristics in apples for applesauce include high sugar solids content, high acidity, aromatic with white or golden

Table 8. Comparison of yellowness (b_L) mean values¹ of applesauces from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Golden Delicious	21.17	20.23	2.94
	Northern Spy	21.03	21.53	0.97
	McIntosh	17.67	18.40	1.00
	Red Delicious	17.53	18.60	2.71
	Idared	16.50	16.83	1.88
	Jonathan	15.67	15.40	1.22
	Rome	15.05	7.23	117.50****
	Cortland	13.20	12.87	2.77
Recent varieties	Mutsu	24.03	23.10	1.10
	Empire (Late)	21.67	21.40	1.32
	Empire Middle)	19.87	20.90	4.43*
	Empire (Early)	17.97	20.93	44.50****
New varieties	Jonagold	20.33	19.43	7.79*
	Honeycrisp	18.70	15.90	48.50****
	Gala	13.57	13.60	0.09
LSD _{0.05} ⁴		1.96	1.71	

1. n=3, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)

2. Applesauces processed after fresh harvest

3. Applesauces processed after 2 month storage

4. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Table 9. Descending rank order for processing characteristics of applesauces processed from 15 apple selections (control¹, 2 months²)

Order No.	Sugar/acid ratio		Consistency	
	Control	2 months	Control	2 months
1	Red Delicious	Red Delicious	Cortland	Honeycrisp
2	Gala	Gala	Empire (Early)	Gala
3	Mutsu	Jonagold	Honeycrisp	<u>Golden Delicious</u>
4	Rome	<u>Golden Delicious</u>	Jonathan	Red Delicious
5	Jonagold	Mutsu	Northern Spy	Jonathan
6	<u>Golden delicious</u> ³	Rome	Empire (Middle)	Idared
7	Empire (Late)	Empire (Late)	Rome	Northern Spy
8	Empire (Middle)	Empire (Early))	Red Delicious	Cortland
9	Honeycrisp	Empire (Middle)	<u>Golden Delicoius</u>	Empire (Middle)
10	Empire (Early)	Idared	Gala	Empire (Early)
11	McIntosh	McIntosh	Jonagold	Rome
12	Idared	Honeycrisp	Idared	Jonagold
13	Cortland	Cortland	McIntosh	McIntosh
14	Jonathan	Jonathan	Empire (Late)	Mutsu
15	Northern Spy	Northern Spy	Mutsu	Empire (Late)

1. Applesauces processed after fresh harvest

2. Applesauces processed after 2 month storage

3. Golden Delicious designated as industry standards for comparative rank order

Table 10. Descending rank order for processing characteristics of applesauces processed from 15 apple selections (control₁, 2 months²)

Orde No.	Lightness (L)		Greenness (-a _L)		Yellowness (b _L)	
	control	2 months	control	2 months	control	2 months
1	Gala	Empire (Early)	Rome	Rome	Mutsu	Mutsu
2	Jonathan	Empire (Late)	Idared	McIntosh	Empire (Late)	Northern Spy
3	Empire (Late)	Empire (Middle)	Empire (Early)	Cortland	Northern Spy	Empire (Late)
4	Cortland	Cortland	Cortland	Jonagold	Jonagold	Empire (Early)
5	Mutsu	Idared	McIntosh	Red Delicious	<u>Golden Delicious</u>	Empire (Middle)
6	Red Delicious	Jonathan	Jonathan	Mutsu	Empire (Middle)	<u>Golden Delicious</u>
7	Jonagold	Northern Spy	Jonagold	Jonathan	Honeycrisp	Jonagold
8	Northern Spy	Mutsu	Mutsu	<u>Golden Delicious</u>	Empire (Early)	Red Delicious
9	Honeycrisp	Jonagold	<u>Golden Delicious</u>	Empire (Early)	McIntosh	McIntosh
10	Empire (Middle)	Red Delicious	Red Delicious	Gala	Red Delicious	Idared
11	Idared	Gala	Northern Spy	Idared	Idared	Honeycrisp
12	<u>Golden</u>	McIntosh	Empire (Middle)	Northern Spy	Jonathan	Jonathan
13	McIntosh	<u>Golden Delicious</u>	Empire (Late)	Empire (Late)	Rome	Gala
14	Empire (Early)	Honeycrisp	Gala	Empire (Middle)	Gala	Cortland
15	Rome	Rome	Honeycrisp	Honeycrisp	Cortland	Rome

1. Applesauces processed after fresh harvest

2. Applesauces processed after 2 month storage

Golden Delicious designated as industry standards for comparative rank order

flesh, variable grain or texture, and sufficient water-holding capacity (Root 1996).

Table 11 shows the analysis of variance for chemical-physical processing qualities of applesauces from 15 apple selections. Significant differences ($P \leq 0.01$) of all attributes were detected for both selection (15 apple selections included: Red Delicious, Golden Delicious, McIntosh, Jonathan, Jonagold, Gala, Empire at early season, Empire at middle season, Empire at late season, Honeycrisp, Cortland, Mutsu, Rome, Idared and Northern Spy) and storage (fresh harvest and 2 month storage). There were significant interactions ($P \leq 0.01$) between selection and storage for all attributes: sugar/acid ratio, consistency, lightness value, greenness value, and yellowness value. Roa et al. (1986) have reported that consistency of applesauce was significantly affected by apple cultivar and firmness as well as screen size which was confirmed by this experiment.

Frozen apple slices

Table 12 shows sugar/acid ratio mean values of frozen apple slices. After fresh harvest, Red Delicious frozen slices showed the highest (27.83 °Brix/malic acid %), while Northern Spy frozen slices showed the lowest sugar/acid ratio (12.14 °Brix/malic acid %) among frozen slices from all apple selections. After storage, Red Delicious frozen slices showed the highest (28.98 °Brix/malic acid %), while

Table 11. Analysis of variance for chemical-physical processing quality of applesauces from 15 apple selections

Sources of variation	df	Sugar/acid ratio	Consistency	Lightness (L)	Greenness (-a _L)	Yellowness (b _L)
Mean squares ¹						
<u>Main effects</u>						
section ²	14	233.80**	0.83**	42.00**	27.72**	73.85**
storage ³	1	320.88**	0.08**	5.96**	0.47**	5.78**
<u>Interaction</u>						
selection X storage	14	15.02**	0.38**	12.76**	6.75**	8.58**
Error	60	0.47	0.01	0.51	0.05	0.27
% CV		26.46	8.75	5.38	49.07	20.18

1. n=3, *=significant at $P \leq 0.05$, **=significant at $P \leq 0.01$

2. Apple selections include: Red Delicious, Golden Delicious, McIntosh, Jonathan, Jonagold, Gala, Empire(at early harvest season), Empire(at middle harvest season), Empire(at late harvest season), Cortland, Northern Spy, Idared, Rome, Honeycrisp,and Mutsu

3. Storages include: control (fresh harvest) and 2 month storage

Table 12. Comparison of sugar/acid ratio¹ mean values² of frozen apple slices from traditional, recent, and new varieties (control³, 2 month storage⁴)

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Red Delicious	27.83	28.98	1.78
	Golden Delicious	19.68	23.96	18.39***
	Rome	18.99	17.04	4.27
	Idared	15.93	17.31	4.84*
	Jonathan	14.50	14.23	0.64
	Cortland	13.65	17.86	32.44****
	McIntosh	12.72	14.60	12.60**
	Northern Spy	12.14	14.54	31.26***
Recent varieties	Empire (Early)	18.82	16.88	30.58***
	Empire (Late)	19.87	17.29	2.81
	Empire (Middle)	20.31	18.54	5.69*
New varieties	Gala	21.47	30.04	3.66
	Jonagold	21.42	28.98	6.63*
	Honeycrisp	13.81	14.61	1.32
LSD _{0.05} ⁵		2.40	3.59	

1. °Brix/malic acid (%)

2. n=3, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)

3. Frozen apple slices processed after fresh harvest

4. Frozen apple slices processed after 2 month storage

5. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Jonathan frozen slices showed the lowest sugar/acid ratio (14.23 °Brix/malic acid %) among frozen slices from all apple selections. Among Empires, both fresh harvested and stored apples harvested at middle season showed the highest sugar/acid ratio, followed by those harvested at late and early season, respectively. From the evaluation of sugar/acid ratios using a paired t-test, Cortland ($P \leq 0.001$), Golden Delicious ($P \leq 0.005$), Northern Spy ($P \leq 0.005$), McIntosh ($P \leq 0.01$), Jonagold ($P \leq 0.05$), and Idared ($P \leq 0.05$) frozen slices showed significantly higher, while Empire (Early) ($P \leq 0.005$) and Empire (Middle) ($P \leq 0.05$) showed lower sugar/acid ratios after storage.

Table 13 shows shear resistance, a physical property related to texture, mean values of frozen apple slices. After fresh harvest, Cortland frozen slices showed the highest (1788 N/100g), while McIntosh frozen slices showed the lowest shear resistance value (272.8 N/100g) among frozen slices from all apple selections. After storage, Northern Spy frozen slices showed the highest (911.60 N/100g), while Empire(Late) frozen slices showed the lowest shear resistance value (183.50 N/100g) among frozen slices from all apple selections. Among Empires, fresh harvest frozen slices processed from apples harvested at early season showed the highest shear resistance value, followed by those from middle and late, respectively. However, after storage, frozen slices processed from apples harvested at

Table 13. Comparison of shear resistance¹ mean values² of frozen apple slices from traditional varieties, recent varieties, and experimental lines (control³, 2 month storage⁴)

Category	Selection	Control	2 month storage	Calculated
Traditional varieties	Cortland	1788.00	182.90	97.60****
	Jonathan	1720.33	765.27	9.82*
	Idared	1449.67	774.37	198.93****
	Rome	1346.00	274.10	361.27****
	Northern Spy	1297.00	911.60	14.91***
	Red Delicious	1257.33	903.40	24.34***
	Golden Delicious	1229.7	296.90	40.83****
	McIntosh	272.8	233.93	1.37
Recent varieties	Empire (Early)	1090.17	211.50	15.45***
	Empire (Middle)	990.20	224.83	41.39****
	Empire (Late)	310.37	183.50	17.85****
New varieties	Gala	1090.67	927.43	4.34*
	Jonagold	845.53	698.20	2.57
	Honeycrisp	765.10	799.43	1.30
LSD _{0.05} ⁵		223.31	112.24	

1. N/100g

2. n=3, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)

3. Frozen apple slices processed after fresh harvest

4. Frozen apple slices processed after 2 month storage

5. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

middle season showed the highest shear resistance value, followed by those harvested at early and late season, respectively. From evaluation of the shear resistance values using a paired t-test, frozen slices from all apple selections except for those from McIntosh, Jonagold, and Honeycrisp had significantly lower shear resistance values after storage. There was no significant difference in shear resistance values between fresh and after storage for McIntosh, Jonagold, and Honeycrisp. The mushy appearance and texture of thawed apple slices is probably due to increased volume of ice crystals when water is frozen causing mechanically damaged cellular membranes, thus resulting in dramatically decreased shear resistance of most cultivars (Desrosier and Tressler 1977). The un-stored apples may contain higher starch and other firming substances such as insoluble pectin to support the tissue, so they were less affected by ice crystal damage.

Table 14 shows drained weight mean values of frozen apple slices. Jonathan frozen slice showed the highest (99.8 %), while Honeycrisp frozen slices showed the lowest drained weights (71.12 %) among frozen slices from all apple selections including both fresh harvest and stored apples. Among Empires, both fresh harvested and stored apples harvested at middle season showed the highest drained weight, followed by those harvested at early and late season, respectively. From the evaluation of the drained

Table 14. Comparison of drained weight¹ mean values² of frozen apple slices from traditional, recent, and new varieties (control³, 2 month storage⁴)

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Jonathan	99.80	99.80	0.16
	Cortland	99.56	99.59	6.11
	Idared	98.03	92.78	4.48*
	Golden Delicious	97.91	94.55	1.89
	Rome	96.79	92.46	4.96*
	Northern Spy	94.41	95.16	1.45
	Red Delicious	90.74	90.19	0.35
	McIntosh	82.61	76.17	5.32*
Recent varieties	Empire (Middle)	95.29	89.89	2.04
	Empire (Early)	90.03	84.30	6.98*
	Empire (Late)	88.83	84.20	4.24
New varieties	Jonagold	92.07	84.54	3.43
	Gala	86.84	98.17	11.87**
	Honeycrisp	71.12	71.24	0.04
LSD _{0.05} ⁵		6.14	7.53	

1. %

2. n=3, t-test, * = significant at t calculated value ≥ 4.303 (t_{0.05} tabulated value), ** = significant at t calculated value ≥ 9.93 (t_{0.01} tabulated value), *** = significant at t calculated value ≥ 14.09 (t_{0.005} tabulated value), **** = significant at t calculated value ≥ 31.60 (t_{0.001} tabulated value)

3. Frozen apple slices processed after fresh harvest

4. Frozen apple slices processed after 2 month storage

5. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

weights using a paired t-test, Gala ($P \leq 0.01$) frozen slices showed significantly higher drain weights, while Rome ($P \leq 0.05$), Idared ($P \leq 0.05$), McIntosh ($P \leq 0.05$) and Empire (Early) ($P \leq 0.05$) showed significantly lower drained weights after storage. Removing water by freezing causes colloidal solutions to become irreversibly dehydrated within cell membranes and thus causes a change in their permeability and elasticity, resulting in loss of rigidity upon thawing (Desrosier and Tressler 1977).

Table 15 shows lightness mean values (L) of frozen apple slices. After fresh harvest, Jonathan frozen slices showed the highest (61.07), while Empire (Early) frozen slices showed the lowest lightness value (35.03) among frozen slices from all apple selections. After storage, Jonathan frozen slices showed the highest (56.03), while Rome frozen slices showed the lowest lightness value (43.33) among frozen slices from all apple selections. Among Empires, frozen slices processed after fresh harvest from apples harvested at late season showed the highest lightness value, followed by those harvested at middle and early season, respectively. However, after storage, frozen slices from late season apples showed the highest lightness value, followed by those harvested at early and middle season, respectively. Evaluation of the lightness values using a paired t-test for Jonagold ($P \leq 0.001$), Gala ($P \leq 0.05$), Idared ($P \leq 0.05$), and Rome ($P \leq 0.05$) frozen slices showed

Table 15. Comparison of lightness (L) mean values¹ of frozen apple slices from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Jonathan	61.07	56.03	2.48
	Northern Spy	59.27	49.00	9.92*
	Cortland	57.50	59.37	4.16
	Idared	56.93	49.17	7.12*
	Golden Delicious	51.47	53.20	1.98
	McIntosh	50.53	43.87	3.00
	Rome	49.00	43.33	6.04*
	Red Delicious	42.73	45.53	1.30
Recent varieties	Empire (Late)	48.67	51.90	2.73
	Empire (Middle)	48.40	44.13	3.60
	Empire (Early)	35.03	51.43	12.08**
New varieties	Gala	58.20	52.47	8.26*
	Jonagold	53.60	46.77	36.82****
	Honeycrisp	49.10	44.57	2.36
LSD _{0.05} ⁴		6.26	6.56	

1. n=3, t-test, * = significant at t calculated value ≥ 4.303 (t_{0.05} tabulated value), ** = significant at t calculated value ≥ 9.93 (t_{0.01} tabulated value), *** = significant at t calculated value ≥ 14.09 (t_{0.005} tabulated value), **** = significant at t calculated value ≥ 31.60 (t_{0.001} tabulated value)

2. Frozen apple slices processed after fresh harvest

3. Frozen apple slices processed after 2 month storage

4. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

significantly lower lightness values, while Empire (Early) ($P \leq 0.01$) showed significantly higher lightness values after storage.

Table 16 shows greenness mean values ($-a_L$) of frozen slices. Processed after fresh harvest, Northern Spy frozen slices showed the highest greenness value (-8.03), while Rome frozen slices showed the lowest greenness value (5.70) among frozen slices from all apple selections. After storage, Honeycrisp and Cortland frozen slices showed the highest greenness value (-7.03), while Rome frozen slices also showed the lowest greenness value (7.10) among frozen slices from all apple selections. Among Empires, after fresh harvest frozen slices processed from late season apples showed the highest greenness value, followed by those from middle and early season apples, respectively. However, after storage, frozen slices processed from late season apples showed the highest greenness value, followed by those from early and late season apples, respectively. Evaluation of the greenness values using a paired t-test for Empire (Early) ($P \leq 0.001$), Red Delicious ($P \leq 0.05$), and Honeycrisp ($P \leq 0.05$) showed significantly higher, while Northern Spy ($P \leq 0.005$), Rome ($P \leq 0.05$), and Idared ($P \leq 0.05$) showed significantly lower greenness values after storage. Again, it should be obvious that the higher the greenness values, the lower the redness values.

Table 16. Comparison of greenness ($-a_L$) mean values¹ of frozen apple slices from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Northern Spy	-8.03	-5.30	14.73***
	Cortland	-6.93	-7.03	0.48
	Idared	-5.77	-4.00	5.30*
	Jonathan	-4.97	-5.00	0.04
	McIntosh	-4.87	-3.73	1.06
	Golden Delicious	-4.70	-5.03	1.00
	Red Delicious	2.63	-0.30	4.97*
	Rome	5.70	7.10	8.08*
Recent varieties	Empire (Late)	-6.97	-6.50	1.21
	Empire (Middle)	-4.33	-5.47	3.82
	Empire (Early)	-1.90	-5.97	46.11****
New varieties	Honeycrisp	-5.57	-7.03	4.40*
	Jonagold	-5.37	-5.27	0.07
	Gala	-5.13	-5.07	0.18
LSD _{0.05} ⁴		5.93	2.97	

1. n=3, t-test, * = significant at t calculated value ≥ 4.303 (t_{0.05} tabulated value), ** = significant at t calculated value ≥ 9.93 (t_{0.01} tabulated value), *** = significant at t calculated value ≥ 14.09 (t_{0.005} tabulated value), **** = significant at t calculated value ≥ 31.60 (t_{0.001} tabulated value)

2. Frozen apple slices processed after fresh harvest

3. Frozen apple slices processed after 2 month storage

4. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Table 17 shows yellowness mean values (b_L) of frozen apple slices. After fresh harvest, Jonagold frozen slices showed the highest (25.97), while Cortland frozen slices showed the lowest yellowness value among frozen slices from all apple selections. After storage, Empire (Late) frozen slices showed the highest (23.77), while Cortland frozen slices showed the lowest yellowness value (16.30) among frozen slices from all apple selections. Among Empires, frozen slices processed from fresh harvested apples harvested at late season showed the highest shear press value, followed by those from middle and early season apples, respectively. However, after storage, frozen slices from late season apples showed the highest yellowness value, followed by those from early and middle apples, respectively. From evaluation of the yellowness values using a paired t-test for Empire (Early) ($P \leq 0.01$), Honeycrisp ($P \leq 0.05$), and Cortland ($P \leq 0.05$) showed significantly higher, while Jonagold showed significantly lower yellowness values after storage.

Table 18 and Table 19 show the rank order of 14 apple selections as processed into frozen apple slices from fresh harvested and stored apples based on chemical-physical processing qualities. Important characteristics for apple slices are firm, maintain integrity of the flesh when diced, and have good color. Sweetness is less important in making slices than in sauce (Root 1996).

Table 17. Comparison of yellowness¹ (b_L) mean values² of frozen apple slices from traditional, recent, and new varieties (control³, 2 month storage⁴)

Category	Selection	Control	2 month storage	Calculated
Traditional varieties	Golden Delicious	23.53	22.47	0.88
	Northern Spy	23.00	19.90	4.15
	Red Delicious	19.63	20.67	1.00
	Jonathan	18.83	20.70	2.94
	McIntosh	18.40	17.33	0.91
	Idared	16.73	19.40	2.98
	Rome	14.90	15.17	0.63
	Cortland	14.27	16.30	7.81*
Recent varieties	Empire (Late)	22.57	23.77	1.35
	Empire (Middle)	19.73	19.43	0.22
	Empire (Early)	16.17	22.50	10.95**
New varieties	Jonagold	25.97	20.67	20.03***
	Honeycrisp	15.97	18.23	6.11*
	Gala	15.83	19.83	3.47
LSD _{0.05} ⁴		4.00	3.72	

1. $n=3$, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)

2. Frozen apple slices processed after fresh harvest

3. Frozen apple slices processed after 2 month storage

4. $n=3$, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Table 18. Descending rank order for processing characteristics of frozen apple slices processed from 14 apple selections (control¹, 2 months²)

Order No.	Sugar/acid ratio		Shear resistance		Drained weight	
	Control	Gala	control	2 months	Control	2 months
1	Red Delicious	Gala	Cortland	Gala	<u>Jonathan</u>	<u>Jonathan</u>
2	Gala	Red Delicious	<u>Jonathan</u>	Northern Spy	Cortland	Cortland
3	Jonagold	Jonagold	Idared	Red Delicious	Idared	Gala
4	Empire	Golden Delicious	<u>Rome</u>	Honeycrisp	Golden Delicious	Northern Spy
5	Empire (Late)	Empire (Middle)	Northern Spy	Idared	<u>Rome</u>	Golden Delicious
6	Golden	Cortland	Red Delicious	<u>Jonathan</u>	Empire (Middle)	Idared
7	<u>Rome</u> ³	Idared	Golden	Jonagold	Northern Spy	<u>Rome</u>
8	Empire (Early)	Empire (Late)	Empire (Early)	Golden Delicious	Jonagold	Red Delicious
9	Idared	<u>Rome</u>	Gala	<u>Rome</u>	Red Delicious	Empire (Middle)
10	<u>Jonathan</u> ³	Empire (Early)	Empire	McIntosh	Empire (Early)	Jonagold
11	Cortland	Honeycrisp	Jonagold	Empire (Middle)	Empire (Late)	Empire (Early)
12	Honeycrisp	McIntosh	Honeycrisp	Empire (Early)	Gala	Empire (Late)
13	McIntosh	Northern Spy	Empire (Late)	Empire (Late)	McIntosh	Honeycrisp
14	Northern Spy	<u>Jonathan</u>	McIntosh	Cortland	Honeycrisp	McIntosh

1. Frozen apple slices processed after fresh harvest

2. Frozen apple slices processed after 2 month storage

3. Jonathan and Rome designated as industry standards for comparative rank order

Table 19. Descending order for processing characteristics of frozen apple slices processed from 14 apple selection (control¹, 2 months²)

Ord No.	Lightness (L)		Greenness (-a _L)		Yellowness (b _L)	
	control	2 months	control	2 months	control	2 months
1	<u>Jonathan</u> ³	Cortland	<u>Rome</u>	<u>Rome</u>	Jonagold	Empire (Late)
2	Northern Spy	<u>Jonathan</u>	Red Delicious	Red Delicious	Golden Delicious	Empire (Early)
3	Cortland	Golden Delicious	Empire (Early)	McIntosh	Northern Spy	Golden Delicious
4	Idared	Gala	Empire (Middle)	Idared	Empire (late)	<u>Jonathan</u>
5	Jonagold	Empire (Late)	Golden Delicious	<u>Jonathan</u>	Empire (Middle)	Red Delicious
6	Gala	Empire (Early)	McIntosh	Golden Delicious	Red Delicious	Jonagold
7	Golden Delicious	Idared	<u>Jonathan</u>	Gala	<u>Jonathan</u>	Northern Spy
8	McIntosh	Northern Spy	Gala	Jonagold	McIntosh	Gala
9	Honeycrisp	Jonagold	Jonagold	Northern Spy	Idared	Empire (Middle)
10	<u>Rome</u> ³	Red Delicious	Honeycrisp	Empire (Middle)	Empire (Early)	Idared
11	Empire (Late)	Honeycrisp	Idared	Empire (Early)	Honeycrisp	Honeycrisp
12	Empire (Middle)	Empire (Middle)	Cortland	Empire (Late)	Gala	McIntosh
13	Red Delicious	McIntosh	Empire (Late)	Honeycrisp	<u>Rome</u>	Cortland
14	Empire (Early)	<u>Rome</u>	Northern Spy	Cortland	Cortland	<u>Rome</u>

1. Frozen apple slices processed after fresh harvest

2. Frozen apple slices processed after 2 month storage

3. Jonathan and Rome designated as industry standards for comparative rank order

Table 20 shows the analysis of variance for chemical-physical processing qualities of frozen apple slices from 14 apple selections. Significant differences ($P \leq 0.01$) of sugar/acid ratios, shear resistance values, lightness values, yellowness values, and drained weights were detected for both apple selection (14 apple selections included: Red Delicious, Golden Delicious, McIntosh, Jonathan, Jonagold, Gala, Empire at early season, Empire at middle season, Empire at late season, Honeycrisp, Cortland, Rome, Idared and Northern Spy) and storage (fresh harvest and 2 month storage). For greenness values, significant differences were detected for selection only. There were significant interactions ($P \leq 0.01$) between apple selection and storage for all attributes.

Subjective Measurements

Based upon USDA grading specification, subjective scores for required processing qualities of adult applesauce and frozen apple slices processed after fresh harvest and after 2 month storage were presented in Table 21 to Table 22 and Table 23 to Table 24, respectively. The traditional varieties were Red Delicious, Golden Delicious, McIntosh, Jonathan, Cortland, Northern Spy, Idared, and Rome. The recent varieties were Empire (with 3 stages of maturity: early harvest, middle harvest, and late harvest), and Mutsu. The new varieties were Honeycrisp, Jonagold, and Gala.

Table 20. Analysis of variance for chemical-physical processing quality of frozen apple slices from 14 apple selections

Sources of variation	df	Sugar/acid ratio	Shear resistance	Lightness (L)	Greenness (-a _L)	Yellowness (b _L)	Drained weight
Mean squares ¹							
<u>Main effects</u>							
section ²	13	141.65**	556535.70**	151.68**	78.37**	43.98**	368.13*
storage ³	1	55.40**	6969773.02*	101.20**	3.44	12.57**	102.77*
<u>Interaction</u>							
selection X storage	13	17.64**	347980.06**	70.64**	6.15**	12.72**	34.63**
Error	56	0.75	2530.20**	3.33	1.78	1.20	3.83
% CV		27.25	58.45	12.29	95.56	16.21	9.03

1. n=3, **=significant at $P \leq 0.05$, *=significant at $P \leq 0.01$
2. Apple selections include: Red Delicious, Golden Delicious, McIntosh, Jonathan, Jonagold, Gala, Empire(at early harvest season), Empire(at middle harvest season), Empire(at late harvest season), Cortland, Northern Spy, Idared, Rome, and Honeycrisp
3. Storages include: control (fresh harvest) and 2 month storage

Table 21. Comparison of quality evaluations of applesauces using subjective measurement¹
(control² vs 2 month storage³)

Apple selection	Storage time	Color	Consistency	Defects	Flavor	Finish	Grade
Red Delicious	control	17	19	17	18	18	B
	2 months	17	19	17	18	18	B
Golden Delicious	control	20	20	18	20	19	A
	2 months	18	18	18	20	19	A
McIntosh	control	15	20	15	19	18	B
	2 months	15	20	15	18	18	B
Jonathan	control	18	19	18	19	19	A
	2 months	19	19	19	19	20	A
Northern Spy	control	10	19	10	18	18	substandard
	2 months	19	19	18	18	18	A
Cortland	control	17	18	16	18	19	B
	2 months	18	19	19	19	19	A
Rome	control	18	19	19	19	18	A
	2 months	5	20	5	19	18	substandard
Idared	control	18	20	19	19	19	A
	2 months	19	19	19	19	19	A

1. USDA applesauce grading specification (USDA, 1974)

2. Applesauces processed after fresh harvest

3. Applesauces processed after 2 month storage

Adult applesauces

USDA grade A applesauces were derived from both after fresh harvest and after 2 month storage of Golden Delicious, Jonathan, Gala, Jonagold, Empire (Late), Empire (Middle), Idared, Honeycrisp, and Mutsu. According to Root (1996), Golden Delicious has been at the top in term of quality because of its high soluble solids and resistance to oxidative browning. Jonathan has been a common cultivar for applesauce processing in Michigan. Northern Spy produced USDA grade A applesauce if it was processed after storage, nonetheless it produced USDA substandard applesauce if it was processed after fresh harvest. According to Wiley and Thompson (1959), Northern Spy is excellent for processing because it has bright yellow flesh, which makes a glossy, bright sauce, excellent flavor, and moderately high in soluble solids. Cortland produced USDA grade B applesauce with apple processed after fresh harvest, but it produced USDA grade A applesauce if allowed 2 month of storage time. It has been reported that with white flesh, Cortland produces a poorly color for sauce (Manhart, 1995). Rome processed after fresh harvest produced USDA grade A; however, processing after 2-month storage produced USDA substandard applesauce. Rome is less desirable than most cultivars because of poor flesh color (Way and McLellan 1989). Sauce made with a high percentage of Rome apples will have an off-flavor and weak, running texture (Root 1996). USDA Grade B applesauce were derived from both after

Table 22. Comparison of quality evaluations of applesauces using subjective measurement¹
(control² vs 2 month storage³)

Apple selection	Storage time	Color	Consistency	Defects	Flavor	Finish	Grade
Mutsu	control	20	20	20	20	20	A
	2 months	20	20	20	20	20	A
Empire (Late)	control	18	20	18	18	19	A
	2 months	19	20	18	15	19	A
Empire (Middle)	control	18	19	18	18	19	A
	2 months	19	20	19	15	19	A
Empire (Early)	control	17	18	18	18	18	B
	2 months	18	20	18	15	18	B
Jonagold	control	17	20	17	19	19	A
	2 months	17	20	17	19	19	A
Gala	control	17	20	18	18	19	A
	2 months	18	18	18	17	19	A
Honeycrisp	control	20	19	18	19	19	A
	2 months	18	18	18	18	19	A

1. USDA applesauce grading specification (USDA, 1974)

2. Applesauces processed after fresh harvest

3. Applesauces processed after 2 month storage

Table 23. Comparison of quality evaluations of frozen apple slices using subjective measurement₁ (control₂ vs 2 month storage₃)

Apple selection	Storage time	Color	Size	Defect	Character	Grade
Red Delicious	control	5	17	5	32	substandard
	2 months	8	17	8	31	substandard
Golden Delicious	control	20	18	20	37	A
	2 months	20	18	19	33	A
McIntosh	control	16	16	18	30	C
	2 months	16	16	18	30	C
Jonathan	control	20	16	19	38	A
	2 months	20	16	18	33	A
Northern Spy	control	16	16	15	33	C
	2 months	16	16	15	32	C
Cortland	control	19	16	16	35	A
	2 months	19	16	15	27	C
Rome	control	20	18	17	35	A
	2 months	20	18	19	32	A
Idared	control	19	16	17	34	A
	2 months	16	16	15	31	C

1. USDA applesauce grading specification (USDA, 1954)

2. Frozen apple slices processed after fresh harvest

3. Frozen apple slices processed after 2 month storage

Table 24. Comparison of quality evaluations of frozen apple slices using subjective measurement¹ (control² vs 2 month storage³)

Apple selection	Storage time	Color	Size	Defects	Character	Grade
Empire (Late)	control	19	16	18	31	C
	2 months	19	16	17	28	C
Empire (Middle)	control	19	16	16	31	C
	2 months	17	16	16	29	C
Empire (Early)	control	5	16	5	32	substandard
	2 months	18	16	18	30	C
Jonagold	control	20	17	20	36	A
	2 months	18	17	16	32	C
Gala	control	19	16	20	34	A
	2 months	18	17	19	33	A
Honeycrisp	control	20	18	20	36	A
	2 months	20	18	19	35	A

1. USDA applesauce grading specification (USDA, 1954)

2. Frozen apple slices processed after fresh harvest

3. Frozen apple slices processed after 2 month storage

fresh harvest and 2 month storage of McIntosh, Red Delicious, and Empire (Early). It has been reported that McIntosh produces watery texture, and dull color for sauce, but it has a high aromatic flavor. Therefore, it is usually blended with other cultivars (Thomas and Ritter, 1958).

Frozen apple slices

USDA grade A frozen apple slices were derived from both after fresh harvest and 2 month storage of Golden Delicious, Jonathan, Gala, Honeycrisp, and Rome. Desrosier and Tressler (1977) have agreed that Jonathan, Rome and Golden Delicious have been the topping list as to frozen quality. Jonagold, Cortland, and Idared produced USDA grade A frozen apple slices if they were processed immediately after fresh harvest, while they produced USDA grade C frozen slices after 2 month storage. However, Empire (Early) produced USDA grade C frozen slices if processed after 2 month storage; additionally, it produced USDA substandard frozen slices if processed after fresh harvest. USDA Grade C frozen apple slices were derived from both after fresh harvest and 2 month storage of Empire (Middle), Empire (Late), McIntosh, and Northern Spy. It has been reported that McIntosh and Cortland tended to disintegrate even when packed soon after harvest (Desrosier and Tressler 1977). In contrast, laboratory tests rated Northern Spy as excellent for all forms of slices and sauce (Way and McLellan, 1989). Red Delicious produced USDA substandard frozen slices.

Table 25 shows descending rank order for quality score of applesauces and frozen apple slices processed from 15 apple selections after fresh harvest and after 2 month storage. Mutsu produced the best applesauces both processed after fresh and 2 month storage. The top five applesauces processed after fresh harvest were mutsu, Red Delicious, Gala, Jonagold, and Empire (Late); while top five applesauces processed after 2 month storage were Mutsu, Jonagold, Empire (Late), Empire (Early), and McIntosh, respectively. Golden Delicious as industrial standard was ranked the eighth when processed after fresh harvest and the ninth when processed after 2 month storage. The top five frozen apple slices processed after fresh harvest were Jonathan, Cortland, Idared, Northern Spy, and Golden Delicious; while top five applesauces processed after 2 month storage were Gala, Jonathan, Red Delicious, Northern Spy, and Cortland, respectively.

Figure 11 shows color quality for applesauces when processed after fresh harvest. As described previously, good quality applesauce presents bright (high lightness value) and golden color (high hue angle). Most applesauces showed high color quality except for Rome, Honeycrisp, and Gala. After 2-month storage, most applesauces showed high color quality except for Honeycrisp, Gala and Idared showed medium color quality and Rome showed low color quality. Idared showed medium color quality with decreased hue angle.

Table 25. Descending rank order for quality score of applesauces¹ and frozen apple slices² processed from 15 apple selections (control³, 2 months⁴)

Applesauces		Frozen apple slices	
Control	2 months	Control	2 months
Mutsu (16.0)	Mutsu (16.0)	Jonathan (18.3)	Gala (15.2)
Red D. (15.7)	Jonagold (15.9)	Cortland (17.8)	Jonathan (13.6)
Gala (14.9)	Red D. (15.7)	Idared (16.3)	Red D. (12.5)
Empire (L) (14.9)	Empire (L) (15.6)	N. Spy (15.1)	N. Spy (12.2)
Jonagold (14.1)	Empire (E) (15.0)	Golden D. (15.0)	Cortland (12.1)
McIntosh (13.3)	McIntosh (14.2)	Rome (14.7)	Idared (11.6)
Idared (13.2)	Empire (M) (13.6)	Gala (13.9)	Golden D. (11.5)
Golden D. (13.1)	Cortland (12.4)	Red D. (13.3)	Jonagold (10.9)
Rome (12.6)	Golden D. (12.2)	Empire (M) (13.1)	Rome (8.5)
Empire (M) (12.2)	Gala (11.9)	Jonagold (13.0)	Empire (E) (8.2)
Honeycrisp (10.8)	Idared (11.8)	Empire (E) (10.2)	Empire (M) (8.2)
Jonathan (10.7)	N. Spy (10.8)	Empire(L) (9.3)	Empire (L) (8.2)
Empire (E) (10.5)	Jonathan (10.7)	McIntosh (7.5)	Honeycrisp (6.9)
N. Spy (10.4)	Honeycrisp (8.9)	Hoenycrisp (7.4)	McIntosh (5.4)
Cortland (10.1)	Rome (8.5)	Mutsu ⁵	Mutsu ⁵

1. Multiple regression equation:
quality score = 0.16(Sugar/acid ratio) - 3.25(Consistency) + 0.11(Lightness) - 0.04(Hue angle) + 16.30
2. Multiple regression equation:
quality score = 0.12(Sugar/acid ratio) + 0.004(Shear resistance) + 0.17(Drained weight) + 0.17(Lightness) - 17.71
3. Applesauces processed after fresh harvest
4. Applesauces processed after 2 month storage
5. Unavailable selection

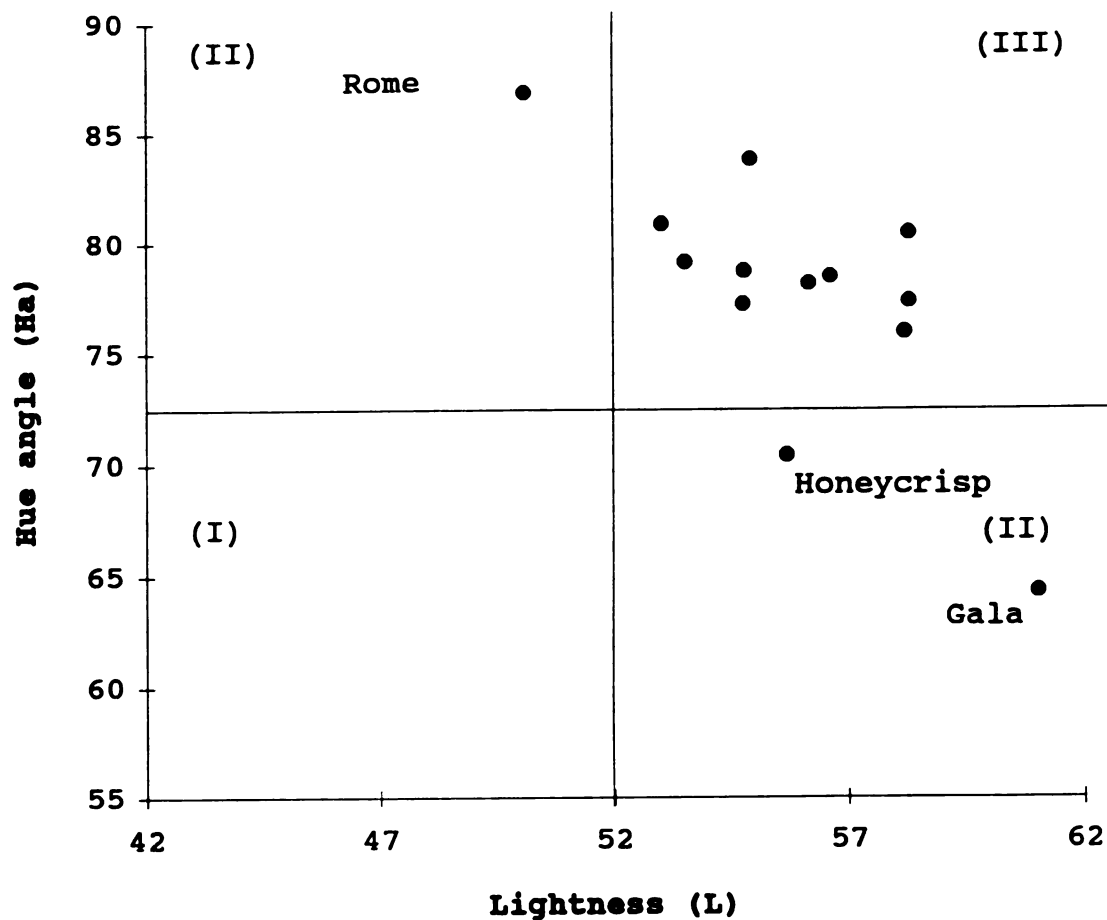


Figure 11. Color quality of applesauces processed from fresh harvest apples [(I) = low color quality, (II) = medium color quality, (III) = high color quality]
 Note: Preferred color quality for applesauce is high lightness value (L) and high hue angle (H_a).

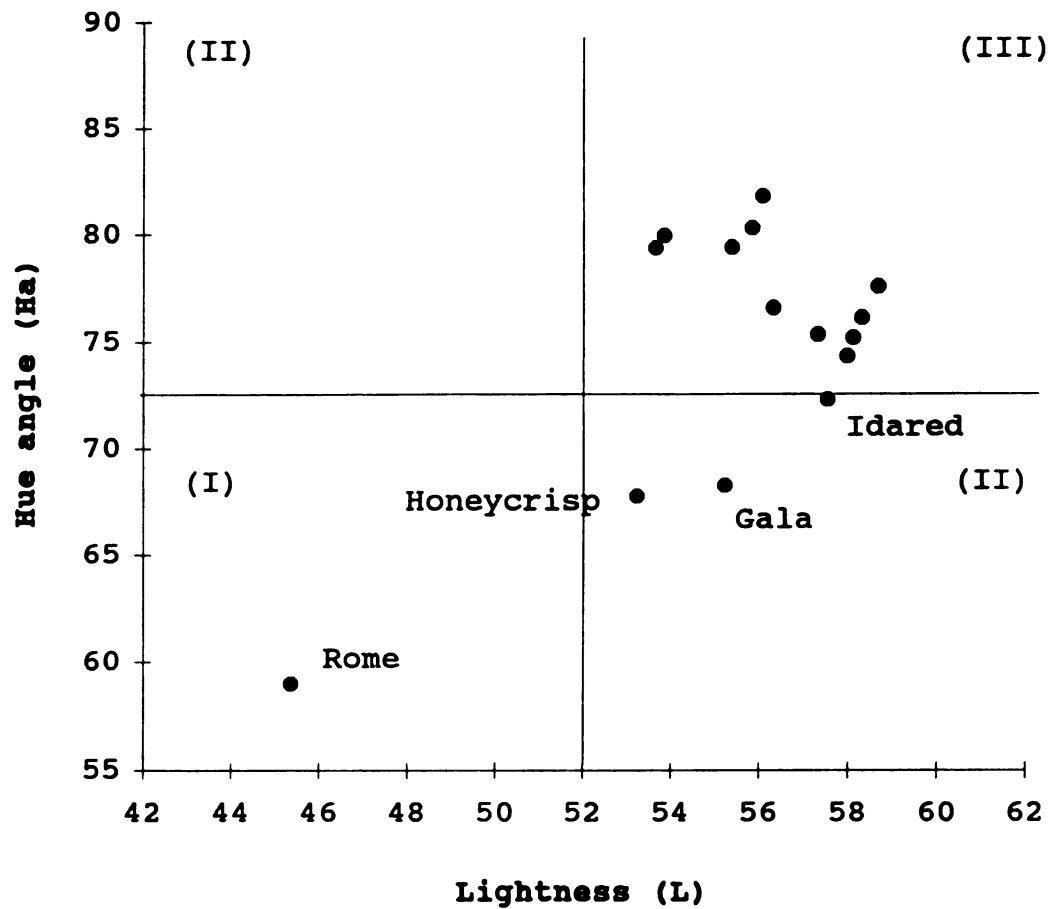


Figure 12. Color quality of applesauces processed from 2-month stored apples [(I) = low color quality, (II) = medium color quality, (III) = high color quality]
 Note: Preferred color quality for applesauce is high lightness value (L) and high hue angle (H_a).

Figure 12 shows color quality for applesauces when processed after 2-month storage.

Sensory Evaluations of Applesauces

Triangle test

Correct identifications of applesauces processed from 15 apple selections were presented in Table 26. Panelists were able to detect the differences between applesauces processed after fresh harvest and after 2 month storage from all apple selections except for Red Delicious and Golden Delicious.

Scaling tests

Table 27 shows color perception mean values of apple sauces. Evaluation of the color perceptions used a paired t-test where panelists attempted to detect the color differences between applesauces processed after fresh harvest and 2 month storage in Empire (Early) ($P \leq 0.01$), Empire (Middle) ($P \leq 0.05$), Golden Delicious ($P \leq 0.05$), Northern Spy ($P \leq 0.05$), and Gala ($P \leq 0.05$). Color perceptions of Empire (Early), Empire (Middle), and Northern Spy scored higher after 2 month cold storage, while those of Golden Delicious and Gala scored lower.

Table 28 shows flavor perception mean values of apple sauces. Evaluation of the flavor perceptions also used a paired t-test. Panelists were able to detect the flavor differences between applesauces processed after fresh

Table 26. Comparison of detectable difference of applesauces between control¹ and two month storage² from traditional, recent, and new varieties in triangle test

Category	Selection	Correct identifications
Traditional varieties	Red Delicious	7 from 12 panelists ^{NS}
	Golden Delicious	7 from 12 panelists ^{NS}
	Jonathan	10 from 12 panelists***
	Cortland	8 from 12 panelists*
	Idared	11 from 12 panelists***
	Rome	8 from 12 panelists*
	Northern Spy	7 from 11 panelists*
	McIntosh	11 from 11 panelists***
Recent varieties	Empire (Late)	7 from 10 panelists*
	Empire (Middle)	9 from 10 panelists***
	Empire (Early)	10 from 10 panelists***
	Mutsu	7 from 11 panelists*
New varieties	Jonagold	8 from 12 panelists*
	Honeycrisp	8 from 12 panelists*
	Gala	8 from 12 panelists*

1. Control sample was applesauce processed after fresh harvest
2. 2 month storage sample was applesauce processed after 2 month storage
3. NS (non-significant difference): The panelists were not likely to be able to detect the difference between apple sauce processed after harvest and apple sauce processed after 2 months storage.
4. * The panelists were likely to detect the difference between apple sauce processed after harvest and apple sauce processed after 2 month storage at the critical value of $P=0.05$.
5. ** The panelists were likely to detect the difference between apple sauce processed after harvest and apple sauce processed after 2 month storage at the critical value of $P=0.01$.

Table 27. Comparison of color perception mean values¹ for applesauce sensory evaluation from traditional, recent, and new varieties (control², 2 month storage³) in scaling tests⁴

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Golden Delicious	7.17	3.67	5.20**
	Red Delicious	6.00	3.17	2.37
	Northern Spy	6.00	7.16	3.80*
	Idared	5.00	6.00	1.12
	Jonathan	3.50	2.83	1.35
	Cortland	2.50	3.33	1.54
	McIntosh	2.50	2.33	0.24
	Rome	2.33	1.83	1.46
Recent varieties	Mutsu	7.50	5.83	1.68
	Empire (Late)	6.00	6.17	0.24
	Empire (Middle)	5.67	6.50	2.71*
	Empire (Early)	3.50	5.67	4.54**
New varieties	Honeycrisp	5.83	6.17	0.47
	Gala	5.33	3.67	2.99*
	Jonagold	4.33	3.33	2.24
LSD _{0.05} ⁵		3.94	3.72	

1. n=6, t-test, * = significant at t calculated value ≥ 2.57 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 4.03 ($t_{0.01}$ tabulated value)
2. Applesauce processed after fresh harvest
3. Applesauces processed after 2 month storage
4. The score ranged from 1 to 9 (1 = not bright, 9 = extremely bright)
5. n=6, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

harvest and 2 month storage only in Cortland. Cortland with 2-month storage produced applesauce scoring significantly

Table 29 shows texture perception mean values of apple sauces. Evaluation of the texture perceptions also used the paired t-test. Panelists were able to detect the texture differences between applesauces processed after fresh harvest and 2 month storage only in Mutsu. Mutsu with 2-month storage produced applesauce scoring significantly lower than applesauce produced from fresh harvest Mutsu ($P \leq 0.05$).

The analysis of variance for three sensory attributes in scaling tests is presented in Table 30. Significant differences due to selection were found in color and flavor, while due to storage were found in texture. It could be interpreted that longer storage time yield smaller particle size, therefore affecting applesauce consistency (Lanza and Kramer 1967). This results of experiment agreed with Wiley and Toldby (1960); who studied factors affecting the quality of canned applesauce including storage time. They found that flavor was not affected by storage, but color and texture improved up to at least 50% of the storage life of the cultivars. McLellan and Massey (1984) who studied effect of post harvest storage and ripening of apple on sensory quality of processed applesauce supported that flavor was not affected by storage, ripening, or cultivar, but color was significantly influenced by those three factors. Texture was not altered significantly due to

Table 28. Comparison of flavor perception mean values¹ for applesauce sensory evaluation from traditional, recent,³ and new varieties (control², 2 month storage³) in scaling tests⁴

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	McIntosh	6.50	6.50	0.00
	Golden Delicious	6.00	5.33	0.93
	Red Delicious	5.67	4.67	2.24
	Jonathan	5.67	4.67	0.76
	Northern Spy	5.33	6.00	0.79
	Idared	4.50	5.17	1.20
	Cortland	4.50	5.17	3.16*
	Rome	4.33	4.17	0.17
Recent varieties	Mutsu	5.33	6.33	0.70
	Empire (Late)	6.50	5.00	1.77
	Empire (Middle)	5.50	5.33	0.25
	Empire (Early)	4.17	4.83	0.67
New varieties	Gala	5.50	4.83	0.79
	Honeycrisp	4.67	4.33	0.32
	Jonagold	4.33	3.33	2.24
LSD _{0.05} ⁵		3.02	4.03	

1. n=6, t-test, * = significant at t calculated value ≥ 2.57 ($t_{0.05}$ tabulated value)
2. Applesauce processed after fresh harvest
3. Applesauces processed after 2 month storage
4. The score ranged from 1 to 9 (1 = extremely undesirable, 9 = extremely desirable).
5. n=6, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Table 29. Comparison of texture perception mean values¹ for applesauce sensory evaluations from traditional, recent, and new varieties (control², 2 month storage³) in scaling tests⁴

Category	Selection	Control	2 month storage	Calculated t
Traditional varieties	Golden Delicious	6.50	4.33	2.38
	McIntosh	5.33	4.17	1.19
	Jonathan	5.50	4.83	0.83
	Northern Spy	5.33	5.67	1.00
	Rome	5.17	4.83	0.40
	Red Delicious	5.17	4.83	0.54
	Cortland	4.33	4.83	0.70
	Idared	4.00	4.83	1.11
Recent varieties	Mutsu	7.17	5.17	2.92*
	Empire (Late)	5.67	5.17	0.81
	Empire (Early)	5.00	5.00	0.00
	Empire (Middle)	4.83	4.50	1.00
New varieties	Gala	5.33	4.00	2.17
	Jonagold	5.17	4.67	2.24
	Honeycrisp	4.50	5.00	1.46
LSD _{0.05} ⁵		2.62	3.56	

1. n=6, t-test, * = significant at t calculated value ≥ 2.57 ($t_{0.05}$ tabulated value)

2. Applesauce processed after fresh harvest

3. Applesauces processed after 2 month storage

4. The score ranged from 1 to 9 (1 = not thick, 9 = extremely thick)

5. n=6, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Table 30. Analysis of variance for sensory evaluations (scaling tests) of applesauces from 15 apple selections

Sources of variation	df	Color	Flavor	Texture
Mean squares ¹				
<u>Main effects</u>				
selection ²	14	27.85**	5.87*	2.44
storage ³	1	6.05	1.61	10.27*
<u>Interaction</u>				
selection X storage	14	7.12**	1.83	2.36
Error	150	3.33	2.97	2.22
% CV		50.30	34.28	30.13

1. * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$

2. Apple selections include: Red Delicious, Golden Delicious, McIntosh, Jonathan, Jonagold, Gala, Empire(at early harvest season), Empire(at middle harvest season), Empire(at late harvest season), Cortland, Northern Spy, Idared, Rome, Honeycrisp, and Mutsu

3. Storages include: no storage(control), and 2 month storage

storage, but cultivar and ripening.

Acceptance tests

Acceptance score mean values for each sensory attribute are presented in Table 31 to Table 34 with least significant difference (LSD) mean separations reported. The analysis of variance for four sensory attributes: color, texture, sweetness, and general acceptance; is presented in Table 35. Significant differences among selections were found for color ($P \leq 0.05$), sweetness ($P \leq 0.05$), and general acceptance ($P \leq 0.05$). The results of acceptance test agreed with that of scaling test on color perception, but disagreed on texture perception. The results of sweetness acceptance contradicted with results of McLellan and Massey (1984) in which perceived sweetness of applesauce was not significantly affected by cultivar.

Figure 13 to Figure 16 show sensory acceptance for each attribute of applesauce from 15 apple selections. Golden Delicious applesauce obtained the highest acceptance score for all attributes except for sweetness. Empire applesauce harvested at late season obtained the highest score for sweetness. However, there were no significant differences in sweetness score among the highest four apple selections: Empire (Late), Mutsu, Golden Delicious, and Empire (Middle). There were no significant differences detected for texture among all applesauces from 15 selections. Mutsu received the second highest color and general acceptance score.

Table 31. Comparison of color preference mean values¹ for applesauce² sensory evaluation from traditional, recent, and new varieties in acceptance tests³

Category	Selection	Mean value	STD ⁴
Traditional varieties	Golden Delicious	7.03	1.50
	Jonathan	5.67	1.42
	Red Delicious	5.00	1.64
	Northern Spy	5.00	1.34
	Cortland	4.30	1.90
	Idared	4.30	1.76
	Rome	3.70	1.95
	McIntosh	3.17	1.44
Recent varieties	Mutsu	6.40	1.89
	Empire (Middle)	5.60	1.45
	Empire (Late)	5.50	1.43
	Empire (Early)	4.43	1.68
New varieties	Honeycrisp	5.97	1.75
	Gala	5.13	1.81
	Jonagold	3.37	1.67

LSD_{0.05}

1.39

1. n=30, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties
2. Applesauces processed after fresh harvest only
3. The score ranged from 1 to 9 (1 = least desirable, 9 = most desirable).
4. Standard deviation

Table 32. Comparison of texture preference mean values¹ for applesauce² sensory evaluation from traditional, recent, and new varieties in acceptance tests³

Category	Selection	Mean value	STD ⁴
Traditional varieties	Golden Delicious	5.60	1.57
	Idared	5.27	1.51
	Rome	5.17	1.74
	Red Delicious	5.07	2.32
	Northern Spy	4.97	1.45
	McIntosh	4.90	2.04
	Jonathan	4.50	1.70
	Cortland	4.63	2.03
Recent varieties	Empire (Late)	5.47	1.20
	Mutsu	5.43	1.91
	Empire (Middle)	5.33	1.56
	Empire (Early)	5.20	1.58
New varieties	Jonagold	5.50	1.66
	Honeycrisp	5.43	1.76
	Gala	5.17	2.53
LSD _{0.05}		1.47	

1. n=30, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

2. Applesauces processed after fresh harvest only

3. The score ranged from 1 to 9 (1 = least desirable, 9 = most desirable).

4. Standard deviation

Table 33. Comparison of sweetness preference mean values¹ for applesauce² sensory evaluation from traditional, recent, and new varieties in acceptance tests³.

Category	Selection	Mean value	STD ⁴
Traditional varieties	Golden Delicious	5.37	1.71
	Rome	4.63	1.77
	Red Delicious	4.00	1.86
	Idared	3.90	1.45
	Northern Spy	3.53	1.41
	Cortland	3.27	1.86
	Jonathan	3.23	1.48
	McIntosh	3.13	1.68
Recent varieties	Empire (Late)	5.53	1.59
	Mutsu	5.40	1.83
	Empire (Middle)	5.07	1.57
	Empire (Early)	4.67	1.21
New varieties	Jonagold	4.47	1.85
	Gala	4.07	2.20
	Honeycrisp	4.00	1.31
LSD _{0.05}		1.41	

1. n=30, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

2. Applesauces processed after fresh harvest only

3. The score ranged from 1 to 9 (1 = least desirable, 9 = most desirable).

4. Standard deviation

Table 34. Comparison of general acceptance mean values¹ for applesauce² sensory evaluation from traditional, recent, and new varieties in acceptance tests³.

Category	Selection	Mean value	STD ⁴
Traditional varieties	Golden Delicious	6.20	1.65
	Red Delicious	4.83	1.90
	Idared	4.70	1.42
	Rome	4.47	1.96
	Northern Spy	4.30	1.42
	Jonathan	4.17	1.44
	Cortland	3.90	1.65
	McIntosh	3.70	1.73
Recent varieties	Mutsu	5.70	1.73
	Empire (Late)	5.63	1.10
	Empire (Middle)	5.60	1.45
	Empire (Early)	5.03	1.19
New varieties	Honeycrisp	5.10	1.49
	Gala	4.73	1.55
	Jonagold	4.10	1.67
LSD _{0.05}		1.32	

1. n=30, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

2. Applesauces processed after fresh harvest only

3. The score ranged from 1 to 9 (1 = least desirable, 9 = most desirable).

4. Standard deviation

Table 35. Analysis of variance for sensory evaluations (acceptance test) of applesauces from 15 apple selections

Sources of variation	df	Color	Sweetness	Texture	General acceptance
Mean squares ¹					
<u>Main effects</u>					
selections ²	14	36.661**	19.876**	3.040	16.146**
Error	435	2.734	2.789	3.243	2.471
% CV		4.97	5.18	4.28	4.81

- * = significant at $P \leq 0.05$, **=significant at $P \leq 0.01$
- Apple selections include: Red Delicious, Golden Delicious, McIntosh, Jonathan, Jonagold, Gala, Empire(at early harvest season), Empire(at middle harvest season), Empire(at late harvest season), Cortland, Northern Spy, Idared, Rome, Honeycrisp, and Mutsu
- Storages include: no storage(control), and 2 month storage

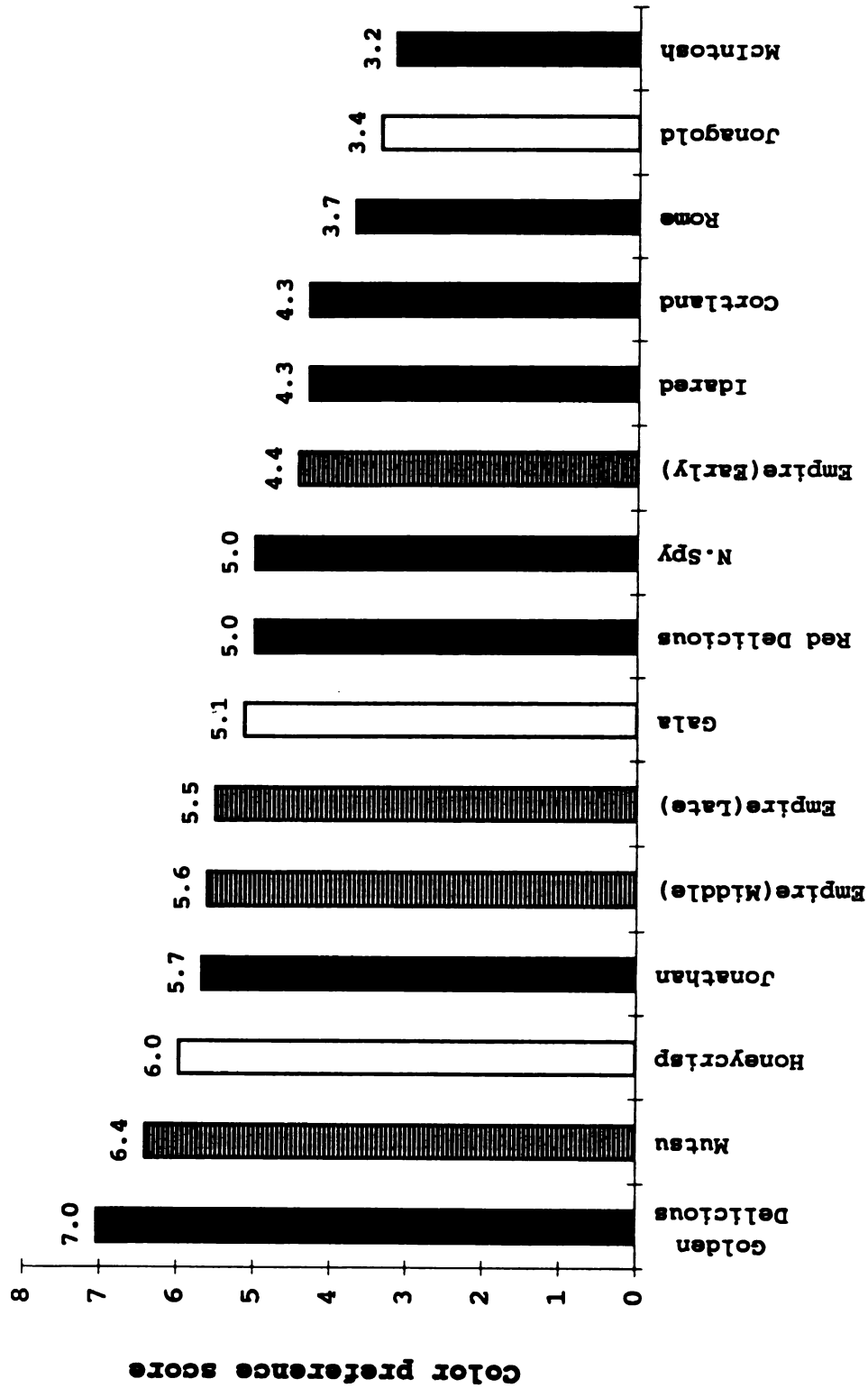


Figure 13. Comparison of color preference score means values for applesauces from 15 apple selections processed after fresh harvest. (9-point scale: 1 = least desirable and 9 = most desirable)

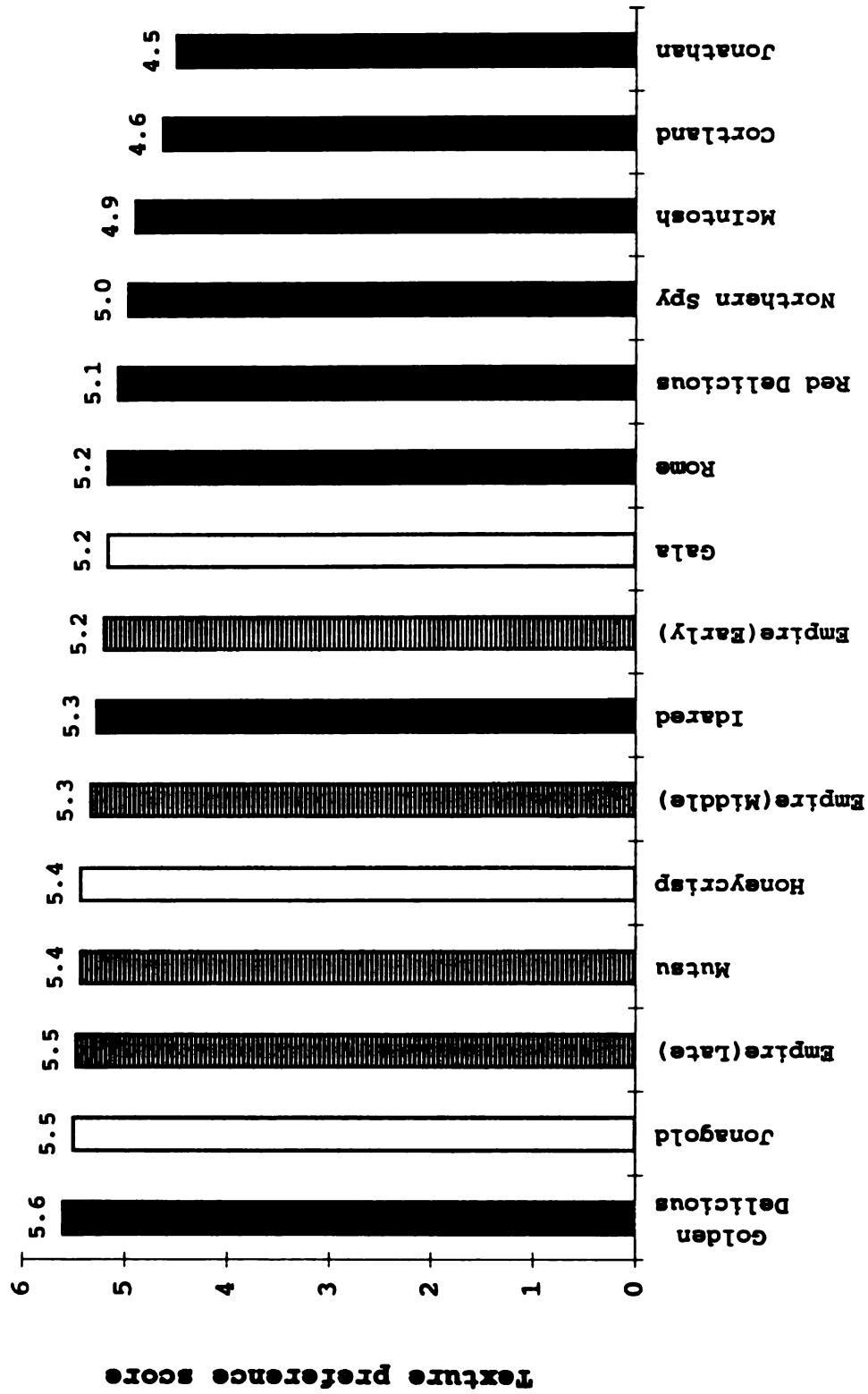


Figure 14. Comparison of texture preference score means values for applesauces from 15 apple selections processed after fresh harvest. (9-point scale: 1 = least desirable and 9 = most desirable)

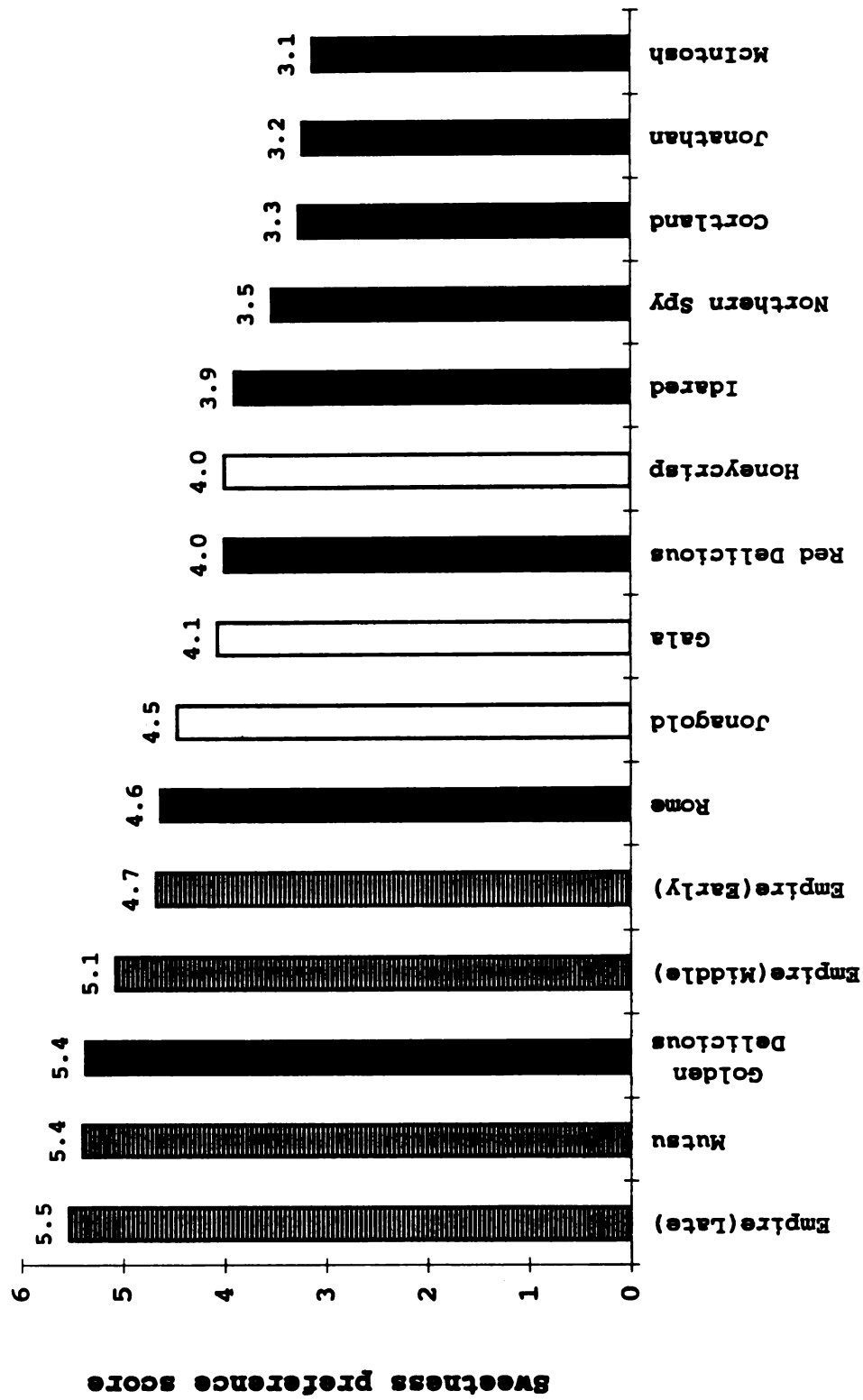


Figure 15. Comparison of sweetness preference score means values for applesauces from 15 apple selections processed after fresh harvest. (9-point scale: 1 = least desirable and 9 = most desirable)

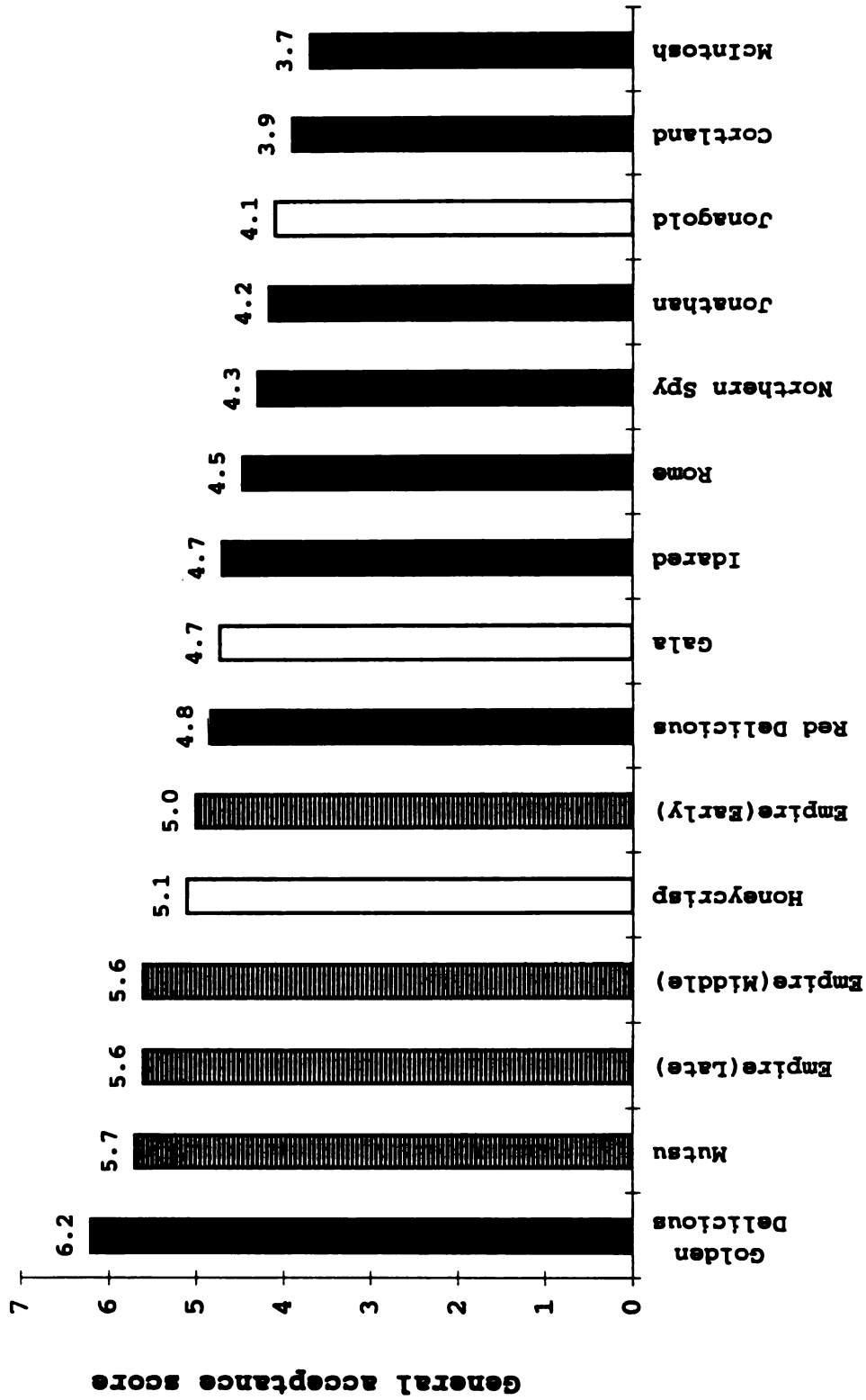


Figure 16. Comparison of general acceptance score means values for applesauce from 15 apple selection processed after fresh harvest. (9-point scale: 1 = least desirable and 9 = most desirable)

sweetness. However, there were no significant differences in sweetness score among the highest four apple selections: Empire (Late), Mutsu, Golden Delicious, and Empire (Middle). There were no significant differences detected for texture among all applesauces from 15 selections. Mutsu received the second highest color and general acceptance score.

SUMMARY AND CONCLUSIONS

Chemical and physical analyses of applesauces from traditional, recent, and new varieties showed significant differences in chemical and physical characteristics including sugar/acid ratios, consistencies, lightness values, greenness values, and yellowness values. The applesauces processed after fresh harvest were compared. Red Delicious showed the highest sugar/acid ratio. Mutsu showed the highest consistency. Gala showed the highest lightness value. Honeycrisp showed the highest greenness value. Mutsu showed the highest yellowness value.

Storage of apples (2 months in 1.1 °C/34 °F) had significant effect on all characteristics including sugar/acid ratio, consistency, lightness value, greenness value, and yellowness value. Most selections showed higher sugar/acid ratios except for Red Delicious which showed significantly lower sugar/acid ratio. Significantly lower consistencies were shown in applesauces produced from Red Delicious, Idared, Honeycrisp and Gala apples, while significantly higher consistencies were shown in applesauces produced from Cortland, Rome, Empire (Early), Empire (Middle) and Jonagold. Significantly higher lightness

values were shown in applesauces produced from Idared, Empire (Middle), Empire (Early) apples, while significantly lower lightness values were shown in applesauces made from Rome, Gala, Jonagold, and Honeycrisp. Most applesauce selections showed lower greenness values except for applesauces made from Idared, Empire (Late), Empire (Middle), Empire (Early) apples which showed significantly higher greenness values. Most selections produced lower yellowness values except for applesauces made from Empire (Early) and Empire (Middle) apples which showed significant higher yellowness values.

Sensory evaluations of applesauces included triangle test, scaling tests, and acceptance tests. Triangle test showed that panelists were able to detect the differences between applesauces processed after fresh harvest and those which were processed after two-month storage for all selections except Red Delicious and Golden Delicious. The scaling tests showed that panelists were able to detect the differences of color and flavor among the 15 selections. The scaling tests also showed that the panelists were able to detect differences of texture after two-month storage. From the scaling test, Mutsu scored brightest in color and thickest in texture; McIntosh and Empire (Late) scored most desirable in flavor. The acceptance tests showed that panelists were able to detect the differences in color, sweetness, and general acceptance among the 15 selctions. From the acceptance test, Golden Delicious scored most

desirable in color, texture and general acceptance; Empire (Late) scored most desirable in sweetness.

Chemical and physical analyses of frozen apple slices from traditional, recent, and new varieties showed significant differences in chemical and physical characteristics including sugar/acid ratios, shear resistances, drained weights, lightness values, greenness values, and yellowness values. The frozen apple slices processed after fresh harvest were compared. Red Delicious showed the highest sugar/acid ratio. Cortland showed the highest shear resistance. Jonathan showed the highest drained weight and lightness. Northern Spy showed the highest greenness value. Jonagold showed the highest yellowness value.

Storage time (2 months in 1.1 °C/34 °F) had significant effects on most characteristics including sugar/acid ratio, shear resistance, lightness value, and yellowness value except for greenness value. Most selections showed higher sugar/acid ratios except for Empire (Early). All selections showed lower shear resistance. Only Idared, Rome, McIntosh and Empire (early) showed significantly lower drained weights. Only Empire (Early) showed significant increase in lightness value when compared to the fresh harvest products. Red Delicious, Empire (Early), and Honeycrisp showed significantly higher greenness values. Most selections showed higher yellowness values except for Jonagold.

Using Multiple regression equations to present rank order of quality score for applesauces and frozen apple slices, Mutsu produced the best quality applesauce when both processed after fresh and after 2 month storage. Jonathan produced the best quality frozen apple slices when processed after fresh harvest, while Gala produced the best quality frozen apple slices when process after 2 month storage.

**STUDY II: ASSESSING THE INFLUENCE OF AMINOETHOXYVINYL-
GLYCINE (AVG) ON PROCESSING QUALITY OF ADULT
APPLESAUCE FROM CONTROLLED ATMOSPHERE STORAGE**

Introduction

Apples for processing are rarely utilized immediately after removal from the trees for many reasons: the intention to permit further ripening of the fruit to make them more suitable for manufacturing of a particular finished product, the necessity of using up previously harvested fruit to avoid excessive spoilage, or simply the need to lengthen the processing season.

Controlled atmosphere (CA) storage has been a successful invention for delaying the senescence of apples. Ripening of many apples cultivars is almost stopped for months in CA storage (Manhart, 1995). There have been numerous studies regarding CA storage of apples (Blanpied and Smock 1983; Meheriuk 1985; Patchen 1971; Ryall and Penzer 1981; Smock and Neubert 1950).

Aminoethoxyvinylglycine (AVG) is another agent used to control the ripening processes of apple fruits. A number of papers have shown that AVG inhibited ethylene biosynthesis, resulting in delaying of ripening, respiration, and pre-harvest drop in apples (Bufler et al. 1984; Child et al. 1984; Bramlage et al. 1980; Ness et al. 1980; Bangerth et al. 1978; Liebermann et al. 1974).

The objectives of this study was to analyze and evaluate the processing qualities of applesauces processed from apples stored under controlled atmosphere and treated with aminoethoxyvinylglycine (AVG).

MATERIALS AND METHODS

SOURCES OF MATERIALS AND SAMPLE PREPARATIONS

This experiment was conducted to assess the processing quality of adult applesauces processed from Jonagold apples with and without AVG treatment. The effect of maturity was also studied.

Apples

Jonagold apples with nine representative harvest dates were used. The nine harvest dates included 16 Sep, 19 Sep, 23 Sep, 26 Sep, 30 Sep, 3 Oct, 7 Oct, 10 Oct, and 14 Oct representing early, middle, and late harvest season, respectively.

Experimental conditions

One-half of the apples for each harvest date were sprayed with 200 ppm aminoethoxyvinylglycine(AVG) 100 gallons/acre, approximately one month before harvest (20 Aug, 1996). Apple sprayed with AVG represented AVG-treated samples. The other half without AVG spray represented untreated controlled samples (UTC). Then all samples were stored in controlled atmosphere storage: 1.3-1.8% O₂, 2-4% CO₂, 0.1°C (32.18°F), and 99.8% relative humidity) until 6 months in the department of Horticulture, Plant and Soil Sciences Building, Michigan State University. The apples

were stored in the CA storage within 1-2 days from the day they were picked. After CA storage all samples were processed into adult applesauces.

Apple Processing

The apples were processed under the same conditions, and process as that for applesauces in study I.

PRODUCT QUALITY EVALUATION

The applesauce quality evaluations were the chemical-physical analyses (objective measurements), which were conducted the same manner as those for applesauces in part I. The chemical-physical analyses (objective measurements) included soluble solids, acidity/pH, color, and consistency.

STATISTICAL ANALYSIS

The effects of AVG treatment and maturity of apple on chemical-physical processing qualities of applesauce were analyzed using the analysis of variance (ANOVA) of the statistical program, Stat View for window, version 4.5. The chemical-physical processing qualities were analyzed as a two-way interaction ANOVA, with AVG treatment and maturity of apple. F values were reported. The significant level were set at $p \leq 0.05$ (*) and $p \leq 0.01$ (**). Coefficient of variation (%CV) expresses the standard deviation as a percent of the calculated mean.

The differences between chemical-physical processing qualities of each harvest date due to AVG treatment were

determined using the t-test statistical program (paired two sample for means), Microsoft excel for Window 95 (Ver.7). The two sets of data were evaluated by comparing the calculated t value with tabulated t value. When t (calculated) value is higher than t (tabulated) value, it indicated significant difference. The significant level were set at $p \leq 0.05$ (*), $p \leq 0.01$ (**), $p \leq 0.005$ (***), and $p \leq 0.001$ (****).

The correlations between sugar content of apple and sugar/acid ratios of applesauce due to AVG treatment, between red percentage of surface color of apple and greenness value of applesauce were determined using linear regression equation from graph creating program, Microsoft excel for Window 95 (Ver.7). The coefficient of determination (r^2) were reported.

RESULTS AND DISCUSSION

Table 36 shows sugar/acid ratio mean values of applesauces processed from untreated control (UTC) and Aminoethoxyvinylglycine treated (AVG) apples after 6 month in control atmosphere (CA) storage. Increasing maturity, due to sequential harvest dates, was related to increases in sugar/acid ratios. From early to late harvest dates, the sugar/acid ratios ranged from 26.73 to 33.84 °Brix/malic acid % in UTC samples and from 25.43 to 29.07 °Brix/malic acid %. Compared with AVG samples using paired t-test, UTC samples showed significantly higher sugar/acid ratios on 19 Sep ($P \leq 0.05$), 26 Sep ($P \leq 0.05$), 30 Sep ($P \leq 0.005$), 3 Oct ($P \leq 0.005$), 7 Oct ($P \leq 0.005$), 10 Oct ($P \leq 0.005$), and 14 Oct ($P \leq 0.001$). The significant differences for sugar/acid ratios between UTC and AVG samples were between middle and late of harvest season. Figure 17 shows comparison for sugar/acid ratios between UTC and AVG applesauces on sequential harvest dates. UTC applesauces showed higher sugar/acid ratio through all maturities. Increasing maturity resulted in increase in different degree.

Figure 18 shows linear regression between sugar content (°Brix) of fresh apples and sugar/acid ratio of applesauces

Table 36. Comparison of sugar/acid ratio¹ mean values² for applesauces³ from Jonagold apples on different harvest dates (AVG⁴, UTC⁵)

Harvest date	UTC	AVG	Calculated t
16.Sep.96	26.73	25.43	2.83
19.Sep. 96	27.91	25.76	7.80*
23.Sep.96	29.58	26.26	3.94
26.Sep.96	30.43	27.38	8.79*
30.Sep.96	31.54	27.65	17.30***
3.Oct.96	31.43	27.39	21.66***
7.Oct.96	32.01	28.59	19.24***
10.Oct.96	31.97	28.31	20.50***
14.Oct.96	33.84	29.07	51.34****
LSD _{0.05} ⁵	2.07	1.24	

1. °Brix/malic acid(%)
2. n=3, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)
3. Applesauces processed from Aminoethoxyvinylglycine (AVG) treated apples after 6 month in controlled atmosphere storage
4. Applesauces processed from untreated controlled apples after 6 month in controlled atmosphere storage
5. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

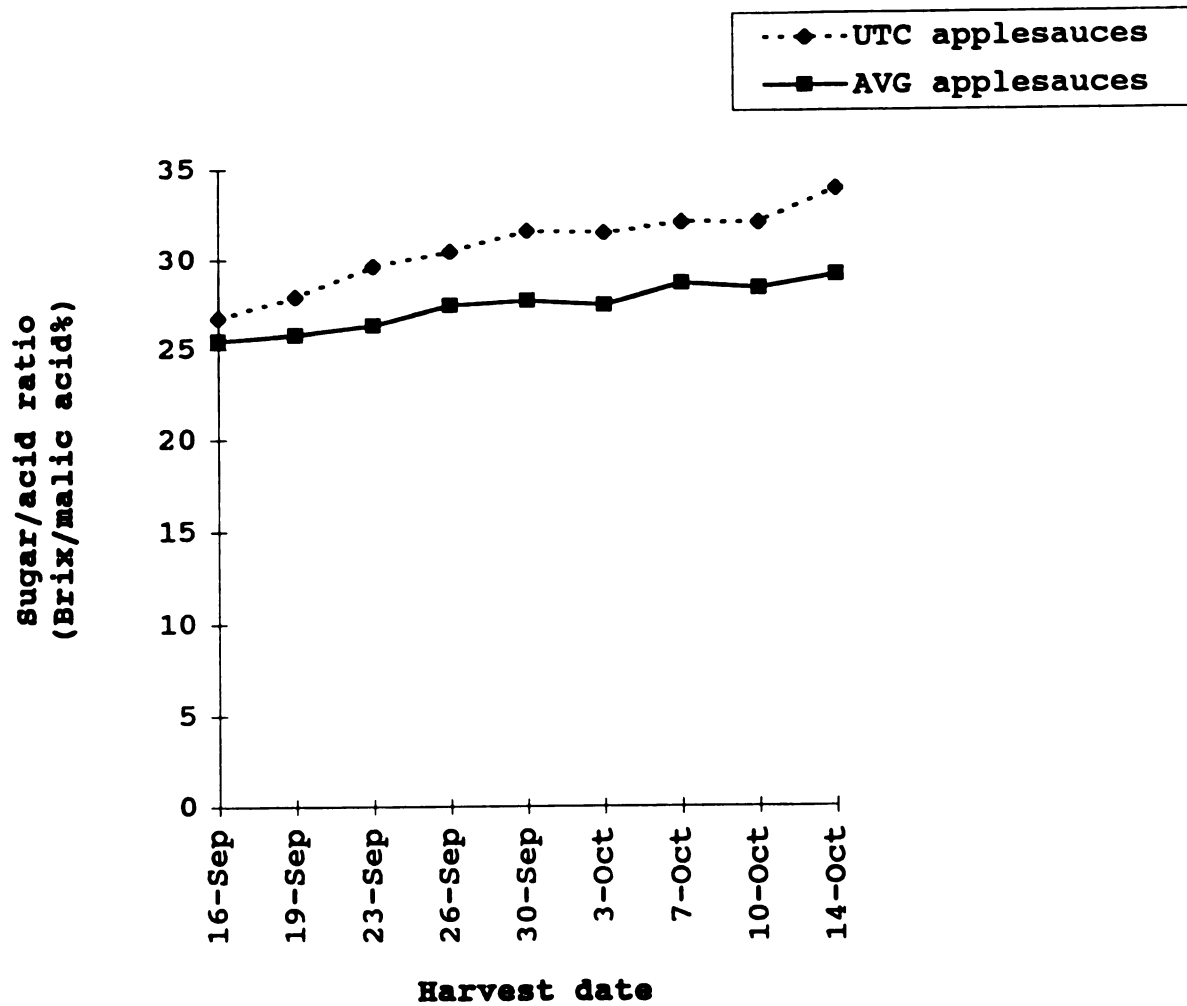


Figure 17. Comparison for sugar/acid ratios of applesauce processed from UTC and AVG apple on sequential harvest dates (UTC = Untreated controlled; AVG = AVG-treated)

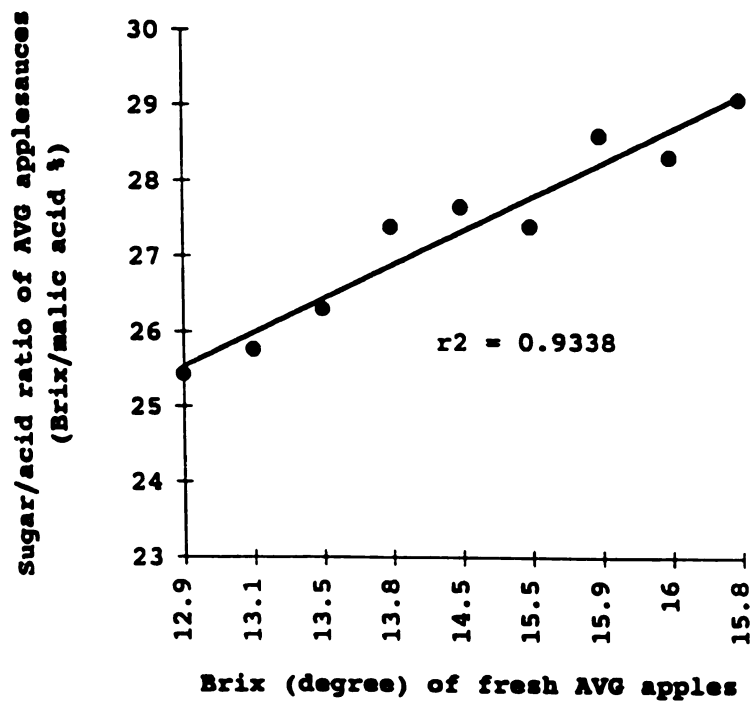
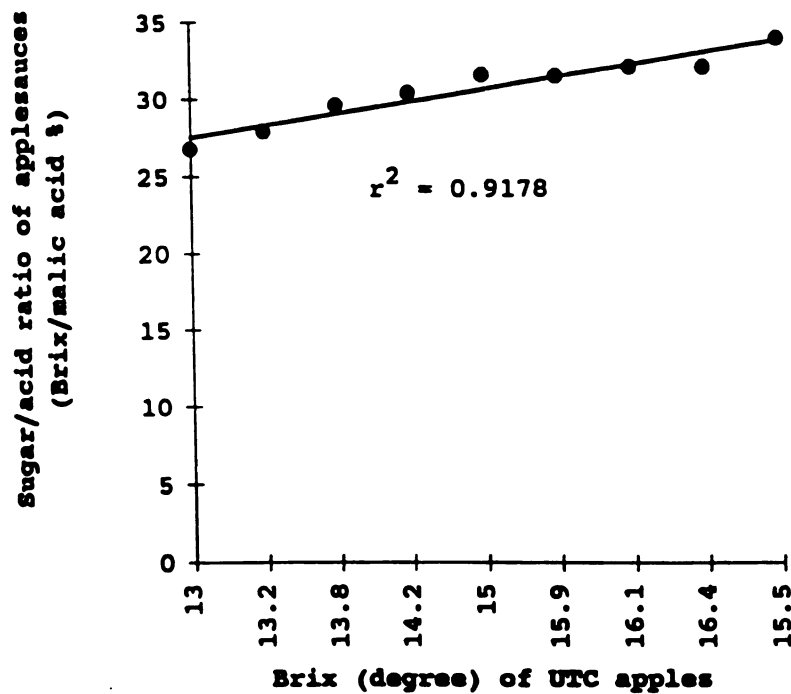


Figure 18. Linear relationship between sugar content ($^{\circ}$ Brix) of apples and sugar/acid ratio ($^{\circ}$ Brix /malic acid %) of applesaues processed from UTC and AVG apples (UTC = Untreated controlled; AVG = AVG-treated)

processed from UTC apples and AVG apples after 6 month in CA storage. Linear relationships were found for both UTC and AVG samples. The coefficient of determination (r^2) for UTC samples was 0.9178, and that for AVG samples was 0.9338. Therefore, we could use sugar content of fresh apples to predict sugar/acid ratio of processed applesauces.

Figure 19 shows comparison for total acidity between applesauces processed from UTC and AVG apples. Decreasing acidity followed sequential harvest dates in both UTC and AVG samples were observed. Chen and Mellenthin (1982) reported that the energy and carbon sources in fruit for the maintenance of living activities during long term storage must be contributed by organic acids rather than sugars after studying storage behavior of 'd' ANJOU' pears in low oxygen and air.

Table 37 shows consistency mean values of applesauces processed from UTC and AVG apples after 6 month in CA storage. Evaluation of the consistencies using a paired t-test showed that there were no significant differences between UTC and AVG samples on each sequential harvest date. However, the processing procedures that were conducted were included improvement of applesauce consistency using additions of their condensates to adjust final consistency. Table 38 shows lightness mean values (L) of applesauces from UTC and AVG apples after 6 month in CA storage. From evaluation of the lightness values using a paired t-test,

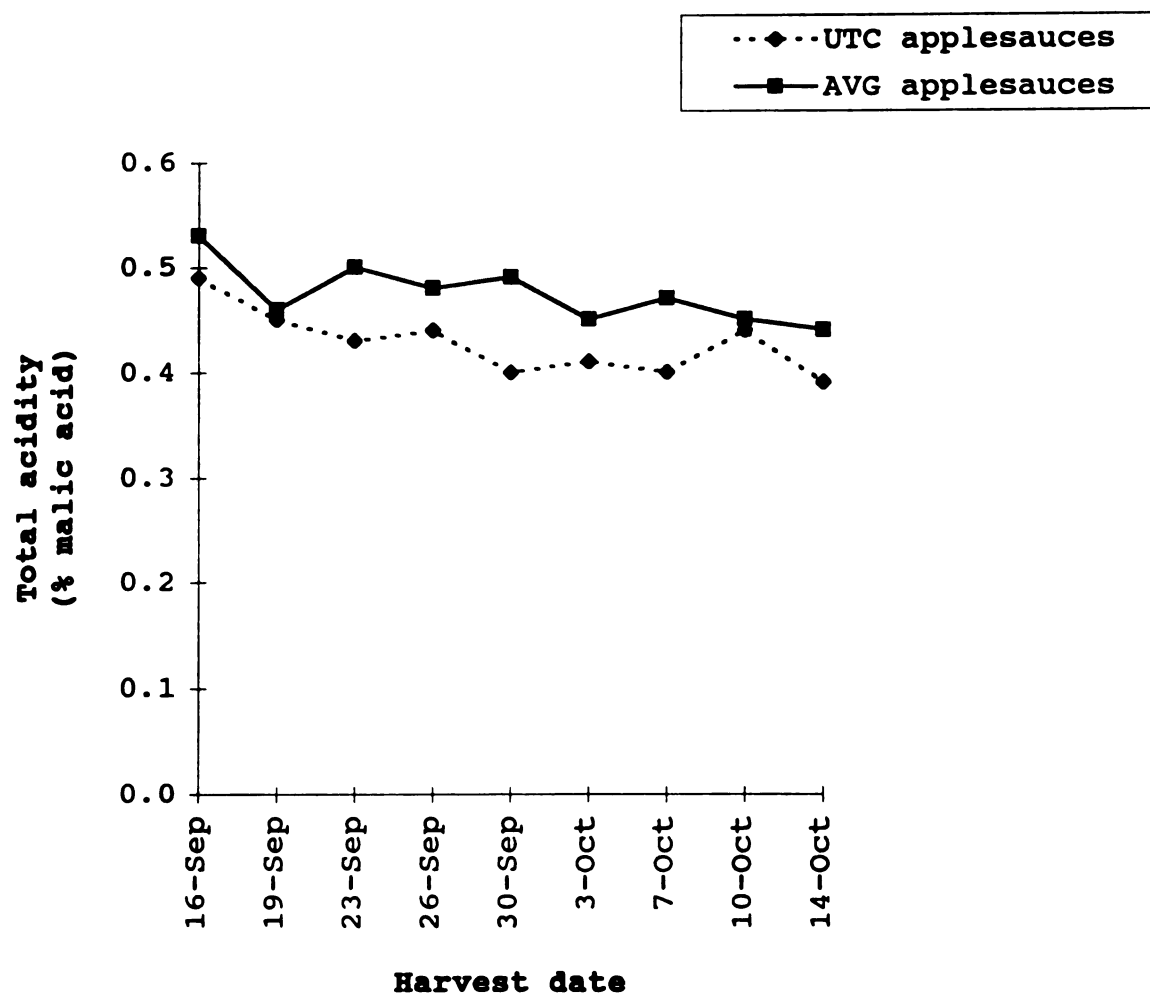


Figure 19. Comparison for total acidity (malic acid %) between applesauces processed from UTC and AVG apples (UTC = Untreated controlled; AVG = AVG-treated)

Table 37. Comparison of consistency¹ mean values² for applesauces³ from Jonagold apples on different harvest date (AVG⁴, UTC⁵)

Harvest date	UTC	AVG	Calculated t
16.Sep.96	4.17	3.85	3.80
19.Sep. 96	3.82	4.03	4.02
23.Sep.96	4.37	4.30	1.00
26.Sep.96	4.23	4.28	1.07
30.Sep.96	4.38	4.29	2.94
3.Oct.96	4.44	4.48	2.74
7.Oct.96	4.47	4.54	1.68
10.Oct.96	4.15	4.16	0.14
14.Oct.96	4.18	4.05	1.49
LSD _{0.05} ⁵	0.31	0.29	

1. USDA flow sheet (cm/minute); higher numbers indicate less limited flow (lower consistency)
2. n=3, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)
3. Applesauces processed from Aminoethoxyvinylglycine (AVG) treated apples after 6 month in controlled atmosphere storage.
4. Applesauces processed from untreated controlled apples after 6 month in controlled atmosphere storage.
5. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

Table 38. Comparison of lightness (L) mean values¹ for applesauces from Jonagold apples on different harvest date (AVG², UTC³)

Harvest date	UTC	AVG	Calculated t
16.Sep.96	55.73	55.60	0.61
19.Sep. 96	55.83	55.18	3.22
23.Sep.96	55.23	54.50	2.82
26.Sep.96	55.07	54.40	3.29
30.Sep.96	54.90	54.93	0.11
3.Oct.96	55.20	55.30	0.48
7.Oct.96	55.00	54.67	2.5
10.Oct.96	55.00	55.80	2.49
14.Oct.96	56.07	55.40	1.60
LSD _{0.05} ⁴	0.13	0.97	

1. n=3, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)
2. Applesauces processed from Aminoethoxyvinylglycine (AVG) treated apples after 6 month in controlled atmosphere storage.
3. Applesauces processed from untreated controlled apples after 6 month in controlled atmosphere storage.
4. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

the significant differences between UTC and AVG samples were not found on each sequential harvest date.

Table 39 shows greenness mean values ($-a_L$) of applesauces from UTC and AVG apples. Increasing maturity, due to sequential harvest dates, was related to decrease in greenness values. From early to late harvest dates, the greenness values ranged from -3.60 to -4.26 in UTC samples and from -4.03 to -4.53 in AVG samples. Evaluation of the greenness value using paired t-test, UTC samples showed significantly lower greenness values on 16 Sep ($P \leq 0.05$), 19 Sep ($P \leq 0.05$), 3 Oct ($P \leq 0.05$), 7 Oct ($P \leq 0.01$), and 10 Oct ($P \leq 0.05$) than AVG samples. The significant differences for greenness value were found between apples in the early and the late harvest season.

Figure 20 shows linear regression between %red on surface color of apples and greenness value of applesauces processed from UTC and AVG apples after 6 month in CA storage. The linear relationship were found for both UTC and AVG samples. The coefficient of determination (r^2) for UTC samples was 0.9443, and that for AVG samples was 0.7506. Therefore, we could use %red on surface color of apples to predict greenness value of processed applesauces. Figure 21 shows comparison for greenness values of UTC and AVG applesauces on sequential harvest dates. UTC applesauces showed lower greenness values through all maturities. However, increasing maturity resulted in decrease in

Table 39. Comparison of greenness ($-a_L$) mean values¹ for applesauces from Jonagold apples on different harvest date (AVG², UTC³)

Harvest date	UTC	AVG	Calculated t
16.Sep.96	-4.26	-4.53	8.00*
19.Sep. 96	-4.17	-4.40	7.00*
23.Sep.96	-4.00	-4.26	3.02
26.Sep.96	-3.90	-4.03	0.92
30.Sep.96	-3.80	-4.23	2.98
3.Oct.96	-3.67	-4.17	5.00*
7.Oct.96	-3.67	-4.03	11.00**
10.Oct.96	-3.63	-3.93	5.20*
14.Oct.96	-3.60	-4.03	2.60
LSD _{0.05} ⁴	0.32	0.45	

1. n=3, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)
2. Applesauces processed from Aminoethoxyvinylglycine (AVG) treated apples after 6 month in controlled atmosphere storage.
3. Applesauces processed from untreated controlled apples after 6 month in controlled atmosphere storage.
4. n=3, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

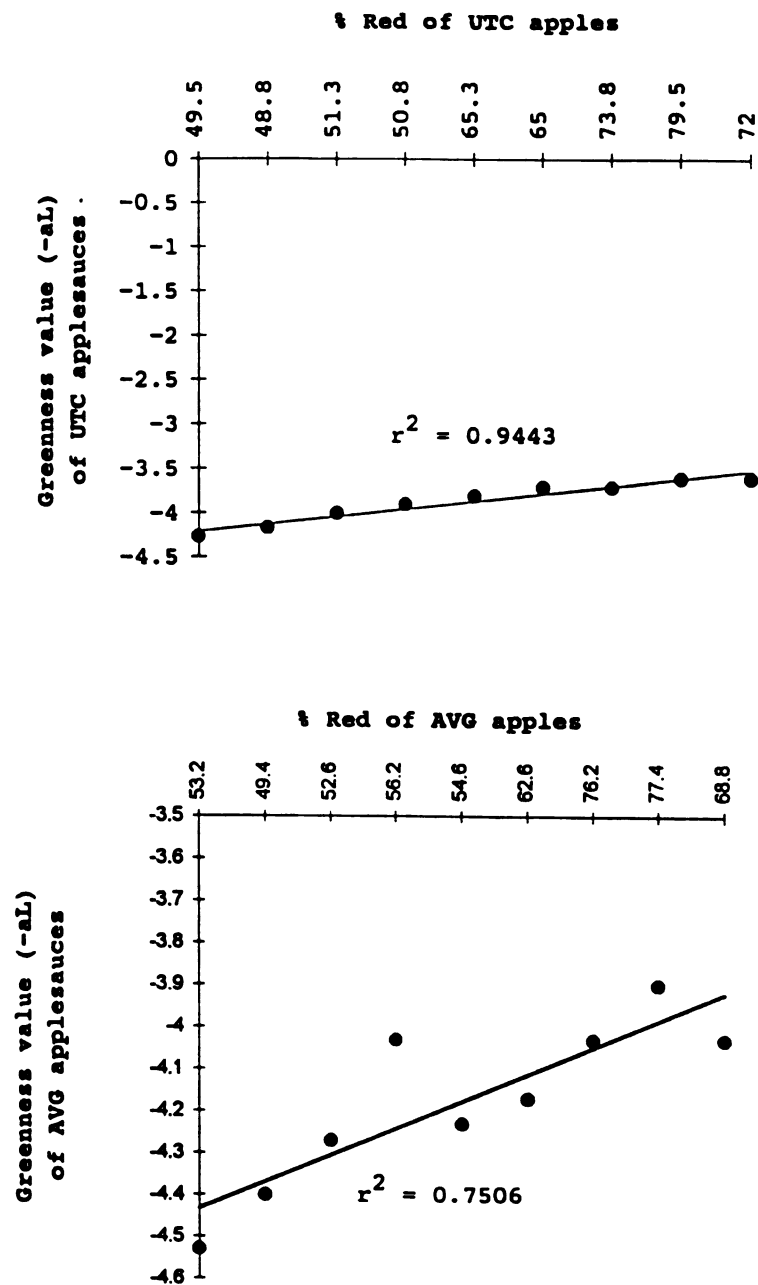


Figure 20. Linear relationship between %red of surface color of apples and greenness value (-a_L) of applesauce processed from UTC and AVG apples (UTC = Untreated controlled; AVG = AVG-treated)

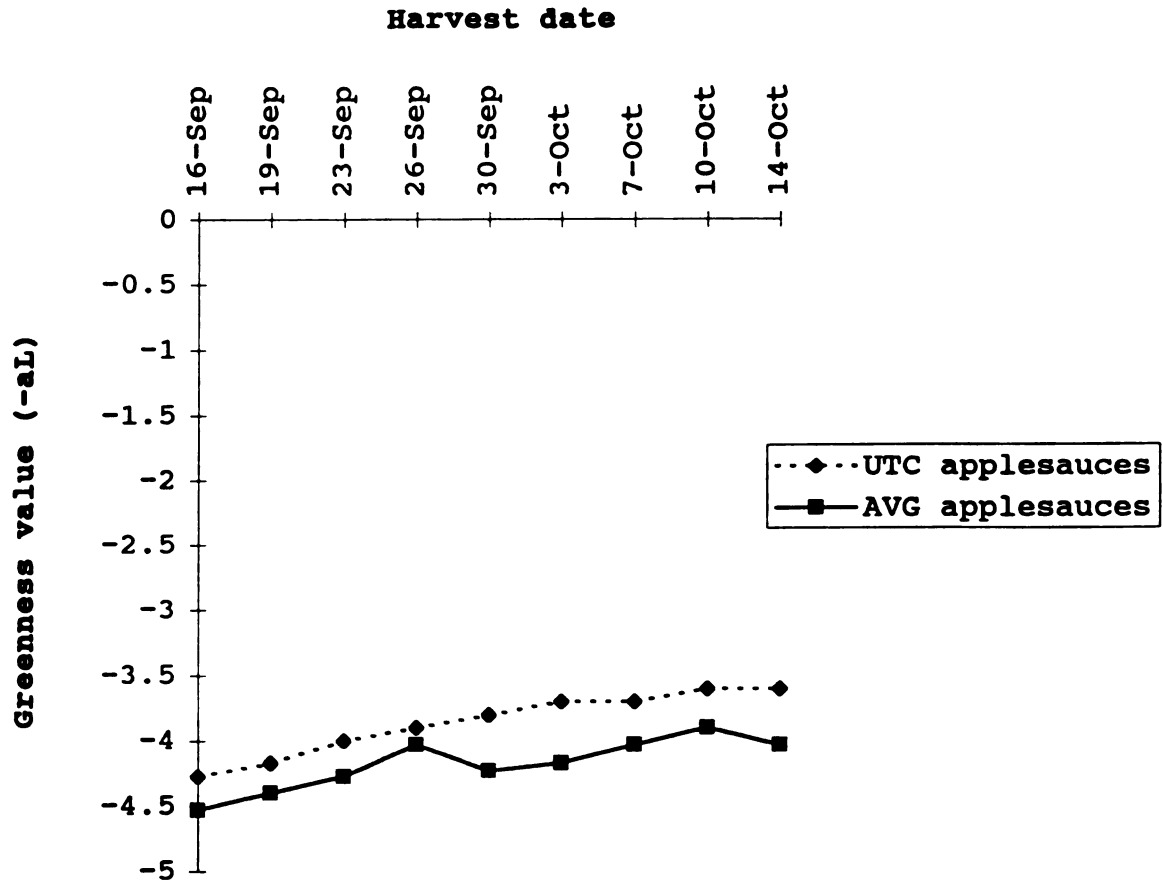


Figure 21. Comparison for total greenness values ($-a_L$) between applesauces processed from UTC and AVG apples (UTC = Untreated controlled; AVG = AVG-treated)

greenness values of both UTC and AVG samples in the same direction.

Table 40 shows yellowness mean values (b_L) of applesauces from UTC and AVG apples. Increasing maturity, due to sequential harvest dates, was related to increase in yellowness values. From early to late harvest dates, the yellowness values ranged from 20.56 to 21.77 in UTC samples and from 21.03 to 22.57 in AVG samples. Evaluation of the yellowness value using paired t-test, UTC samples showed significantly lower yellowness values on 26 Sep ($P \leq 0.05$), 30 Sep ($P \leq 0.01$), 3 Oct ($P \leq 0.05$), 7 Oct ($P \leq 0.01$), 10 Oct ($P \leq 0.01$), and 14 Oct ($P \leq 0.01$) than AVG samples. The significant differences for yellowness values were found between apples from middle and the late harvest season. Figure 22 shows comparison for yellowness values of UTC and AVG applesauces on sequential harvest dates. UTC applesauces showed lower yellowness values through all maturities. However, increasing maturity resulted in decrease in yellowness values during the early and middle harvest season and then slightly increase in yellowness values at the late harvest season of both UTC and AVG samples in the same direction.

The analysis of variance for chemical-physical processing qualities of applesauces is presented in Table 41. The effects of treatment (UTC and AVG) and harvest

Table 40. Comparison of yellowness (b_L) mean values¹ for applesauces from Jonagold apples on different harvest date (AVG², UTC³)

Harvest date	UTC	AVG	Calculated t
16.Sep.96	20.56	21.03	0.96
19.Sep. 96	20.27	20.90	1.73
23.Sep.96	19.27	20.53	3.64
26.Sep.96	19.70	20.92	8.92*
30.Sep.96	19.82	21.10	13.83**
3.Oct.96	20.90	21.43	6.05*
7.Oct.96	20.83	21.27	13.00**
10.Oct.96	20.92	21.17	6.60*
14.Oct.96	20.85	21.2	4.04
LSD _{0.05} ⁴	1.39	2.24	

1. $n=3$, t-test, * = significant at t calculated value ≥ 4.303 ($t_{0.05}$ tabulated value), ** = significant at t calculated value ≥ 9.93 ($t_{0.01}$ tabulated value), *** = significant at t calculated value ≥ 14.09 ($t_{0.005}$ tabulated value), **** = significant at t calculated value ≥ 31.60 ($t_{0.001}$ tabulated value)
2. Applesauces processed from Aminoethoxyvinylglycine (AVG) treated apples after 6 month in controlled atmosphere storage.
3. Applesauces processed from untreated controlled apples after 6 month in controlled atmosphere storage.
4. $n=3$, Least significant difference (LSD_{0.05}) mean separation; means are significantly different at $p \leq 0.05$ between varieties

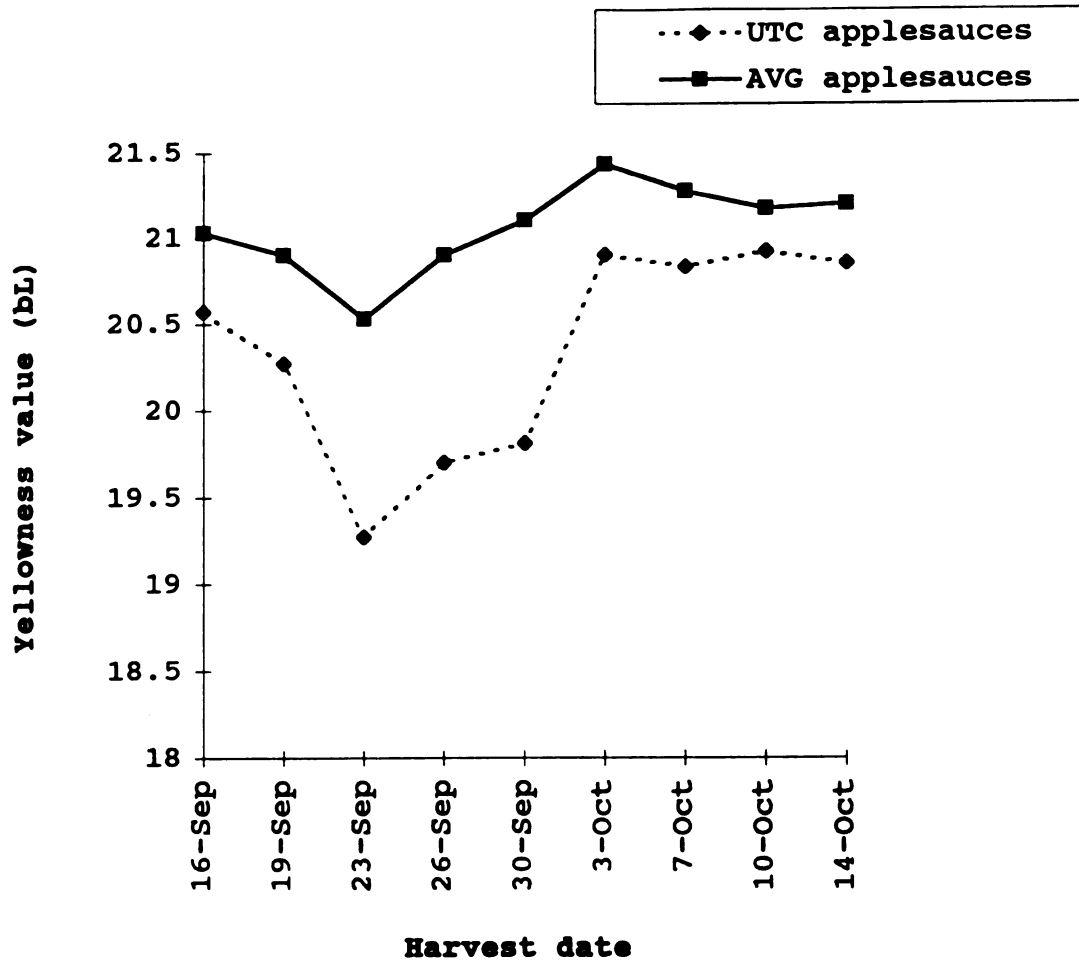


Figure 22. Comparison for yellowness values (b_L) between applesaues processed from untreated control and AVG treated apples

Table 41. Analysis of variance for chemical-physical processing quality of applesauces processed from Jonagold apples

Sources of variation	df	Sugar/acid ratio	Consistency	Lightness (L)	Greenness (-a _L)	Yellowness (b _L)
Mean squares ¹						
<u>Main effects</u>						
treatment ²	1	146.13**	0.004	0.84**	1.43**	6.90**
harvest date ³	8	17.90**	0.24**	0.89**	0.28**	1.08**
<u>Interaction</u>						
treatment X harvest date	8	1.61**	0.04**	0.39**	0.02	0.26
Error	36	0.20	0.008	0.10	0.01	0.26
% CV		8.34	5.08	0.95	7.04	3.44

1. n=3, *=significant at P ≤ 0.05, **=significant at P ≤ 0.01

2. Treatments include: UTC applesauces and AVG applesauces

3. Harvest dates include: 9 harvest dates

date (9 harvest dates) were found on sugar/acid ratios ($P \leq 0.01$), lightness values ($P \leq 0.01$), greenness values ($P \leq 0.01$), and yellowness values ($P \leq 0.01$). However, consistency was affected by only harvest date. There were significant interactions of harvest date and treatment on sugar/acid ratio ($P \leq 0.05$), consistency ($P \leq 0.01$), and lightness value ($P \leq 0.01$).

It could be interpreted that aminoethoxyvinylglycine (AVG) inhibits ethylene synthesis and, consequently, ripening processes in apples (Bangerth, 1978). The ethylene productions of both UTC and AVG samples through sequential harvest dates are presented in appendix I. After 6 month in CA storage, the most obvious result describing the influences of AVG on the ripening processes of apples, and ultimately the applesauces, is the retardation of the expected increase of sugar/acid ratio and acidity loss. Therefore using AVG may enhance the apple flavor of applesauce or other apple processed products, because organic acids in apples have been shown to be contributors to their own fruit flavor (Dimick and Hoskin, 1983). Many studies have shown that AVG also improves fruit firmness (Child et al., 1984 and Ness and Romani, 1979), which is consistent with the firmness test for fresh apples presented in appendix I. However, no significant difference in applesauce consistency due to AVG treatment found in this study could be accounted for as a result of the consistency

adjustment during processing steps and the limitation of storage time. Mohr (1989) who studied the influence of cultivar, fruit maturity and fruit anatomy on applesauce particle size and texture reported that the particle size distribution in sauce made from Idared showed little change until the apples had been stored for 8 months, when an increase in the proportion of large (> 0.1 mm) particles occurred. Spartan, McIntosh, Red Delicious, and Northern Spy also showed little change until late storage (8 months).

The lower greenness values in AVG applesauces could also be due to the effects of AVG delaying loss of chlorophyll pigment. However, the yellowness values in AVG applesauces were higher than those in UTC applesauces through all maturities (all harvest date). Jonagold, the cultivar used in this study, may need required time for the initiation of alteration of yellow pigments. Another explanation for the difference in yellowness values could be attributed to the effect of temperature on the efficiency of AVG. Matso et al. (1977) described that AVG is less effective in controlling ethylene production at low temperature and the present results of yellowness value measurements with cold stored apples (0.1°C) may confirm this.

SUMMARY AND CONCLUSIONS

Aminoethoxyvinylglycine (AVG) significantly affected the over all chemical and physical characteristics of applesauces including sugar/acid ratio, consistency, lightness value, greenness value, and yellowness value. AVG applesauces had lower sugar/acid ratios than UTC applesauces after 6 month in CA storage (1.3-1.8% O₂, 2-4% CO₂, 0.1°C). However, AVG applesauces also had higher total acidities, greenness values and yellowness values. The significant differences of consistencies and lightness were not found on each sequential harvest date.

Apple maturity significantly affected the chemical and physical characteristics of applesauces including sugar/acid ratio, lightness, greenness, and yellowness values. Increasing sugar/acid ratio, greenness and yellowness values of UTC and AVG applesauces were related to increasing maturity. Lightness values were decreasing during the early harvest season and then increasing during the late harvest season.

From linear regression, sugar content (°Brix) of fresh apple could be used to predict the sugar/acid ratio of both UTC and AVG applesauces; and red percentage of surface color

of fresh apples could also be used to predict the greenness values of both UTC and AVG applesauces.

APPENDIX I

Apple production by cultivar in the United States
(1986-1987)

Cultivar	Primary Region	Production (tons)
Delicious (all)	West	1,917,500
Golden Delicious	West	650,500
McIntosh	East	380,750
Rome Beauty	EAST	265,000
Grainy Smith	West	198,250
Jonathan	Central	179,250
York	East	141,250
Stayman	East	116,000
Cortland	East	79,500
Newtown	West	79,500
Winesap	West	77,750
Northern Spy	East	62,750
Rhode Island	East	62,000
Greening Gravenstein	West	44,250

Commercial U.S. production¹ by cultivars (Manhart, 1995)

Cultivar	1987	1988	1989
Red Delicious	114,940,000	88,570,000	97,180,000
Golden Delicious	41,370,000	36,560,000	36,370,000
McIntosh	16,500,000	15,380,000	15,980,000
Granny Smith	10,550,000	12,010,000	14,250,000
Rome	15,140,000	13,900,000	13,510,000
Jonathan	9,570,000	8,320,000	8,790,000
York	6,800,000	7,000,000	5,750,000
Stayman	5,220,000	4,710,000	4,410,000
Newtown	4,250,000	3,930,000	4,150,000
Cortland	3,120,000	2,550,000	2,790,000
R.I. Greening	2,730,000	2,250,000	3,420,000
Winesap	4,070,000	3,520,000	3,630,000
Idared	3,440,000	3,350,000	4,160,000
Northern Spy	3,080,000	2,400,000	2,730,000
Gravenstein	2,550,000	1,850,000	2,140,000
All others	12,588,000	11,736,000	12,442,000
Grand total	255,918,000	218,036,000	231,702,000

1. USDA statistics (42-pound boxes)

Production figures for 1992-1993 from USDA figures and estimates¹ (Manhart, 1995)

Cultivar	1992	1993
Red Delicious	108,690,000	108,070,000
Golden Delicious	39,060,000	37,450,000
Granny Smith	16,830,000	16,370,000
Rome	15,230,000	16,230,000
McIntosh	16,810,000	14,730,000
Jonathan	9,160,000	8,120,000
York	6,720,000	6,720,000
Idared	5,060,000	5,060,000
Fuji (estimated)	N/A	4,580,000
Gala (estimated)	N/A	4,170,000

1. In millions of 42-pound boxes

Top 10 states by apple production¹ (Manhart, 1995)

State	1992	1993
Washington	114,286,000	114,286,000
Michigan	25,714,000	26,190,000
New York	27,857,000	24,286,000
Califirnia	20,000,000	20,238,000
Pennsylvania	11,905,000	13,095,000
Virginia	8,810,000	9,048,000
North Carolina	5,714,000	7,619,000
West Virginia	5,357,000	5,119,000
Oregon	4,167,000	3,690,000
Idaho	1,786,000	3,571,000

1. USDA records (estimated for 1993)

Analysis of major sources of supply and major uses of apples by country and region, 1989-1990 (O'Rourke, 1994)

Region	Production	Import	Supply	Fresh consumption	Fresh export	Processing	Withdrawal
Belgium-Lux	296,965	162,652	459,617	230,671	162,038	59,408	7,500
Denmark	92,500	49,622	142,122	102,973	4,149	35,000	0
France	1,851,550	113,900	1,965,450	1,033,350	665,100	200,000	67,000
Germany, W.	1,762,047	628,871	2,390,918	1,831,735	51,925	492,858	14,400
Greece	280,135	25	280,160	194,072	4,888	1,000	80,200
Italy	2,081,000	73,150	2,154,150	1,299,750	253,100	522,500	78,800
Netherlands	375,000	198,500	573,500	295,761	202,500	68,310	6,929
Spain	685,700	126,550	812,250	675,700	11,550	125,000	0
U.K.	342,550	474,459	817,009	750,545	29,012	16,630	20,822
Total EC	7,767,447	1,827,72	9,595,176	6,414,557	1,384,262	1,520,706	275,651
Austria	254,700	14,150	268,850	266,350	500	2,000	0
Norway	59,683	42,197	101,880	80,029	0	9,921	11,930
Sweden	85,400	80,778	166,178	157,773	1,405	7,000	0
Switzerland	255,580	4,828	260,408	130,677	201	129,530	0
W. Europe	655,363	141,953	797,316	634,829	2,106	148,451	11,930

SOURCE: USDA, FAS. Fresh Delicious Fruit Reports. Washington, D.C. (unpublished, occasional attache' report)

Analysis of major sources of supply and major uses of apples by country and region, 1989-1990 (O'Rourke, 1994)

Region	Production	Import	Supply	Fresh consumption	Fresh export	Processing	Withdrawal
Hungary	954,500	0	954,500	295,500	326,500	332,500	0
Yugoslavia	523,000	0	523,000	293,000	30,000	200,000	0
E. Europe	1,477,500	0	1,477,500	588,500	356,500	532,500	0
Canada	500,000	105,000	605,000	323,000	87,500	194,500	0
Mexico	483,530	11,000	494,530	258,258	0	236,272	0
U.S.	4,398,000	117,250	4,515,250	2,229,000	340,000	1,946,250	0
N. America	5,381,530	233,250	5,614,780	2,810,258	427,500	2,377,022	0
Japan	1,057,000	0	1,057,000	842,500	1,400	213,100	0
Taiwan	15,380	104,039	119,419	118,668	0	750	0
Turkey	1,850,000	0	1,850,000	1,673,459	84,042	92,500	0
Asia	2,922,380	104,039	3,026,419	2,634,627	85,442	306,350	0
Argentina	1,067,500	0	1,067,500	222,500	225,000	620,000	0
Australia	332,500	0	332,500	193,525	24,475	114,500	0
Brazil	360,000	100,000	460,000	456,950	3,050	0	0
Chile	741,000	0	710,000	110,000	327,500	272,500	0
New Zealand	409,938	3,120	413,058	56,058	210,207	146,293	0
S. Africa	558,600	0	558,600	204,482	221,618	132,500	0
S. Hemisphere	3,438,538	103,120	3,541,658	1,244,015	1,011,850	1,285,793	0
Total Reported	21,642,758	2,410,0	24,052,84	14,326,786	3,267,660	6,170,822	287,581

SOURCE: USDA, FAS. Fresh Delicious Fruit Reports. Washington, D.C. (unpublished, occasional attache' report)

Importance of various quality factors to different processed products (LaBelle, 1981)

Quality factor	Desired level	Baked apple	Fresh or frozen	Canned	Dehydro frozen	Applesauce	Juice concentrate	Hard cider & wine
Variety	a ¹	++ ²	++	++	++	+		+
Maturity	full		++			+	++	++
Condition:								
ripeness	medium			- ₃				++
damage	low	+++	+++	++	++	+		
decay	low	+++	+++	++	++	++	++	+
Size	med.-	+	++	++	++ ⁴ , b ⁴	++		
Shape	low		++	++	+	+		
Seed pocket	small	+++	+++	++	++			
Specific	high		-	++	-			
Skin color	not red		+		+	++		
Flesh color	yellow		++	+	+	+++	+	
Firmness	firm	+++	++	+++	++	+		
Soluble solids	high	+			+++	++	+++	
Total solids	high				+++	++		
Total acid	medium	++	+	++		++	-	-
pH	medium	++	+	++		++	-	-
Volatile	medium	++	+			++	++	
Tannin	low							--
Rate of	low		++	+	+++	++	+	
Juiciness	medium	--	-		-	-	+	+

1. Varietal importance is based on the usual practice of marketing as single varieties without blending

2. + ++ +++ = degree of importance

3. - -- = importance opposite to normally desired level indicated in the second column

4. If diced rather than sliced, the larger the better, so long as still machine-peelable

APPENDIX II

Fresh maturity test¹ of selected apples (Study I)

Selection	Harvest date	Weight ²	Ethylene ³	Red ⁴	Firmness ⁵	Starch ⁶	Sugar ⁷
Cortland	09/20	129	0.09	78.5	87.0	1.1	11.2
Red Delicious	10/08	161	1.54	98.4	79.7	3.1	12.4
Gold Delicious	10/08	132	0.15	4.1	83.2	5.7	14.2
Honeycrisp	09/17	-	0.64	72.5	67.2	2.5	-
Idared	10/11	181	0.34	79	77.2	5.0	12.5
Gala	10/13	152	0.39	95.5	85.9	1.4	10.6
Jonagold	10/27	159	0.11	8.9	80.8	5.6	13
Rome	10/15	174	21.61	92.1	94.56	5.4	12.2
Mutsu	10/18	262	9.34	15.5	92.56	5	16.5
N. Spy	10/11	227	13.81	13.7	93.0	3.9	12
Red Delicious	10/08	178	19.73	98.7	79.2	3.5	13.3
(Red Chief)							

1.n=10, mean values

2.grams

3.ppm or mcroliters of ethylene

vapor per liter of air

4.8red of surface color: measured by eyes

5.Newtons

6.Measured by Iodine test and

compared to the reference chart

for each variety scale from 1 to 9

7.°Brix

Comparison of yeild¹ of applesauce processed from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage
Traditional varieties	McIntosh	75.65	62.00
	Cortland	68.20	38.80
	Jonathan	67.80	48.60
	Red Delicious	66.90	55.70
	Northern Spy	65.60	65.20
	Golden	65.02	50.80
	Rome	59.50	66.80
	Idared	55.84	72.80
Recent varieties	Mutsu	76.00	68.70
	Empire (Early)	73.00	48.00
	Empire (Late)	68.60	52.00
	Empire (Middle)	64.05	57.00
New varieties	Honeycrisp	69.30	62.50
	Jonagold	63.46	60.80
	Gala	58.30	61.10

1. as % of initial weight (lb) of selected apples

2. Applesauces processed after fresh harvest

3. Applesauces processed after 2 month harvest

Comparison of yeild¹ of frozen apple slices processed from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage
Traditional varieties	McIntosh	80.16	79.73
	Rome	76.69	71.74
	Golden	72.35	67.26
	Red Delicious	71.96	60.30
	Idared	68.44	82.90
	Jonathan	68.44	75.38
	Cortland	68.32	74.99
	Northern Spy	62.56	71.78
Recent varieties	Empire (Late)	67.30	63.98
	Empire (Middle)	65.09	60.42
	Empire (Early)	59.69	63.80
New varieties	Honeycrisp	69.18	73.02
	Jonagold	67.10	75.70
	Gala	57.30	57.04

1. as % of initial weight (lb) of selected apples

2. Frozen apple slices processed after fresh harvest

3. Frozen apple slices processed after 2 month harvest

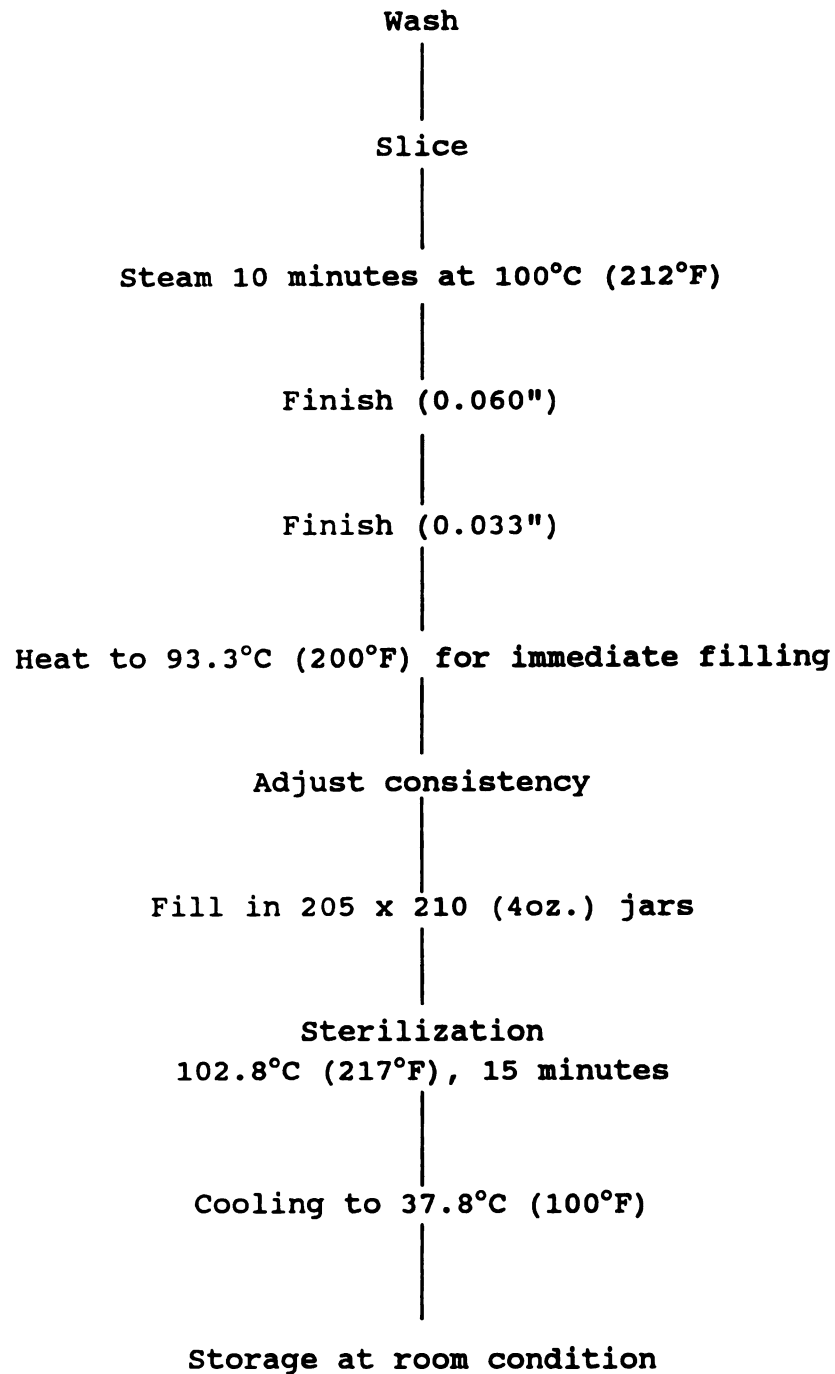
Comparison of yeild¹ of apple puree processed from traditional, recent, and new varieties (control², 2 month storage³)

Category	Selection	Control	2 month storage
Traditional varieties	Cortland	79.70	55.83
	Red Delicious	75.90	68.30
	Golden	75.40	73.00
	Northern Spy	71.96	72.80
	Jonathan	71.90	65.40
	McIntosh	68.44	44.00
	Idared	62.82	78.40
	Rome	56.60	80.40
Recent varieties	Mutsu	78.80	63.90
	Empire (Late)	78.69	42.00
	Empire (Middle)	76.32	46.00
	Empire (Early)	70.05	45.00
New varieties	Honeycrisp	82.10	75.76
	Gala	76.80	75.23
	Jonagold	75.20	70.00

1. as % of initial weight (lb) of selected apples

2. Apple puree processed after fresh harvest

3. Apple puree processed after 2 month harvest



Flow diagram for baby apple puree process

Chemical-physical processing qualities of baby apple puree processed from traditional, recent, and new varieties (control¹ vs 2 month storage²)

Selection	Harvest date	Process date	Sugar/acid ratio ³		Consistency ⁴		Viscosity ⁵		Lightness (L)		Redness (a _L)		Yellowness (b _L)	
			avg	std	avg	std	avg	std	avg	std	avg	std	avg	std
Red	10/08	10/16	37.7	0.50	3.67	0.06	2.6	0.07	37.80	0.10	5.17	0.12	11.9	0.1
Delicious	12/04	12/04	5	0.88	3.73	0.06	6	0.02	36.67	0.15	4.97	0.21	0	0
Golden	10/08	10/16	25.1	25.1	4.50	0.00	2.7	0.20	38.20	1.15	2.90	0.56	15.6	0.8
Delicious	12/04	12/04	2	2	4.30	0.00	2	0.01	38.20	1.15	2.90	0.56	3	7
McIntosh	09/18	12/13	20.3	0.25	3.07	0.12	2.3	0.08	37.73	0.06	1.20	0.10	14.1	0.0
Jonathan	09/23	02/12	4	0.38	3.57	0.12	3	0.01	40.13	0.25	0.63	0.06	3	6
		10/07	15.8	0.50	5.90	0.10	1.3	0.30	41.00	0.36	5.20	0.17	14.2	0.1
Cortland	09/20	20 Nov	0	0.23	5.37	0.12	7	0.50	40.33	0.35	5.83	0.25	0	7
		10/07	16.6	0.24	5.50	0.00	1.7	0.90	42.23	0.64	2.00	0.44	13.5	0.4
Northern	10/11	11/11	1	3.44	5.17	0.14	0	0.40	38.13	0.91	4.93	0.38	3	7
		10/22	12.7	1.10	5.63	0.15	1.3	0.01	44.57	0.06	0.10	0.10	18.0	0.1
Idared	10/11	12/13	8	0.07	5.30	0.10	7	0.02	43.73	0.55	1.60	0.10	0	0
		10/22	16.5	16.5	4.42	0.14	2.3	0.50	40.27	0.12	3.00	0.10	14.5	0.1
Rome	10/15	12/13	0	0	5.08	0.14	4	0.01	40.73	0.50	3.57	0.31	0	0
		10/22	24.7	0.26	5.73	0.06	1.5	0.06	33.80	0.17	7.27	0.21	10.5	0.2
		12/13	1	0.21	4.50	0.10	7	0.01	29.87	0.38	12.7	0.26	0	0

1.Apple puree processed after fresh harvest

2.Apple puree processed after 2 month storage

3.°Brix/malic acid(%)

4.numbers of graduation on a Bostwick consistometer covered by the preceding edge of the product in 5 seconds at 25°C

5.10^6 Adam units, measured by Brookfield Digital Viscometer (Model DV-II, Brookfield Engineering Laboratories Inc., Stoughton , MA) at 25°C.

Chemical-physical processing qualities of baby apple puree processed from traditional, recent, and new varieties (control¹ vs 2 month storage²)

Selection	Harvest	Process	Sugar/acid ³			Consistency ⁴			Viscosity ⁵			Lightness			Redness			Yellowness		
			date	avg	std	avg	std	avg	std	avg	std	avg	std	avg	std	avg	std	avg	std	
Mutsu	10/18		10/30	23.7	0.83	5.07	0.12	1.7	0.50	45.00	0.20	2.00	0.26	19.77	0.15					
			12/13	2	0.54	4.33	0.06	7	0.10	44.03	0.57	3.80	0.44	19.63	0.31					
	09/25		12/13	23.2	0.19	4.50	0.00	1.0	0.96	37.40	0.17	7.30	0.72	14.10	0.10					
Empire			02/12	1	0.33	4.15	0.13	2	0.07	38.73	0.15	4.90	0.17	14.17	0.15					
	09/28		12/13	22.6	0.28	4.42	0.14	1.3	0.10	34.27	0.15	8.33	0.15	12.13	0.12					
			02/12	8	0.36	3.58	0.14	1	0.07	38.47	0.21	5.47	0.35	14.43	0.15					
(Middle) Empire	10/03		12/13	23.4	0.18	4.68	0.16	1.8	0.04	37.57	0.38	4.10	0.10	14.33	0.15					
			02/12	8	0.24	3.32	0.16	4	0.36	39.87	0.15	6.20	0.26	15.00	0.10					
			09/25	18.2	0.64	5.50	0.17	1.7	0.07	41.43	0.12	0.70	0.20	15.63	0.06					
Gala			11/11	6	0.12	4.90	0.10	8	0.01	40.80	0.62	1.50	0.20	15.07	0.32					
	09/13		09/25	28.4	1.19	4.80	0.00	1.8	0.01	48.30	0.36	-	0.25	13.40	0.20					
			11/11	7	0.25	4.17	0.15	7	0.30	44.83	0.32	0.83	0.20	13.77	0.21					
Jonagold	09/27		10/16	19.4	0.30	5.17	0.29	2.2	0.40	43.17	0.46	1.33	0.25	16.60	0.17					
			12/04	8	1.16	3.43	0.12	1	0.01	42.00	0.46	0.33	0.31	16.10	0.10					

1. Apple puree processed after fresh harvest

2. Apple puree processed after 2 month storage

3. °Brix/malic acid(%)

4. numbers of graduation on a Bostwick consistometer covered by the preceding edge of the product in 5 seconds at 25°C

5. 10⁻⁶ Adam units, measured by Brookfield Digital Viscometer (Model DV-II, Brookfield Engineering Laboratories Inc., Stoughton, MA) at 25°C.

USDA grading specification for applesauces (subjective test; USDA, 1974)

Sample size: 3" X 3 1/4" cylinder level full (100 grams)

Factors	Grade-Point Score					
	A			B		Substandard
	20	19	18	17	16	
color	bright, practically uniform, typical of varieties used, no discoloration due to oxidation or scorching			may be dull color, but reasonably uniform, may be slightly brown pink or gray - not off color		15 or less off color
consistency (@ 20 °C) flow free liquor	4.5-5.0 cm 0 To	5.0-5.5 cm 0.35 cm To	5.5-5.6 cm 0.7 cm To	6.5-7.5 cm 0.85 cm To	7.5-8.5 cm 1 cm	8.5 cm + 1.0 cm +
defects stamens seed particles, peel, carpel, discolored serious discolored	0 0 but, not more than: 0	1-2 1/4 cm (2)	3 1/4 cm (2)	4 1/4 cm (2) but, not more than: 3/8 cm (2)	5 1 cm (2) 1/4 cm (2)	6 or more 1 cm (2) + 1/4 cm (2) +
finish apple particles	evenly divided, tender, crisp, not salvy or pasty, any pasty or salvy sauce is not to be graded grade A			evenly divided, may be slightly pasty or salvy		salvy, pasty, or lumpy
Flavor brix unsweetened	good apple flavor, free of off flavors 9.0 degrees			reasonably good apple flavor, not more than slight off flavors 9.0 degree		poor flavor or off flavor < 9.0 degrees

USDA grading specification for frozen apple slices (subjective test; USDA, 1954)

Sample size: 16 oz.

color			size			defects				character		
score	grade	score	% off	grade	score	% dmged	% ser	carpel	grade	score	% mushy	grade
20		20	0-2		20	0-2	0-0.25	0"		40	0	
19	A	19	2-4	A	19	2-3	0.25-.5	0-1/4"	A	39	0-1	
18		18	5-8		18	3-4	0.5-0.75	1/4-1/2"		38	1-2	A
17		17	8-10		17	4-5	0.75-1.0	1/2-3/4"		37	2-3	
16		16	11-14		16	6-9	2-2.25	1"		36	3-4	
15	C	15	15-19	C	15	9-12	2.25-2.5	1 1/4"	C	34-35	4-5	
14		14	20-25		14	12-15	2.5-3	1 1/4"		33	6-7	
should present the typical color of that variety		whole or nearly whole slices shall be 95-100% by weight. 90% minimum fall into this category. (10% allowed for grade A per oz. Sample)			<u>damage</u> green peel that exceeds 1/4" aggregate area. red peel that exceeds 1/4" aggregate area. light brown bruise that exceeds 1/4" area or is more than 1/4" deep (5% allowed for grade A per 16 oz. Sample)		<u>carpel</u> not more than an area of 1/4 square inch per 16 oz. of fruit for grade A			28	12-15	C
		<u>harmless extran matter</u> leaves, stems, cores and portion of cores fall into this category										mushy apples are scored according to firmness slices or portions of slices that are pulpy mass and of a consistency approximating applesauce (5% allowed for grade A per 16 oz. Sample)
		<u>seriously damaged</u> blossom end material, dark brown bruises, insect damage. Other internal or external discoloration. (1% allowed/16 oz. sample)										<u>seeds</u> two seeds allowed for grade A per 32 oz. sample

**MICHIGAN STATE
UNIVERSITY**

August 3, 1997

TO: Mark A. Uebersax
204 G.M. Trout FSHN Building

RE: IRB#: 97-461
TITLE: SENSORY EVALUATION OF APPLESAUCE
REVISION REQUESTED: N/A
CATEGORY: 1-G
APPROVAL DATE: 07/30/97

The University Committee on Research Involving Human Subjects' (UCRIHS) review of this project is complete. I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and methods to obtain informed consent are appropriate. Therefore, the UCRIHS approved this project and any revisions listed above.

RENEWAL: UCRIHS approval is valid for one calendar year, beginning with the approval date shown above. Investigators planning to continue a project beyond one year must use the green renewal form (enclosed with the original approval letter or when a project is renewed) to seek updated certification. There is a maximum of four such expedited renewals possible. Investigators wishing to continue a project beyond that time need to submit it again for complete review.

REVISIONS: UCRIHS must review any changes in procedures involving human subjects, prior to initiation of the change. If this is done at the time of renewal, please use the green renewal form. To revise an approved protocol at any other time during the year, send your written request to the UCRIHS Chair, requesting revised approval and referencing the project's IRB # and title. Include in your request a description of the change and any revised instruments, consent forms or advertisements that are applicable.



OFFICE OF
RESEARCH
AND
GRADUATE
STUDIES

**PROBLEMS/
CHANGES:**

Should either of the following arise during the course of the work, investigators must notify UCRIHS promptly: (1) problems (unexpected side effects, complaints, etc.) involving human subjects or (2) changes in the research environment or new information indicating greater risk to the human subjects than existed when the protocol was previously reviewed and approved.

If we can be of any future help, please do not hesitate to contact us at (517)355-2180 or FAX (517)432-1171.

Sincerely,

University Committee on
Research Involving
Human Subjects
(UCRIHS)

Michigan State University
246 Administration Building
East Lansing, Michigan
48824-1046

517/355-2180
FAX 517/432-1171

David E. Wright
David E. Wright, Ph.D.
UCRIHS Chair

DEW:bed

✓ CC: Korada Sunthanont

The Michigan State University
IDEA is Institutional Diversity
Excellence in Action

MSU is an affirmative action,
equal opportunity institution

Approval for human subject application from University
Committee on Research Involving Human Subjects

Fresh maturity test¹ for Jonagold apples² on sequential harvest dates (Study II)

Harvest date	Weight ⁵		Ethylene ⁶		Red ⁷		Firmness ⁸		Starch ⁹		Sugar ¹⁰	
	UTC ³	AVG ⁴	UTC	AVG	UTC	AVG	UTC	AVG	UTC	AVG	UTC	AVG
09/16/96	192.5	198.4	0.09	0.03	49.5	53.2	86.55	87.13	1.60	1.46	13.0	12.9
09/19/96	197.5	176.5	0.07	0.01	48.8	49.4	83.66	84.82	2.10	1.74	13.2	13.1
09/23/96	205.0	193.2	0.11	0.02	51.3	52.6	81.88	84.64	3.18	2.40	13.8	13.5
09/26/96	214.8	210.8	0.32	0.04	50.8	56.2	79.43	81.35	2.90	2.30	14.2	13.8
09/30/96	209.0	196.2	0.45	0.08	65.3	54.6	80.77	82.33	3.78	3.06	15.0	14.5
10/03/96	223.8	201.2	1.04	0.43	65.0	62.6	81.10	82.33	5.00	3.82	15.9	15.5
10/07/96	232.0	207.0	2.21	0.12	73.8	76.2	79.66	83.75	6.30	4.60	16.1	15.9
10/10/96	224.3	208.2	4.88	0.59	79.5	77.4	78.21	79.12	6.63	6.36	16.4	16.0
10/14/96	229.0	209.8	4.97	0.88	72.0	68.8	73.87	78.41	8.13	8.13	15.5	15.8

1.n=5, mean values from 5 grown areas

2.For the study of AVG treatment and maturity

3.Untreated control apples

4.AVG treated apples

5.grams

6.ppm or mcroliters of ethylene

vapor per liter of air

7.½red of surface color:

measured by eyes

8.Newtons

9.Measured by Iodine test and

compared to the reference chart

for each variety scale from 1 to 9

10.°Brix

LIST OF REFERENCES

REFERENCES

- Adams, D.O. and Yang, S.F. 1979. Ethylene biosynthesis: Identification of 1-aminocyclopropane-1-carboxylic acid as an intermediate in the conversion of methionine to ethylene. *Proc. Natl. Acad. Sci. U.S.A.* 76: 170-174.
- Amerine, M.A.; Pangborn, R.M.; and Roessler, E.B. 1965. *Principles of sensory evaluation*. Academic Press, New York.
- Anderson, R.E. 1967. Experimental storage of eastern grown "Delicious" apples in various controlled atmospheres. *Proc. Amer. Soc. Hort. Sci.* 91: 810-820.
- Anderson, J., Liebermann, M., Mattoo, A. and Chalutz, E. 1978. Rhizobitoxine analogs (enol ether amino acids) as inhibitors of ethylene and amino acid incorporation. *Plant Physiol.* 61: S-495.
- Anderson, J., Liebermann, M., Mattoo, A. and Chalutz, E. 1979. Influence of enol ether amino acids, inhibitors of ethylene biosynthesis, on aminoacyl transfer RNA synthetases and protein synthesis. *Plant Physiol.* 64: 289-292.
- Anon. 1993. Apple marketing clinic report #94. *International Apple Institute*. McLean, VA.
- Baker, J.E., Lieberman, M. and Anderson, J.D. 1978. Inhibition of ethyleneproduction in fruit slices by a rhizobitoxine analog and free radical scavengers. *Plant Physiol.* 61: 886-888.
- Bangerth, F. 1978. The effects of substituted amino acids on ethylene biosynthesis, respiration, ripening, and preharvest drop of apple fruits. *J. Am. Soc. Hortic. Sci.* 103: 401-404.
- Bartley, I.M. 1976. Changes in the glucans of ripening apples. *Phytochem.* 15: 625-626.
- Bartley, I.M. 1986. Changes in sterol and phospholipid composition of apples during storage at low temperature and low oxygen concentration. *J. Sci. Food Agric.* 37: 31-36.

- Beach, S.A., Booth, M.O. and Taylor, O.M. 1903. *The Apples of New York*. Report of the New York Experiment Station, II, Ithaca, NY.
- Beebe-Center, J.G. 1932. *The psychology of pleasantness and unpleasantness*. Van Nostrand Reinhold, New York.
- Berglund, P.T., Lau, K. and Holm, E.T. 1992. Improvement of triangle test data by use of incentives. North Dakota State University, Fargo, ND
- Beruter, J. 1985. Sugar accumulation and changes in the activities of related enzymes during development of the apple fruit. *J. Plant Physiol.* 121: 331-341.
- Beyer, E.M. 1985. Ethylene Metabolism. *Ethylene and Plant Development*. Edited by Robert, J.A. and Tucker, G.A. Univ. Nottingham, School of Agriculture, Sutton Bonington, England.
- Blackman, F.F. and Parija, P. 1928. Analytic studies in plant respiration I: The respiration of a population of senescent ripening apples. *Proc. Roy. Soc. B.* 103: 412.
- Blanpied, G.D., and Smock, R.M. 1983. *Storage of Fresh-market Apples*. Cornell Univ. Coop. Ext. Info. Bull. 191.
- Boller, T., Herner, R.C. and Kende, H. 1979. Assay for and enzymatic information of an ethylene precursor, 1-Aminocyclopropane-1-carboxylic acid. *Planta.* 145: 293-303.
- Borochoy, A., Halevy, A.H. and ShiniZky, M. 1982. *Plant Physiol.* 69: 296.
- Bourne, M.C. 1982. *Food Texture and Viscosity: Concept and Measurement*. Academic Press Inc., New York.
- Bramlage, W.J.; Greene, D.W.; Antio, W.R. McLaughlin, J. M. 1980. Effects of aminoethoxyvinylglycine on internal ethylene concentration and storage of apples. *J.* 1981. *Am. Soc. Hortic. Sci.* 105: 847-851.
- Buck, M.L., Dryden, E.C. and Hills, C.H. 1955. Chromatographic comparison of nonvolatile acids of fresh and stored apple juice concentrate. *J. Food. Chem.* 3:960.
- Bufler, G. 1984. Ethylene-enhanced 1-aminocyclopropane-1-carboxylic acid synthase activity in ripening apples. *Plant Physiol.* 75: 192-195.

- Burg, S.P. and Thimann, K.V. 1959. The physiology of ethylene formation in apples. *Proc. Natl. Acad. Sci.* 45: 335-344.
- Burg, S.P. and Burg, E.A. 1965. Ethylene action and the ripening of fruit. *Science*. 148: 1190-1196.
- Burg, S.P. and Burg, E.A. 1967. Molecular requirements for the biological activity of ethylene. *Plant Physiol.* 42:144.
- Burg, S.P. and Burg, E.A. 1969. Interaction of ethylene, oxygen and carbon dioxide in the control of fruit ripening. *Qual. Plant. Mater. Veg.* 19: 185.
- Cald, J.S., Culpepper, C.W., and Demaree, K.D. 1955. Quality of frozen apples related to variety and ripeness. *J. Agr. Food Chem.* 3:513
- Chen, P.M. and Mellenthin, W.M. 1982. Storage behavior of 'd'ANJOU' pears in low oxygen and air. *Controlled Atmospheres for Storage and Transport of Perishable Agricultural Commodities*. (ed Richardson, D.G. and Meheriuk, M.). Timber Press, Beaverton, OR.
- Child, R.D., Anthony, A.W., Gordon, V.H. and Christopher R.B. 1984. The effects of Aminoethoxyvinylglycine on Maturity and Post-harvest Changes in Cox's Orange Pippin Apples. *J. Sci. Food Agric.* 35: 773-781
- Childers, N.F. and Sherman, W.B. (eds.) 1988. *The Peach*. Horticultural Pub., Gainesville, FL.
- Dalrymple, D.G. 1967. The development of controlled atmosphere storage of fruit. *USDA Div. Marketing Util. Serv., Federal Ext. Serv. Pamph.*
- Daoud, H.N., and Luh, B.S. 1971. Effect of partial replacement of sucrose by corn syrup on quality and stability of canned applesauce. *J. Food Sci.* 36: 419-422.
- Desrosier, N.W. and Tressler, D.K. 1977. Freezing fruits. *Fundamentals of Food Freezing*. AVI Publishing Company, Inc., Westport, Connecticut.
- Diane M.B., Laszlo P.S., and Hui Y.H. 1996. Volume 2. *Processing Fruits: Science and Technology: Major Processed Products*. Technomic Publishing Company, Inc. Lancaster, Pennsylvania.
- Dilley, D.R. 1962. Malic enzyme activity in apple fruit. *Nature*. 196: 387-88.

- Dimick, P.S. and Hoskin, J.C. 1983. Review of apple flavor-State of the art. CRC Critical Reviews in Food Science and Nutrition. 18: 387-409.
- Drake, S.R., Nelson, J.W., and Powers, J.R. 1979. The influence of controlled atmosphere storage and processing conditions on the quality of applesauce from "Golden Delicious" apples. J. Am. Soc. Hort. Sci. 104(1): 68-70.
- Drawert, F., Heimann, W., Emberger, R., and Tressl, R. 1983. Über die biogenese von aromastoffen. Phytochemistry. 7: 881.
- Dryden, E.C. and Hills, C.H. 1957. Consumer preference studies on apple sauce: sugar-acid relation. Food Technol. 11: 589.
- Durocher, J. and Roskis, G. 1949. L'Emploi des sels de calcium dans l'industrie des conserves alimentaires. L'Officiel de la Conserve. 4: 25.
- Fidler, J.C. and North, C.J. 1967. The effect of storage on the respiration of apples I. The effect of temperature and concentration of carbon dioxide and oxygen on the production of carbon dioxide and uptake of oxygen. J. Hort. Sci. 42: 189-206.
- Flath, R.A., Black, D.R., Guadagni, D.G., McFadden, W.H. and Schultz, T.H. 1967. Identification and organoleptic evaluation of compounds in Delicious apples essence. J. Agri. Food Chem. 15: 29-35.
- Foley, J. and Buckley, J. 1977. Pasteurization and thermisation of milk and blanching of fruit and vegetables. *Food Quality and Nutrition: Research Priorities for Thermal Processing*. (ed. Downey, W.K.). Applied Science Publishers Ltd., Essex, England.
- Forsyth, F.R., Eaves, C.A., and Lightfoot, H.J. 1969. Storage quality of McIntosh apples as effected by removal of ethylene from the storage atmosphere. Can. J. Plant Sci. 49: 567-572.
- Frenkel, C., Klein, I. and Dilley, D.R. 1968. Protein synthesis in relation to ripening of pome fruits. Plant Physiol. 43: 1146-1153.
- Gebhardt, S.E.; Cutrufelli, R. and Matthews, R.H. 1982. Composition of foods. Agric. Handbook 8-9. U.S. Dept. of Agriculture, Washington, DC.

- Giovanelli, J.; Owens, L.D. and Mudd, S.H. 1971. Mechanism of inhibition of spinach β -cystathionase by rhizobitoxine. *Biochem Biophys. Acta* 227: 671-84.
- Gross, J., Zachariae, A., Lenz, F. and Eckhardt, G. 1978. Carotenoid changes in the peel of the "Golden Delicious" apples during ripening and storage. *Zeitschrift fur pflanzenphysiologie*. 89: 321-332.
- Greig, W.S.; Bedford, C.L.; and Larzelere. 1962. Consumer preferences among apple varieties in fresh and processed forms. *Mich. Agric. Exp. Stn. Q. Bull.* 44(3): 511-13.
- Hall, G.C. 1989. Refrigerated, frozen, and dehydrofrozen apples. *Processed Apple Products*, Van Nostrand Reinhold, New York, NY, pp. 1-29.
- Hartmann, C. 1963. L'Activite aldolasique des tissus de pomme et de poire pendant la maturation et la senescence des fruits. *Phytochem.* 2: 407-11.
- Heldman, D.R. 1992. Food freezing. *Handbook of Food Engineering*. (ed. Heldman, D.R. and Lund, D.B.). Marcel Dekker, Inc. New York, Basel, Honkong.
- Herner, R.C., Kader, A.A., Romani, R.J., Staby, G.L., and Watada, A.E. 1984. Terminology for the Description of Developmental Stages of Horticultural Crops. *HortScience*. 19(1):20
- Hoffman, N.E. and Yang, S.F. 1980. Changes of 1-aminocyclopropane-1-carboxylic acid content in ripening fruit in relation to their ethylene production rates. *J. Am. Soc. Hort. Sci.* 105: 492-495.
- Holdsworth, S.D. 1979. *Effects of Heating on Food Stuffs: Fruits* (Ed.) R. J. Priestly. Applied Science Publisher, London.
- Hoogzand, C. and Doesburg, J.J. 1961. Effect of blanching on texture and pectin of canned cauliflower. *Food Technol.* 15: 160.
- Hsu, E.J. 1975. Factors affecting microflora in processed fruits. *Commercial Fruit Processing*. (ed. Luh, B.S. and Woodroof, J.G.). AVI Publishing Co, Inc. Westport, CT.
- Hulme, A.C. and I.S.C. Woollorton. 1962. Separation of the enzymes present in the mitochondrial fraction from apple peel. *Nature*. 196: 388-89.

- Hultin, H.O. and Milner, M. 1978. Role of hormones in ripening and senescence. *Postharvest Biology and Biotechnology*. Food & Nutrition Press, Inc. Westport, Connecticut.
- IFT Sensory Evaluation Div. 1975. Business meeting at 35th Ann. Meet., Inst. Of Food Technologists. Chicago, IL.
- IFT Sensory Evaluation Div. 1981. Sensory evaluation guide for testing food and beverage product and guidelines for preparation and renew papers reporting sensory evaluation data. *Food Technol.* 35(11): 50.
- Jamison, W. 1980. Use of hypobaric conditions for refrigerated storage of meats, fruits, and vegetables. *Food Technol.* 34(3): 64.
- Kader, A.A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. *Food Technol.* 40: 99-104.
- Kertesz, Z.I. , Eucare, M., and Fox, G. 1959. A study of apple cellulose. *Food res.* 24: 14-19.
- Kim, K.S., Lee, K.L., Hong, S.Y., and Sohn, T.H. 1969. Studied on the reduced pressure storage of fruit. II. Preservation of Jonathan under various storage chamber pressures. *J. Korean. Agr. Chem. Soc.* 11: 77.
- Knee, M. 1972. Anthocyanin, carotenoid, and chlorophyll changes in the peel of Cox's Orange Pippin apples during ripening on and off the tree. *J. Exp. Botany.* 23: 184-96.
- Knee, M. 1973. Polysaccharide changes in cell walls of ripening apples. *Phytochem.* 12: 1543-1549.
- Knee, M. 1978. Properties of polygalacturonate and cell cohesion in apple fruit cortical tissue. *Phytochem.* 17: 1257-1260.
- Knee, M. 1980. Methods of measuring green color and chlorophyll content of apple fruit. *J Food Technol.* 15: 493-500
- Knee, M. and Bartley, I.M. 1981. Composition and metabolism of cell wall polysaccharides in ripening fruits. *Recent Advances in the Biochemistry of Fruits and Vegetables* (eds J. Friend and M.J.C. Rhodes). Academic Press, London.
- Knee, M. and Hatfield, A. 1981. Benefits of ethylene removal during apple storage. *Ann. Biol.* 98: 157.

- Knee, M.; Hatfield, S.G.S. and Smith, S.M. 1989. Evaluation of various indicators of maturity for harvest of apple fruit intended for long-term storage. *J. Hort. Sci.* 64: 413-419.
- Knee, M. 1993. *Pome Fruits. Biochemistry of Fruit Ripening.* eds G.B. Seymour, J.E. Taylor and G.A. Tucker). First edition. Chapman & Hall, New York.
- Kramer, A., Burkarst, G.J., and Rogers, H.P. 1951. The shear press: a device for measuring food quality. *The Canner.* 112(5): 34.
- Kramer, A. 1955. Food quality and quality control. *Handbook of Food and Agriculture.* (ed. By Blanck). Reinhold Publ. Co., New York
- Kramer, A. 1973. Food Texture: Definition, measurement and relation to other food quality attributes. *Texture Measurements of Foods.* A. Kramer and S. Szczesniak, S. (Ed.). Reidel Publ, Dordrecht, Netherlands. P. 1
- LaBelle R.L., Schallenberger, R.S., Way, R.D, Matlick, L.R. and Moyer, J.C. 1960. The relationship of apple maturity to applesauce quality. *Food Technol.* 14:463-468.
- LaBelle, R.L., Schallenberger, R.S., and Moyer, J.C. 1961. How to choose the best apples for sauce. *Canner/Packer.* 130(8):30
- LaBelle, R.L. 1981. Apple quality characteristics as related to various processed products. *Quality of Selected Fruits and Vegetables of North America*, American Chemical Society, Washington, DC, pp.61-76.
- Laconti, J.D. and Kertesz, Z.I. 1941. Identification of Capectate as the tissue firming compound formed by treatment of tomatoes with CaCl. *Food Research.* 6: 449.
- Lal Kaushal, B.B. and Sharma, P.C. 1995. *Apple. Handbook of Fruit Science and Technology: Production, Composition, Storage, and Processing.* (Salunkhe, D.K. and Kadam, S.S., eds.). Marcel Dekker, New York.
- Lanza, J. and Kramer, A. 1967. Objective measurement of graininess in applesauce. *Proc. Am. Soc. Hort. Sci.* 90: 491.
- Lau, O.L., and Looney, N.E. 1982. Improvement of fruit firmness and acidity in controlled-atmosphere-stored "Golden Delicious" apples by a rapid O₂ reduction procedure. *J. Amer. Soc. Hort. Sci.* 107(4): 531-534.

- Lau, O.L., Yastremski, R., and Heheriuk, M. 1986. Influence of maturity, storage procedure, temperature, and oxygen concentration on quality and disorders of "McIntosh" apples. *J. Amer. Soc. Hort. Sci.* 111(6): 93-99.
- Lee, C.Y. 1975. New blanching techniques. *Korean J. Food Sci. Technol.* 7: 2, 100-106.
- Lee, C.Y. and Mattick, L.R. 1989. Composition and nutritive value of apple products. *Processed Apple Products*. Van Nostrand Reinhold, New York, New York.
- Lerner, A.B. and Fitzpatrick, T.B. 1950. Biochemistry of melanin formation. *Physiol. Rev.* 30: 91-126
- Lidster, P.D., Tung, M.A., Garland, M.R., and Porritt, S.W. 1979. Texture Modification of processed apple slices by a postharvest heat treatment. *J. Food Sci.* 44: 998-1000, 1007
- Lidster, P.D., Forsyth, F.R., and Lightfoot, H.J. 1980. Low O₂ and CO₂ atmospheres for storage of McIntosh apples. *Can. J. Plant Sci.* 60: 299-301.
- Lidster, P.D., Lightfoot, H.J., and McRae, K.B. 1983. Fruit quality and respiration of McIntosh apples in response to ethylene, very low oxygen and carbon dioxide storage atmospheres. *Sci.Hort.* 20: 71-83.
- Liebermann, M.; Kunishi, A.T; Owens, L.D.1974. *Specific Inhibitors of Ethylene Production as Retardants of the Ripening Process in Fruits*. Colloq. Int. Cent. Natl. Rech. Sci. No.238, Paris.
- Liu, F.W. 1979. Interaction of daminozide, harvesting date, and ethylene in CA storage on McIntosh apple quality. *J. Amer. Soc. Hort. Sci.* 104: 599-601.
- K.
- Looney, N.E. and Patterson, M.E. 1967. Chlorophyllase activity in apples and bananas during the climacteric phase. *Nature.* 214: 1245-46.
- Lougheed, E.C., Franklin, E.W., Miller, S.R., and Proctor, J.T.A. 1973. Firmness of McIntosh apples as effected by alar and ethylene removal from the storage atmosphere. *Can. J. Plant Sci.* 53: 317-322.
- Lougheed, E.C., Murr, D.P., and Berard, L. 1978. Low pressure storage for horticultural crops. *Hort. Sci.* 13:21.
- Luh, B.S. and Kamber, P.J. 1963. Chemical and color changes in canned apple sauce. *Food Technol.* 105: 105-108.

- Luh, B.S., Feinberg, B., Chung, J.I. 1975. Freezing of fruits. *Commercial Fruit Processing*. (ed. Luh, B.S. and Woodroof, J.G.). AVI Publishing Co, Inc. Westport, CT.
- Lutz, J.M. and Hardenberg, R.E. 1968. U.S. Dept. Agr. Handbook 66.
- Matso, A.V., Baker, J.E., Chalutz, E., Liebermann, M. 1977. Effect of temperature on the Ethylene synthesizing systems in apple, tomato, and *Penicillium digitatum*. *Plant Cell Physiol.* 18: 715-719.
- Manhart, W. 1995. *Apples for the Twenty-First Century*. Published by the North American Tree Company, Portland, OR.
- Massey, L.M. 1989. Harvesting, storing, and handling processing apples. *Processed Apple Products*. Van Nostrand Reinhold, New York, New York.
- McGlasson, W.B. 1970. The ethylene factor. *The Biochemistry of Fruits and Their Products*. Vol. 1. A.C. Hulme (Editor). Academic Press, New York.
- McLellan, M.R.; Lind, L.R.; and Kime, R.W. 1984. Determination of sensory components accounting for intervarietal variation in applesauce and slice using factor analysis. *J. Food Sci.* 49: 751-55.
- Meheriuk, M. 1985. Controlled-atmosphere storage conditions for some more commonly grown apple cultivars. In *Proc. Fourth Controlled-Atmosphere Res. Conf.* North Carolina State Univ., Raleigh, 395-421.
- Mohr, W.P. 1989. Influence of cultivar, fruit maturity and fruit anatomy on apple sauce particle size and texture. *Int. J. Food Sci. Technol.* 24: 403-413.
- Morre, D.J. 1975. Membrane biogenesis. *Ann. Rev. Plant Physiol.* 26: 441-481.
- Moskowitz, H.R. 1983. Product testing and sensory evaluation of foods. *Marketing and R&D Approaches*. Food and Nutrition Press, Westport, CT.
- Nelmes, B.J. and Preston, R.D. 1968. Wall development in apple fruits: a study of the life history of a parenchyma cell. *J. Exp. Botany.* 19: 496.
- Ness, P.J. and Romani, R.J. 1980. Effects of aminoethoxy-vinylglycine and countereffects of ethylene on ripening of Bartlett pear fruits. *Plant Physiol.* 65: 372-376.

- North, C.J., Bubb, M., and Cockburn, J.T. 1976. Storage of Cox's Orange Pippin apples in 1% oxygen. East Malling Annual Rpt. For 1975.
- Owens, S.D.; Lieberman, M. and Kunishi, A. 1971. Inhibition of ethylene production by rhizobitoxine. *Plant Physiol.* 48:1-4.
- O'Rourke, A.D. 1994. World apple supplies. *The World Apple Market*. Food products press. An Imprint of the Haworth Press, Inc, New York, London, Norwood (Australia).
- Patchen, G.O. 1971. *Storage of Apples and Pears*. Marketing Res. Rep. 924. U.S. Dept. of Agriculture.
- Piggott, J.R. 1988. Second edition. Scaling and ranking methods. *Sensory Analysis of Foods*. Elsevier Science Publishers Ltd. Barking, Essex IG11 8JU, England.
- Poste, L.M., Mackie, D.A., Butler, G. and Larmond, E. 1991. Descriptive test. *Laboratory Methods for Sensory Analysis of Food*. Canada Communication Group-Publishing Centre, Ottawa, Canada K1A 0S9.
- Potter, N.N. 1986. 4th Edition. Heat preservation and processing. *Food Science*. AVI Publishing Co, Inc. Westport, CT.
- Pratt, H.K. and Goeschl, J.D. 1969. Physiological roles of ethylene in plants. *Ann. Rev. Plant Physiol.* 20:541-548.
- Rees, D.A. 1972. Shapely polysaccharides. *Biochem. J.* 126: 257.
- Reid, M.S., Rhodes, M.J.C. and Hulme, A.C. 1973. Change in ethylene and CO₂ during the ripening of apples. *J. Sci. Food Agric.* 24: 971-979.
- Reid, M.S. 1992. Ethylene in postharvest technology. *Postharvest Technology of Horticultural Crops*. 2nd ed. Edited by Kader, A.A. Division of Agriculture and Natural Resources, University of California, Oakland, California.
- Reiner, M and Scott Blair, G W. 1967. Rheological terminology. *Rheology Theory and Application*. Vol. IV. (ed. F.R. Eirich). Academic Press, New York.
- Rhodes, M.J.C. and Woollorton, L.S.C. 1967. The respiration climacteric in apple fruits. The action of hydrolytic enzymes in peel tissue during the climacteric period in fruit detached from the tree. *Phytochem.* 6: 1-12.

- Richardson, T. and Hyslop, D.B. 1985. Enzyme. Food Chemistry. (Fennema, O.R., ed.). Marcel Dekker, Inc., New York.
- Root, W.H. 1996. Apples and apple processing. *Major Processed Products*. L.P. Somogyi, D.M. Barrett, and Y.H. Hui, eds. Technomic Publishing Company Inc., Lancaster, Pennsylvania.
- Ryall, A.L. and Lipton, W.J. 1972. Refrigerated storage. *Handling, Transportation, and Storage of Fruits and Vegetables*. V.1. The AVI Publishing Co, Inc. Westport, CO.
- Ryall, A.L. and Pentzer, W.T. 1974. *Handling, Transportation, and Storage of Fruits and Vegetables*. AVI. Westport, CT. p. 1.
- Ryall, A.L., and Penzer, W.T. 1981. Handling, transportation, and storage of fruits and vegetables. Vol. 2, Fruits and Nut Crops. 2nd ed. AVI Publishing Co., Westport, CT.
- Salunkhe, D.K. and Wu, M.T. 1973. Effects of subatmospheric pressure storage on ripening and associated chemical changes of certain deciduous fruits. J. Am. Soc. Hort. Sci. 98: 113.
- Salunkhe, D.K. and Desai, B.B. 1984. *Postharvest Biotechnology of fruits*. Vol. I. CRC Press, Boca Raton, Florida. P.1.
- Shallenberger, R.S., Moyer, J.C., LaBelle, R.L., Robinson, W.B., and Hand, D.B. 1963. Firmness of canned apple slices as affected by maturity and steam-blanch temperature. Food Technol. 17: 102-104.
- Sharples, R.O., Chappell, D.J., and Sharp, L.E. 1978. Semi-commercial scale storage of Cox's Orange Pippin apples in 1.25%O₂. East Malling Annu. Rep. 1977.
- Shewfelt, R.L. 1986. Postharvest treatment for extending the shelf life of fruits and vegetables. Food Technol. 40(5): 70-89.
- Shipway, M.R. and Bramlage, W.J. 1973. Effects of CO₂ on activity of apple mitochondria. Plant Physiol. 51: 1095.
- Simpson, K.L. 1985. Chemical changes in natural food pigments. *Chemical Changes in Food during Processing*. (ed. Richardson, T. and Finley, J.W.). AVI Publishing Co, Inc. Westport, CT.

- Singh, R.P. and Heldman, D.R. 1993. 2nd edition. Food freezing. *Introduction to Food Engineering*. Academic Press, Inc. San Diego, CA.
- Smock, R.M. 1942. Influence of controlled atmosphere storage on the respiration of McIntosh apples. *Bot. Gaz.* 104: 178-184.
- Smock, R.M. and Neubert, A.M. 1950. *Apples and Apple Products*. Interscience Publ., New York.
- Steinbuch, E. 1976. Improvement of texture of frozen vegetables by stepwise blanching treatments. *J. Food Technol.* 11: 313-316.
- Stone, H. and Sidel, J.L. 1985. *Sensory Evaluation Practices*. Academic Press, Orlando, Florida.
- Szczesniak, A.S. 1963. Classification of texture characteristics. *J. Food Sci.* 28: 385.
- Szczesniak, A.S. 1973. Instrumental methods of texture measurements. *Texture Measurements of Foods*. (ed. A. Kramer and A.S. Szczesniak). D. Reidel Publishing Co., Boston.
- Tannenbaum, S.R. and Young, V.R. 1985. Vitamins and minerals. *Food Chemistry*. (Fennema, O.R., ed.). Marcel Dekker, Inc., New York.
- Timberlake, C.F. 1981. Anthocyanins in fruits and vegetables. *Recent Advances in the Biochemistry of Fruits and Vegetables*. (eds J. Friends and M.J.C. Rhodes). Academic Press, London.
- Thomas, F.B. and Ritter, C.M. 1958. Varietal influences on quality of applesauce blends. *Penn. Agric. Exp. Stn. Progress Rep.* 193
- Tucker, G.A. 1993. Introduction. *Biochemistry of Fruit Ripening*. Edited. Seymour, G.B., Taylor, J.E., and Tucker, G.A. Chapman & Hall, London.
- Tufts, W.P. 1929. Seasonal temperature and fruit ripening: A preliminary report. *Proc. Am. Soc. Hort. Sci.* 26: 163.
- USDA. 1954. United states standards for Grades of frozen apple, U.S. Dept. of Agriculture, Agricultural Marketing Service, Fruit and Vegetable Division, Processed product standardization and inspection branch, Washington, D.C.

- USDA. 1974. United states standards for Grades of canned applesauce, U.S. Dept. of Agriculture, Agricultural Marketing Service, Fruit and Vegetable Division, Processed product standardization and inspection branch, Washington, D.C.
- Upshaw, S.C.; Lopez, A.; Williams, H.L. 1978. Essential elements in apples and canned applesauce. J. Food Sci. 43: 449-56.
- Van Buren, J.P., Moyer, J.C., and Wilson, D.E. 1960. Influence of blanching conditions on sloughing, splitting, and firmness of canned snap beans. Food Technol. 14: 233.
- Van Buren, J.P. 1967. Pectic substances of sweet cherries and their alteration during SO₂ brining. J. Food Sci. 32: 435.
- Van Straten, S. 1977. Volatile compounds in food. TNO. Zeist.
- Way, R.D. and McLellan, M.R. 1989. Apple cultivars for processing. *Processed Apple Products*, Van Nostrand Reinhold, New York, NY, pp. 1-29.
- Whistler, R.L. and Daniel, J.R. 1985. 2nd ed. Carbohydrate. *Food Chemistry*. (Fennema, O.R., ed.). Marcel Dekker, Inc., New York.
- Whiting, G.C. 1970. Sugars. *Biochemistry of Fruits and Their Products*. Vol. 1. (ed. AC. Hulme). Academic Press, London.
- Wiley, R.C. and Thompson, A.H. 1959. *Influence of Apple Variety, Maturity, and Storage on the Quality of Canned Slices*. Nat. Cannery Assoc. Information Letter No. 1720.
- Wiley, R.C. and Thompson, A.H. 1960. Influence of apple variety, maturity, and storage on the quality of canned slices. Proc. Amer. Soc. Hort. Sci. 75: 61.
- Wiley, R.C. and Toldby, V. 1960. Factors affecting the quality of canned apple sauce. Proc. Am. Soc. Hort. Sci. 76: 112.
- Wiley, R.C. and Stemberge, G.E. 1961. Factors influencing apple texture. Proc. Am. Soc. Hort. Sci. 77: 60.
- Williams, A.A., Tucknott, O.G. and Lewis, M.J. 1977. 4-methoxyallylbenzene, an important aroma component of apples. J. Sci. Food Agric. 28: 185-190.

- Woodroof, J.G. and Luh, B.S. 1975. Fruit wasting, Peeling, and preparation for Processing. *Commercial Fruit Processing*. The AVI Publishing Company, Inc, Westport, Connecticut, pp.78-99.
- Workman, M. 1963. Controlled atmosphere studies on Turley apples. *Proc. Amer. Soc. Hort. Sci.* 83: 126-134.
- Yamaki, S. and Ishikawa, K. 1986. Roles of four sorbitol related enzymes and invertase in the seasonal alteration of sugar metabolism in apple tissue. *J. Am. Soc. Hort. Sci.* 111: 134-137.
- Yang, S.F. 1975. Ethylene biosynthesis in fruit tissues. *Facteurs et Regulation de la Maturation des Fruits*. Centre National de la Recherche Scientifique, Paris.
- Yang, S.F. and Hoffman, N.E. 1984. Ethylene biosynthesis and its regulation in higher plants. *Ann. Rev. Plant Physiol.* 35: 155-89.
- Young, C.T. 1975. Composition and nutritive value of raw and processed fruits. *Commercial Fruit Processing*. (ed. Luh, B.S. and Woodroof, J.G.) AVI Publishing Co, Inc. Westport, CT.