AN ABSTRACT OF THE THESIS OF

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Title: Effect of Maturity and Storage on Quality of 'Gala', 'Braeburn', and 'Fuji' Apples.

Abstract approved: ______________________________
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In apples, the rapid changes occurring in fruit metabolism when approaching maturity affect their quality at harvest and after storage. The interest in the newly introduced cultivars, 'Gala', 'Braeburn' and 'Fuji' has initiated the following study on maturity indices and storage in the conditions of the Pacific Northwest.

'Gala', 'Braeburn' and 'Fuji' apples were sampled at weekly intervals from 108 to 143 days after full bloom (DAFB), 133 to 189 DAFB and 138 to 187 DAFB, respectively. Fruit color, firmness, soluble solids concentration (SSC), titratable acidity (TA), pH, starch hydrolysis and internal ethylene were determined at harvest. The same parameters except starch hydrolysis and internal ethylene were measured on fruits after regular storage at 0 ± 0.5C, every 6 wks for 'Gala', and 8 wks for 'Braeburn' and 'Fuji'. Additionally, apples were evaluated for overall liking

(OL), firmness, sweetness, tartness and flavor intensities by a consumer taste panel approximately every 4 wks for 'Gala' and every 8 wks for 'Braeburn' and 'Fuji',until January, May and June, respectively.

A principal component analysis (PCA) showed that all the measured maturity indices were important and the model could not be reduced.

All the maturity indices could be used in 'Gala' to determine that the physiological maturity was attained 122 DAFB. Fruits harvested at that stage had the highest storage potential (January) but their color was not fully developed, whereas those harvested later had the best quality after short-term storage (October-November).

Results of the sensory data and observation of fruit physiological disorders such as scald and internal breakdown led to establish that only fruits picked 168 and 175 DAFB had the best storage potential (April) for 'Braeburn'. SSC and hue angle of the ground color were the most obvious parameters on which to predict optimum harvest date in 1991. Internal ethylene showed the autocatalytic rise earlier, 154 DAFB. Starch index increased 175 DAFB.

'Fuji' fruits picked 173 and 180 DAFB were the only ones free from scald and retaining good quality after 8 months storage. The only reliable indices at harvest were the starch index and hue value of the ground color. 'Fuji' apples produced low levels of ethylene.

A multivariate analysis of the data with 5 sensory descriptor variables revealed that a taste panel could differentiate between maturity stages. The loss of firmness and acidity occurring during maturation and in storage was well perceived, but firmness was the only instrumental variable correlated to sensory firmness. Additionally, changes in sweetness and in flavor not revealed by the analytical data were described. OL, sweetness and flavor ratings were not rated independently, but tartness and firmness were. Sweetness ratings contrasted those of tartness and firmness.

EFFECT OF MATURITY AND STORAGE ON QUALITY OF 'GALA', 'BRAEBURN', AND 'FUJI' APPLES

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Typed by Anne Plotto

To Bob and Monine,
for their unconditional love

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"The teacher who walks in the shadow of the temple, among his followers, gives not of his wisdom but rather of his faith and his lovingness. If he is indeed wise he does not bid you enter the house of his wisdom, but rather leads you to the threshold of your own mind." (Khalil Gibran, 'The Prophet', 1923).

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CHAPTER 1

INTRODUCTION

'Gala', 'Braeburn' and 'Fuji', three apple cultivars recently introduced in the United States, are having an increasing interest among growers in the main production areas in the world.

'Gala' originated in New Zealand in 1934 and is a cross between 'Kid's Orange Red' (from 'Cox's Orange Pippin' and 'Red Delicious') and 'Golden Delicious' (Gordon, 1990). It was released in 1960, and known in the European markets since the mid-80's. 'Gala' is round to oval, small to medium size, pale to golden yellow with bright red blush and stripes. The flesh is yellow creamy, and the texture is crisp, with a tendency to become soft after storage. The fruit is sweet and subacid, with an aromatic flavor (Gordon, 1990).

'Braeburn' is a chance seedling from 'Lady Hamilton' discovered in 1952 at Waiwhero, Nelson, New Zealand (Manhart, 1987). The fruit has a truncated and elongated shape, and is medium in size. It has a narrow stem cavity. The color is of a yellowish green with broken red stripes (Stebbins, 1991). The texture is sharp and crisp. The fruit is high in organic acids and sugar content, with a strong flavor. It has consistently received high ratings in taste tests (Stebbins, 1991).

'Fuji' is a cross between 'Red Delicious' and 'Rall's Janet' obtained in 1939 at the Morioka research station in Japan (Gordon, 1990). It is very popular among Asian consumers and represents 45% of the Japanese apple production. The fruit is round, medium to large, firm, crisp and juicy. Sugar levels of 14 to 16° Brix are normal. Late harvested fruit develop water core, which does not affect their shelf life. The fruit is pale green with a pink to red blush and stripes. 'Fuji' is a late harvest variety and has an excellent storage capacity (Gordon, 1990).

All three varieties have numerous sports, mainly based on the degree of red color.

The quality of apples and their storage potential are partly and strongly determined by the stage of maturity at harvest (Olsen, 1982). The physiological stage of climacteric fruits is usually identified by following respiration rate and/or ethylene production (Knee et al., 1989; Olsen, 1982), the latter being the most practically used (Sfakiotakis and Dilley, 1973). Other components which change in the final developmental stage of apples are size, color, firmness, sugars, starch and malate content (Knee et al., 1989). All the constituents measured to determine apple maturity vary from year to year, with cultural practices and growing area, and therefore, have accounted for the lack of a single maturity standard (Olsen 1982). However, the pattern of ethylene production is a varietal characteristic (Chu, 1988; Watkins et al., 1989) and correlations of ethylene with other indices such as starch index have provided for indices easier to measure in the field (Lau, 1988; Walsh et al., 1991). However, work is still needed for the finding of predictive indices of maturity.

If size, color and firmness determine commercial quality grade (USDA Standards for Grades of Apples, 1964), firmness, sugars, malate and other metabolite and volatile content affect fruit eating quality (Watada et al., 1981). Also, the latter components change in storage, as fruit further matures and gets senescent. Quality in foods implies some measure of acceptability which ultimately results from the consumer's opinion (Williams, 1981). The common attributes associated with quality in apples include texture such as crispness, juiciness (Williams and Langron, 1983; Watada et al., 1980), hardness, toughness, mealy (Watada et al., 1980), taste, such as sweetness, tartness, astringent (Watada et al., 1980) and aroma (Williams, 1981).

The objectives of the present study were to initiate a database of the maturity indices for 'Gala', 'Braeburn' and 'Fuji' under the Pacific Northwest conditions, and identify the ones that could be used to predict optimum fruit quality for different storage duration. Additionally, a concern was to know if there was any taste difference between apples harvested at weekly intervals. Therefore, consumer panels were performed on each variety separately, over a period of 6 to 8 months. Panelists rated apples for their preference, and for the intensity of taste and firmness perceived. In order to understand the relations between fruit characteristics and its sensory ratings, and possibly to set thresholds for quality, sensory data were compared to instrumental measurements.

CHAPTER 2

LITERATURE REVIEW

CHANGES OCCURRING IN FRUIT DURING DEVELOPMENT AND MATURATION

Terms describing the developmental stages of horticultural crops have been employed in the literature with some discrepancies concerning their meaning and definition. Watada et al. (1984) defined "development" as the series of processes from the initiation of growth to death of a plant or plant part, "growth" as the irreversible increase in physical attributes of a developing plant or plant part, and "maturation" as the stages of development leading to the attainment of physiological or horticultural maturity.

Maturity is the most vague of all: horticultural or commercial maturity is understood to be when the crop is consumable. Physiological maturity includes physical and biochemical parameters which change during the ripening process. In some fruits, the climacteric period is associated with an increase in respiratory ability and the autocatalytic production of ethylene (Watada et al., 1984). Senescence follows maturity and leads to tissue death.

A review of biochemical and physiological changes occurring in apple fruit during ripening is presented in this chapter.

Carbohydrate metabolism

It is now well known that sorbitol is the main photosynthate translocate in the Rosaceae family (Bieleski and Redgwell, 1985; Yamaki and Ishikawa, 1986; Hansen, 1970). This was shown by applying $^{14}CO_2$ to apricot (Bielesky and Redgwell, 1985) and apple (Hansen, 1970) leaves: the majority of ^{14}C was incorporated into sorbitol, and sucrose to a lesser extent (Hansen, 1970). Both sugars were later translocated into the fruit (Hansen, 1970), and readily transformed into fructose, glucose and sucrose (Yamaki and Ishikawa, 1986). Under certain climatic conditions and in some apple varieties, accumulation of sorbitol in the intercellular spaces of the fruit results in vitreous flesh named water core (Williams, 1966).

In the early stages of fruit formation, a high acid invertase activity and the absence of detectable sucrose suggested that sucrose is the main carbohydrate source for cellular growth in the young fruit (Berüter, 1985). After "June drop" and until maturity, a high activity of sorbitol-6-phospho-dehydrogenase resulted in high levels of fructose (45 to 60% of total sugars) and the decrease in invertase activity allowed sucrose to accumulate in the fruit (Berüter, 1985; Yamaki and Ishikawa, 1986). Glucose, under the action of sorbitol oxidase, increased until starch started accumulating (Berüter, 1985; Krotkov and Helson, 1946), remained constant or decreased, and increased again when starch breakdown occurred after the climacteric rise (Berüter, 1989). In 'McIntosh' apple, starch hydrolysis occurred during the climacteric rise, after which both sucrose and fructose increased. The post-climacteric stage was characterized by a decrease in total sugars (Krotkov and Helson, 1946).

Quality and quantity of the different sugars after harvest have been variable from study to study. Fructose and glucose increased after harvest (Chan et al., 1972; Krotkov and Helson, 1946). Sorbitol and sucrose remained at low levels, although increasing slightly (Chan et al., 1972). The variations in sugar levels may be attributed to the year, nutritional status of the tree, degree of maturity at harvest and reserves in the fruit, and genotype.

Acid metabolism

Organic acids play a major role during fruit ripening as a source of energy for respiratory oxidation (Ulrich, 1970; Haynes and Archbold, 1928). The main pathway for oxidation of acids is the tricarboxylic acid (TCA) or Krebs cycle (Ulrich, 1970).

In a study on 'McIntosh' apple, the amount of total organic acids increased sharply from June to August, dropped precipitously at the beginning of the pre-climacteric stage, then decreased constantly during maturation and ripening (Krotkov et al., 1951). Generally, the decreases in organic acid content during fruit ripening is accompanied with a simultaneous increase in sugars (Satyan and Patwardhan, 1983).

Malic acid is the predominant organic acid in apples and is 80 to 90% of the total acid content at maturity (Krotkov et al., 1951; Ulrich, 1970). According to Satyan and Patwardhan (1983), labelled malic acid injected into fruits after harvest was recovered as respiratory CO_2 (60 to 75%), other organic acids (20 to 30%), amino acids (3 to 6%), and sugars (0.5 to 1.5%). This study not only showed the contribution of organic acids in fruit respiration, but also the metabolic conversion of organic acids into sugars and amino acids. Decarboxylation of malic acid in respiration has been called the "malate effect" and is under the control of the NADP-dependent malic enzyme (Hulme and Rhodes, 1970). Its activity increases during the climacteric stage in apple and pear (Ulrich, 1970).

The pH of apple juice drops during the first 6 weeks after bloom, then increases steadily during the rest of fruit development and maturation (Krotkov et al., 1951). Those authors suggested that pH is a better indicator of the ontogenic stage of apple fruit than respiratory rate or carbohydrate content.

Fruit respiration

In all fruits, respiration, as measured by CO_2 production, decreases sharply during cell division (fruit set), then decreases slowly but steadily during cell enlargement (fruit growth). In climacteric fruit such as apples, the ripening process is characterized by a sudden respiratory rise, and the climacteric peak is the point of maximum CO_2 and ethylene production (Watada et al., 1984).

The overall respiratory process is an oxidative and reductive reaction in which substrates are oxidized to CO_2 and absorbed O_2 is reduced to form water. During this reaction, part of the energy is stored in the form of adenosine triphosphate (ATP), and the remaining is lost as heat. Substrates which can be used include starch, sugars, organic acids, fats and proteins under certain conditions, the former three being the main sources in apple. As an example, apples stored for 6 weeks at 18°C had a respiratory quotient ($RQ=CO_2$ produced/O_2 absorbed) of 0.93, suggesting sugars were the source of energy for the respiratory cycle, and at 33°C, it was of 1.39 indicating malic acid oxidation (Gerber (1897) quoted by Ulrich, 1970). Respiratory reactions include glycolysis in which starch and glucose are catabolized into pyruvic acid, TCA cycle where organic acids are oxidized to CO_2 and water, and the electron transport chain coupled with the formation of ATP (Eskin, 1990). The pentose phosphate pathway is an alternative reaction to glycolysis to produce pyruvic acid. Both pathways function during the ripening of apple (Hulme and Rhodes, 1970). These reactions produce ATP, which during the climacteric rise represent a supply of chemical energy in excess of the demand of the growing tissue (Brady,. 1987).

Simultaneously with the increase of respiration in the fruit, there is an increase in the level of endogenous ethylene and in the red and yellow pigments in the peel tissue. Chlorophyll degrades, reserves (starch, organic acids) are lost, pectic substances break down, and the profile of volatile compounds changes (Eskin, 1990).

An increase in protein synthesis is paralleled with increased amounts of ribonucleic acid (RNA) and enzymatic activity (Brady, 1987). The question has arisen whether an increase in respiration occurs to provide energy for polysome formation, or if respiration is a result of RNA requiring energy for translation. The exact amount of ATP yielded in the respiratory climacteric is not known, nor are the absolute rates of protein synthesis, hence the order of appearance of those reactions is not known (Brady, 1987).

Ethylene production

Ethylene (C_2H_4) has been shown to regulate many aspects of plant growth and development and plays an essential role in fruit ripening (Yang, 1980). In the early 1930's, Kidd and West (1930) observed that the vapors produced by ripe apples stimulated respiration and ripening of unripe apples (Hulme and Rhodes, 1970) and were later identified as ethylene. The design and construction of the gas chromatograph in the late 1950's allowed the quantification of ethylene produced by the fruit (Hulme and Rhodes, 1970).

Biosynthesis of ethylene and its regulation in plants revealed methionine (met) as the precursor of ethylene (Yang and Hoffman, 1984). The low level of methionine in apple tissue suggested that this compound was recycled (Baur and Yang, 1972). Indeed, the methionine cycle, with S-adenosylmethionine (SAM) and 1-aminocyclopropane-1-carboxylic acid (ACC) as key intermediates, is now well accepted (Yang, 1980; Yang and Hoffman, 1984).

Methionine-adenosyltransferase catalyses the reaction of methionine into SAM (Yang and Hoffman, 1984). It is not a rate limiting enzyme in ethylene biosynthesis since SAM is constantly synthesized and utilized in other reactions such as methylation and polyamine synthesis.

The conversion of SAM to ACC is the rate limiting step in ethylene production since it requires de novo synthesis of ACC synthase (Campbell and Labavitch, 1991; Oeller et al., 1991; Yang and Hoffman, 1984). ACC synthase is a labile enzyme with a half life of 30 minutes (Yang and Hoffman, 1984). Genes encoding ACC synthase have been identified. They belong to a multigene family whose members are differentially expressed in response to environmental, developmental and hormonal factors (Theologis et al., 1993). The stoichiometry of the reaction SAM --> ACC gives 5'-methylthioadenosine (MTA) as the second product (Yang and Hoffman, 1984).

MTA enters in the recycling pathway of methionine and is cleaved to 5-methylthioribose (MTR) and adenine. MTR is first phosphorylated to 5-methylthioribose-1-phosphate (MTR-1-P) by a kinase, and then metabolized to 2-keto-4-methylthiobutyrate (KMB). KMB is transaminated to methionine (Yang and Hoffman, 1984).

The last step in ethylene formation is the oxidation of ACC to ethylene (Yang, 1980). In vitro, ascorbic acid acts as a co-substrate, and Fe^{2+} and CO_2 as cofactors (Dilley et al., 1993; Smith and John, 1993; Yang et al., 1993). ACC oxidase, the ethylene forming enzyme (EFE), has been purified and is described by Yang et al. (1993) and Dilley et al. (1993). The fact that the purified enzyme requires CO_2 (Smith and John, 1993; Yang et al., 1993) is in agreement with previous studies reporting CO_2 as a promoter of ethylene under certain environmental conditions (Yang and Hoffman, 1984). Immunocytolocalization using optical and electron microscopy revealed the major part of ACC oxidase activity in the cell wall space of ripening tomato fruit (Latché et al., 1993).

Ethylene acts as a feedback regulator on its own biosynthesis. In response to wounding, the feedback is negative (Imaseki et al., 1988). In ripening, it is autocatalytic and persistent (McMurcie et al., 1972). McMurcie et al. (1972) distinguished two systems; system I is the initial production of ethylene, common to climacteric and non-climacteric fruit and flowers and is part of the ageing process. The ethylene produced in system I and/or exogenous ethylene trigger system II characterized by a massive production of ethylene. System II occurs in climacteric fruit and corresponds to the respiratory rise (McMurcie et al., 1972).

In non-climacteric fruit such as citrus, exogenous ethylene stimulates respiration with a reversible effect, the rate of chlorophyll loss, and changes in the pectins of the flesh (Rhodes, 1970). In climacteric fruit such as tomato, the loss of epidermis chlorophyll is enhanced by ethylene but is initiated before ethylene production increases (Goodenough, 1986). Also in apple (Reid et al., 1973) and melon (Lyons et al., 1962) fruit, the increase in ethylene concentration appears coincidentally with the increase of internal CO_2.

The recent technique using antisense RNA to inactivate ACC synthase in tomato has clarified the effect of ethylene in the ripening process (Oeller et al., 1991). In antisense tomato, ethylene controls the climacteric respiration rise, fruit softening, changes in color due to the accumulation of lycopene, and aroma formation (Oeller et al., 1991). Although antisense tomatoes remain firm, polygalacturonase (PG) mRNA is expressed as in the normal fruit. It is concluded that PG may not be solely responsible for tomato fruit softening (Oeller et al., 1991). Indeed, Goodenough (1986) reported that acid invertase, a cell wall hydrolysing enzyme, is initiated by ethylene.

In tomato, the change in metabolism of starch, sugars, and organic acids is independent of ethylene (Goodenough, 1986), though there is no information on the effect of ethylene on the enzymes of glycolysis. Jeffery et al. (1984) reported that the activity of the TCA cycle was not changed with the removal or the addition of ethylene. Similarly, malic enzyme activity, responsible for the malate effect, is not enhanced by ethylene. The respiratory pathway appears to be more complex than previously thought.

Although such mechanisms can be explained for tomato, they may be different in other fruit.

Among substances stimulating ethylene production, IAA exerts its effect by inducing the synthesis of ACC synthase (Yang and Hoffman, 1984). In fruit tissue, oligosaccharide and oligopectins resulting from cell wall hydrolysis stimulate ethylene synthesis (Campbell and Labavitch, 1991; Yang and Hoffman, 1984) and have been proposed as regulators in ripening (Brady, 1987).

Several inhibitors of ethylene synthesis have been tested and they can be classified according to the level of inhibition. Inhibitors such as aminoethoxyvinylglycine (AVG) or aminooxyacetic acid (AOA) are pyridoxal phosphate-linked enzyme inhibitors and act on ACC synthase (Yang and Hoffman, 1984). All other inhibitors act on the conversion of ACC to ethylene (Yang and Hoffman, 1984). These include uncouplers of oxidative phosphorylation, some membrane disruptors, Co^{2+}, Ni^{2+}, free radical inhibitors such as n-propyl gallate. Polyamines have also been shown to inhibit ethylene biosynthesis at the ACC oxidase level. Because polyamines and ethylene share a common precursor (met), Yang and Hoffman (1984) suggest the need for more studies to elucidate their relationship in plants.

Texture

Fruit texture is related to cell wall structure, and firmness loss during ripening is a consequence of enzymatic activity on cell wall constituents (Eskin, 1990). The complexity of the cell wall architecture has inspired numerous and various models, most of them built after hydrolyzing the macromolecules, identifying the fragments, and reconstructing the polymers. In edible parts of plants, the primary cell wall is composed of cellulose fibrils located in a matrix of pectic substances, hemicellulose, proteins, low-molecular weight solutes, and water (Van Buren, 1979). Lignin is part of the secondary cell wall and is virtually absent in mature fruit.

Pectic substances play a major role in cementing and holding together the long chains of cellulose. They comprise one-third of the dry matter of the primary cell wall, and consist of 1,4-α-D-galacturonic acid, with rhamnogalacturonan side chains (Van Buren, 1979). The hemicellulose component constitutes a group of noncellulosic, nonpectic substances extractable by alkaline solution (Eskin, 1990). As an example, xyloglucans appear to be involved in the cross-linking of each cellulose microfibril through hydrogen bonds (Eskin, 1990).

Biosynthesis of the complex cell wall polysaccharides has not been completely explained but appears to continue during senescence. Cell walls of apple incorporated methyl groups into polygalacturonate from ^{14}C-methionine during ripening (Knee, 1978). The glycosyl donor for the formation of polysaccharides are the sugar nucleotides obtained from monosaccharides and ATP in the presence of nucleoside tri-phosphate. The general reaction is:

$$\text{ATP-glucose} + \text{acceptor} \rightarrow \text{Glycosyl-acceptor} + \text{ADP}$$

The mechanism of polymerization of the sugar nucleotides to complex cell wall polysaccharides is poorly understood, although the enzymes involved appear to be membrane bound (Eskin, 1990).

Fruit softening is attributed to an increase in soluble pectic substances, with a concomitant decrease in insoluble pectins (protopectins) (Brady, 1987; Eskin, 1990). The hydrolysis of pectins is catalyzed by two groups of enzymes, polygalacturonase (PG) and pectin methyl esterase (PME) (Eskin, 1979). PG would only act on the demethylated region of the polygalacturonan, which is brought about by the action of PME. Only exo-polygalacturonase has been found in apple (Bartley, 1978). PG may be both exo- and/or endo-polygalacturonases in other fruit (Pressey and Avants, 1973; 1976). PG activity in 'Delicious' apple was undetectable until the onset of the climacteric (Liang et al., 1982). It rose rapidly after harvest, and decreased gradually one month after the climacteric. The alcohol-insoluble fraction of pectic acids decreased concomitantly with PG activity, while the amount of soluble fractions increased. Fruit softening occurred 20 days after the rise of PG activity (Liang et al., 1982).

The loss of firmness in apple has also been attributed to ß-galactosidase activity (Bartley, 1974; 1977), but Knee et al. (1989) and Dick et al. (1990) did not find any change in this enzyme activity during the ripening course of apple. The mechanism of cellulose degradation is still not well known in fruit. According to Eskin (1990), a cellulase complex would degrade the cellulose microfibrils allowing the penetration of pectic enzymes in the middle lamella of the cell wall.

Color

The most obvious signs of fruit maturation are changes in the skin color. Color changes start with chlorophyll degradation, exposing the yellow carotenoids (Eskin, 1990; Gorski and Creasy, 1977; Kvåle, 1967). A decrease of chlorophyll and chloroplast carotenoids followed by an increase in chromoplast carotenoids was reported during persimmon ripening (Ebert and Gross, 1985).

Knee (1972) reported a continuous decrease in chlorophyll during apple maturation, with a sharp drop at the onset of the climacteric. Total carotenoids followed the reverse trend. Knee also reported some disagreement in the literature as to the quality and quantity of carotenoids present in apples. In 'Cox's Orange Pippin' he found ß-carotene decreasing during ripening; lutein, violaxanthin, and neoxanthin decreased slightly or remained constant; xanthophyll mono- and di-esters increased over ten-fold during ripening. Similar changes but different ratios were found on 'Golden Delicious' by Gorski and Creasy (1977). A further study revealed a more complex system for carotenoid pigments, including partially and fully esterified carotenols (Knee, 1988). Free carotenols esterify with a pool of common fatty acids, including oleate, but excluding linoleate and linolenate (Knee, 1988).

Because red color is an important parameter for market acceptance, the mechanisms of anthocyanin synthesis have been widely studied. In his extensive review, Saure (1990) summarizes the present knowledge on the subject, pinpointing multiple contradictions, but also drawing a general explanation of the process and the external factors affecting the formation of red color.

In the group of anthocyanins, cyanidin-3-galactoside (idaein), cyanidin-3-arabinoside, and cyanidin-7-arabinoside have been identified in ripe apple skin (Van Buren, 1970). In apples, anthocyanin synthesis prevails during the phase of intense cell division of the fruit and during fruit ripening. In the later phase, anthocyanin formation rate is different according to the stage of maturity and to the cultivar. Chalmers et al. (1973) observed an accumulation of anthocyanins on detached mature 'Jonathan' apples, whereas the accumulation stopped on unripe detached fruits. Therefore they suggested to investigate further on the rate of accumulation of anthocyanins as an indicator of maturity. Anthocyanin formation is absolutely light-dependent (Saure, 1990), but the degree of the light response is cultivar and maturity dependent (Chalmers et al., 1973). The light response is related to a phytochrome-dependent process. When apples were covered with bags one month after bloom and the bags removed one month before harvest, fruit color intensity increased substantially (Kikuchi, 1964). It is suggested that bagging increases phytochrome content (Saure, 1990). Additional UV-B (280-320 nm) treatment increased phytochrome effectiveness and therefore, anthocyanin formation (Arakawa, 1988).

The endogenous control of anthocyanin formation may be regulated by gibberellins (GA) (Saure, 1990). Applied GA_3 delays the loss of chlorophyll, the increase in carotenoids, the softening of fruit, and other processes (Saure, 1990). GA_3 may suppress phenylalanine ammonia-lyase (PAL) activity, which is one of the enzymes controlling flavonoid and anthocyanin synthesis (Faragher and Chalmers, 1977; Eskin, 1990). Assuming GA control anthocyanin concentration by repressing their synthesis would explain the effect of low temperatures on color development. Low temperatures induce a reversion of free GA to bound GA. Also, ethylene and/or ABA would act as a GA antagonist, counteracting its inhibitory effect on anthocyanin formation (Saure, 1990). Chalmers and Faragher (1977a; 1977b) suggested that ethylene increased PAL activity, which in turn stimulated anthocyanin synthesis.

The relation of sugars to anthocyanin is not clear, and results are contradictory. Saure (1990) reported various feeding experiments on apple discs where sucrose and/or glucose and/or galactose stimulated anthocyanin formation. On the other hand, there is no difference in the sugar content of the red apple cultivars and their red sports (Seipp and Roemer, 1984), and bagging fruit increases color formation but the total sugar content of bagged fruit is lower than the unbagged fruit (Proctor and Lougheed, 1976).

Cultural practices such as summer or dormant pruning, fertilization, thinning, and also the rootstock, are all meant to regulate the leaf/fruit ratio, therefore influencing fruit size, maturity, and color.

Aroma

Identifying chemicals responsible for fruit and vegetable aroma has been a subject of investigation since the beginning of the century (Dimick and Hoskin, 1983). With the advent of gas chromatography, mass spectrometry, complemented with infra-red and nuclear magnetic resonance, the list of identified compounds grew to about 200 for most fruit (Nursten, 1970). Assessing an odor significance to a chemical compound has been the initial motivation for food scientists and flavorists interested in synthesizing the aroma. Difficulties arise as to the analytical methods employed since secondary aromas develop rapidly upon crushing the cell. Stopping enzymatic processes is necessary if juices are analyzed. The list of aromas reported for apples differs whether headspace of intact fruit, distillation, or solvent extraction is analyzed (Nursten, 1970).

From 'Delicious' apple essence, Flath et al. (1967) reported ethyl-2-methylbutyrate, hexanal, and 2-hexenal as the character impact components, with odor thresholds of 0.1 ppb, 5 ppb, and 17 ppb, respectively. Drawert (1975) considered hexanal and hexenals, with their green grassy odor, as secondary aroma or "wound hormone". He showed how *trans*-2-hexenal appeared upon crushing the cells and increased very rapidly, being present only in apple juice.

On testing the juice of 40 apple cultivars using the combined GC/MS and sniffing (CHARM) method, Cunningham et al. (1986) came to the conclusion that the odor cannot be described by simple variation in the concentration of a few chemicals. For all the cultivars tested, they found that hexyl-butanoate and ethyl-butanoate, with a fruity apple odor, and hexyl-hexanoate, with an apple peel-like odor, contributed significantly to the overall apple aroma.

Numerous studies list the volatile composition of apple varieties (Cunningham et al., 1986; Flath et al., 1967; Kakiuchi et al., 1986; Yajima et al., 1984), but more interesting for the horticulturist is how the compounds vary in quality and quantity with cultural practices, maturity and storage. De Pooter et al. (1987) reported that aldehydes predominate in immature apples. Esters and aliphatic alcohols appeared as a consequence of fruit ripening (Flath et al., 1967). In turn, ß-damascenone is a storage compound (Cunningham et al., 1986). Mattheis et al. (1991) reported that overall aldehydes were high in immature apples and decreased during the ripening season to zero levels for butanal, pentanal, (E)-2-hexenal, and heptanal. Most esters appeared later, along with ethylene, and increased dramatically with ripening. Some esters appeared before ethylene and the authors suggested that 2-methylbutylacetate could be used as a maturity index. Sapers et al. (1977) correlated total volatiles with maturity indices such as acidity and firmness.

If biogenesis of aroma during fruit development and maturation is well recognized, most of the pathways and their control are still under speculation. Paillard (1979) reported the varietal effect on volatile synthesis: yellow skin apples produced mainly acetic acid esters, whereas butyric acid esters were predominant in red skin varieties. Feeding apple discs (Paillard, 1979) or intact fruit (De Pooter et al., 1981) with short chain aliphatic acids resulted in the production of the corresponding alcohol. In intact fruit treated with propionic acid, propanal was an intermediate prior to esterification of propanol (De Pooter et al., 1981).

Since esters of butyl and hexyl acetate are the principal aroma compounds synthesized by apple, ß-oxidation of fatty acids has been proposed by Paillard (1979) and Bartley et al. (1985) as a pathway in alcohol formation. The resulting short chains of acyl-CoA are reduced to aldehydes, which are in turn hydrogenated to the corresponding alcohol (Barley et al., 1985). Acetyl CoA is involved in the esterification of alcohols. Feeding a whole apple with alcohol resulted in the corresponding acetate ester (Bartley et al., 1985). The ester synthetase had still to be characterized. Acetate could also be the result of ß-oxidation of butyrate (Paillard, 1979).

By analogy with yeast fermentation, one could see the implication of a coenzyme A in ester formation:

RCoSCoA + R'OH ---> RCOOR' + CoASH (Nursten, 1970).

Bartley et al. (1985) also suggested that alcohols such as butanol arose from hydrolysis of the esters by esterase. An esterase has been isolated by Goodenough (1983) from 4 months after petal fall, with an increase in activity until maturity. The ester synthesizing systems seem to be present early in the climacteric fruit. The substrate level appears to be the limiting factor (De Pooter et al., 1981; Paillard, 1979).

Sources other than fatty acids have been identified for alcohols and aldehydes. In tomato, an enzyme has been isolated converting amino acids into alcohols and aldehydes through transamination (Yu et al., 1968).

The pathway for aldehyde formation is less understood. Although alcohols can be dehydrogenated to aldehyde by alcohol dehydrogenase, another source of aldehydes are amino acids, via the α-oxo acids or via the Strecker reaction with α-dicarbonyl compounds (Nursten, 1970), or via reduction of acyl-CoA (Bartley et al., 1985).

From studies with ^{14}C labelled compounds, Drawert (1975) concluded that trans-2-nonenal and cis-6-nonadienal derived from linoleate and linolenate, respectively, as a result of lipoxygenase and aldehyde lyase activity. De Pooter and Schamp (1989) have proposed the following sequence for ester formation during ripening:

linoleic acid ---> hexanal ---> hexanoic acid ---> C6 esters.
↑
lipoxygenase (isolated from apple)

ASSESSING MATURITY INDICES FOR HARVESTING APPLE FRUIT

For economic reasons, fruit should be harvested when quality criteria can be best satisfied (Knee and Smith, 1989). Quality can be considered on external aspects -- size, color, fruit uniformity, absence of blemishes, rot, spots, and on internal characteristics -- texture, juiciness, flavor, aroma (Kupferman, 1983), as well as nutritional value.

Both the grower and fieldperson have an impact on quality with cultural practices. Numerous studies have shown the effect of mineral nutrition on firmness and breakdown of apple (Fallahi et al., 1988; Marmo et al., 1985). The position of the fruit on the branch and in the tree, regulated by pruning, has an effect on metabolite content (Lespinasse, 1970).

Finally, the time of harvest is significant because rapid changes in fruit metabolism occur close to maturity. The physiological stage at harvest can affect: 1) fruit quality as perceived by the consumer for fresh consumption, 2) fruit storage potential, and 3) fruit quality for processing. Maturity indices can be quite different according to the destination of the crop.

Ideally, changes in maturity indicators should occur before the optimum harvest date to have a predictive value (Knee et al., 1989). To be recommended, a maturity index should be: measurable and constant, correlated with an aspect of fruit quality, give independent information, and be of practical use.

Measuring enzymatic activities prior to and after harvest has been considered. The increase in ACC oxidase (ethylene formation enzyme) activity as related to ACC (1-aminocyclopropane 1-carboxylic acid) content and internal ethylene in 'Jonagold' apple has been suggested as a physiological marker by Uthaibutra and Gemma (1990). Lipoxidase activity, preceding ethylene production and the respiratory climacteric could be used in 'Cox's Orange Pippin' apple (Meigh et al., 1967). The activity of esterase isolated from 'Cox's Orange Pippin' apple and related to its final aroma was proposed by Goodenough (1983), although Knee et al. (1989) didn't observe any change on it when they measured it in this cultivar's fruit. No significant change was observed either in the activities of ß-galactosidase or malic enzyme (Knee et al., 1989). However, many factors can affect enzyme activities measured in vitro and for that reason, immunological and nucleic acid probes could be developed as a more reliable tool for maturity measurements (Knee et al., 1989).

Physiological maturity of climacteric fruit can be recognized by following the rate of respiration of the developing fruit (Olsen, 1982). The best stage for picking fruit for optimum quality is recognized to be just at the beginning of the pre-climacteric rise (Smock, 1948), although, for practical reasons, it may be argued that all the fruits in the orchard should be picked at the same stage. Measurements of respiratory rates are difficult for commercial use. Autocatalytic ethylene production coincides with the start of the climacteric rise (Sfakiotakis and Dilley, 1973), therefore an attempt to use internal ethylene as a maturity index has been made in numerous studies (Blankenship and Unrath, 1988; Chu, 1984; Knee et al., 1989; Sfakiotakis and Dilley, 1973; Walsh et al., 1991). According to one study, the rise of internal ethylene concentration values were from 0.05 ppm before the climacteric rise to 100 ppm at the peak (Sfatiotakis and Dilley, 1973).

The variation between fruits and from year to year of internal ethylene is such that assessing harvesting date on that parameter alone is not reliable (Blankenship and Unrath, 1988; Chu, 1984). However, the pattern of ethylene increase remains the same for each variety (Chu, 1988; Watkins et al., 1989). It can be of interest to correlate ethylene evolution to other indices to confirm physiological maturity (Chu, 1988), and some studies are being done on new commercially-grown varieties (Watkins et al., 1989). For example, on 'Jonagold' apple, internal ethylene concentration was correlated to starch index (Lau, 1988); on 'Gala' apple, Walsh et al. (1991) found a correlation between ethylene headspace and starch index, "a" value for ground color, soluble solids, red color, firmness, and fruit weight.

Apples already producing detectable ethylene have passed the pre-climacteric minimum and may be too advanced for long-term storage. Other compounds changing in quantity, or appearing before ethylene, should be better indicators for predicting harvest. Knee et al. (1989) suggested looking at xanthophyll esters, and Mattheis et al. (1991) mentioned 2-methylbutyl acetate as an early ester volatile in 'Delicious' apple. Both compounds appear before the rise of the climacteric ethylene. But they are still under investigation and require special equipment not yet available in the field.

Indices other than ethylene production currently available to the industry include fruit size, flesh firmness, soluble solids, titratable acidity, starch breakdown (iodine test), seed color, respiration rate, skin color (ground and surface color), and flesh chlorophyll (Kupferman, 1983; Olsen, 1982). Calendar date, number of days from full bloom (DFFB or DAFB), accumulated heat units (Watkins, 1981), and days from T-stage (Stoll, 1968) can be added to the list. None of them can be used alone, and all of them should be tested on the new cultivars in every growing location.

Variation in the fruit population in the same orchard, between orchards, and from year to year has accounted for the lack of one single maturity standard (Olsen, 1982). A maturity program currently operating in the State of Washington is based on weekly changes of maturity indicators. It is the modification in the steady rate of change of a given measure that signals the initiation of maturity (Olsen, 1986). Fruits approaching harvest often show a sudden drop in firmness and an increase in soluble solids and starch breakdown (Olsen, 1982). Variation of some measurements within the fruit (firmness, soluble solids, color) and within the tree should be considered when sampling and monitoring harvesting (Shaw and Rowe, 1982; Kupferman, 1986).

STORAGE

Examination of fruit picked at different stages after storage is necessary to complement maturity studies. Firmness after storage has been correlated with DFFB and starch breakdown 80% of the time, with soluble solids at harvest 70% of the time on 'Red Delicious' (Ingle and D'Souza, 1989). Fruit quality was affected by harvest date, but none of the maturity indicators tested could predict apple quality after storage (Knee et al., 1989). Correlations between starch and firmness at harvest were lost after storage, indicating that starch at harvest would not predict further firmness changes (Knee et al., 1989). However, the firmness of fruit after storage correlated with the firmness at harvest and the position of the fruit on the climacteric curve (Knee et al., 1990).

Experience shows that the later picked fruit had the most desirable dessert quality soon after harvest, but as the storage season progressed, preference shifted towards the earlier picked fruit (Olsen, 1982).

Maturity studies have often been complemented with taste panels in an attempt to have a measurable parameter for quality (Bidabe et al., 1969; Knee and Smith, 1989; Saltviet, 1983). Often, maturity indices were looked at for fruit which was destined for immediate consumption. Blanpied (1974) established a maturity index line with the firmness:soluble solids ratio, for a given geographic region, and was able to predict harvest within one week. He used this scale to separate fruits from mature (acceptable eating quality) to immature (not acceptable) (Blanpied, 1979). When comparing stored 'Cox's Orange Pippin', a 16 member taste panel could discriminate fruits harvested at a week interval from a reference harvest date in a paired comparison test (Knee and Smith, 1989). The apples were classified for the differences perceived in acidity, sweetness, firmness and toughness. As the time interval from the central sampling date increased, a difference between harvests could be detected in more attributes. The best eating quality was considered to be at the climacteric peak, when volatiles such as butanol, butylacetate, and ethylene were present at high levels in the fruit (Knee and Smith, 1989).

Apples stored in 1 to 2% oxygen in controlled atmosphere (CA) storage tend to maintain their acidity level and stay firmer than when stored at higher levels (2 to 3% O_2) (Meheruik, 1985). Controlled atmosphere also inhibited the formation of flavor volatiles (Guadagni et al., 1971; Smith, 1984; Streif and Bangerth, 1988; Willaert et al., 1983), except those of ethanol and acetaldehyde (Meigh, 1957). Acetaldehyde and ethanol accumulate in senescing apples (Fidler, 1951; 1968) and citrus (Bruemmer, 1986; Roe and Bruemmer, 1974) as a result of pyruvate decarboxylation:

$$\text{pyruvate} \xrightarrow[\text{pyruvate decarboxylase}]{H^+ \rightarrow CO_2} \text{acetaldehyde} \xrightarrow[\text{alcohol dehydrogenase}]{NADH \rightarrow NAD^+} \text{ethanol}$$

The reaction is promoted by low O_2 and high CO_2 (Bruemmer, 1986; Fidler, 1968) and also ethylene (Bruemmer, 1986). Under anaerobic conditions, ethanol and acetaldehyde can accumulate to phytotoxic levels (Clijsters, 1965; Jackson et al., 1982), the latter being the most toxic. Ethanol accumulated during anaerobic storage of 'Cox's Orange Pippin' could diffuse and be metabolized when the apples were re-exposed to air, provided accumulated ethanol was below 120 mg/100 g (Fidler and North, 1971).

In controlled atmosphere, volatile production decreased with increasing CO_2 and reducing O_2, but not linearly (Streif and Bangerth, 1988). Up to 3% O_2, CO_2 was the main factor for inhibiting volatiles. Below 3% down to 1% O_2, volatiles decreased significantly, reducing the aroma of 'Golden Delicious'. Recovery of apple aroma was possible if the fruits were held in regular refrigerated storage at 1C for 3 weeks before shipping. The loss of aroma was irreversible after more than seven months of CA storage. The lack of flavor reported on apples stored in low oxygen atmosphere might be due to early picking before the production of volatile esters, and the reduced rate of activity of all the metabolic pathways in storage (Yahia et al., 1990).

SENSORY QUALITY OF APPLE

Once the physiological and pathological disorders have been controlled by appropriate horticultural and storage practices, the eating quality is the final goal of getting horticultural crops to the consumer (Knee and Smith, 1989).

Among available tools for the researcher to contribute to the better understanding of quality are descriptive analyses where a panel of trained people describes the product's sensory attributes, which can be compared with instrumental measurements, and acceptance tests (Stone and Sidel, 1985). Acceptance tests usually precede large-scale consumer market research. The nine-point hedonic scale and paired comparison tests are the most commonly used techniques (Stone and Sidel, 1985).

Quantitative descriptive analysis (QDA)(R) has been used to describe 'Cox's Orange Pippin' and has resulted in an extensive language (Williams and Carter, 1977). Forty-five attributes were categorized in appearance, external and internal aroma, feel of apple in hand, taste, texture, and after-taste. This study helped understanding which are the important flavor criteria in 'Cox's Orange Pippin' and how they changed with storage. It also pinpointed the difficulties encountered with the fresh product where the variation within a fruit was as great as the variation between fruits (Williams and Carter, 1977).

Watada et al. (1980) chose 15 attributes to describe eating quality of apples: hardness, crispiness, toughness, mealiness, sponginess, juiciness, sweetness, acidity, astringency, starchiness, spiciness, vegetativeness, mustiness, cardboardy flavor, and fruitiness. The intensity of the attributes were plotted on a circular graph and differences of patterns between varieties, or due to duration of storage, were observed.

Instrumental measurements have been extensively correlated with sensory attributes. Sweetness and acidity are the most important taste attributes in fruit (Bidabe et al., 1969; Thiault, 1975; Visser et al., 1968; Vangdal, 1985). Visser et al. (1968) showed a high correlation between perceived sweetness and % total sugars as measured with a hand refractometer, and between perceived acidity and pH of apple and pear juice. The amount of acids affected the perceived sweetness intensity more than the sugars affected perceived acidity (Visser et al., 1968). Tasters tended to overestimate sweetness in fruit with low acid content. However, they did not overestimate acidity in fruit with a sugar content. They found it increasingly difficult to discern differences in acidity below or above certain pH values: at or above a pH of 3.8 to 4.0, acidity was no longer discernable and the fruit was considered "flat" (Visser et al., 1968). Vangdal (1985) reported that there was a better correlation between flavor and the soluble solids:acidity ratio than flavor and each of those components alone. The index SSC+10(TA) established by Thiault (1975) for 'Golden Delicious' has been widely used in Europe as a quality index.

Although of practical use, soluble solids and titratable acidity don't give any indication of the quality of sugars and acids, and the effect on the palate of each of them is not equal. In solution, fructose tastes sweeter than sucrose, which tastes sweeter than glucose (Shallenberger and Birch, 1975). Malic acid, which is predominant in apples and pears, has a longer effect on the taste buds with less intensity than citric acid

(Gardner, 1966). Peaches with a low malic/citric acid ratio were perceived as being more tart than those with a higher ratio (Souty and André, 1975). Bidabe et al. (1969) determined that reducing sugars and sucrose affected fruit quality differently. Reducing sugars were correlated with quality in 'Idared' and 'Granny Smith', and not in 'Golden Delicious' and 'Richared', while sucrose was correlated with quality for all four varieties. The ratio of sucrose:titratable acidity was a better indication of quality than the ratio total of soluble sugars:titratable acidity (Bidabe et al., 1969). Gorin et al. (1975) proposed sucrose, citrate, and malate as criteria of shelf-life for 'Golden Delicious' apples. Malate was preferred since it decreased faster than citrate during storage. When the decrease in sucrose levelled off, the apples had attained their limit of acceptability, as judged by a panel of 6 experienced tasters. At that stage, malate was below 0.4 g/100 g (Gorin et al., 1975).

Other compounds interact with sugars and acids on taste. Watada et al. (1981) showed that in 'Golden Delicious', 58% of the acidity (taste attribute) variation was attributed to titratable acidity, soluble solids, and two volatiles , whereas in 'York Imperial', 63% of the acidity variation was due to titratable acidity, soluble solids, and two other volatiles. Fifty percent of the sweetness variation was attributed to soluble solids, ethyl acetate, and two ester-volatiles. The chemical components analyzed by Watada et al. (1981) did not correlate with other sensory attributes such as floral fruitiness, spiciness, and astringency. Six experienced judges found that flavor of 'Golden Delicious' deteriorated faster than texture and the sweet/sour ratio in storage (Gorin et al., 1975).

The problem in relating sensory attributes to chemical components lies in the difficulty in delineating the attributes for sensory rating and in the lack of understanding of the relationships the chemical components have on each other in terms of sensory response (Watada and Abbott, 1985).

With the development of gas chromatography, flavor volatiles have been studied extensively for determining apple quality based on volatile composition (Watada and Abbott, 1985). Changes of volatiles during maturation and storage have been reviewed previously. Although the individual components have been described using the CHARM analysis method (Cunningham et al., 1986), there is no agreement in the literature on which specific volatile is important for good quality apples. Discrepancies probably are due to the selection of aroma as "characteristic" of apple odor (Watada and Abbott, 1985).

If taste and aroma contribute largely to apple overall quality, texture has been considered even more significant (Ananthakrishna et al., 1983; Mast and Faldheim, 1983; Wills et al., 1980). The Ottawa Texture Measuring System (OTMS) is an instrument that gives a measure of texture and juiciness by compressing a slice of apple, and the Magness Taylor pressure tester gives the resistance of the fruit flesh at one point (Ananthakrishna et al., 1983). OTMS values were better correlated to overall quality (sensory) than titratable acidity, refractive index and Magness Taylor values (Ananthakrishna et al., 1983). Therefore, OTMS has been recommended for use as an index for apple quality (Ananthakrishna et al., 1983). The Magness Taylor penetrometer does not give any indication on texture but is still widely used to measure apple firmness (Watada and Abbott, 1985).

Color has an influence on sensory quality. Quality of 'Golden Delicious' apples which varied in color from blush/yellow to yellow and to green was assessed by 12 panelists in such a way that they couldn't see the color; they ranked the fruit in a decreasing order for aroma (Gormley, 1981). One can argue that it is true with one specific variety in one specific condition. In another context, color had little correlation with overall quality for 'Cox's Orange Pippin' in the trained panel led by Williams (1979). Still, fruit aspect and color have an impact on the consumer. Green 'Golden Delicious' apples were perceived less sweet and ripe than blushed fruit in a consumer study throughout Europe (Crochon, 1989). A study on processed food (potato puree and apple juice) has clearly shown the taste/color relationship for the consumer. Same products were perceived differently for their flavor if coloring was added (Urbanyi, 1982). In the case of apple, color is commercially used for grading without considering internal quality (USDA Standards for Grades of Apples, 1964).

Sensory tests are time consuming. Therefore, physical and/or chemical measurements would be useful to provide an index of quality. But Williams (1979) points out the mathematical nature of such data: "whilst they may give an indication as to causes of hedonic quality, they do not in themselves imply any causative relationship. Furthermore, products with identical descriptive characteristics may be ranked differently by different tasters and those with different characteristics ranked hedonically the same".

CHAPTER 3

'GALA', 'BRAEBURN' AND 'FUJI' APPLES: MATURITY INDICES AND QUALITY AFTER STORAGE

ABSTRACT

'Gala', 'Braeburn' and 'Fuji' apples were sampled at weekly intervals in the year 1991 from a commercial orchard near Wenatchee (WA). Harvest dates ranged from 108 to 143 days after full bloom (DAFB), 133 to 186 DAFB and 138 to 187 DAFB, respectively. Twenty fruits were evaluated on the day of harvest and after 7 days at room temperature for internal ethylene, skin color, firmness, starch hydrolysis, total soluble solids concentration (SSC), pH and titratable acidity (TA). Color, firmness, SSC and TA were again measured on 15 fruits of each cultivar after 6, 12, 18 and 24 wks for 'Gala', and 8, 16, 24 and 32 wks for 'Braeburn' and 'Fuji' of regular storage at 0 ± 0.5C. A consumer taste test was conducted approximately every 4 wks on 'Gala' and every 8 wks on 'Braeburn' and 'Fuji' in the Sensory Science Laboratory at Oregon State University (Corvallis, OR) in individual booths. Fifty to 60 untrained panelists participated in each test. They were presented six pieces of unpeeled apple in random order from 6 harvest dates and were asked to rate for their preference on a 9-point hedonic scale. The optimum harvest date was determined retrospectively.

Horticultural maturity of 'Gala' was attained 122 DAFB for long-term storage (January). At that stage, starch index (SI) was highly variable, SSC was at 11^{o} Brix and

ethylene production was 1 ppm at harvest, but fruit color was not fully developed yet. Later harvested fruit had the best eating quality after short-term storage in October and November. Fruits of 'Braeburn' picked 168 and 175 DAFB had the best storage potential (April). SSC and hue angle of the ground color were the most obvious parameters to determine harvest date in 1991. Autocatalytic internal ethylene was present after 7 days ripening in fruits harvested 154 DAFB. Starch index increased 175 DAFB. Earlier harvested fruit developed scald and later harvests had very low quality ratings after 24 wks in storage. Internal ethylene in 'Fuji' fruit stayed at low levels and without autocatalytic production and therefore could not be used as a physiological predictor of maturity. The only reliable indices were the starch index and hue value of the ground color. The former increased suddenly and the latter decreased by 173 DAFB. Only fruits picked 173 and 180 DAFB were free from scald and retained good quality after 8 months storage. A Principal Component Analysis (PCA) showed that for the three cultivars, all the measured indices were important and entered in the first four principal components, accounting for 69 to 75% of the total variance.

INTRODUCTION

Among the many new varieties of apples, 'Gala', 'Braeburn' and 'Fuji' have received special attention from growers in the main producing areas in the world. 'Gala' is the result of a cross between 'Kid's Orange Red' ('Cox's Orange Pippin' X 'Red Delicious') and 'Golden Delicious', originated in New-Zealand in 1934 (Gordon, 1990). 'Braeburn' is a chance seedling from 'Lady Hamilton' and was discovered in 1952 in the Nelson area of New Zealand (Manhart, 1987). 'Fuji' was selected from a cross between 'Red Delicious' and 'Rall's Janet' in 1939 at the station of Morioka in Japan (Gordon, 1990). All three varieties have numerous sports, mainly classified on the degree of red color. The increasing acreage planted in the Pacific Northwest with these varieties has necessitated the following fruit maturity study to identify practical indices that can be used to predict optimum fruit quality for different storage durations.

The optimum picking date has been stated to be just at the beginning of the respiration climacteric in 'McIntosh' apple (Smock, 1948). In climacteric fruit, such as apple, the increase in ethylene production appears coincidentally with the increase of internal CO_2 (Reid et al., 1973). In practice, ethylene measurements are preferred to respiration rate, and a delay between detectable ethylene and the autocatalytic production has permitted adjustment of picking date for numerous cultivars (Chu, 1988; Knee et al., 1989; Watkins et al., 1989). The year to year variation of ethylene production as well as the distinctive pattern for each cultivar has accounted for the lack of a single value as an index for maturity (Blankenship and Unrath, 1988; Chu, 1988). Although still under discussion, ethylene has been used as a physiological indicator of maturity and correlated with other parameters that are easier to measure in the field. Among them are starch index (Lau, 1988; Walsh et al., 1991), "a" value for ground color, soluble solids, red color, and firmness (Walsh et al., 1991). The loss of chlorophyll and increase of carotenoids has also been associated with the climacteric rise in 'Cox's Orange Pippin' apple (Knee, 1972). In the end, however, the true optimum harvest date can be assessed only after examining fruit out-of-storage (Ingle and D'Souza, 1989; Knee and Smith, 1989).

Maturity studies have often been complemented with taste panels in an attempt to define measurable indices for quality (Blanpied, 1979; Knee and Smith, 1989; Saltviet, 1983). A taste panel conducted by Knee and Smith (1989) showed that a perceived decrease in acidity and a decrease in firmness accounted for the participants' ability to discriminate between stored fruit from different harvest dates.

Principal Component Analysis (PCA) is a multivariate statistical analysis used as an explanatory technique to identify patterns and/or outliers in a dataset (Derde and Massart, 1985; Federer et al., 1987; Iezzoni and Pritts, 1991; Resureccion, 1988). PCA is also used to eliminate redundancy when multicollinearity exists between variables (Iezzoni and Pritts, 1991). PCA reduces dimensionality of a dataset by taking a linear combination of the original interdependent variables into a smaller set of independent factors which account for the maximum proportion of variance (Iezzoni and Pritts, 1991; Piggot and Sharman, 1986). Each of the combinations are called Principal Components (PCs). They are normal and mutually orthogonal and represent a new coordinate system through the original data (Iezzoni and Pritts, 1991; Zervos and Albert, 1992). An analysis of principal components often reveals relationships that were not previously suspected (Johnson and Wichern, 1992).

In the work reported herein, physical and chemical changes occurring during the ripening process of 'Gala', 'Braeburn', and 'Fuji' apples were measured at harvest and after storage. Variation happening during maturation was examined using the PCA tool. Consumer taste tests evaluated quality, after storage, of fruit harvested at weekly intervals over a 6-week period. These data were then used retrospectively to determine optimum picking dates for each variety.

MATERIALS AND METHODS

Plant material

Fruits of 'Royal Gala', standard 'Braeburn', and 'Fuji' ('Moriho-fu # 2' strain) were sampled weekly from a commercial orchard near Wenatchee, WA, on 15, 15 and 40 trees, respectively. The 6-yr old 'Gala' trees were grafted onto M7 rootstock and trained to a vertical axis. 'Braeburn' trees had been topgrafted 4 yrs earlier on 3 yr old 'Delicious' trees previously grafted onto seedling, M7, and M106 rootstocks, and were free standing. 'Fuji' on M26 rootstock were in their 4th leaf and trained to a vertical axis.

Fruits that appeared to be the most mature based on ground color and fruit size were picked on each sampling date. For each sampling, 20 fruits were evaluated on the day of harvest, and another 20 fruits were evaluated after 7 days at 20C. An additional 120 fruits were put into regular storage (0-1C) for later evaluation as described in the storage study. Sampling dates for the three cultivars ranged from: 12 Aug. to 16 Sept. [(108 to 143 days after full bloom (DAFB)] for 'Royal Gala', 5 Sept. to 28 Oct. (133 to 186 DAFB) for 'Braeburn', and 9 Sept. to 28 Oct. (138 to 187 DAFB) for 'Fuji'. Fruits of 'Braeburn' and 'Fuji' from the last harvest date were exposed to a frost at -3C on the night before harvest, which explains why there was less than one week interval between the last two harvests of 'Braeburn'.

Maturity indices

Internal ethylene (IE) was quantified as described by Williams and Patterson (1962). An 18-gauge stainless steel syringe covered with a rubber septum was inserted through the calyx end of the apple into the core cavity. One ml headspace samples were collected using a gastight syringe inserted through the septum of the stainless steel syringe and analyzed by gas chromatography using a Hewlett-Packard 5880 GC with a flame ionization detector. The glass column (30 cm, 0.32 cm i.d.) was packed with 80-100 mesh Porapack Q and held isothermally at 50C. Injector and detector temperatures were 150C and 200C, respectively. Gas flows for N_2 carrier, H_2, and air were 25, 20, and 340 $ml \cdot min^{-1}$, respectively.

Color was measured with a 'Minolta' CR-300 chromameter calibrated to a white standard illuminant condition C(6774K). Two readings were taken per apple on the spot containing the least (shaded, or ground side of the fruit) and the most (sun-exposed, or surface side of the fruit) red color. The tristimulus L*, a*, b* measurement mode of the CIE (Commission Internationale d'Eclairage) color space was used, as it relates to the human eye response to color and has uniform visual spacing (Francis and Clydesdale, 1975) and is the most reported in the literature (Kappel et al., 1992; Singha et al., 1991; Smith and Stow, 1985; Walsh and Voltz, 1990). L* is a measure of lightness and ranges from black = 0, to white =100. For a given value of L*, positive a* indicates a hue of red-purple and negative a* indicates green; positive b* indicates yellow and negative b* indicates blue. Since those values are not independent variables, it is usually more appropriate to reduce the three coordinate values into two values (Francis, 1980). For a determined lightness L* and on a plane with a* and b* as orthogonal axes, hue ($\tan^{-1}$ b*/a*) is the angle between the line joining the origin to the point (a*, b*) and the a* axis (Francis, 1980; McGuire, 1992). Chroma

($c^*=(a^{*2}+b^{*2})^{1/2}$) is an index measuring the color intensity and represents the hypotenuse of a right triangle created by joining points (0,0), (a^*,b^*) and (a^*,0) (McGuire, 1992).

Over the maturity range measurements, a^*, a^*/b^* and hue angle were highly correlated ($r > \pm 0.97$) for both ground and surface color and in all three varieties. The sun exposed side was not considered since the red color varies with environmental factors (Saure, 1990) and is not representative of fruit maturity (Walsh and Voltz, 1990). However, the percentage of red and measures of hue angle (quality of the red) and chroma (intensity) are included in appendices 3.1, 3.2 and 3.3 for the reader's information. The variation of L^* of the ground color was small over the maturity range studied, therefore, only the hue angle of the ground color is reported.

Firmness was measured on three pared sides of the fruit, avoiding the sun-exposed side, with an EPR-1 electronic pressure tester (Lake City Technical Products, Kelowna, BC, Canada) equipped with an 11-mm tip. The extent of fruit starch hydrolysis was estimated after staining a horizontal section of the fruit with a 0.5% potassium iodine solution and rated on a 1-6 scale (1=full starch, 6=clear of starch). Total soluble solids concentration (SSC) of the juice was measured with a hand-held refractometer (Atago N1). Ten ml of juice was titrated with 0.1N KOH to a malic acid endpoint of pH=8.2. Initial pH of the juice was also recorded.

Storage

Thirty fruits of each harvest date were pulled from the cold storage 6, 12, 18 and 24 wks after harvest for 'Gala', and 8, 16, 24 and 32 wks after harvest for

'Braeburn' and 'Fuji'. Fifteen fruits were analyzed on the following day, and the other 15 fruits after 7 days at 20C. Color, firmness, soluble solids concentration and titratable acidity were again quantified as previously described.

Scald was rated on a 0-3 scale (none to severe). When an internal disorder was present in the fruit, unaffected skin and flesh were analyzed for mineral content following the method used by Raese and Staiff (1983) and compared with the healthy fruit of the same lot.

Taste tests

A consumer taste test was conducted approximately every 4 wks after harvest on 'Gala' and every 8 wks on 'Braeburn' and 'Fuji' fruit in the Sensory Science Laboratory at Oregon State University (Corvallis, OR) in individual booths. Fifty to 60 students and staff from Oregon State University participated in the tests. Only one variety was tasted per session. Twenty fruits of each harvest date were removed from storage and held at 20C for 4 days prior to testing.

Six pieces of unpeeled apple cut longitudinally and representing each harvest date were presented to the panelists. Overall liking was rated by using a nine-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike and 9=like extremely. The taste tests were conducted under red lighting to mask the color variation of the fruit skin due to maturity stages. Spring water (Aqua Cool, Portland, OR) was provided for rinsing between samples. Fruits were presented on a tray in a randomized, balanced, complete block design.

Statistical analysis

Maturity indices data of each cultivar are reported as means of 20 fruits with standard errors. Principal component analysis (PCA) was performed on the harvest data. The data were first standardized by using a general linear model (GLM), with harvest date as a main effect and the maturity indices as independent variables, to remove the effect of harvest date. PCA was performed on the correlation matrix of the residuals of the GLM. The total variance accounted for by each principal component (PC) is called the eigenvalue (Iezzoni and Pritts, 1991). Eigenvalues above and equal to one have been suggested for choosing the number of components explaining most of the variation (Piggot and Sharman, 1986). Correlations between ethylene, the physiological indicator used for maturity, and other indices are also reported. In the storage study, each fruit attribute was subjected to an analysis of variance (ANOVA). Data were analyzed as an AxBxC factorial with harvest date, weeks in storage and days of ripening at 20C as the factors. ANOVA was also performed on the data of each taste test session, with harvest date as the main effect and panelist as a blocking effect. All statistical analyses were performed with the Statistical Analysis System (SAS Institute Inc., Cary, NC).

RESULTS

Maturity indices

'Gala'

At harvest, the increasing fruit weight and SSC began to level off after the fourth sampling date, reaching values of 180g and 11.5° Brix, respectively (Fig. 3.1). Fruit firmness and TA decreased, while pH increased regularly during the whole sampling period. During the middle of the harvest season, the starch index (SI) increased and hue angle of the ground color decreased rapidly, both curves indicating points of inflection. Internal ethylene concentration at harvest was low on the second sampling date (0.24 $\mu l \cdot l^{-1}$) and it increased up to 2.81 $\mu l \cdot l^{-1}$ on the last harvest date. Some fruits sampled at 115 DAFB (19 Aug.) started producing high levels of ethylene (above 100 $\mu l \cdot l^{-1}$) after one week at 20C which indicates the autocatalytic ethylene production, corresponding to system II of the McMurcie model (McMurcie et al., 1972). The average ethylene production was above 100 $\mu l \cdot l^{-1}$ on the seventh day at 20C for mid-season samples (129 DAFB, 2 Sept.) and later. This corresponded to the dates following the inflection points of SI and hue angle and to the levelling off of fruit weight and SSC. Similarly, very little starch was left in the fruit ripened for 7 days after the 129 DAFB sampling and, as a consequence, SSC didn't increase much. Fruits from inside and outside the trees were picked on the last sampling, resulting in a high variation in SSC.

Ethylene was positively correlated with SSC (r=0.452), SI (r=0.267) and pH (r=0.257) and negatively correlated with hue angle of the ground color (r=-0.232) (Table 3.1).

In 'Gala', the five first PCs with an eigenvalue above one accounted for 75% of the total variation (Table 3.2). The first PC explained 23% of the variance and the color variables were carrying the same weight. The percentage of red color contrasted to L* and hue of the ground and surface color. The second PC explained 19% of the variance and represented the variables indicating intrinsic fruit quality. Starch index, internal ethylene, SSC and pH contrasted to TA and firmness, confirming the increasing/decreasing trend of each group of variable. PC3, explaining 13% of the variance is more difficult to interpret. Ground color variables, as well as fruit weight, were contrasted to surface color, firmness and SSC. Fruit weight had the highest coefficient in the fourth PC, which accounted for 11% of the variance. The fifth PC accounted for 9% of the variance and was represented mainly by TA.

'Braeburn'

Fruit weight had a great variation over the sampling season. The final weight of 195g was reached 161 DAFB (3 Oct.) (Fig. 3.2). Little starch breakdown was observed at the early harvests [SI=1 from 133 to 147 DAFB (5 to 19 Sept.)]. SI increased slowly from 154 to 168 DAFB (26 Sept. to 10 Oct.). It remained low (SI=1.6) even on the 7 days ripened fruits, until 175 DAFB with greater values (SI=3 to 4) after 7 days at 20C. Hue angle decreased regularly after 147 DAFB. Ground color changed into a more yellow green between 161 and 175 DAFB. pH and SSC rise followed a S-shaped curve with inflection point between 161-168 DAFB. Firmness and TA decreased linearly. The pattern of ethylene production seemed to follow the description given by McMurcie et al. (1972) after 7 days at 20C for the fruit picked after 154 DAFB. Ethylene was equal to 1 $\mu l \cdot l^{-1}$ at harvest, and above 100 $\mu l \cdot l^{-1}$ after 7 days at 20C for the fruit sampled 175 DAFB (17 Oct.) and after. At the same time, SSC, pH and TA reached 11° Brix, 3.4 and 0.59% malic acid, respectively and remained at these levels. Ethylene was positively correlated with SSC (r=0.315), pH (r=0.304), SI (r=0.183), and negatively correlated with TA (r=-0.247) (Table 3.1).

In 'Braeburn', the five first PCs accounted for 69% of the total variance (Table 3.3). The percentage of red color contrasted to L* and hue of the surface color and to TA in the first PC, accounting for 25% of the variance. The second PC explained 13% of the variance and was a combination of L* of the ground color, internal ethylene, SSC, pH and L* of the surface color. Firmness and TA were contrasted to starch index in the third PC (13% of the variance). Fruit weight and hue of the ground color were part of the fourth PC (9% of the variance). The same variables, as well as L* of the ground color were in PC5 (9% of the variance).

'Fuji'

'Fuji' fruit is distinctive from the other varieties studied by its large size (235 to 255 g) and its sweetness (14° Brix on the latest harvest) (Fig. 3.3). Internal ethylene increased steadily up to 1 $\mu l \cdot l^{-1}$. Only fruits from the latest harvest date (184 DAFB - 28 Oct.) and ripened for a week at 20C had an ethylene level of 13 $\mu l \cdot l^{-1}$. Those fruits had been exposed to a frost at -3C during the morning hours. 'Fuji' has already been reported to produce low levels of ethylene, but with a steady increase throughout the sampling season (Watkins et al., 1989). The autocatalytic production of ethylene was initiated 3 to 5 days after harvest on fruit picked 174 DAFB (Kato et al., 1978). The increase observed in our sample might be the autocatalytic rise normally occurring in 'Fuji' fruit at that time (Kato et al., 1977; Kato et al., 1978), or a response to being exposed to frost. SI at harvest was low (1.5 to 2) until 166 DAFB (7 Oct.), although starch index increased 159 DAFB after the fruits were ripened for 7 days. SSC increased and firmness decreased steadily during the sampling period. The decrease of TA to its lowest value on 159 DAFB (30 Sept.) was followed by an increase of pH 166 DAFB (7 Oct). No change in the ground color was visually perceived until 173 DAFB (14 Oct.) although hue angle was decreasing regularly after 159 DAFB. The ground color remained green, but became lighter at the end of the season, giving more brilliance to the red of the surface color. Also, more red had developed on the entire fruit surface (Appendix 3.3). Water core, normally produced in 'Fuji' fruit (Gordon, 1990), appeared on the last harvest (187 DAFB). Ethylene was correlated with water core ($r=0.354$), SSC ($r=0.231$) and TA, and negatively correlated to SI ($r=-0.354$) and hue angle of the ground color ($r=-0.330$) (Table 3.1).

In 'Fuji', the first five PCs accounted for 71% of the variance (Table 3.4). The first PC was a combination of color measurements (except L* of the ground color), SSC, TA and starch index, and accounted for 27% of the variation. The second PC (13% of the variance), represented color measurements. The third PC (11% of the variation), was a combination of ground color, acidity (pH and TA), and firmness. PC4 included fruit weight, water core and pH (10% of the variance), and PC5 water core, ethylene and pH (9% of the variance).

Storage

The analysis of variance for each cultivar determined that the main effects, harvest date (HD), time in storage (TS) and days of ripening at 20C (RIPE), and their interactions were significant (Appendices 3.4, 3.5 and 3.6). The F values for the main effects were usually at least one and up to two orders of magnitude greater than the interaction F values. Most of the variation observed was attributable to the main effects.

In general, similar patterns in changes of fruit attributes were observed 7 days at 20C after removal from storage. Therefore, only the data obtained at the removal of the fruit out of storage are reported. If differences were observed between variables measured on fruit removed from storage and those sampled one week after removal, these are discussed.

'Gala'

A change in ground color, measured by hue angle, was observed in fruits harvested on the first three sampling dates and stored, resulting in a shift from green to pale yellow (Fig. 3.4). These same fruits became even more yellow after 7 days at 20C. There was no difference in the ground color of the last sampling dates fruits from harvest to when fruit was removed from storage and ripened for one week.

SSC from the fruit sampled on the first three harvest dates increased in storage, ranged from 11.5 to 12° Brix similar to late harvests, and remained at this level. This suggests that fruit from all the harvests had the same starch reserves. Fruit firmness and TA generally decreased for successive harvest dates and in storage. The loss in firmness was linear throughout harvest and storage. For fruit ripened 7 days at 20C, the loss of firmness ranged from 20 to 35N from initial sampling date over the 24 wks storage period after 7 days at 20C (Appendix 3.7). The late harvests had lower TA and lost relatively less acidity than the earlier harvests. Fruit held in storage the longest (24 wks) had low acidity (approximately 0.2% malic acid), with little differences between harvest dates. pH increased regularly in storage. In contrast to TA, differences were observed in pH between harvest dates on the last pulling out of storage (24wks). No storage disorder was observed on 'Gala' after 24 wks in storage.

'Braeburn'

The hue angle of the ground color decreased during the harvest period and in storage (Fig. 3.5). Except for the two early harvests [147 and 154 DAFB (19 and 26 Sept.)] where fruit remained green, the ground color changed from pale green to yellow in storage. Surface color became more brilliant, the dull red changing to orange-red. As in 'Gala', SSC of all harvest dates reached 11-12° Brix, and remained at that level in storage (Fig. 3.5). For fruit ripened 7 days at 20C, the loss in firmness from harvest was between 28 and 35N over the 32 wks storage period (Appendix 3.8). TA decreased at the same rate for all harvest dates and throughout storage. pH was lower at harvest and after 8 wks of storage for all sampling dates. It increased significantly after the longer storage durations (24 and 32 wks).

Approximately 10% of the fruit had corky tissue in the flesh at harvest after 168 DAFB (10 Oct.) (Table 3.5). The intensity of this disorder did not evolve in storage. Some corky tissue appeared on earlier picks after storage. Although few samples were analyzed and variation of mineral content was large, corky tissue appeared to be related to high N/Ca in the flesh and low Ca in the skin (Table 3.6). Early harvested 'Braeburn' fruits had scald after 24 and 32 wks in storage (Table 3.7).

'Fuji'

Hue angle of the ground color decreased with harvest date in storage (Fig. 3.6), although fruit did not become yellow until the last two harvest dates. SSC of the fruits from the first four harvests increased in storage whereas it stayed constant for the later harvest dates. In contrast to 'Gala' and 'Braeburn', early harvested fruit's SSC never reached the level of the late harvests. After storage, it ranged from 12.5° Brix for the early harvests to 13.5° Brix for the late harvests. SSC tended to be lower after 32 wks in storage for most harvest dates. Firmness generally decreased as fruit matured and as storage durations increased. Over all the harvest dates, there was little differences in firmness between unstored fruit and fruit stored 8 wks. However, the loss of firmness was greater for fruit stored 32 wks, especially for fruit sampled mid-season and later. After 7 days at 20C, the loss of firmness from initial sampling date was of 10, 19 and 10 N for the first three harvests, and of 25, 18, 14 and 12 N for the last four harvests (Appendix 3.9). The decrease of TA and increase of pH was steady throughout storage for all harvest dates. The final TA was very low after 32 wks in storage and for late harvested fruit (0.1% malic acid).

'Fuji' fruit seems to be more prone to scald than 'Braeburn', since this disorder appeared after 16 wks in storage (Table 3.8). On the latest stored fruit (32 wks), only two harvest dates were scald free [173 and 180 DAFB (14 and 21 Oct.)].

Taste tests

The analysis of variance for each cultivar and each testing session are reported in appendices 3.10, 3.11 and 3.12.

'Gala'

The ratings for overall liking tended to decrease as the apples stayed longer in storage (Fig. 3.7). On the first taste test (1 Oct.), fruits picked 129 DAFB (2 Sept.) and later were rated best. After one and two months in storage (taste tests of 5 Nov. and 7 Dec.), the preference ratings shifted towards earlier harvest dates. The three harvest dates from 122 (26 Aug.) to 136 DAFB (9 Sept.) were rated the best. On the last taste panel (21 Jan.), only fruits picked 122 DAFB (26 Aug.) were acceptable. Fruit from other dates was soft (below 60 N) or had developed an off-flavor.

'Braeburn'

The early panel (7 Nov.) rated the harvest of 168 DAFB (10 Oct.) as the best, yet there was little difference in overall liking between the dates, with the exception of the last harvest date (Fig. 3.8). On the next panel (7 Jan.), the later harvests were preferred to the early ones, a significantly lower rating being given to the first harvest.

No differences in liking were observed during the next panel, on 18 Feb.. The last two taste tests (14 Apr. and 26 May) revealed the limit of storability of 'Braeburn' apple in regular storage because of scald appearing from the early harvests in longer storage (Table 3.7). Also, off-flavor and soft fruit were found on the late harvests. The most acceptable apples in the last taste test were those harvested on 168 DAFB (10 Oct.).

'Fuji'

As in 'Gala', a decrease in the overall liking ratings was noted as fruit stayed longer in storage (Fig. 3.9).

The early panel (12 Nov.) rated a mid-season harvest, 173 DAFB (14 Oct.), as the best. Two months later (14 Jan.), the next week harvest date (180 DAFB - 21 Oct.) was rated significantly better than the others. On the following taste test, the same harvest dates (173 and 180 DAFB) were rated best. On the 25 Apr. taste test, no significant difference was noted between harvest dates. The overall liking ratings were very low on the last taste test. Yet, the 173 DAFB harvest had the highest OL rating.

DISCUSSION

Maturity indices at harvest

Principal component analysis showed that for all three varieties, all the indices measured were important and none of them could be deleted. The amount of variation explained by each PC was within similar ranges for all three cultivars. Generally, color measurements entered in the first PC, corroborating the sampling method based principally on color. The 'Gala' dataset could be reduced into its first two PCs, with the first PC as a color component and the second PC as internal fruit characteristics. For 'Braeburn', surface color was more a factor of variation than ground color, since the lightness (L*) of the ground color entered in the second component and the hue value of the ground color entered in the fourth component only. Indeed, the visual change of the ground color was more perceived as a lightening of the green rather than an increase of yellowness, as observed on 'Gala' skin. In 'Fuji', color entered in the first and second PCs. The second PC was only a combination of color measurements, with L* and hue of the surface color contrasting L* and hue of the ground color. At this point, it is worth mentioning work regarding color measurements. Because the human eye can distinguish 10 million colors, we loose a lot of information in reporting colors into mathematical data (Francis, 1980). In reporting our data, we reduced color measurements for each ground and surface color from a three dimensional system into a two dimensional one. Therefore, color variables could not be reduced more.

PCA, as an explanatory technique, was performed on the raw data (data not shown) and component scores plotted along the first PCs. It revealed that the sampling method was according to the maturity gradient. However, datapoints were overlapping between harvest dates. This was particularly true for 'Braeburn' where the measurements on the last sampled fruits had a great variation.

Fruit quality after storage to confirm optimum picking date

The determination of the optimum harvest date, based on the rate of change of specific and combination of maturity indices, as practiced by the Washington State maturity program (Olsen, 1982), was revealed here to be effective also for the new apple cultivars 'Gala', 'Braeburn' and 'Fuji'. Consumer taste test data verified the optimum picking date. Ethylene was used as a physiological marker of maturity.

IE concentration increased in 'Gala' fruit harvested 122 DAFB and held 7 days at 20C, indicating the beginning of physiological ripening (Fig. 3.1). Fruit harvested on that day retained its sensory quality longer (Fig. 3.7), indicating that if stored in regular atmosphere for a long-term storage, 'Gala' apples should be picked earlier. Concomitant with this ability to produce autocatalytic ethylene, an increase in starch breakdown was observed 122 DAFB. SSC was at 11^{o} Brix but fruit color was not fully developed. Later harvested 'Gala' fruit (129 and 136 DAFB) developed full color and flavor, and was the best for short-term storage (November-December). The last harvested fruit (143 DAFB) failed in storage, and early harvested fruit (108 DAFB) never developed good sensory quality. Since all the maturity indices were included in the first two PCs with equivalent loadings (except fruit weight), any of the measured parameters could be used to predict harvest. In practice, starch index and ground color changes are the most easy to use in the field. They were also best correlated to ethylene, as well as SSC and pH. As a refinement of the method, sampling twice a week might be preferable for 'Gala', since changes approaching harvest occur rapidly.

As determined by the taste panels, 'Braeburn' fruit harvested 168 DAFB (10 Oct.) were the most acceptable in the last two taste tests (14 Apr. and 26 May) (Fig. 3.8). A significant change in SSC, as well as in hue angle of the ground color, occurred one week earlier (Fig. 3.2). Starch index increased and became more variable in the fruit after 7 days at 20C on 168 DAFB. IE concentration was 0.5 $\mu l \cdot l^{-1}$ on this date. Fruit harvested prior to this date was already capable of producing autocatalytic ethylene when held at room temperature (Fig. 3.2). The ripening of early harvested fruits in storage resulted in a great variability between apples within a sampling date. This was probably the reason why panelists could not find any significant differences in OL between the harvest dates on the panel of 18 Feb. (Fig. 3.8). Fruit harvested early developed scald after 24 wks in storage (Table 3.7). Scald is a physiological disorder that develops on apples or pears after a period of storage (Ryugo, 1988). It is characterized by a superficial browning and is confined to the cells of the hypodermis (Bain and Mercer, 1963). Anet (1972) showed the effect of maturity on the appearance of scald, unripe fruit being more susceptible. Late harvested fruit developed corky tissue in the flesh in 10% of the apples (Table 3.5). Therefore, 'Braeburn' fruit harvested 168 and 173 DAFB had the best storage potential, later harvests being best for short-term storage. Based on the rate of change during maturation, SSC, ground color measurements (including hue angle and L*) and the starch index after 7 of days ripening, were the most obvious maturity indices for this particular study. SSC and pH were best correlated with ethylene, but hue of the ground color was not (Table 3.1). The results of PCA suggested that by explaining most of the variance, surface color and TA (PC1), followed by SSC, pH, ethylene and L* of the ground color (PC2) (Table 3.3) best described the changes occurring during maturation. The results from different approaches in analyzing maturity data confirmed the necessity of measuring more than one parameter at harvest.

'Fuji' fruit harvested 173 and 180 DAFB (14 and 21 Oct.) was given the highest overall liking ratings across taste tests (Fig. 3.9). Only the fruit picked at that stage was free of scald after 8 months storage (Table 3.8). The only significant changes noticed in the maturity indices at those dates were the increase in starch index and decrease of the hue angle of the ground color (Fig. 3.3). The highest quality stored fruit had a starch index above 2.5 at harvest. Fruit from the latest harvest which was exposed to frost prior to picking never reached high liking levels (Fig. 3.9). Although starch index, hue angle of the ground color and SSC were well correlated with ethylene (Table 3.1), internal ethylene concentration could not be used as a predictor of harvest in 1991 since it stayed low and never induced the autocatalytic production. Furthermore, ethylene was positively correlated with TA and negatively correlated to SI because standardized data were used for the calculation of the correlation coefficients. The signs of those coefficients do not reflect the changes occurring simultaneously for those indices. Because water core appear late in the season in 'Fuji' (Gordon, 1990), it could not be used as a predictor of harvest. Watercore had the highest correlation coefficient with ethylene ($r=0.354$). Both variables had high loading only in PC4 (water core) and

PC5 (ethylene), confirming that they were less important in explaining the variance of the dataset. Hue angle of the ground color and starch index were included in the first PC (27% of the variation), in combination with surface color, SSC and TA (Table 3.4) indicating that all were important in describing changes occurring at maturity.

Acceptability and fruit quality

Besides verifying the best harvest date for apples, taste tests could be used to set a threshold of acceptability for some parameters. The lowest firmness standards prior to shipment for 'Red' and 'Golden Delicious' are 53 and 48N, respectively (Washington State Department of Agriculture, 1990). When the overall liking was at its minimum, 'Gala' firmness was still above 50N (Fig. 3.3 and 3.7). For 'Braeburn', the loss of firmness as measured by the Magness Taylor penetrometer did not seem to be the major factor responsible for the decreasing consumer acceptability. Values between 75 and 80N might be the cut-off point for the loss of quality between 16 and 24 wks in storage, but yet, at 24 wks storage, the little difference in firmness between harvest dates (Fig. 3.5 and Appendix 3.8) could not explain the difference in overall liking expressed on the taste test of 14 Apr. and 26 May (Fig. 3.8). A change in texture, not measured by the penetrometer, may be a better explanation for the loss of quality of 'Braeburn'. 'Fuji' fruit did not seem to reach an unacceptable level of firmness when some panelists described it as "firm and juicy" on the taste test of 25 April. Most of the fruit had a firmness of 60 to 70N after 32 wks in storage and 7 days ripening (Fig. 3.6 and Appendix 3.9).

The variation in SSC for all three cultivars was too small to explain the differences in overall liking ratings. However, the increase in storage of total sugars to a determined level indicating hydrolysis of starch was not observed for the early harvests of 'Fuji' (Fig. 3.6). Those fruits had one degree Brix less than riper fruits, which might have affected their quality.

Acidity is an important factor in determining apple quality (Bidabe et al., 1969; Vangdal, 1985; Watada et al., 1980). Gorin et al. (1975) found that 0.4% malic acid as the lower limit for 'Golden Delicious' acceptability. In a further study, Frijter (1979) found that there was no relationship between the range of 0.39-0.45% malate given by Gorin, and acceptability. In our study, all harvest dates of 'Gala' were in the range of 0.23-0.25% malic acid after 24 wks in storage (Fig. 3.4), but no comment was made as to their acceptability on the last taste test. No conclusion can be drawn since panelists were comparing fruits between harvest dates. For 'Braeburn', malic acid was between 0.5 and 0.3% and pH between 3.6 and 4.0 when all harvest dates were given low overall liking ratings after 24 wks in storage (Fig. 3.5 and 3.8). 'Fuji' fruit had a very low malic acid level after 32 wks in storage (≈0.1%) (Fig. 3.6). Apples were described as "acceptable, firm and juicy, but tasteless". Visser et al. (1968) reported that for apple and pear with pH above 3.8 to 4.0, acid was no longer discernable and the fruit was qualified as "flat". 'Fuji' juice's pH was above 3.95 for all harvest dates after 24 wks in storage (Fig. 3.6). Also, with such low level of acidity, apples may taste sweeter (Visser et al., 1968). 'Fuji' being already a sweet apple, high SSC combined with a low acidity may explain the low ratings given during the last two taste tests (Fig. 3.9) because the majority of people like sweet/tart apples, while very few like very sweet ones (Stebbins et al., 1992).

Conclusion

A good maturity index should be of practical use, be correlated with an aspect of fruit quality and give independent information (Knee et al., 1989). Besides commercial value, size and color are the two criteria on which growers can choose which fruit to harvest. If sampling for predicting maturity is based on the change of those factors, the same person should sample weekly. Also, surface color depends on cultural factors and climate. Chlorophyll concentration has been recommended as an indicator of apple maturity (Clijsters, 1969), but its correlation with fruit weight implies that it is an indirect measure of fruit growth (Knee et al., 1989). Furthermore, increasing nitrogen levels increase green color in 'Golden Delicious' apple (Fallahi et al., 1985; Williams and Billingsley, 1974). The visual changes in ground color were relevant for ripening in all three cultivars although the change was more in the quality of green (hue) for 'Braeburn' and 'Fuji', opposed to the change of green to yellow for 'Gala'. Firmness, SSC, and TA are commonly used as quality descriptors. They could not be used as maturity indicators alone, but their changes during ripening provided valuable information. Since their change in storage is not constant from year-to-year and between varieties, quality after storage is not predictable (Knee et al., 1989). The sudden increase in 'Braeburn' SSC was relevant of important changes in the fruit maturation, as well as the increase of pH and decrease of TA in 'Fuji'. SSC plateaued on the late sampling of 'Gala' and 'Braeburn', indicating hydrolysis of starch reserves in the fruit. Indeed, starch index is of practical use in the field. In our study, it was a good indicator of maturity for 'Gala' and 'Fuji', but not in 'Braeburn'. The fact that the starch index did not increase while SSC did in 'Braeburn' shows the inaccuracy in measuring starch degradation by the iodine test. A measure of amylose and amylopectin, two starch components, might be preferable. Internal ethylene was a valuable physiological indicator. After letting fruit ripen at room temperature, ethylene levels indicated the induction of system II of McMurcie's model (McMurcie et al., 1972) in 'Gala' and 'Braeburn'. Our data confirmed that 'Fuji' is a low ethylene producer. It would be interesting to see if 'Fuji' behaves like 'Granny Smith' for production of ACC synthase and ACC oxidase before and after cold treatment, as described by Larrigaudière and Vendrell (1993), since both cultivars are late ripening apples.

Table 3.1. Correlation coefficients between internal ethylene and other maturity indices during the ripening of 'Gala', 'Braeburn' and 'Fuji' apples.

Cultivar	Ground color hue	Firmness	Soluble solids concentration	pH	Titratable acidity	Starch index	Water core
Gala (n=120)	-0.232 *	n.s.	0.452 ***	0.257 **	n.s.	0.267 **	-
Braeburn (n=180)	n.s.	n.s.	0.315 ***	0.304 ***	-0.247 **	0.183 *	-
Fuji (n=160)	-0.330 ***	n.s.	0.231 **	n.s.	0.214 **	-0.354 ***	0.354 ***

n.s., **, *** non significant or significant at $P < 0.01$ and $P < 0.001$, respectively.

Table 3.2. Eigenvectors (weights) and eigenvalues of the principal component axes of 'Gala' dataset at harvest.

Variable	Principal Components 1	2	3	4	5
Weight	0.00	0.13	**-0.26**	**-0.62**	**0.36**
% Red color	**-0.45**	0.06	-0.22	-0.13	-0.01
L* ground color	**0.31**	0.21	**-0.45**	**0.39**	0.13
Hue ground color	**0.39**	0.01	**-0.42**	**0.30**	0.09
L* surface color	**0.48**	0.02	**0.30**	-0.21	0.10
Hue surface color	**0.47**	-0.09	**0.37**	-0.14	0.07
Firmness	-0.18	**-0.28**	**0.33**	**0.40**	0.04
SSC	-0.08	**0.42**	**0.29**	**0.33**	0.21
pH	0.05	**0.42**	0.22	-0.12	-0.14
Titratable acidity	-0.03	**-0.33**	-0.02	0.02	**0.71**
Starch index	0.03	**0.53**	-0.04	-0.02	-0.05
Internal ethylene	-0.22	**0.34**	0.19	0.11	0.51
Eigenvalue	2.76	2.30	1.56	1.28	1.11
Proportion (% variance)	0.23	0.19	0.13	0.11	0.09
Cumulative (% variance)	0.23	0.42	0.55	0.66	0.75

Table 3.3. Eigenvectors (weights) and eigenvalues of the principal component axes of 'Braeburn' dataset at harvest.

Variable	Principal Components 1	2	3	4	5
Weight	0.16	-0.17	0.15	**0.65**	**0.44**
% Red color	**-0.41**	-0.22	-0.13	0.06	0.28
L* ground color	0.14	**0.50**	-0.22	0.10	**-0.40**
Hue ground color	0.28	0.07	0.04	**0.41**	**-0.39**
L* surface color	**0.41**	**0.31**	0.16	-0.26	0.29
Hue surface color	**0.44**	0.11	0.24	-0.25	0.32
Firmness	-0.05	0.22	**-0.57**	-0.23	0.30
SSC	-0.28	**0.41**	-0.18	0.16	0.25
pH	-0.24	**0.37**	0.18	0.09	0.11
Titratable acidity	**0.38**	-0.10	**-0.33**	0.16	0.23
Starch index	-0.18	-0.01	**0.49**	-0.28	0.01
Internal ethylene	-0.17	**0.45**	0.30	0.28	0.12
Eigenvalue	3.00	1.57	1.50	1.12	1.04
Proportion (% variance)	0.25	0.13	0.13	0.09	0.09
Cumulative (% variance)	0.25	0.38	0.51	0.60	0.69

Table 3.4. Eigenvectors (weights) and eigenvalues of the principal component axes of 'Fuji' dataset at harvest.

Variable	Principal Components				
	1	2	3	4	5
Weight	0.05	0.29	-0.07	**0.58**	-0.14
% Red color	**-0.34**	0.22	-0.27	-0.04	-0.17
L* ground color	0.09	**0.51**	**0.43**	0.01	0.28
Hue ground color	**0.31**	**0.43**	**0.35**	-0.04	0.16
L* surface color	**0.36**	**-0.39**	0.13	0.10	0.12
Hue surface color	**0.39**	**-0.43**	0.16	0.11	0.09
Firmness	-0.24	-0.13	**0.37**	-0.29	0.22
SSC	**-0.31**	-0.08	0.08	-0.32	0.29
pH	0.18	0.13	**-0.40**	**-0.38**	**0.39**
Titratable acidity	**-0.33**	-0.14	**0.40**	0.18	-0.08
Starch index	**0.36**	0.11	-0.24	-0.09	0.05
Internal ethylene	-0.27	-0.07	-0.15	0.32	**0.44**
Water core	-0.10	-0.07	-0.17	**0.41**	**0.58**

Table 3.4 (continued)

Variable	Principal Components				
	1	2	3	4	5
Eigenvalue	3.46	1.72	1.46	1.32	1.21
Proportion (% variance)	0.27	0.13	0.11	0.10	0.09
Cumulative (% variance)	0.27	0.40	0.51	0.61	0.70

Table 3.5. Percentage of fruit with internal cork tissue in 'Braeburn' at harvest and after 8, 16, 24 and 32 weeks in storage.

		Weeks in storage			
DAFB	At harvest	8	16	24	32
147	0	0	0	6.9	3.7
154	0	0	0	0	5.0
161	0	10.0	3.0	3.3	0
168	10.0	15.0	6.7	6.9	20.0
175	12.5	10.0	6.7	16.0	5.0
182	10.0	15.0	27.6	13.8	10.0
186	10.0	15.0	13.3	16.7	5.0

Table 3.6. 'Braeburn' mineral analysis for N, Ca and N/Ca ratio of fruit flesh and skin after short- (December) and long-term (March) storage[z].

	Storage					
	December 1991			March 1992		
Fruit type	N (%)	Ca (ppm)	N/Ca	N (%)	Ca (ppm)	N/Ca
	Flesh					
Healthy	0.33	368	8.40	0.29	163	18.24 b
Corky	0.30	359	9.34	0.35	144	24.53 a
	Skin					
Healthy	0.41	875 a	4.78	0.48	501	9.82
Corky	0.40	756 b	5.32	0.51	421	12.23

[z] Mean separations for each part of the fruit was by T-test, Alpha=0.05. Means are of 13 (December) and 6 (March) replications.

Table 3.7. Percentage and degree of scald[z] in 'Braeburn' fruit harvested on 7 dates and stored for 16, 24 and 32 weeks in refrigerated storage (0C).

Weeks in storage (0C), and days at 20C.	Incidence of Scald % (degree)						
	DAFB						
	147	154	161	168	175	182	186
16 wks							
1	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
24 wks							
1	0	0	0	0	0	0	0
7	64.3 (1.4)	33.3 (0.9)	40.0 (0.7)	0	0	0	0
32 wks							
1	20.0 (0.5)	30.0 (0.5)	0	0	0	0	0
7	84.6 (2.5)	60.0 (1.6)	10.0 (0.3)	0	0	0	0

[z] Percentage = number of scalded fruits/total fruits of the sample.

Degree of scald = 0-3, none to severe.

Table 3.8. Percentage and degree of scald[z] in 'Fuji' fruit harvested on 7 dates and stored for 16, 24 and 32 weeks in refrigerated storage (0C).

Weeks in storage (0C), and days at 20C.	Incidence of Scald % (degree)						
	DAFB						
	145	152	159	166	173	180	187
16 wks							
1	0	0	0	0	0	0	0
7	0	73.3 (1.4)	66.7 (1.2)	0	0	0	0
24 wks							
1	0	0	0	0	0	0	0
7	40.0 (1.0)	33.3 (0.8)	42.9 (0.9)	0	0	0	0
32 wks							
1	66.7 (0.9)	80.0 (1.3)	70.0 (1.1)	20.0 (0.2)	0	0	20.0 (0.3)
7	78.6 (1.7)	90.0 (2.0)	90.0 (2.3)	70.0 (2.0)	0	0	40. 0 (0.6)

[z] Percentage = number of scalded fruits/total fruits of the sample.

Degree of scald = 0-3, none to severe.

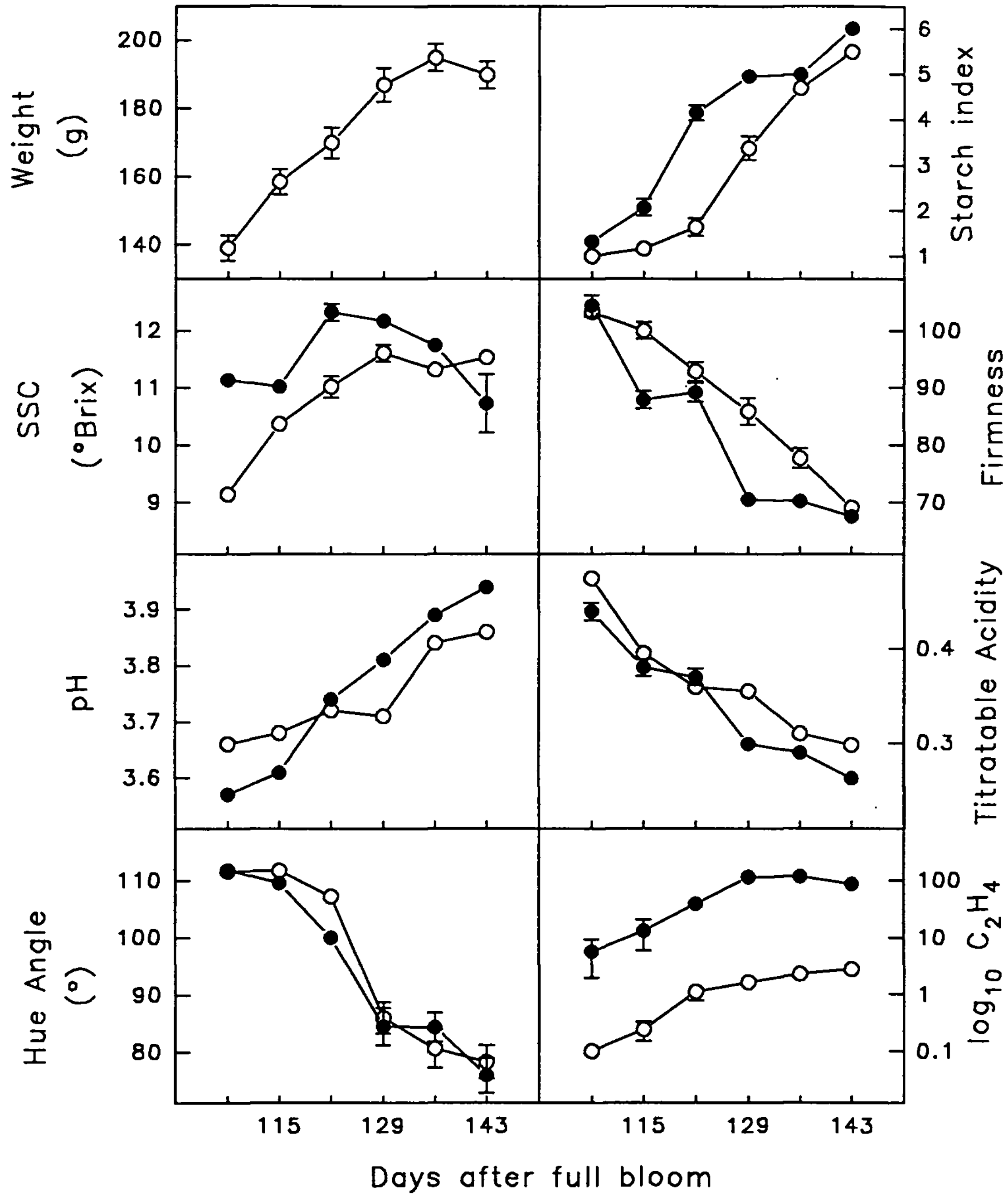

Figure 3.1. Changes in fruit weight, starch index, soluble solids concentration (SSC), firmness, pH, titratable acidity, hue value of the ground color and internal ethylene concentration ($\log_{10}C_2H_4$), of 'Gala' fruit harvested on 6 dates in 1991 at harvest (○) and after 7 days at 20C (●). Each point is a mean of 20 fruits and vertical bars represent ±SE.

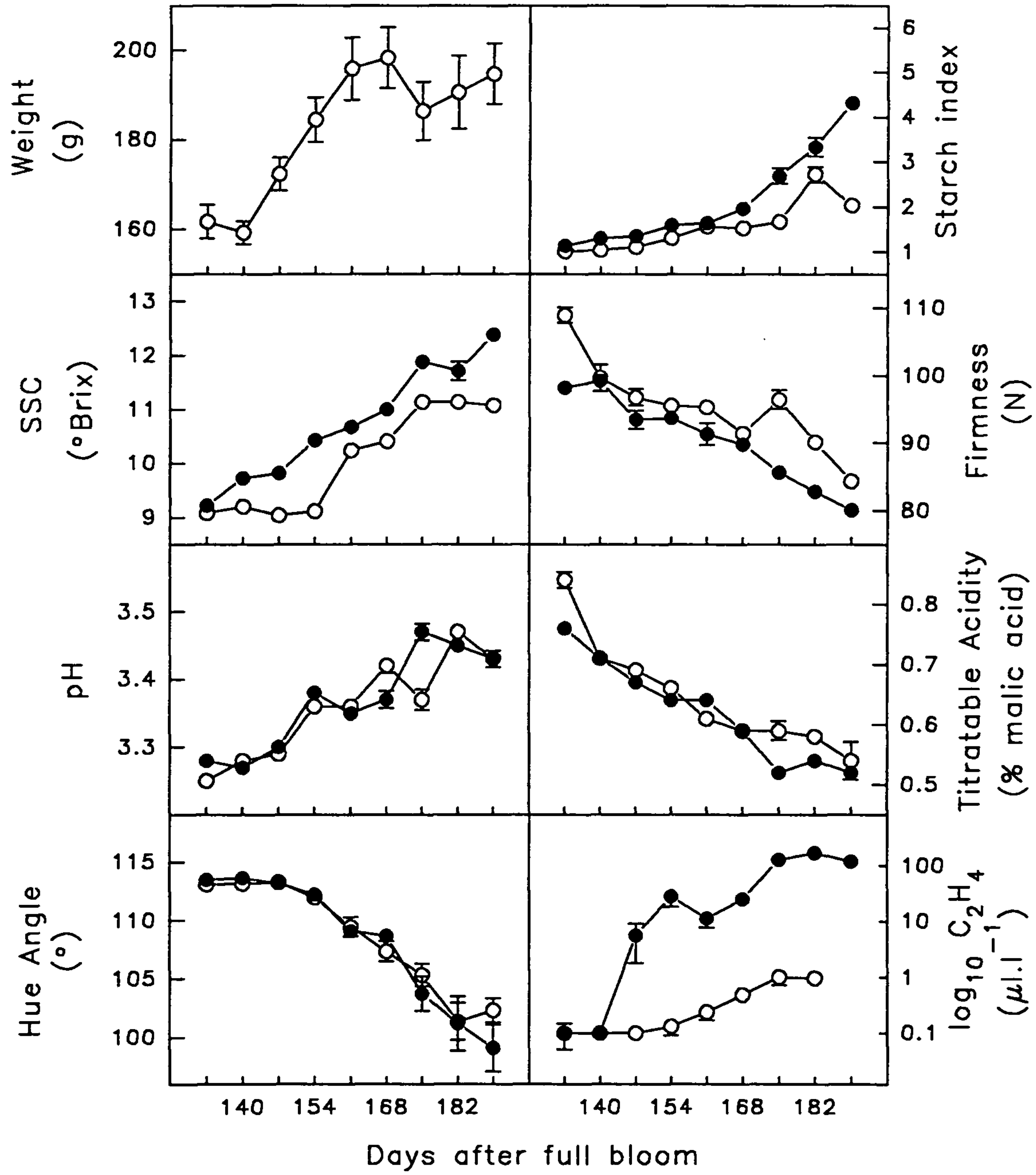

Figure 3.2. Changes in fruit weight, starch index, soluble solids concentration (SSC), firmness, pH, titratable acidity, hue value of the ground color and internal ethylene concentration ($log_{10}C_2H_4$), of 'Braeburn' fruit harvested on 9 dates in 1991 at harvest (o) and after 7 days at 20C (•). Each point is a mean of 20 fruits and vertical bars represent ±SE.

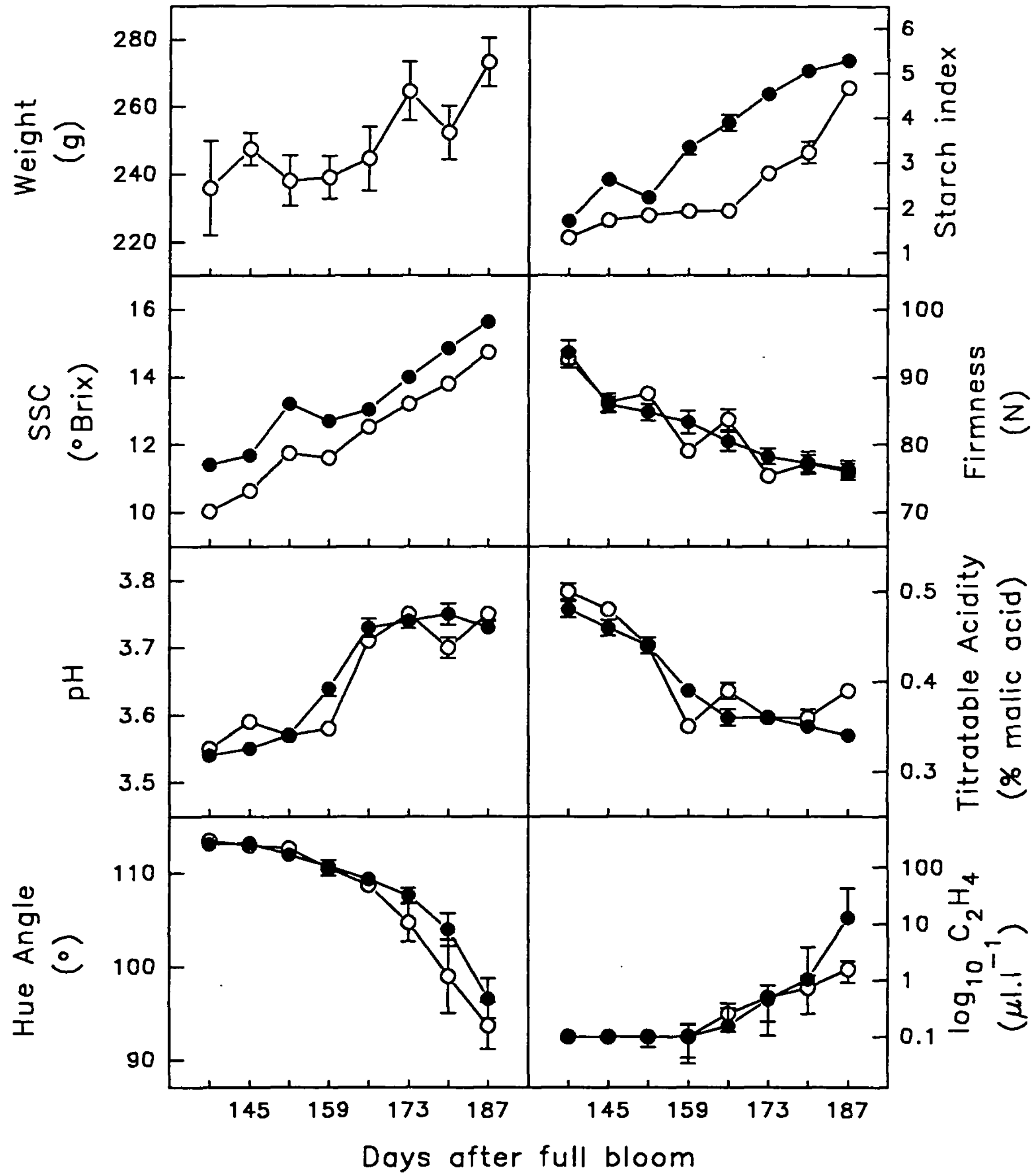

Figure 3.3. Changes in fruit weight, starch index, soluble solids concentration (SSC), firmness, pH, titratable acidity, hue value of the ground color and internal ethylene concentration ($log_{10}C_2H_4$), of 'Fuji' fruit harvested on 8 dates in 1991 at harvest (o) and after 7 days at 20C (●). Each point is a mean of 20 fruits and vertical bars represent ±SE.

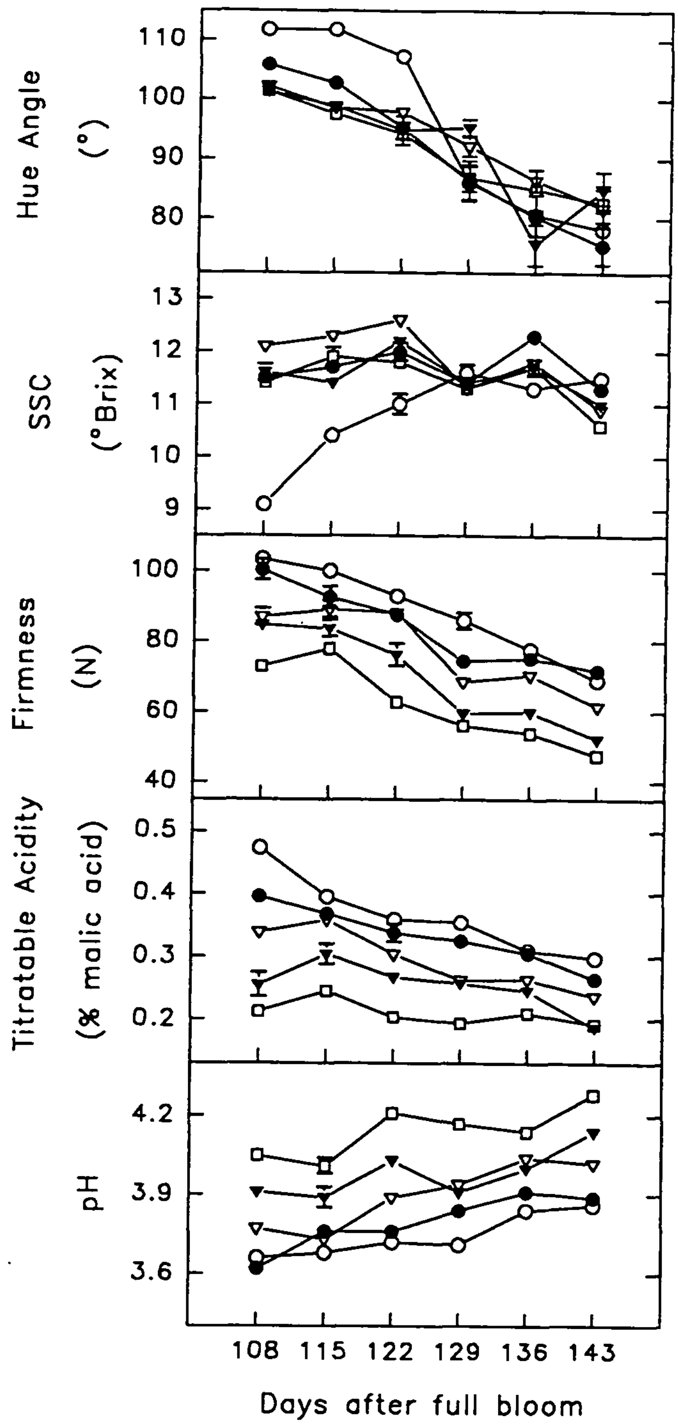

Figure 3.4. Characteristics of 'Gala' fruit at harvest (○) and stored 6 (●), 12 (▽), 18 (▼) and 24 (□) weeks in regular storage (0C), removed and held at room temperature for one day. Each point is a mean of 15 fruits and vertical bars represent ± SE.

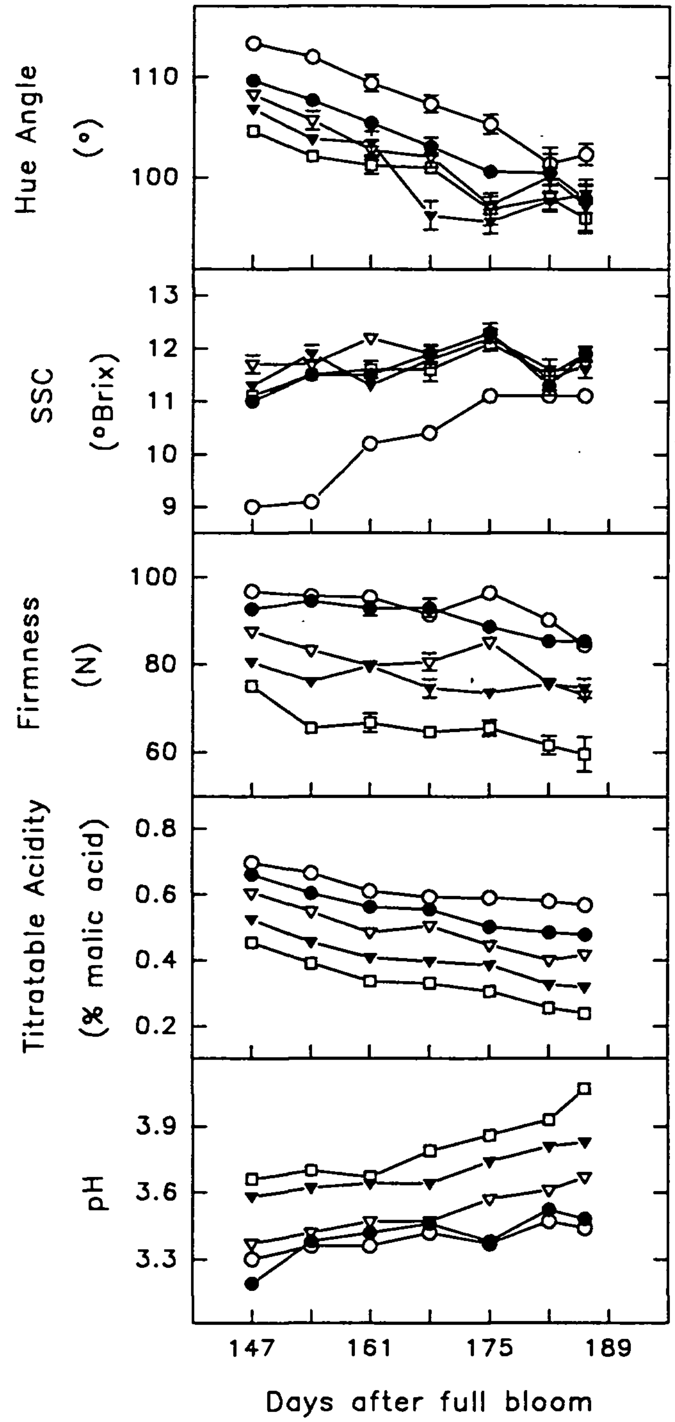

Figure 3.5. Characteristics of 'Braeburn' fruit at harvest (○) and stored 8 (●), 16 (▽), 24 (▼) and 32 (□) weeks in regular storage (0C), removed and held at room temperature for one day. Each point is a mean of 15 fruits and vertical bars represent ± SE.

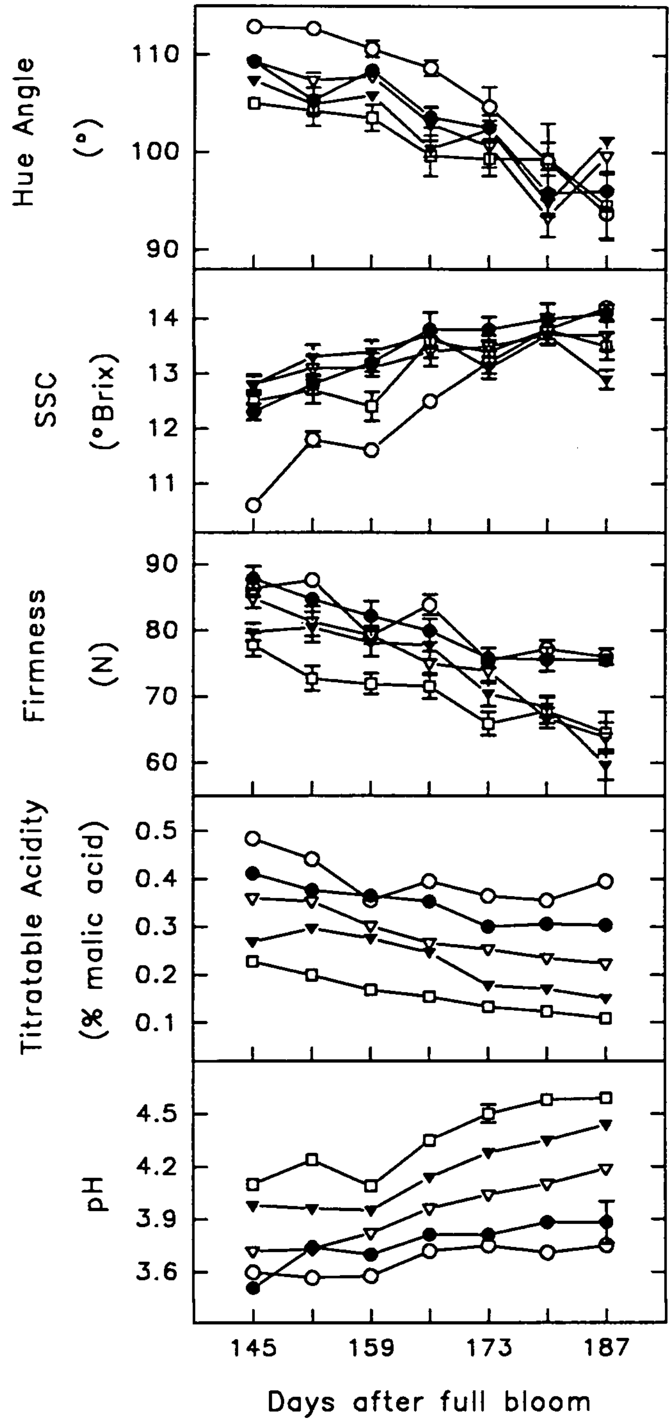

Figure 3.6. Characteristics of 'Fuji' fruit at harvest (○) and stored 8 (●), 16 (▽), 24 (▼) and 32 (□) weeks in regular storage (0C), removed and held at room temperature for one day. Each point is a mean of 15 fruits and vertical bars represent ± SE.

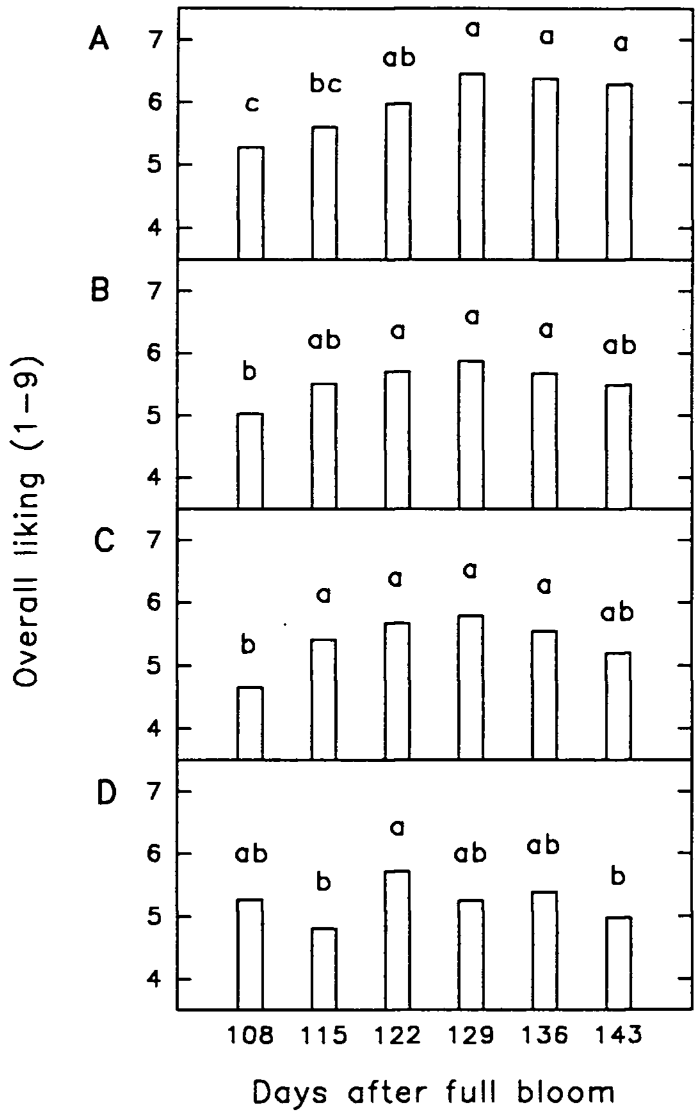

Figure 3.7. Sensory ratings for overall liking (9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely) for 'Gala' apples harvested on 6 dates. Taste test dates and respective panelist numbers (n) were: (A) 7 Oct. (58), (B) 11 Nov. (59), (C) 7 Dec. (49) and (D) 21 Jan. (60). Mean separations were by the Waller-Duncan k-ratio t-test, K=100. Bars with the same letter are not significantly different from one another within a taste panel.

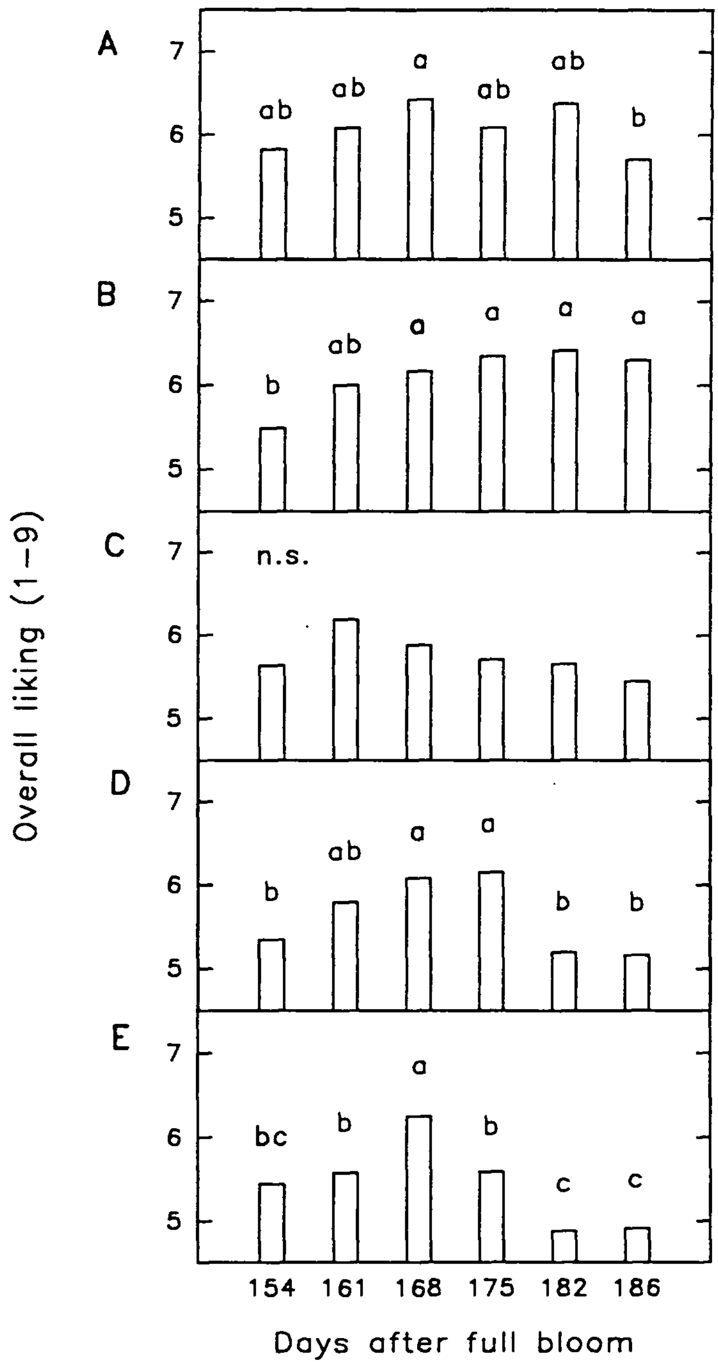

Figure 3.8. Sensory ratings for overall liking (9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely) for 'Braeburn' apples harvested on 6 dates. The taste test dates and respective panelists numbers (n) were: (A) 7 Nov. (58), (B) 7 Jan. (57), (C) 18 Feb. (56), (D) 14 Apr. (54) and (E) 26 May (58). Mean separations were by the Waller-Duncan k-ratio t-test, K=100. Bars with the same letter are not significantly different from one another within a taste panel.

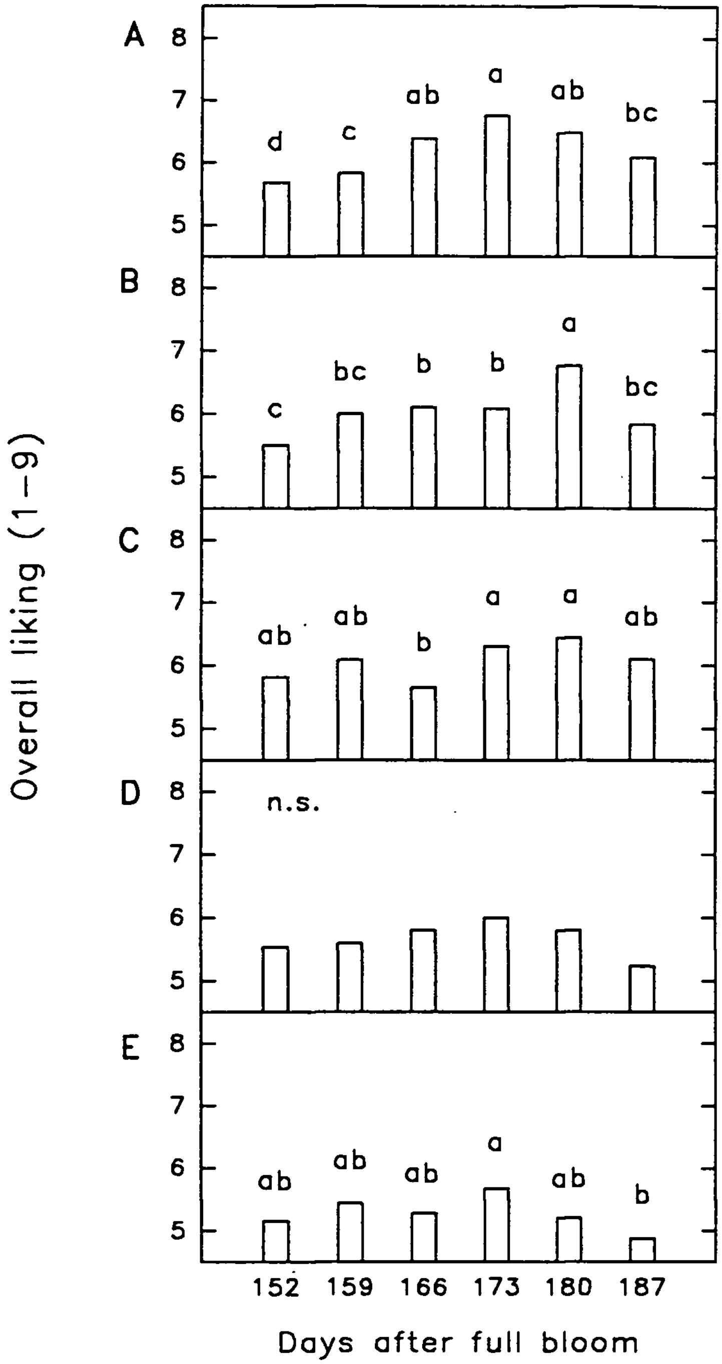

Figure 3.9. Sensory ratings for overall liking (9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely) for 'Fuji' apples harvested on 6 dates. The taste test dates and respective panelists numbers (n) were: (A) 12 Nov. (59), (B) 14 Jan. (58), (C) 25 Feb. (57), (D) 25 Apr. (60) and (E) 2 Jun. (57). Mean separations were by the Waller-Duncan k-ratio t-test, K=100. Bars with the same letter are not significantly different from one another within a taste panel.

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CHAPTER 4

MATURITY AND STORAGE AFFECT THE EATING QUALITY OF 'GALA', 'BRAEBURN' AND 'FUJI' APPLES

ABSTRACT

'Gala', 'Braeburn' and 'Fuji' apples were harvested at weekly intervals for 6 wks and stored in regular atmosphere at 0C. Fruits were evaluated four or five times for overall liking (OL), firmness, sweetness, tartness and flavor intensities by a consumer panel, at approximately one or two month intervals for 'Gala', 'Braeburn' and 'Fuji'. Firmness, titratable acidity (TA) and soluble solids concentration (SSC) from a subsample of tasted fruits were also analyzed. Panelists described quite accurately the loss of firmness and acidity occurring during maturation and in storage but firmness was the only instrumental variable correlated to the firmness ratings in the sensory tests. Additionally, panelists described changes in sweetness not revealed by the instrument, and changes in flavor. Data revealed multicollinearity for OL, sweetness and flavor ratings. A multivariate factor analysis determined that the five attributes explained 75 to 78% of the variation of the dataset in the first two factors. The first factor was a combination of OL, flavor and sweetness in all three cultivars. The second and third factors were tartness and firmness, alone or in combination, depending on the cultivar and the panel. The plots of the mean factor scores provided a multivariate technique to illustrate that panelists could differentiate between the stages of maturity of apples.

Early harvests, late harvests with little storage and late harvests after long-term storage were well separated along the first two factors. Intermediate harvest dates were generally clustered at the intersection of the two factors.

INTRODUCTION

Horticultural and storage practices are aimed at producing fruit free of pathological and physiological disorders. After those requirements have been satisfied, eating quality is the criterion for good storage (Knee and Smith, 1989). One of the factors affecting apple storage capacity and their eating quality is the maturity stage at harvest (Olsen, 1982). Maturity studies have often been complemented with taste panels to determine the effect of harvest date on fruit quality, with or without storage (Bidabe et al., 1969; Blanpied, 1979; Knee and Smith, 1989; Saltveit, 1983). Because taste tests are time consuming, attempts to correlate sensory values to instrumental measurements such as firmness, soluble solids concentration (SSC), titratable acidity (TA) and pH have been investigated (Ananthakrishna et al., 1983; Gorin, 1973; Visser et al., 1968; Wills et al., 1980). Those easily measurable parameters are commonly used to determine apple condition (Watada et al., 1981). But the diversity of sensory methods - intensity or hedonic scale, trained or semi-trained panelists - used to describe apples have produced diverse results in the literature. The poor knowledge of interactions between chemical compounds, and between chemical and textural components of apples explains the difficulty in relating sensory attributes to analytical measurements (Watada and Abbott, 1985). Besides that, the variation occurring within fruit is often as great as the variation between fruits, making studies on fresh products more difficult (Williams and Carter, 1977).

The purpose of multivariate statistical methods such as Principal Components Analysis (PCA) and factor analysis is to discover which variables in the dataset form coherent subsets that are independent of one another (Tabachnick and Fidel, 1989). Both PCA and factor analysis explain the variance-covariance structure with a few orthogonal linear combinations of the original variables (Johnson and Wichern, 1992; Tabachnick and Fidel, 1989). Factor analysis differs from PCA in that it excludes unique (or specific) and error variance from the model, resulting in an approximation of the observed variance-covariance matrix instead of its reproduction (Tabachnick and Fidel, 1989). Factor analysis summarizes a pattern of correlated measured variables into a few underlying, but unobservable, random quantities called factors (Johnson and Wichern, 1992).

Canonical correlations measure the strength of associations between two distinct sets of variables (Johnson and Wichern, 1992). The method can be compared to a multiple regression where several variables are on both sides of the equation (Tabachnick and Fidel, 1989). Each set of variables is combined to produce, for each side, a predicted value that has the highest correlation with the predicted value on the other side. Canonical correlations try to reveal along how many dimensions the variables in one set relate to the variables in the other (Tabachnick and Fidel, 1989). Limitations of canonical correlations that explain its rarity in the literature are mainly due to the interpretability and the jargon associated to it. The pairs of linear combinations of each variable are called the canonical variate, and their correlations canonical correlations (Johnson and Wichern, 1992).

The primary objective of our study was to see if consumers could perceive a difference between apples harvested at weekly intervals. Preference ratings helped adjusting the optimum time of harvest (Chapter 3). Data concerning the intensity perceived by the panelists of some simple attributes such as firmness, sweetness, tartness and flavor provided complementary information as to the effect of apple maturity on taste. The relation of the sensory scores between each other, giving indication on the general appreciation of apples, can be of interest to growers and marketers. Finally, we related sensory data to a few physical and chemical measurements.

MATERIALS AND METHODS

Fruits of 'Royal Gala', standard 'Braeburn' and 'Fuji' 'Morio-fu #2' strain were sampled weekly as described in Chapter 3, and air-stored at 0C. Four and five consumer taste tests were conducted for each cultivar at approximately 4 wk intervals for 'Gala', and 8 wk intervals for 'Braeburn' and 'Fuji' in the Sensory Science Laboratory at Oregon State University (Corvallis, OR). Twenty fruits of each harvest date were removed from storage and held at 20C for 4 days prior to testing. Fifty to 60 students and staff from Oregon State University participated in the tests. Only one variety was tested per session.

Six pieces of unpeeled apple cut longitudinally, one slice representing each of the six harvest dates, were presented to the panelists. Overall liking (OL) was rated by using a nine-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike and 9=like extremely. Firmness, sweetness, tartness and flavor intensities were rated on a nine-point category scale with the words low/high anchored at both ends. Panelists were seated in individual booths lit with a red lighting to mask the color variation of the fruit skin due to maturity stages. Spring water (Aqua Cool, Portland, OR) was provided for rinsing between samples. Fruits were presented on a tray in a randomized, balanced, complete block design. Each apple served three panelists and was cut into 5 sections: three for the taste test and two for analysis. Sixteen to 20 apples representing each harvest date were used in each panel.

A subsample of five fruits for 'Gala' from all panels, and five and ten 'Braeburn' and 'Fuji' fruits taken from the first two and the last three panels, respectively, were analyzed for firmness and chemical characteristics. Firmness was measured on two opposite pared sides of the apple, with a Magness-Taylor pressure tester equipped with an 11-mm tip. The punctured sections were juiced and frozen for further analysis. Total soluble solids concentration (SSC) of the juice was measured with a hand-held refractometer (Atago N1). Ten ml of juice was titrated with 0.1N NaOH to a malic acid endpoint of pH=8.2. Initial pH of the juice was also recorded.

Statistical analysis

A multivariate analysis of variance (MANOVA) was performed on the data of each taste test session, with harvest date as the main effect, panelist as a blocking effect and with overall liking, firmness, sweetness, tartness and flavor intensities as dependent variables. Significance tests in MANOVA are based on the multivariate normal distribution and homogeneity of variance-covariance matrices (Tabachnick and Fidel, 1989). Univariate normality was verified for the residuals of the general linear model (GLM), and equality of variance-covariance matrices tested with the Box's test (Morrison, 1976). A large number of panelists (more than 45) was used to overcome the variability due to untrained consumers and to increase the significance of the test. A stepwise multiple linear regression was performed on the sensory ratings, with overall liking as the dependent variable, and firmness, sweetness, tartness and flavor as the independent variables.

Factor analysis with initial principal components extraction was first performed on the covariance matrix of the raw data, for each harvest date and taste test. The variance-covariance matrix was used because data measurements were in the same scale for all variables. In order to pool the six harvest dates within a panel, the residuals of the GLM used in MANOVA were used in the next analyses. A factor analysis of the residuals with initial principal components extracted the maximum variance from the dataset. The significant factors were thereafter extracted and rotated to understand the underlying meaning of variables. The distribution of the datapoints was visualized after plotting the factor mean scores along the first significant factors extracted from the covariance matrix of the raw data.

Canonical correlation was performed on the analytical and sensory subsets of data. Also, a stepwise linear regression was performed for each sensory score as dependent variable, and firmness, soluble solids concentration (SSC) and titratable acidity (TA) as independent variables.

All statistical analyses were performed with Statistical Analysis System (SAS Institute Inc., Cary, NC).

RESULTS

Effect of harvest date on sensory ratings

Box's test (Morrison, 1976) revealed inequality of covariance matrices in the first taste test session (7 Oct.) of 'Gala'. Although MANOVA is robust to violation of the assumption of equality of covariance matrices (Tabachnick and Fidel, 1989) results concerning the first panel should be taken cautiously. The variance-covariance matrices were equal in the remaining taste tests of 'Gala', and in all taste panels of 'Braeburn' and 'Fuji' (Chi-square value not significant at the 0.0001 level). Therefore, the pooled covariance matrix was used in further calculations of Wilk's Lambda value to test the likelihood of equal population mean vectors in MANOVA. Harvest date and panelist effects were significant across all taste test sessions for all three varieties (Appendices 4.1, 4.2 and 4.3). Variation due to panelists generally occurs in consumer panels because the panelists use different parts of the scale.

Sensory scores were analyzed as univariate ANOVA and the separation of means for harvest date effect was performed using the Waller-Duncan k-ratio t-test, K=100, for each testing session (Fig. 4.1, 4.2 and 4.3). Generally, OL decreased with apple storage time for all three varieties. For the early taste tests, late harvests were preferred for 'Gala' and 'Braeburn', while intermediate harvests of 'Fuji' were given a higher rating. For 'Gala' and 'Braeburn' stored late, preference shifted to mid-season harvest dates. A rather constant rating for OL across storage was given to 'Gala' and 'Braeburn' fruits harvested 122 DAFB (26 Aug.) and 161 DAFB (3 Oct.), respectively. For 'Fuji' apple, late stored fruit was given very low OL ratings, with little, if any, significant difference between harvest dates. Overall liking ratings as related to harvest date and storage were discussed in Chapter 3.

The ratings given to flavor intensity had a similar trend to those of OL. This was especially true for 'Gala' (Fig. 4.1). For 'Braeburn', significant differences in flavor ratings were not found by the panelists on 7 Nov. and 18 Feb.. On the late taste tests (14 Apr. and 26 May), late harvests [182 and 186 DAFB (24 and 28 Oct.)] and the earliest one [154 DAFB (26 Sept.)] were given a significantly lower rating for flavor (Fig. 4.2). Flavor intensity ratings of 'Fuji' decreased considerably after 6 and 8 months in storage (panels of 25 Apr. and 2 June), except for the first harvest where they were low across all taste tests (Fig. 4.3). Their means were not significantly different across harvests on the panels of 25 Feb. and 25 Apr..

Sweetness intensity ratings were generally higher for the riper apples. Also, they tended to be significantly lower on the first two harvest dates, for all three varieties. An example of this is sweetness of 'Fuji' fruit tested on 25 Apr. (Fig. 4.3). For 'Fuji' on the taste test of 2 June, sweetness ratings were low, except for the fruit harvested on 173 DAFB (14 Oct.).

Tartness intensity ratings tended to follow the reverse trend than those given to sweetness. Differences between fruits harvested early and those harvested late were more pronounced for tartness than for sweetness ratings. This was illustrated for 'Gala' on the taste tests of 7 Oct. and 21 Jan. (Fig. 4.1), for 'Braeburn' on the panels of 14 Apr. and 26 May (Fig. 4.2), and for 'Fuji' on the last three panels (Fig. 4.3). Ratings for tartness intensity in 'Fuji' were the lowest on the panels of 25 Apr. and 2 June.

The ratings for firmness intensity were decreasing across harvest dates and across taste tests for all three varieties. Differences were higher between harvest dates as fruit stayed longer in storage. The decrease was rather regular for 'Gala' and 'Fuji' fruit. Firmness ratings dropped sharply on the last harvest dates of 'Braeburn' [182 and 186 DAFB (24 and 28 Oct.)] on the last three taste panels.

Structure of the sensory dataset

For all three varieties, the GLM-MANOVA procedure gives the partial correlation coefficients from the error sums of squares and cross product (SSCP) matrix (Appendices 4.4, 4.5 and 4.6). Overall liking (OL) was highly correlated with flavor (r=0.7 to 0.8), sweetness (r=0.5 to 0.6) and firmness (r=0.3 to 0.6) across all taste tests in all three varieties. Positive correlations were also found between sweetness and flavor (r=0.4 to 0.6), firmness and tartness (r=0.2 to 0.4), and firmness and flavor (r=0.2 to 0.5). The levels and significance of correlations for OL, firmness and tartness, sweetness and tartness, sweetness and firmness, and tartness and flavor varied in each taste test. Sweetness was negatively correlated with tartness on two tests out of four for 'Gala' (r=-0.1 and -0.2) and on the first three taste tests of 'Braeburn' (r=-0.2 to -0.4).

Stepwise linear regressions of perceived intensity of sensory attributes over OL for each taste test are shown in Appendix 4.7. For all three varieties, flavor was entered first and the partial R^2 ranged from 0.49 to 0.65. Sweetness or firmness explained an additional one to 7% of the variation, and tartness entered in the model on the panel of 7 Oct. for 'Gala', 18 Feb. for 'Braeburn', and on the panels of 25 Feb. and 2 June for 'Fuji', with partial $R^2 \leq 02$.

A factor analysis of the raw data, for each harvest date and taste test, revealed that for all three varieties, OL, flavor and sweetness had generally an important weight in the first factor, accounting for 45 to 60% of the variance, relative to tartness and firmness intensities (data not shown). Tartness was important in factor two, accounting for 20 to 30% of the variance, and firmness was important in factor three most of the time. This was not verified in all the performed analyses, therefore the residuals of the GLM from the previous MANOVA were used for further analysis to pool harvest dates within a taste panel.

In 'Gala', the first two factors accounted for 75, 75, 76 and 77% of the variance with an eigenvalue above one, for the panels of 7 Oct., 11 Nov., 7 Dec. and 21 Jan., respectively (Table 4.1). The third factor explained an additional 11, 12, 12, and 9% of the variation in each taste test session. Loadings in factor one were within the same order of magnitude, indicating that all variables had equivalent weight in explaining the model, except generally a little less for tartness. Factor two was heavily loaded with tartness (it ranged from 0.70 to 0.87 across taste tests). Firmness was also important in this factor (from 0.27 to 0.65), and was contrasted to sweetness (from -0.60 to -0.43). In the first three panels, the third factor was mainly loaded with firmness. In the fourth panel, sweetness and tartness were equally loaded, and firmness was contrasting them.

In 'Braeburn', the first two factors with an eigenvalue above one accounted for 77, 79, 75, 73 and 78% of the variance for the panels of 7 Nov., 7 Jan., 18 Feb., 14 Apr. and 26 May, respectively (Table 4.2). On the panels of 18 Feb. and 14 Apr., factor three had an eigenvalue above one and explained an additional 11 and 13% of the variance, respectively. Factor three accounted for 9% of the variance in the remaining panels. As in 'Gala', factor one was generally a linear combination of all five sensory attributes with higher loadings on OL and flavor, and explained 49 to 58 % of the variation. Tartness had a significantly lower loading in factor one on the panels of 7 Nov., 7 Jan., 18 Feb. and 26 May , but not in the panel of 14 Apr.. Firmness had a lower loading on the panel of 7 Jan.. Tartness was mainly a component of factor two, with loadings ranging from 0.72 to 0.92 across taste tests. Generally, firmness was also important in this factor (0.32 to 0.57), and sweetness contrasted firmness and tartness with loadings of -0.64 to -0.49. Firmness was the main variable entering in factor three, except in the panel of 26 May where tartness (0.49) contrasted firmness (-0.43).

In 'Fuji', the first two factors with an eigenvalue above one explained 77, 77, 74, 74 and 77% of the variance for the panels of 12 Nov., 14 Jan., 25 Feb., 25 Apr. and 2 June, respectively (Table 4.3). The third factor with an eigenvalue above one explained an additional 13 and 11% of the variance in the panels of 25 Apr. and 2 June, respectively. Factor three accounted for 10% of the variance in the remaining panels. Factor one was a linear combination of OL, flavor and sweetness on the panels of 12 Nov. and 14 Jan. and explained 54% of the variance. Firmness entered in the combination on the panels of 25 Feb. and 25 Apr. (53 and 52% of the variance, respectively), and factor one was a linear combination of all attributes on the taste test of 2 June (62% of the variance), with higher loadings on OL and flavor. Tartness was the main component of factor two on the panels of 12 Nov., 25 Feb. and 25 Apr., contrasted by sweetness. Tartness and firmness, contrasted by sweetness were components of factor two on 14 Jan. and 2 June. Firmness was the major component of factor three, except in the panel of 12 Nov., where sweetness and OL contrasted each other.

Factor rotation is ordinarily used after extraction to maximize high correlations and minimize low ones (Tabachnick and Fidel, 1989), allowing a simpler structure of the dataset (Johnson and Wichern, 1992). "Factor rotation is akin to sharpening the focus of a microscope to see the details clearly" (Johnson and Wichern, 1992). VARIMAX is one of the procedures that maximizes variance. After extracting and rotating the first two factors with orthogonal VARIMAX rotation, loadings were high on OL, flavor and sweetness in the first factor for all three varieties (Appendices 4.8, 4.9 and 4.10). In 'Gala', the second factor was mainly a component of tartness, followed by firmness. In 'Braeburn', tartness and firmness were the main components of factor two in all the panels except on 7 Jan. where tartness contrasted sweetness. In 'Fuji', tartness was the major component of factor two on the panels of 12 Nov., 14 Jan. and 25 Feb.. Tartness contrasted sweetness on the panel of 25 Apr., and it was combined with firmness on the panel of 2 June.

Because the first two factors had similar patterns, we were able to combine the data and extract factors from the pooled covariance matrices of all taste tests within each variety. An orthogonal rotation of the first two factors confirmed the linear combination of OL, flavor and sweetness in factor one of all three varieties, and tartness and firmness in factor two of 'Gala' and 'Braeburn' (Table 4.4). Factor two was made up only with tartness in 'Fuji' and extraction of a third factor was necessary to include firmness, implying that the variability of 'Fuji' dataset was spread in a three dimensional system. The plot of the mean scores along the first two ('Gala' and 'Braeburn') and three ('Fuji') factors extracted from the pooled covariance matrix of the raw data provided a multivariate method to differentiate between harvest dates and storage for each apple cultivar.

In 'Gala', before factor rotation, taste test sessions (letter symbols) were decreasing along factor one (all sensory variables with equal weight)(Fig. 4.4). The first two panels were all on the positive side of factor one. Harvest dates (numeric symbols), or apple maturity were decreasing along factor two (tartness and firmness), with the first two harvest dates forming a group separate from the next harvests. After extraction and rotation, fruit harvested 129, 136 and 143 DAFB (2, 9 and 16 Sept.), and without significant storage (7 Oct. panel) was given the highest ratings in overall liking, flavor and sweetness (highest scores on factor one) (Fig. 4.4). On the other side, fruit harvested early [108 and 115 DAFB (12 and 19 Aug.)] was not ripe, and had the lowest scores on factor one and factor two (tartness and firmness). Intermediate harvests were clustered at the intersection of the factors, mostly on the positive side of factor one (overall liking, flavor and sweetness). Harvests of 136 and 143 DAFB (9 and 16 Sept.) on the November, December and January taste tests, as well as 122 and 129 DAFB (26

Aug. and 2 Sept.) on the January taste panel, had negative scores on factor two (tartness and firmness). Late harvested fruit [143 DAFB (16 Sept.)] after long-term storage (21 Jan.) had low scores on all factors, indicating low ratings in all attributes.

For 'Braeburn', before factor rotation, harvest of 168 DAFB (10 Oct.) on the November and January panels, 175 DAFB (17 Oct.) on the January panel, 182 DAFB (24 Oct.) on the November and January panels, and 186 DAFB (28 Oct.) on the January panel had the highest score on factor one, which is a linear combination of all sensory attributes (Fig. 4.5). Late harvest dates on late panels [182 DAFB (24 Oct.) on 14 Apr. and 26 May, 186 DAFB (28 Oct.) on 18 Feb., 14 Apr. and 26 May] had low scores on factor one and factor two (tartness contrasted to sweetness). The first harvest date, 154 DAFB (26 Sept.), on all taste tests had the highest scores on tartness, and intermediate scores on factor one. The remaining harvest dates and taste panels were at the intersection of factor one and two, in a decreasing order along factor two. Rotation of the factors did not change the clustering pattern of the data. It only emphasized the sensory attributes characterizing apples harvested and tasted at a specific date (Fig. 4.5). Fruit with positive scores on OL, sweetness and flavor (factor one) was from intermediate harvest dates [168 and 175 DAFB (10 and 17 Oct.)] at any time after storage and late harvest dates [182 and 186 DAFB (24 and 28 Oct.)] on the November and January panels. Unripe fruit harvested early [154 DAFB (26 Sept.)] at any storage time, and late harvested fruit stored late [182 and 186 DAFB (24 and 28 Oct.) on February, April and May panels] had all negative scores on factor one (OL, flavor and sweetness) with a clear separation along factor two (tartness and firmness) between .

We could notice a decreasing gradient along factor two (tartness and firmness) with a constant score on factor one for the harvest of 161 DAFB (3 Oct.) on four taste panels.

For 'Fuji' before rotation, intermediate harvests [166 to 180 DAFB (7 Oct. to 21 Oct.)] on the November and January panels had the highest scores on factor one (all sensory attributes) (Fig. 4.6). The first harvest date [152 DAFB (23 Sept.)] on all taste tests except the last one, and harvest of 159 DAFB (30 Sept.) on April panel had a negative score on factor one and the highest scores on factor two. All harvest dates except the one of 173 DAFB (14 Oct.) on the last taste panel (2 June) and including 187 DAFB (28 Oct.) on the April panel were in a decreasing order along factor two, their scores being constant and negative on factor one. Harvest of 159 DAFB (30 Sept.) on the first three panels, and 173 DAFB (14 Oct.) on the January panel were clustered on the positive center of the plot. Intermediate harvest dates on late panels [173 DAFB (14 Oct.) on the panels of 25 Feb., 25 Apr. and 2 June, 180 DAFB (21 Oct.) on the panels of 25 Feb. and 25 Apr.] and the last harvest date on early panels [187 DAFB (28 Oct.) on 12 Nov. and 14 Jan.] had positive scores on factor one, and negative scores on factor two. After extracting and rotating the first three factors, the clustering of mean harvest dates and taste panels was almost similar in the plot along factor one (OL, flavor and sweetness) with factor two (tartness) (Fig. 4.7). The first harvest on all taste panels, and all harvest dates except the one of 173 DAFB (14 Oct.) on the last panel, had the lowest scores on factor one, the first group being positive on tartness and the latter negative. Intermediate harvest dates and taste panels had positive scores on factor one. There was a decreasing gradient along factor two with harvest date and panel session.

Extracting the third factor showed principally the separation between early and intermediate harvests on early panels, and late stored fruit along the firmness axis. The first two harvest dates [152 and 159 DAFB (23 and 30 Sept.)] had positive scores on factor two, and negative on factor one. Intermediate harvest dates [166, 173 and 180 DAFB (7, 14 and 21 Oct.)] on the first panel had high scores on factor one and two. Fruit harvested 180 DAFB (21 Oct.) on the January panel had the highest score on factor one and zero score on factor two and three. Last harvest dates [180 and 187 DAFB (21 and 28 Oct.)] on the late panels (April and June) had low scores on the three factors.

Relation between sensory and analytical data

Fruit firmness, SSC, TA and pH of subsamples of tasted apples are presented in Table 4.5, 4.6 and 4.7. When comparing the ratings given to firmness, sweetness and tartness (Fig. 4.1, 4.2 and 4.3), and the corresponding analytical measurements, the general trends could be pointed out: The decrease of firmness measured with the penetrometer was paralleled by a decrease in sensory firmness ratings over harvest date and storage for all three varieties. Fruit SSC had little variation, whereas the ratings for sweetness were generally lower on the early harvests compared to the late harvests. TA decreased slightly (and pH increased) with harvest date. The decrease in tartness was more important in 'Gala' and 'Braeburn' than the corresponding acidity measurements. In 'Fuji', the decrease in tartness ratings paralleled the decrease in TA on the last three panels.

Canonical correlation analyses extracted two, one and two pairs of canonical variate for 'Gala', 'Braeburn' and 'Fuji', respectively (Table 4.8). The first canonical variate in 'Gala' was primarily firmness for the sensory data, and pressure measurements for the analytical data (Table 4.9). For 'Braeburn' and 'Fuji', it was tartness and firmness for the sensory data, and titratable acidity (TA) and pressure measurements for the analytical data. The second canonical variate was tartness and flavor for the sensory data in 'Gala', and TA for the analytical data. It was primarily sweetness, and SSC for 'Fuji'. The first canonical correlation was 0.53 for 'Gala', and was largely due to the correlations between sensory firmness and pressure measurements (Table 4.10). It was of 0.41 for 'Braeburn', and due to the correlation between tartness and firmness (sensory) with TA and, to a lesser extend, pressure measurement. For 'Fuji', the first canonical correlation was of 0.44, and due to the correlation between firmness and tartness, and pressure measurement and TA. Correlations between analytical measurements and the second canonical variate of the sensory ratings were too low to be of any interest. The proportion of variability in one set of variables explained by all of the other set was small (0.065 and 0.112 for 'Gala', 0.058 and 0.075 for 'Braeburn', and 0.073 and 0.115 for 'Fuji'), indicating that none of the set was a good predictor of the other.

Multiple linear regressions of sensory ratings over analytical measurements revealed models with very low R^2 values for overall liking, flavor, sweetness and tartness (Table 4.11). Firmness measurement and TA explained best the variation in sensory firmness, but R^2 were still very low (0.23 to 0.16).

DISCUSSION

A multivariate analysis of variance on the sensory data showed a strong effect of harvest date in each taste test session. The univariate ANOVA allowed a mean separation for each attribute with the Waller-Duncan k-ratio t-test, but it could not provide the best combination of attributes to be able to distinguish between samples. In turn, the degree of correlation between attributes and their relative importance to the differentiation of the samples could clearly be seen from examining factor loadings.

Relations between sensory attributes

Correlations and factor analysis revealed collinearity between overall liking, flavor and sweetness in all three varieties. A multiple linear regression showed that flavor explained 50 to 60% of the variation of OL. Indeed, ratings for OL and flavor had similar patterns across harvest date per taste panel (Fig. 4.1, 4.2 and 4.3). Ananthakrishna et al. (1983) reported high correlations between overall quality and aroma ($r=0.92$) and overall quality and taste ($r=0.89$) for 'Red Delicious' apples. Flavor sensus stricto is the result of the perception of a combination of volatile and non-volatile components, the former resulting in sensory aroma and the latter in taste sensation (Williams, 1979). If high (low) flavor implied good (bad) taste, we can see why flavor ratings affected OL. During our taste panels, we explained to the consumers to rate flavor as "whatever you think apple flavor should be". Therefore, panelists would rate flavor according to their cultural background and to which kind of apple they were used to eat. On a university campus, people are originated from various states and countries. Asian people mostly consume 'Fuji' type of apples, high in sugars and low in acidity, Northern Europeans and Eastern North-Americans know better tart apples such as 'McIntosh' or 'Cox's Orange Pippin', and Southern Europeans and Western North-Americans find on their market more 'Red' and 'Golden Delicious' apples, sweet and tart. This diversity among panelists, added to the fact that the term "flavor" includes a broad sensory definition, may explain the variability and non significance in the means of flavor ratings on two panels out of five for 'Braeburn' and 'Fuji'. Williams and Carter (1977) pointed out that the differences in scoring are most often due to improper understanding of the terms, differences between panelists, and differences between apples.

Factor analysis provided a method to understand how the attributes were interrelated. The grouping of overall liking, flavor and sweetness on one factor, and firmness and tartness on the others showed that the ratings of the first group of attributes affected each other, independently from tartness and firmness. The higher loadings for OL, flavor and sweetness in factor one indicated that variability was higher along these attributes than along firmness and tartness.

Factor loadings were similar in all 'Gala' taste tests (Table 4.1). OL, flavor and sweetness explained best the variation of the dataset, followed by tartness and firmness in the first three factors. Sweetness loadings were as high as firmness, with a sign opposite to firmness and tartness in factor three, suggesting that sweetness was inversely perceived to tartness and firmness. The results from factor analysis in 'Braeburn' were more variable between taste panels, but again, OL and flavor explained most of the variation of the dataset, followed by tartness (factor two) and firmness (factor three) (Table 4.2). On the last panel (26 May), the fact that tartness and firmness had similar loadings in factor three suggests that after long-term storage, low acidity and soft apples affected equivalently the corresponding sensory ratings. In 'Fuji', as the apples stayed longer in storage and were tasted late in the season, more attributes entered in factor one to explain the total variance (Table 4.3). In other words, OL, sweetness and flavor were responsible for sensory variation when fruit had optimum firmness (penetrometer) and acidity, after short-term storage; as fruit ripened in storage and lost firmness and acidity, more differences were perceived on tartness and firmness intensities between harvest dates. Tartness was generally a component of factor two and firmness of factor three. The structure of factor three in the first taste panel was different from any other, with sweetness contrasting OL. It could be speculated that the relatively high sweetness in 'Fuji' apple affected OL. Also, this factor could be ignored since its eigenvalue was small (0.67).

The similarities of factor patterns for all three varieties could mean that panelists were consistent in rating apples, but also that our ballot may not have been explicit enough. To understand the underlying reasons why fruit is given a particular rating, it is important to ask as many specific questions as possible (Williams and Langron, 1983). On the other hand, a questionnaire on a consumer panel must be simple and short. Adding the juiciness attribute in our scoresheet would certainly have provided extra information without complicating the ballot. It has been previously reported among attributes associated with the quality of apple (Watada and Abbott, 1985). Some panelists commented about 'Fuji' on the panel of April, that it was "firm and juicy".

Effect of time of harvest and storage on apple's description

The distribution of the mean ratings along the first two factors for 'Gala', 'Braeburn' and three factors for 'Fuji' suggests that panelists could perceive the changes occurring in apples during ripening and maturation. Identically, panelists could differentiate between one week of harvest of 'Cox's Orange Pippin' (Knee and Smith, 1989) and between storage conditions of 'Cox's Orange Pippin' and 'Suntan' apples (Williams and Langron, 1983). In our study, the distribution of apple samples along the first two factors suggested that the first extracted factor could be interpreted as an overall quality factor, and the last two factors as ripening factors (Fig. 4.4, 4.5 and 4.7). In practice, USDA inspectors evaluate maturity of apples by judging firmness attributes (Abbott et al., 1992). High ratings for tartness and firmness on the first harvest dates for 'Braeburn' and 'Fuji', first and second harvest dates for 'Gala', were invariably associated to low scores on OL, flavor and sweetness. This suggested that unripe fruit has not developed full flavor yet, and high levels of tartness and firmness do not necessarily imply high taste and liking. Ripe fruit (last two harvests) without significant storage was highly rated for OL, flavor and sweetness with zero scores on firmness and tartness, suggesting that tartness and firmness were at their optimum and did not affect preference and taste ratings. According to Williams (1981), if fruit has optimum texture, overall quality will be improved by better taste and aroma, which was the case in the tree-ripe and unstored 'Gala' fruit [harvests of 129, 136 and 143 DAFB

(2, 9 and 16 Sept.) on October panel]. Apple fruit ripen in storage, therefore samples of intermediate harvest dates had fruit with various degrees of maturation, explaining a less obvious separation of the means and the clustering of the data at the factors' intersection. Senescent fruit (last harvest date on January panel for 'Gala', last two harvest dates on April and May panels for 'Braeburn' and last harvest date on June panel for 'Fuji') had low scores on all attributes.

Relating sensory data to instrumental measurements

Firmness sensory ratings were the best related to firmness measurements on apples in our study. Still, only 16 to 20% of sensory firmness variation was explained by firmness measurements. In a trained panel of 20 persons, Ananthakrishna et al. (1983) reported a correlation coefficient of -0.56 between texture and pressure measurements of 'Red Delicious'. Firmness measurements were correlated with overall liking (r=0.71) and texture (r=0.67) for 'Red Delicious' tasted by a panel of 15 staff members (Wills et al., 1980). In our study, the correlation between the first pair of canonical variate represented by sensory firmness, and firmness measurement was of r=0.50 in 'Gala'. For 'Braeburn' and 'Fuji', it seems like both losses of acidity and firmness occurring during maturation and senescence affected identically perceived tartness and firmness, as shown by the first canonical pair of variate represented by firmness and tartness (sensory), and TA and firmness measurements. It is not clear if the decrease in acidity affected firmness sensory as well as tartness, or if fruit softening affected tartness and firmness ratings. However, because of the small proportion of variability in one set of canonical variables explained by all of the other set, the predictive value of TA and firmness measurements to sensory ratings was insignificant. To conclude, the Magness Taylor pressure tester gives a good approximation of the sensory firmness in our study as in others (Abbott et al., 1992; Ananthakrishna et al., 1983; Smith and Stow, 1985; Wills et al., 1980), but it does not give any indication on the mouthfeel given by a bite in the apple. Correlations were improved if several texture profile variables measured with the Instron universal testing instrument were retained to explain texture attributes in a descriptive sensory profile (Abbott et al., 1984).

If the decrease of apple firmness with maturation at harvest and in storage could be perceived in all three cultivars, the decrease of acidity was well perceived in 'Fuji' only, on the panels of 25 Feb., 25 Apr. and 2 June. Panelists could differentiate as little differences as 0.08% malic acid, at such low levels of 0.08 to 0.16% malic acid, with corresponding pH of 4.0 to 4.6. Those results contradict with the findings of Visser et al. (1968) in which above pH=3.8, acidity was no longer discernable. In 'Gala', 'Braeburn' and 'Fuji', the mean separations for sweetness ratings were more important than for SSC, showing that SSC is not representative of the intensity of perceived sweetness. With such low differences as 1°Brix between samples, Knee and Smith (1989) suggested that panelists were measuring differences in acidity when rating for sweetness intensity. Our results could imply similar conclusion as sweetness ratings tended to be lower for unripe fruit which had a higher TA. But pH or TA were not correlated to sweetness (data not shown), nor were SSC/TA ratio for none of the varieties. Untrained panelists and the absence of any reference standard in our panel could explain the lack of correlations between sensory and instrumental measurements. When trained panelists were used in a descriptive profile, Watada et al. (1981) found that TA and SSC explained 50% of perceived acidity and sweetness. A few volatile compounds explained some additional variation, suggesting that more than soluble sugars and titratable acidity are responsible for perceived sweetness and tartness in apple. However, the amount of variation explained by the volatile compounds was small.

Overall liking was not explained by either of the measurements in our study. Diverse and contradictory results are found in the literature as to relating sensory and analytical data. Williams (1979) points out that usually, statistical relationships are applicable within the experimental data only. Gorin (1973) could not establish a threshold in sucrose and L-malic acid content in 'Golden Delicious' below which apples were not acceptable, since it changed every year. Overall liking was correlated in 'Red Delicious' apple with firmness and TA (Wills et al., 1980); it was negatively correlated to TA in another study with 20 panelists (Ananthakrishna et al., 1983). In a consumer survey over Europe, overall quality of 'Golden Delicious' and 'Granny Smith' was related to sugars and the sugars and acidity combined (Crochon, 1989).

The failure in explaining sensory ratings with a few analytical measurements reveals the complexity of sensory receptors. Also, for a better knowledge of the effect of chemical components on taste, individual sugars and acids as well as flavor volatiles, should be identified in 'Gala', 'Braeburn' and 'Fuji' apple and related, alone and in combination, to their sensory descriptors with a descriptive sensory technique. Watada and Abbott (1985) and Williams (1979) insisted on the importance of the methodology, as first identifying which quality criteria characterize the tested product and then rating for the intensity (Watada et al., 1980) or acceptance (Williams and Langron, 1983) of the major ones. With fresh product such as apple, one must also consider the variability occurring within the fruit as much as between fruits.

Conclusion

A multivariate factor analysis illustrated globally how the different maturity stages of apples were appreciated by untrained panelists, whereas the univariate ANOVA described the differences perceived for each attribute. The rotation of factors clarified the effect of the sensory attributes on which the samples were differentiated. The principal components extraction method revealed that OL, flavor and sweetness attributes were defining the first factor, which could be therefore interpreted as a taste and quality factor. For 'Gala' and 'Braeburn', tartness and firmness were describing the second factor, which could be interpreted as a ripening factor. For 'Fuji', the same attributes were unrelated and were defining factor two and three.

The multivariate correlations, canonical and multiple regression, showed no significant predictive value of firmness, TA and SSC on the sensory attributes.

Table 4.1. Factor loadings, eigenvalue, proportion and cumulative variance explained by each factor for 'Gala' apples, per taste test session. Factor analysis was performed on the covariance matrix of the residuals of the GLM-MANOVA (model: OL, sweetness, tartness, firmness, flavor = harvest date, panelist).

Taste test date	Sensory attribute	Factor 1	2	3	4	5
7 Oct.	Overall liking	**0.90**	-0.09	-0.08	-0.18	-0.38
	Flavor	**0.84**	-0.18	-0.08	-0.34	0.38
	Sweetness	**0.67**	**-0.55**	-0.12	0.48	0.06
	Tartness	**0.46**	**0.84**	-0.24	0.16	0.05
	Firmness	**0.61**	0.27	**0.74**	0.10	0.03
	Eigenvalue	4.19	2.02	0.87	0.67	0.50
	Proportion var.	0.51	0.24	0.11	0.08	0.06
	Cumulative var.	0.51	0.75	0.86	0.94	1.00
11 Nov.	Overall liking	**0.89**	-0.10	0.07	-0.20	0.38
	Flavor	**0.90**	-0.12	0.16	-0.21	-0.31
	Sweetness	**0.59**	**-0.61**	0.02	0.53	0.00
	Tartness	0.24	**0.84**	**0.44**	0.22	0.02
	Firmness	**0.58**	**0.55**	**-0.59**	0.09	-0.04
	Eigenvalue	3.96	2.23	0.96	0.65	0.42
	Proportion var.	0.48	0.27	0.12	0.08	0.05
	Cumulative var.	0.48	0.75	0.87	0.95	1.00
7 Dec.	Overall liking	**0.91**	-0.17	-0.02	-0.21	-0.33
	Flavor	**0.86**	-0.18	-0.29	-0.20	0.33
	Sweetness	**0.65**	**-0.59**	0.04	0.48	0.01
	Tartness	**0.58**	**0.70**	-0.34	0.22	-0.05
	Firmness	**0.71**	**0.32**	**0.62**	0.00	0.11
	Eigenvalue	4.64	1.53	0.97	0.53	0.40
	Proportion var.	0.58	0.19	0.12	0.07	0.05
	Cumulative var.	0.58	0.76	0.88	0.95	1.00

Table 4.1 (continued)

Taste test date	Sensory attribute	Factor 1	2	3	4	5
21 Jan.	Overall liking	**0.92**	-0.01	-0.13	-0.17	-0.34
	Flavor	**0.89**	-0.07	-0.08	-0.26	0.37
	Sweetness	**0.74**	**-0.43**	**0.36**	0.37	0.01
	Tartness	0.21	**0.87**	**0.42**	-0.12	-0.01
	Firmness	**0.45**	**0.65**	**-0.38**	0.47	0.07
	Eigenvalue	4.69	2.29	0.81	0.80	0.51
	Proportion var.	0.52	0.25	0.09	0.09	0.06
	Cumulative var.	0.52	0.77	0.86	0.94	1.00

Table 4.2. Factor loadings, eigenvalue, proportion and cumulative variance explained by each factor for 'Braeburn' apples, per taste test session. Factor analysis was performed on the covariance matrix of the residuals of the GLM-MANOVA (model: OL, sweetness, tartness, firmness, flavor = harvest date, panelist).

Taste test date	Sensory attribute	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
7 Nov.	Overall liking	**0.89**	-0.11	-0.08	0.18	-0.38
	Flavor	**0.88**	-0.13	0.18	-0.42	0.08
	Sweetness	**0.65**	**-0.52**	0.17	0.40	0.34
	Tartness	0.26	**0.90**	0.33	0.12	0.02
	Firmness	**0.59**	**0.51**	**-0.60**	0.00	0.21
	Eigenvalue	4.29	2.45	0.85	0.68	0.51
	Proportion var.	0.49	0.28	0.10	0.08	0.06
	Cumulative var.	0.49	0.77	0.86	0.94	1.00
7 Jan.	Overall liking	**0.92**	0.17	-0.12	0.02	-0.34
	Flavor	**0.84**	0.36	-0.02	-0.28	0.29
	Sweetness	**0.73**	**-0.50**	0.36	0.28	0.11
	Tartness	-0.18	**0.92**	0.33	0.12	-0.04
	Firmness	0.19	**0.45**	**-0.58**	0.59	0.27
	Eigenvalue	3.82	2.34	0.69	0.54	0.44
	Proportion var.	0.49	0.30	0.09	0.07	0.06
	Cumulative var.	0.49	0.79	0.87	0.94	1.00
18 Feb.	Overall liking	**0.91**	-0.03	-0.09	-0.20	-0.34
	Flavor	**0.90**	-0.09	-0.20	-0.17	0.32
	Sweetness	**0.63**	**-0.57**	0.16	0.50	-0.01
	Tartness	0.28	**0.81**	-0.36	0.37	-0.02
	Firmness	**0.52**	**0.57**	**0.63**	-0.03	0.06
	Eigenvalue	5.30	2.48	1.14	0.90	0.52
	Proportion var.	0.51	0.24	0.11	0.09	0.05
	Cumulative var.	0.51	0.75	0.86	0.95	1.00

Table 4.2 (continued)

Taste test date	Sensory attribute	Factor 1	2	3	4	5
14 Apr.	Overall liking	**0.89**	-0.08	0.15	-0.09	-0.41
	Flavor	**0.89**	-0.06	-0.12	-0.36	0.26
	Sweetness	**0.62**	**-0.64**	-0.19	0.41	0.10
	Tartness	**0.52**	**0.72**	-0.40	0.22	-0.02
	Firmness	**0.53**	0.32	**0.72**	0.23	0.20
	Eigenvalue	5.41	2.07	1.31	0.82	0.62
	Proportion var.	0.53	0.20	0.13	0.08	0.06
	Cumulative var.	0.53	0.73	0.86	0.94	1.00
26 May	Overall liking	**0.91**	-0.11	-0.06	-0.22	0.33
	Flavor	**0.88**	-0.14	0.20	-0.26	-0.31
	Sweetness	**0.68**	**-0.49**	0.17	0.51	0.02
	Tartness	0.30	**0.80**	**0.49**	0.11	0.09
	Firmness	**0.75**	**0.46**	**-0.43**	0.18	-0.11
	Eigenvalue	6.13	2.09	0.97	0.86	0.53
	Proportion var.	0.58	0.20	0.09	0.08	0.05
	Cumulative var.	0.58	0.78	0.87	0.95	1.00

Table 4.3. Factor loadings, eigenvalue, proportion and cumulative variance explained by each factor for 'Fuji' apples, per taste test session. Factor analysis was performed on the covariance matrix of the residuals of the GLM-MANOVA (model: OL, sweetness, tartness, firmness, flavor = harvest date, panelist).

Taste test date	Sensory attribute	Factor 1	2	3	4	5
12 Nov.	Overall liking	**0.88**	-0.01	**-0.39**	0.00	0.26
	Flavor	**0.90**	0.01	-0.10	-0.04	-0.42
	Sweetness	**0.90**	-0.37	**0.46**	-0.06	0.12
	Tartness	0.30	**0.93**	0.17	-0.09	0.06
	Firmness	0.31	0.16	0.11	0.93	-0.01
	Eigenvalue	3.81	1.66	0.67	0.56	0.42
	Proportion var.	0.54	0.23	0.09	0.08	0.06
	Cumulative var.	0.54	0.77	0.86	0.94	1.00
14 Jan.	Overall liking	**0.91**	0.11	-0.02	-0.24	-0.31
	Flavor	**0.90**	0.15	-0.17	-0.18	0.33
	Sweetness	**0.82**	-0.35	0.03	0.45	-0.02
	Tartness	-0.03	**0.93**	-0.24	0.26	-0.05
	Firmness	0.31	0.50	**0.80**	0.02	0.08
	Eigenvalue	3.94	1.74	0.75	0.59	0.34
	Proportion var.	0.54	0.24	0.10	0.08	0.05
	Cumulative var.	0.54	0.77	0.87	0.95	1.00
25 Feb.	Overall liking	**0.91**	-0.01	-0.06	-0.08	-0.41
	Flavor	**0.87**	-0.12	0.09	-0.39	0.28
	Sweetness	**0.69**	**-0.48**	-0.31	0.42	0.15
	Tartness	0.39	**0.86**	-0.29	0.09	0.11
	Firmness	**0.58**	0.23	**0.70**	0.35	0.04
	Eigenvalue	4.15	1.58	0.87	0.69	0.49
	Proportion var.	0.53	0.20	0.11	0.09	0.06
	Cumulative var.	0.53	0.74	0.85	0.94	1.00

Table 4.3 (continued)

Taste test date	Sensory attribute	Factor 1	2	3	4	5
25 Apr.	Overall liking	**0.93**	0.04	0.01	-0.17	-0.33
	Flavor	**0.91**	0.02	-0.20	-0.18	0.32
	Sweetness	**0.63**	**-0.62**	-0.09	0.47	-0.01
	Tartness	0.27	**0.87**	-0.22	0.34	-0.02
	Firmness	**0.46**	0.20	**0.85**	0.10	0.11
	Eigenvalue	4.86	1.99	1.22	0.72	0.49
	Proportion var.	0.52	0.21	0.13	0.08	0.05
	Cumulative var.	0.52	0.74	0.87	0.95	1.00
2 June	Overall liking	**0.91**	0.04	-0.07	-0.21	0.35
	Flavor	**0.92**	-0.06	-0.13	-0.20	-0.29
	Sweetness	**0.75**	**-0.55**	0.11	0.36	0.03
	Tartness	**0.54**	**0.62**	-0.43	0.38	-0.01
	Firmness	**0.56**	**0.44**	**0.70**	0.05	-0.05
	Eigenvalue	5.98	1.47	1.11	0.65	0.49
	Proportion var.	0.62	0.15	0.11	0.07	0.05
	Cumulative var.	0.62	0.77	0.88	0.95	1.00

Table 4.4. Factor loadings, communalities and variance explained by each factor for 'Gala', 'Braeburn' and 'Fuji' apples after two factors extraction and rotation. Factor analysis was performed on the pooled covariance matrix of all taste tests.

Cultivar	Sensory attribute	Factor 1	Factor 2	Communality
Gala	Overall liking	**0.84**	0.34	0.83
	Flavor	**0.84**	0.28	0.78
	Sweetness	**0.84**	-0.17	0.74
	Tartness	-0.05	**0.91**	0.83
	Firmness	0.30	**0.69**	0.57
	Variance	3.81	2.55	
Braeburn	Overall liking	**0.86**	0.29	0.83
	Flavor	**0.84**	0.31	0.80
	Sweetness	**0.81**	-0.26	0.73
	Tartness	-0.08	**0.90**	0.81
	Firmness	0.34	**0.65**	0.54
	Variance	4.49	2.69	
Fuji	Overall liking	**0.84**	0.35	0.83
	Flavor	**0.84**	0.33	0.82
	Sweetness	**0.86**	-0.19	0.79
	Tartness	-0.03	**0.93**	0.86
	Firmness	0.33	0.44	0.30
	Variance	4.10	2.08	

Table 4.5. Fruit firmness, soluble solids concentration (SSC), titratable acidity (TA), and pH of 'Gala' apples harvested on 6 dates, and tested on 4 dates.[z]

Taste test date	DAFB	Firmness (N)[a]	SSC (°Brix)[b]	TA (%malic)[b]	pH[b]
7 Oct.	108	87.6 a	10.6 bc	0.266 a	3.79 d
	115	82.7 b	10.6 bc	0.247 ab	3.89 c
	122	77.4 c	11.6 a	0.238 bc	3.92 bc
	129	74.7 c	11.4 a	0.250 ab	3.98 ab
	136	65.8 d	11.1 ab	0.222 c	3.96 abc
	143	63.2 d	10.4 c	0.220 c	4.02 a
11 Nov.	108	84.5 a	9.4 b	0.196 bc	4.01 ab
	115	79.6 b	11.0 a	0.235 a	3.90 b
	122	75.2 c	9.2 b	0.172 c	4.01 ab
	129	72.1 d	10.1 ab	0.201 bc	4.11 a
	136	66.3 e	10.5 ab	0.210 ab	4.09 a
	143	63.2 f	9.8 ab	0.190 bc	4.12 a
7 Dec.	108	75.6 a	11.5	0.232 a	4.07
	115	74.7 a	10.8	0.224 ab	4.15
	122	75.6 a	11.7	0.209 abc	4.21
	129	66.3 b	11.7	0.207 bc	4.14
	136	61.8 c	11.1	0.178 d	4.10
	143	59.6 c	10.9	0.193 cd	4.27

Table 4.5 (continued)

Taste test date	DAFB	Firmness (N)[a]	SSC (°Brix)[b]	TA (%malic)[b]	pH
21 Jan.	108	74.7 b	11.2 ab	0.189	-
	115	79.2 a	10.7 ab	0.177	-
	122	68.1 c	11.9 a	0.188	-
	129	60.9 d	10.6 b	0.199	-
	136	57.4 e	11.3 ab	0.192	-
	143	52.5 f	10.7 ab	0.165	-

[z] Mean separations within a column and taste test were by the Waller-Duncan k-ratio t-test, K=100. Numbers with the same letter are not significantly different from one another within a column and by taste test.

[a] n=20 fruits

[b] n=20 fruits on the taste tests of 7 Oct., 11 Nov., 7 Dec.

n=5 fruits on the taste test of 21 Jan.

Table 4.6. Fruit firmness, soluble solids concentration (SSC), titratable acidity (TA), and pH of 'Braeburn' apples harvested on 6 dates, and tested on 5 dates.[z]

Taste test date	DAFB	Firmness (N)[a]	SSC (°Brix)[b]	TA (%malic)[b]	pH[b]
7 Nov.	154	81.8 a	11.7 a	0.478 a	-
	161	80.9 a	11.0 a	0.415 ab	-
	168	77.4 ab	9.9 ab	0.394 ab	-
	175	73.8 b	11.3 a	0.330 ab	-
	182	77.0 ab	9.2 ab	0.323 ab	-
	186	73.8 b	7.9 b	0.303 b	-
7 Jan.	154	85.0 ab	10.5	0.495 a	-
	161	84.5 ab	10.2	0.385 b	-
	168	85.4 a	10.4	0.405 b	-
	175	82.7 abc	11.7	0.439 ab	-
	182	81.0 bc	11.0	0.407 b	-
	186	80.1 c	10.3	0.398 b	-
18 Feb.	154	78.7 a	11.5 c	0.459 a	3.62 d
	161	76.5 a	12.2 ab	0.441 ab	3.63 cd
	168	77.4 a	12.1 ab	0.401 bc	3.68 abc
	175	77.0 a	12.0 ab	0.411 b	3.66 bcd
	182	70.3 b	12.3 a	0.364 c	3.71 a
	186	68.5 b	11.8 bc	0.403 bc	3.69 ab

Table 4.6 (continued)

Taste test date	DAFB	Firmness (N)[a]	SSC (°Brix)[b]	TA (%malic)[b]	pH[b]
14 Apr.	154	73.8 ab	11.5	-	3.68 c
	161	71.2 b	11.8	-	3.74 ab
	168	76.1 a	12.1	-	3.70 bc
	175	77.4 a	12.1	-	3.77 a
	182	63.2 c	11.9	-	3.66 c
	186	62.7 c	11.9	-	3.71 abc
26 May	154	71.2 a	11.6	0.350 a	3.75 d
	161	65.8 c	11.9	0.327 a	3.81 cd
	168	69.8 ab	11.9	0.288 b	3.87 bc
	175	66.7 bc	12.1	0.274 bc	3.88 b
	182	56.0 e	11.5	0.236 d	3.97 a
	186	59.6 d	11.5	0.240 cd	4.00 a

[z] Mean separations within a column and taste test were by the Waller-Duncan k-ratio t-test, K=100. Numbers with the same letter are not significantly different from one another within a column and by taste test.

[a] n=20 fruits

[b] n=5 fruits for the taste tests of 7 Nov. and 7 Jan.

n=10 fruits for the remaining taste tests.

Table 4.7. Fruit firmness, soluble solids concentration (SSC), titratable acidity (TA), and pH of 'Fuji' apples harvested on 6 dates, and tested on 5 dates.[z]

Taste test date	DAFB	Firmness (N)[a]	SSC (°Brix)[b]	TA (%malic)[b]	pH[b]
12 Nov.	152	81.8 a	13.2 ab	0.251 ab	-
	159	75.2 b	11.9 b	0.222 b	-
	166	75.2 b	12.4 b	0.242 ab	-
	173	74.3 b	13.8 ab	0.257 ab	-
	180	76.1 b	14.9 a	0.282 a	-
	187	67.6 c	12.5 b	0.208 b	-
14 Jan.	152	82.7 a	12.3 b	0.169 b	-
	159	79.2 a	13.8 ab	0.275 a	-
	166	73.8 bc	13.9 ab	0.219 ab	-
	173	74.3 b	12.0 b	0.217 ab	-
	180	71.2 cd	15.6 a	0.285 a	-
	187	68.1 d	14.2 ab	0.212 ab	-
25 Feb.	152	77.8 a	12.4	0.228 a	4.04 b
	159	78.3 a	12.5	0.223 ab	4.03 b
	166	68.5 bc	12.8	0.187 bc	4.15 ab
	173	69.8 b	12.3	0.186 bc	4.15 ab
	180	65.8 cd	11.7	0.173 c	4.09 ab
	187	62.7 d	12.0	0.157 c	4.20 a

Table 4.7 (continued)

Taste test date	DAFB	Firmness (N)[a]	SSC (°Brix)[b]	TA (%malic)[b]	pH[b]
25 Apr.	152	77.4 a	13.5	0.308 a	4.02 d
	159	76.5 a	13.6	0.265 b	4.06 d
	166	68.5 b	14.0	0.171 c	4.27 c
	173	65.8 b	13.4	0.135 d	4.33 bc
	180	65.4 b	13.9	0.134 d	4.42 b
	187	57.4 c	13.4	0.090 e	4.65 a
2 June	152	74.7 a	13.2 ab	0.163 a	4.31 c
	159	73.4 a	13.1 ab	0.165 a	4.22 c
	166	68.1 b	13.5 ab	0.130 b	4.43 b
	173	68.1 b	13.3 ab	0.100 c	4.54 ab
	180	62.3 c	13.8 a	0.114 bc	4.49 b
	187	58.3 c	12.5 b	0.085 c	4.63 a

[z] Mean separations within a column and taste test were by the Waller-Duncan k-ratio t-test, K=100. Numbers with the same letter are not significantly different from one another within a column and by taste test.

[a] n=20 fruits

[b] n=5 fruits for the taste tests of 12 Nov. and 14 Jan.

n=10 fruits for the remaining taste tests.

Table 4.8. Canonical correlations, and the associated p-value[z], between sensory and analytical measurements for 'Gala', 'Braeburn' and 'Fuji' apples.

Gala		Braeburn		Fuji	
Canonical correlation	p-value	Canonical correlation	p-value	Canonical correlation	p-value
0.53	0.0001	0.41	0.0001	0.44	0.0001
0.11	0.0453	0.13	0.0862	0.19	0.0001
0.05	0.4485	0.09	0.1919	0.10	0.0589

[z] p-value for test of hypothesis that current canonical correlation and all below are zero.

Table 4.9. Canonical structure of 'Gala', 'Braeburn' and 'Fuji' dataset: Correlations between the sensory ratings and the analytical measurements, and their respective canonical variables.

	Gala		Braeburn		Fuji	
	Variate		Variate		Variate	
Variables	1	2	1	2	1	2
OL	0.09	0.35	0.47	0.42	0.39	0.52
Flavor	0.02	**0.65**	0.29	0.04	0.39	0.54
Sweetness	-0.20	0.31	-0.05	0.23	0.08	**0.79**
Tartness	0.47	**0.77**	**0.75**	-0.58	**0.67**	-0.45
Firmness	**0.90**	0.04	**0.85**	0.30	**0.88**	0.41
Pressure	**0.96**	-0.12	**0.63**	0.69	**0.89**	0.35
SSC	-0.13	0.56	-0.08	0.52	0.12	**0.87**
TA	0.44	**0.89**	**0.89**	-0.14	**0.89**	-0.09

Table 4.10. Canonical structure of 'Gala', 'Braeburn' and 'Fuji' dataset: Correlations between the sensory ratings and the analytical measurements, and the opposite canonical variables.

	Gala		Braeburn		Fuji	
	Variate		Variate		Variate	
Variables	1	2	1	2	1	2
OL	0.05	0.04	0.19	0.05	0.17	0.10
Flavor	0.01	0.07	0.12	0.01	0.17	0.10
Sweetness	-0.10	0.04	-0.02	0.03	0.04	0.15
Tartness	0.25	0.09	**0.31**	-0.08	**0.30**	-0.09
Firmness	**0.48**	0.00	**0.35**	0.04	**0.39**	0.08
Pressure	**0.51**	-0.01	**0.26**	0.09	**0.39**	0.07
SSC	-0.07	0.06	-0.03	0.07	0.05	0.17
TA	0.23	0.10	**0.37**	-0.02	**0.39**	-0.02

Table 4.11. Stepwise regression of sensory attributes over firmness measurements, titratable acidity (TA) and soluble solids contents (SSC) of 'Gala', 'Braeburn' and 'Fuji' apples, data of all panels pooled.

Sensory attribute	Cultivar	Model R^2	Variable entered (partial R^2)		
Overall liking	Gala	0.003	TA (0.003)	-	-
	Braeburn	0.045	Firmness (0.03)	TA (0.006)	SSC (0.005)
	Fuji	0.045	TA (0.03)	SSC (0.009)	Firmness (0.003)
Flavor	Gala	0.005	TA (0.005)	-	-
	Braeburn	0.010	Firmness (0.01)	-	-
	Fuji	0.045	TA (0.03)	SSC (0.01)	Firmness (0.004)
Sweetness	Gala	0.012	Firmness (0.007)	SSC (0.005)	-
	Braeburn	-	-	-	-
	Fuji	0.022	SSC (0.02)	-	-
Tartness	Gala	0.071	Firmness (0.05)	TA (0.01)	SSC (0.004)
	Braeburn	0.098	TA (0.08)	SSC (0.02)	-
	Fuji	0.095	TA (0.08)	SSC (0.009)	Firmness (0.006)
Firmness	Gala	0.225	Firmness (0.21)	TA (0.005)	SSC (0.01)
	Braeburn	0.123	TA (0.10)	Firmness (0.02)	SSC (0.004)
	Fuji	0.158	Firmness (0.14)	TA (0.02)	-

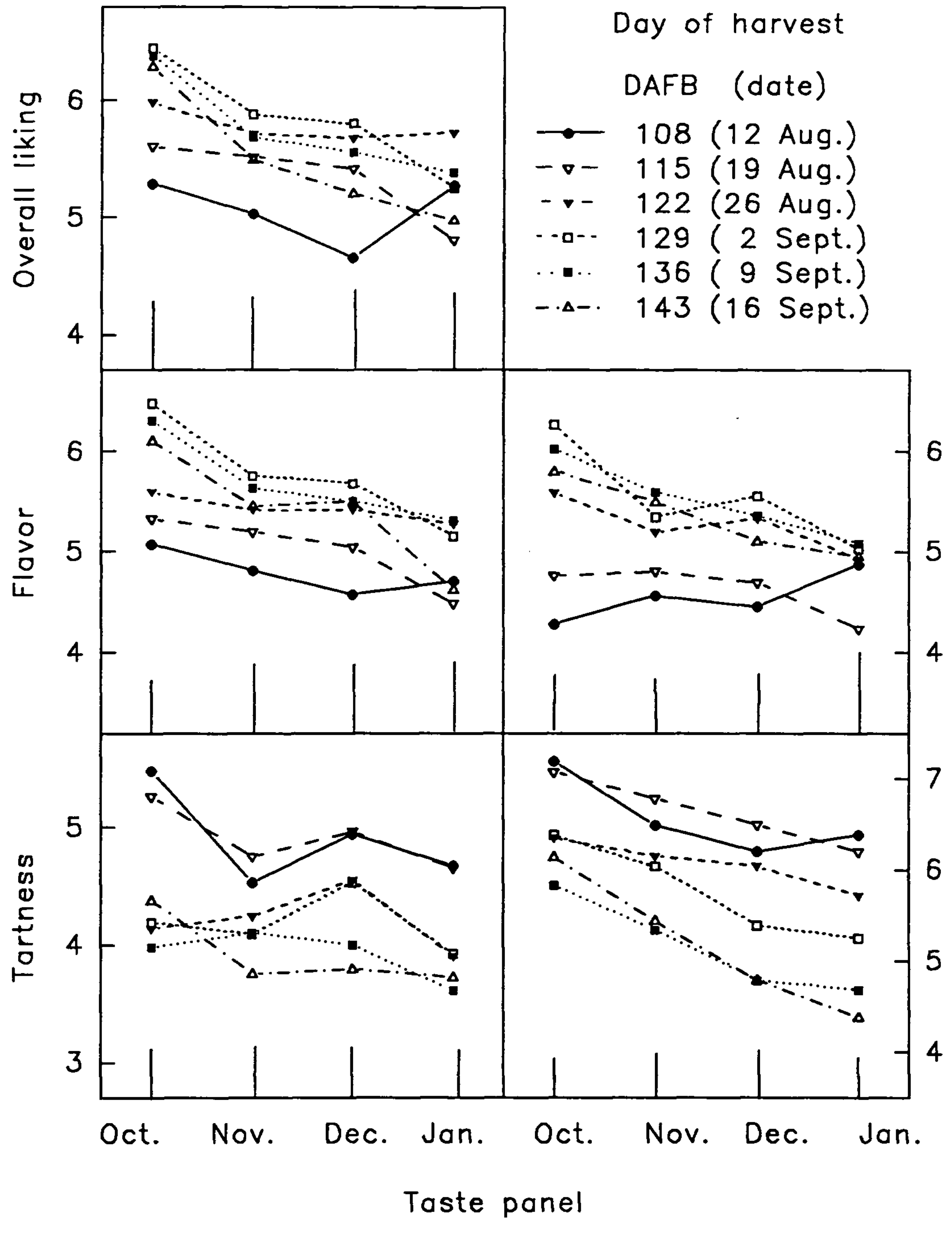

Figure 4.1. Sensory ratings for overall liking (9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely), flavor, sweetness, firmness and tartness intensities (scale: 1 to 9 = low to high) for 'Gala' apples harvested on 6 dates and tested on 4 dates. Means of 58, 59, 49 and 60 panelists are reported within the Oct., Nov., Dec. and Jan. taste panels, respectively. Vertical lines from the abscise represent the MSD values from the Waller-Duncan k-ratio t-test, K=100.

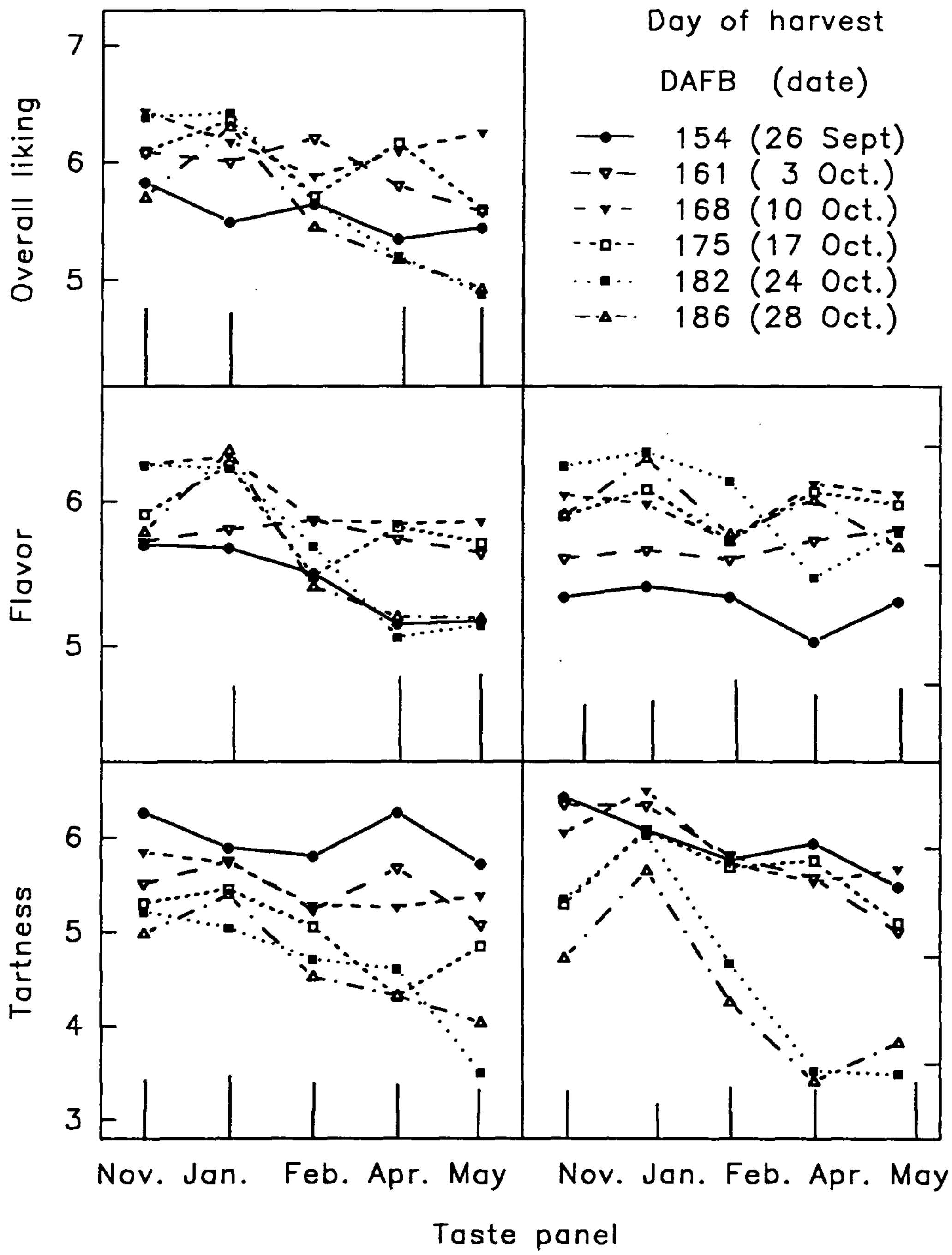

Figure 4.2. Sensory ratings for overall liking (9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely), flavor, sweetness, firmness and tartness intensities (scale: 1 to 9 = low to high) for 'Braeburn' apples harvested on 6 dates and tested on 5 dates. Means of 58, 57, 56, 54 and 58 panelists are reported within the Nov., Jan., Feb., Apr. and May taste panels,respectively. Vertical lines from the abscise represent the MSD values from the Waller-Duncan k-ratio t-test, K=100.

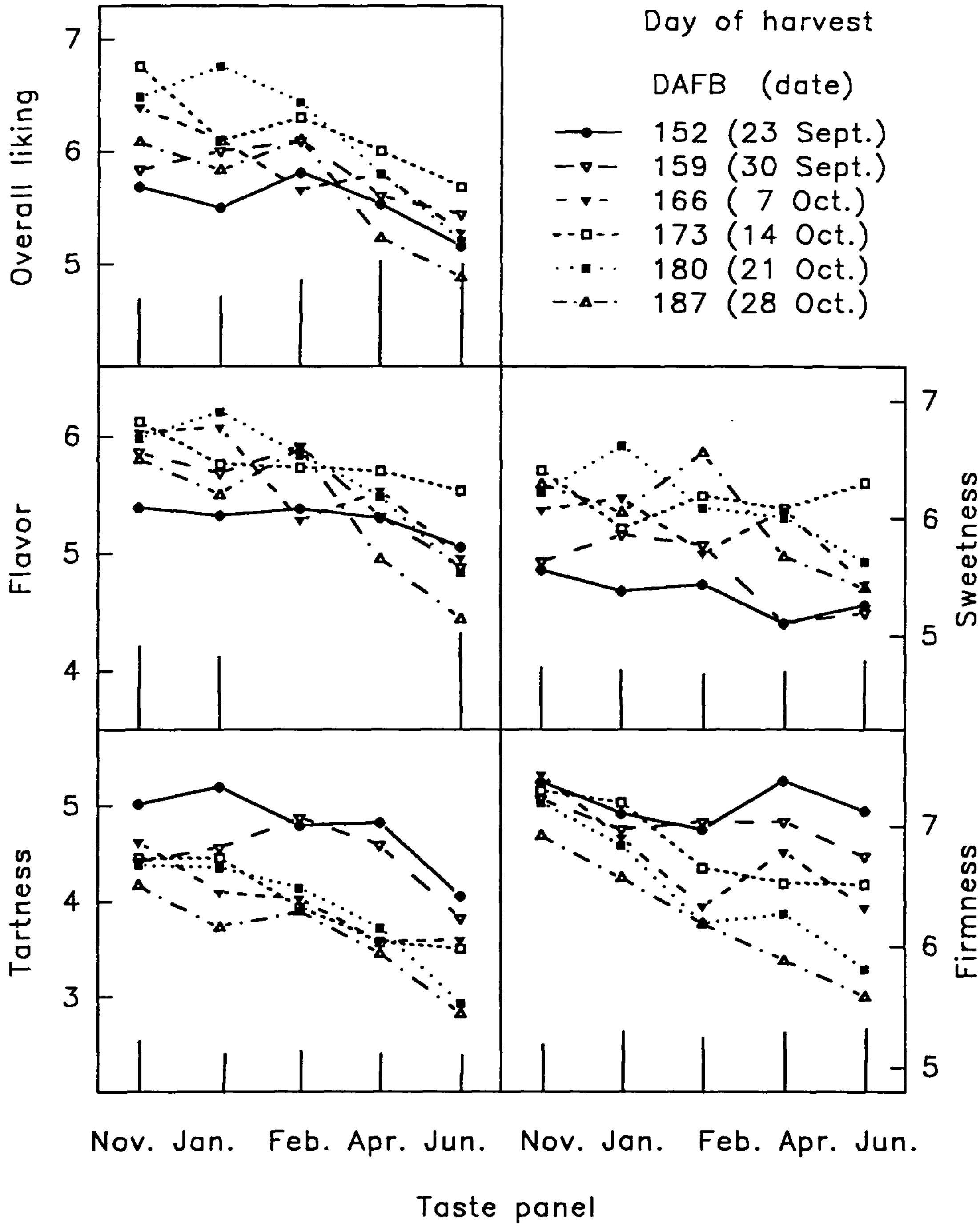

Figure 4.3. Sensory ratings for overall liking (9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely), flavor, sweetness, firmness and tartness intensities (scale: 1 to 9 = low to high) for 'Fuji' apples harvested on 6 dates and tested on 5 dates. Means of 59, 58, 57, 60 and 57 panelists are reported within the Nov., Jan., Feb., Apr. and Jun. taste panels, respectively. Vertical lines from the abscise represent the MSD values from the Waller-Duncan k-ratio t-test, K=100.

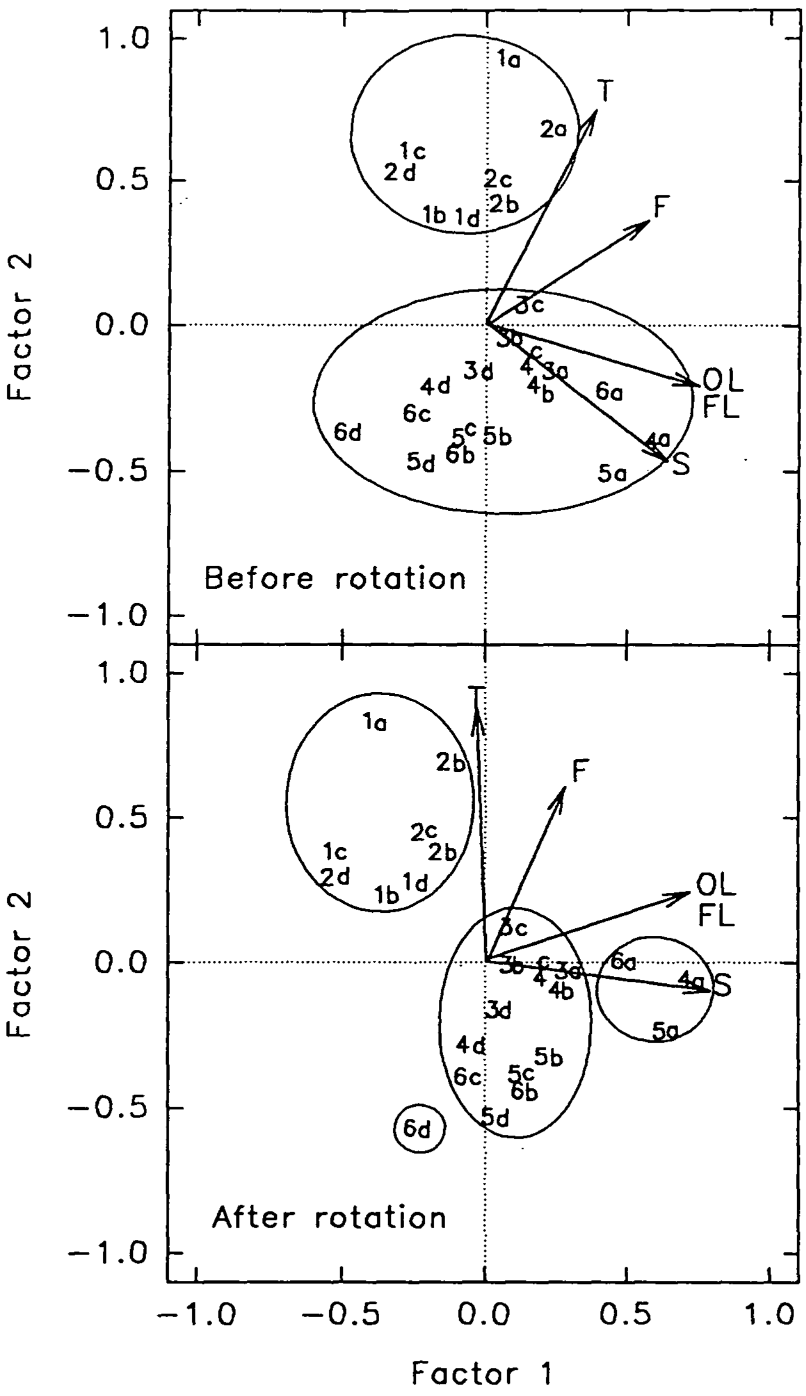

Figure 4.4. Mean factor scores of sensory attributes given to 'Gala' apples harvested on 6 dates and tested on 4 dates, before and after VARIMAX rotation. Numbers represent the day of harvest: 1=108, 2=115, 3=122, 4=129, 5=136 and 6=143 DAFB, and letters the day of the taste panel: a=Oct., b=Nov., c=Dec. and d=Jan.. Means of 58, 59, 49 and 60 panelists are reported within each taste panel, respectively.

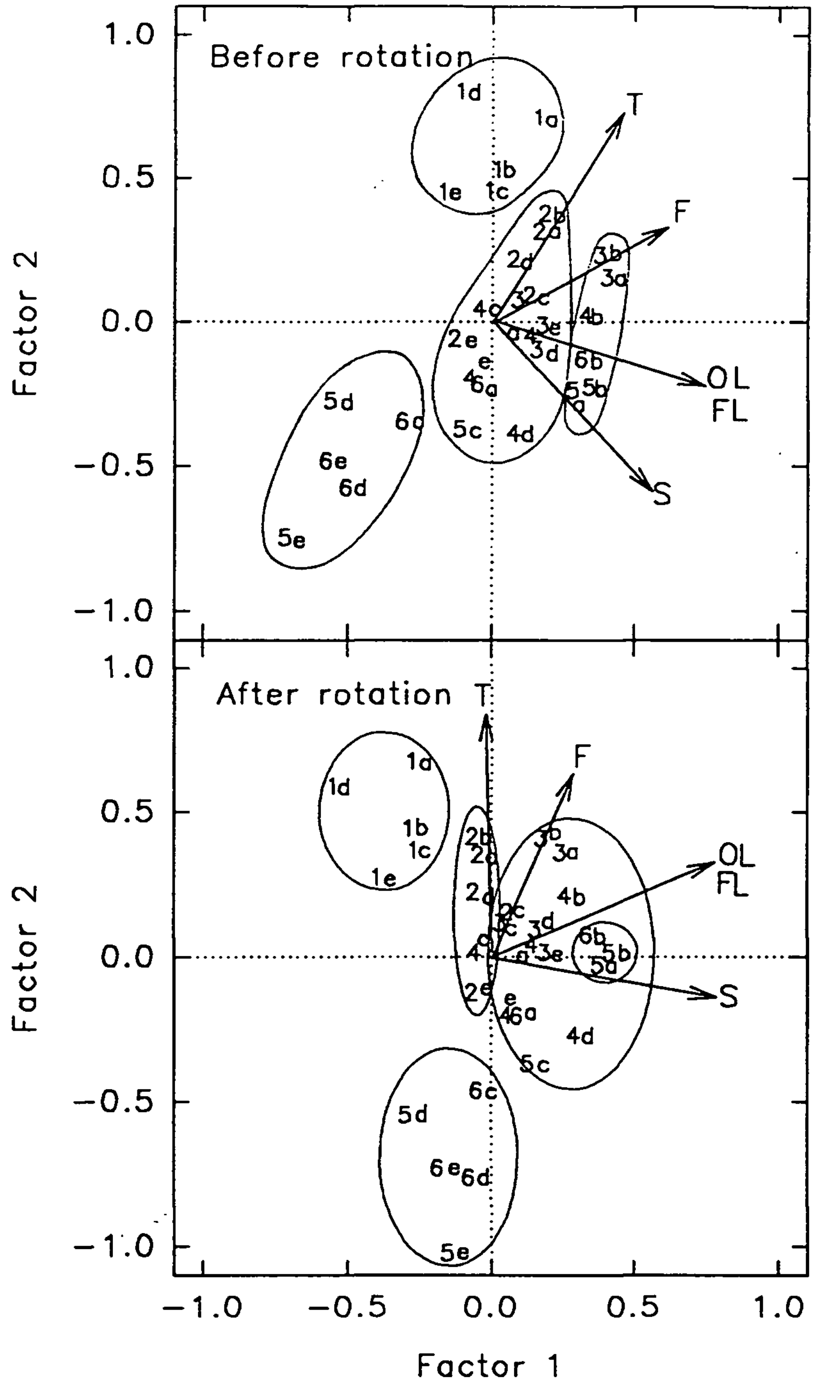

Figure 4.5. Mean factor scores of sensory attributes given to 'Braeburn' apples harvested on 6 dates and tested on 5 dates, before and after VARIMAX rotation. Numbers represent the day of harvest: 1=154, 2=161, 3=168, 4=175, 5=182 and 6=186 DAFB, and letters the day of the taste panel: a=Nov., b=Jan., c=Feb., d=Apr. and e=May. Means of 58, 57, 56, 54 and 58 panelists are reported within each taste panel, respectively.

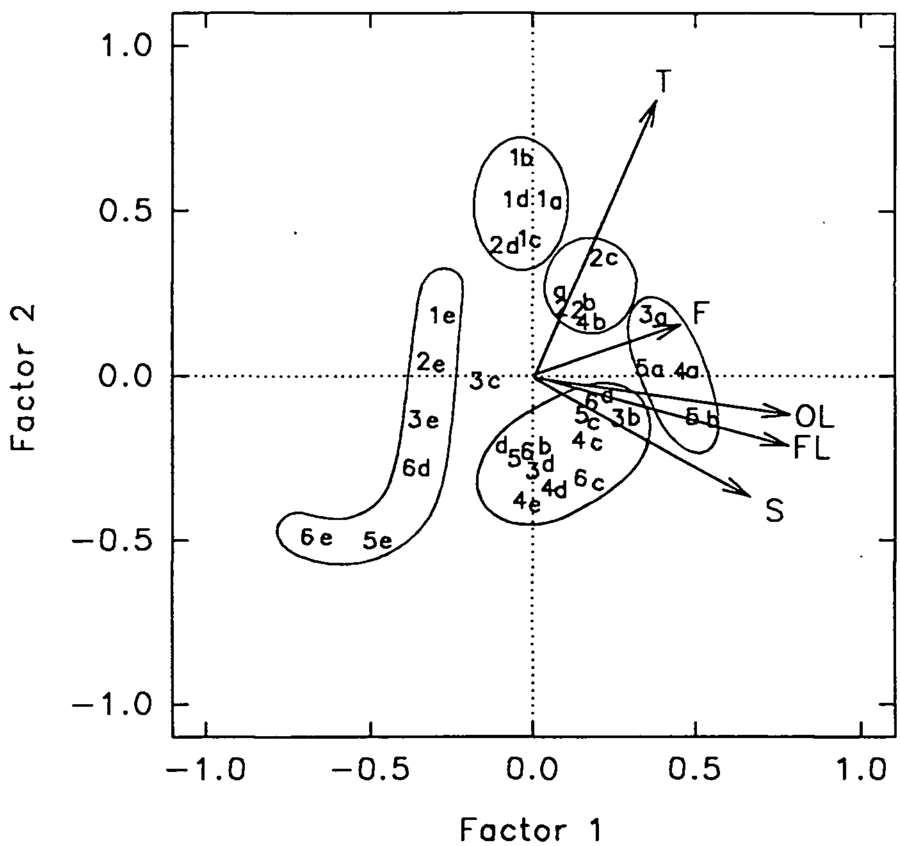

Figure 4.6. Mean factor scores of sensory attributes given to 'Fuji' apples harvested on 6 dates and tested on 5 dates, before VARIMAX rotation. Numbers represent the day of harvest: 1=152, 2=159, 3=166, 4=173, 5=180 and 6=187 DAFB, and letters the day of the taste panel: a=Nov., b=Jan., c=Feb., d=Apr. and e=Jun.. Means of 59, 58, 57, 60 and 57 panelists are reported within each taste panel, respectively.

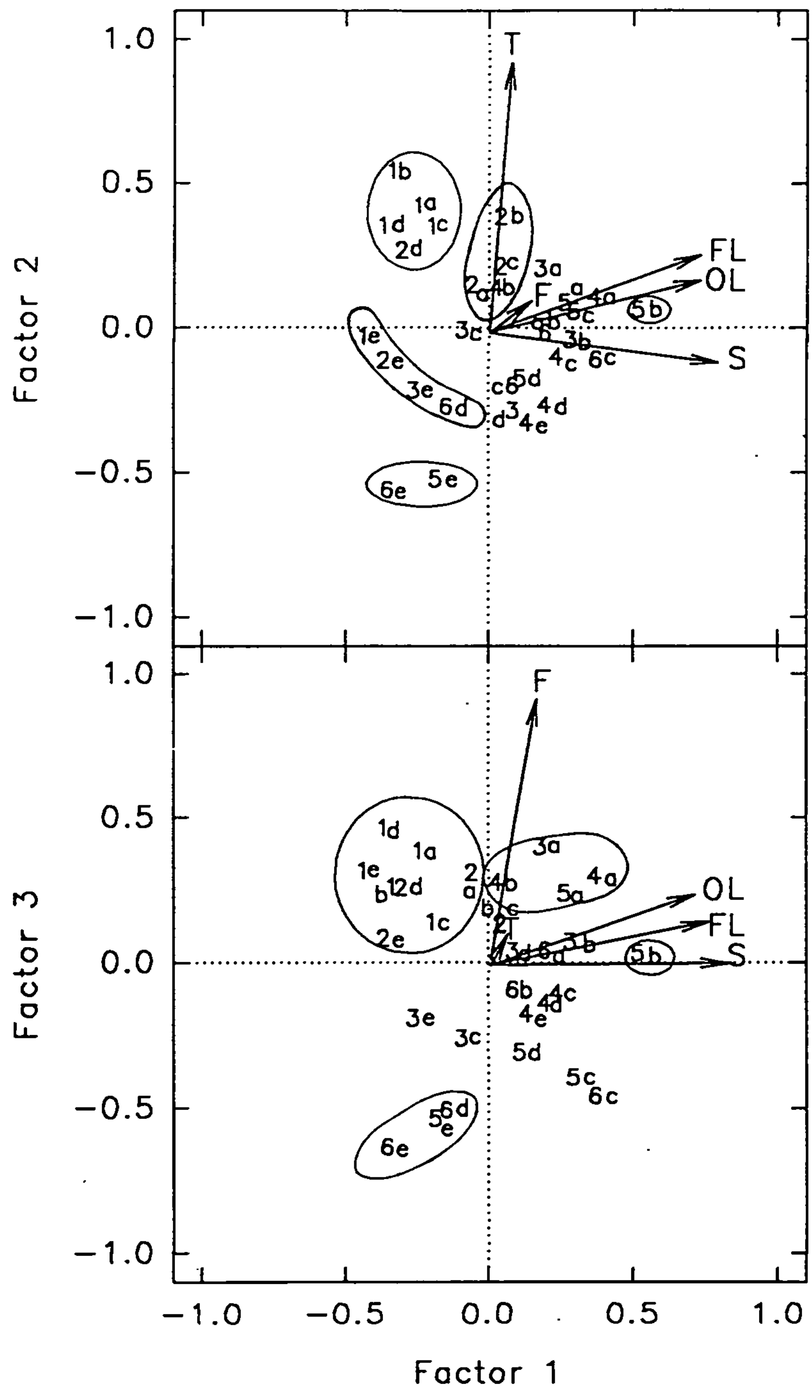

Figure 4.7. Mean factor scores of sensory attributes given to 'Fuji' apples harvested on 6 dates and tested on 5 dates, after VARIMAX rotation. Numbers represent the day of harvest: 1=152, 2=159, 3=166, 4=173, 5=180 and 6=187 DAFB, and letters the day of the taste panel: a=Nov., b=Jan., c=Feb., d=Apr. and e=Jun.. Means of 59, 58, 57, 60 and 57 panelists are reported within each taste panel, respectively.

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CHAPTER 5

CONCLUSION

A method to forecast the day of harvest such as practiced by the Apple Maturity Program of the Washington state, and based on the rate of change of specific and combination of maturity parameters has revealed effective for the new apple cultivars 'Gala', 'Braeburn' and 'Fuji'. In 1991, changes in color were relevant as predictors of ripening in all three cultivars; starch index, commonly used as a maturity indicator (Lau, 1988; Walsh et al., 1991) appeared useful only in 'Gala' and 'Fuji'. In turn, soluble solids concentration (SSC) which is the product of starch degradation, was the best indicator in 'Braeburn'. Ethylene production at harvest and after 7 days ripening at room temperature was used as the physiological marker of maturity. Unfortunately, gas-chromatographs are not yet available to growers for extended use.

For more accurate methods, with the advent of better knowledge on enzymatic activities associated with maturation, there should be a potential to develop enzymatic assays to predict maturity. Enzymes of the ethylene formation pathway are currently under investigation. ACC oxidase has been suggested by Uthaibutra and Gemma (1990), but its predictive value is questionable since its activity is concomitant with ethylene production (Larrigaudière and Vendrell, 1993). Prior to ACC oxidase, mere accumulation of ACC synthase would not be a good indicator because it does not always lead to production of ethylene (Larrigaudière and Vendrell, 1993). Since starch is of such an extended use as a maturity indicator, the group of amylases could be looked at.

Finally, volatiles other than ethylene and appearing before ethylene are being investigated (Mattheis et al., 1991). Ultimately, though, a screening of volatiles for all varieties under all climatic conditions would be necessary for conclusive use as maturity indicator of apple.

Post-storage testing of 'Gala', 'Braeburn' and 'Fuji' apples by consumer panels gave enough accurate information to adjust for cultural practices such as the time of harvest. Unfortunately, information is given a-posteriori. Furthermore, consumer panels are time consuming. Understanding the underlying factors affecting hedonic taste has been explored by a few group of researchers only. For 'Gala', 'Braeburn' and 'Fuji' apples, overall liking was strongly influenced by the perception of flavor and sweetness. Tartness and firmness were rated independently of the first group of attributes in 'Gala' and 'Breaburn', and also independently of each other in 'Fuji'. Panelists could differentiate between the stages of maturity of apples by using those sensory descriptors. Indeed, they gave better information about apple quality than a few instrumental measurements. The loss of fruit firmness normally occurring during maturation and ripening was the best perceived by the panelists. Likewise, the loss of acidity was perceived to a lesser degree.

A descriptive trained panel conducted in parallel on the fruit from the same lot would have given more information on the sensory attributes of apples. But the limitations of obtaining valid intensity scores in a descriptive profile are the amount of time and the number of trained people needed for the analysis. A consumer panel is also time-costly and instrumental measurements are usually preferred to qualify and quantify apple characteristics. Unfortunately, data provided by easy-to-use apparati are too inaccurate to give any indication, except pressure measurements such as the Magness-Taylor penetrometer. On the other hand, even if more complicated techniques were to extract and analyze more compounds, the effect of each of those on taste is not insured. This is partly accounted to the complexity of sensory receptors, and to the nature of fresh products such as fruit. Nevertheless, the inconsistent results in relating instrumental measurements to sensory descriptors found in the literature would require more systematic tests. Therefore place is open for research to achieve the final objective of producing fruit with high acceptance on the market.

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APPENDIX

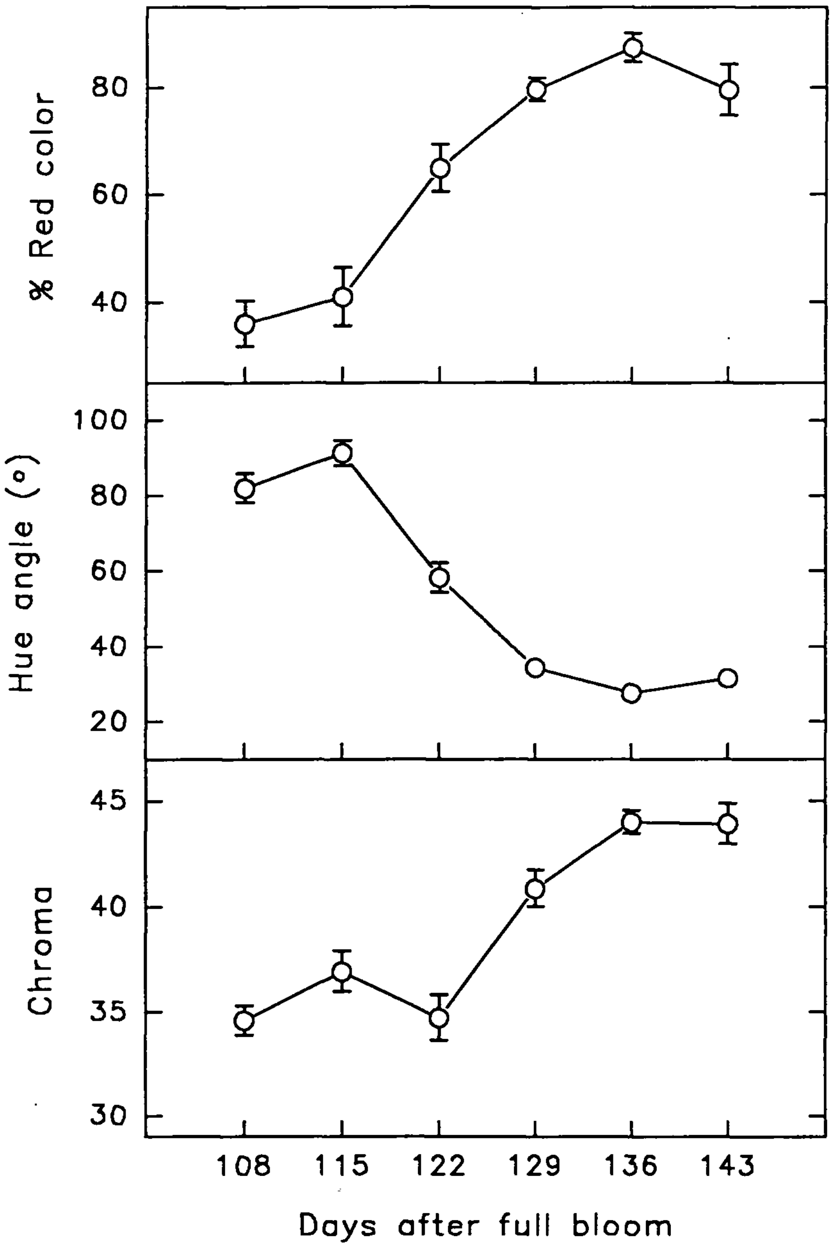

Figure 3.1. Changes in surface color as measured with %red, hue angle and chromaticity of 'Gala' fruit harvested on 6 dates. Each point represents a mean of 40 (%red color) and 20 (hue angle and chroma) fruits and vertical bars ±SE.

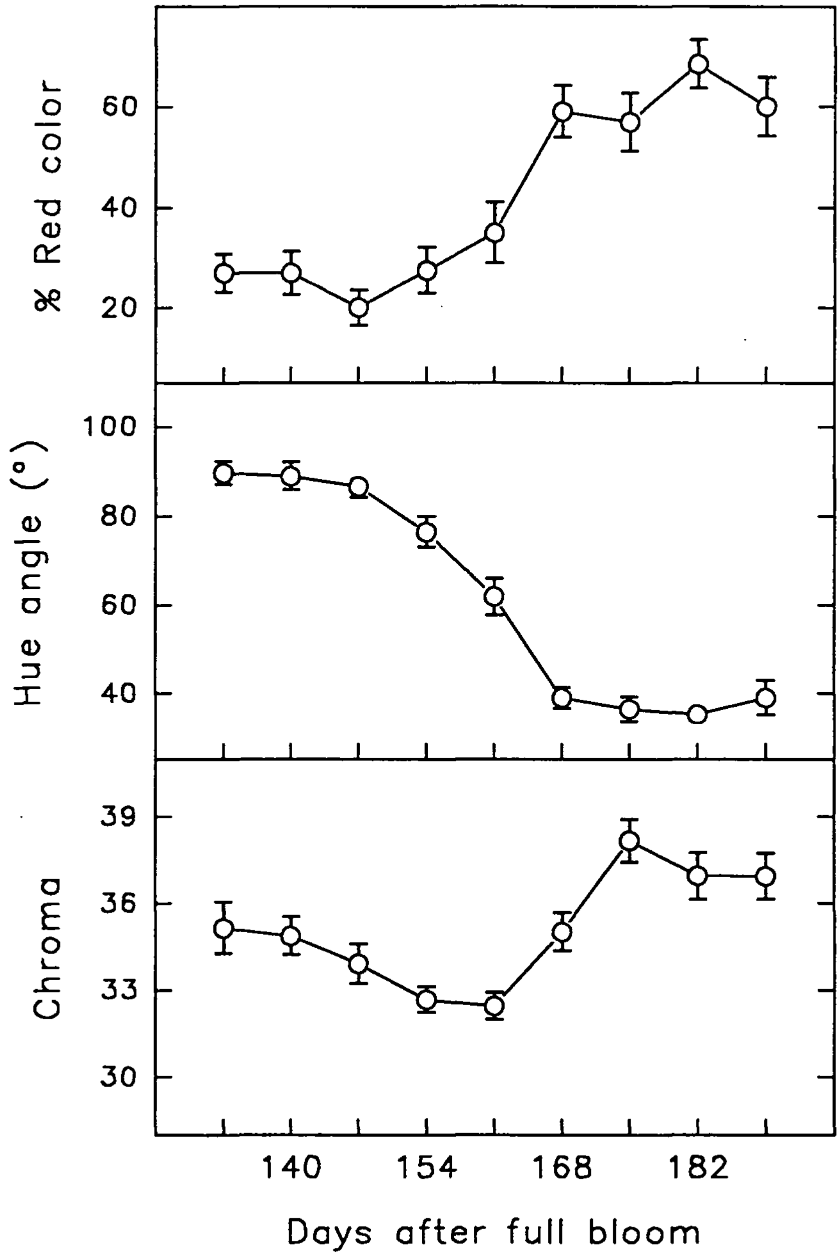

Figure 3.2. Changes in surface color as measured with %red, hue angle and chromaticity of 'Braeburn' fruit harvested on 9 dates. Each point represents a mean of 40 (%red color) and 20 (hue angle and chroma) fruits and vertical bars ±SE.

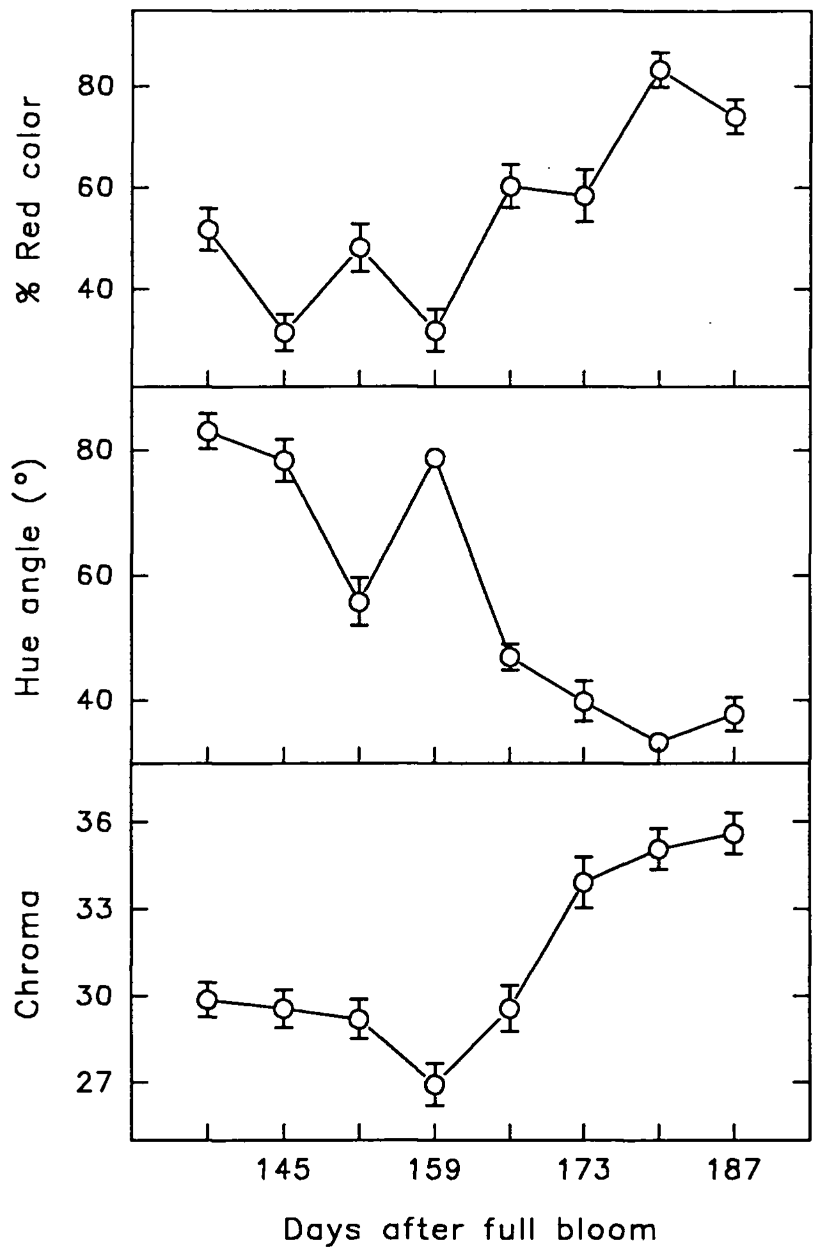

Figure 3.3. Changes in surface color as measured with %red, hue angle and chromaticity of 'Fuji' fruit harvested on 8 dates. Each point represents a mean of 40 (%red color) and 20 (hue angle and chroma) fruits and vertical bars ±SE.

Table 3.4. Analysis of variance of 'Gala' fruit characteristics, sampled at 6 harvest dates (HD), stored for 5 durations (ST) and held one and 7 days at 20C for ripening (RIPE).

		F value and significance					
Sources of Variation	df	Firmness	SSC	pH	TA	Hue ground	Hue surface
HD	5	450.18 ***	54.40 ***	184.85 ***	201.65 ***	188.90 ***	374.28 ***
ST	4	375.47 ***	53.14 ***	912.88 ***	798.62 ***	11.37 ***	4.75 **
HDxST	20	3.60 ***	12.67 ***	8.93 ***	16.25 ***	8.20 ***	6.85 ***
RIPE	1	135.18 ***	30.55 ***	305.17 ***	323.18 ***	7.66 **	4.01 *
HDxRIPE	5	9.84 ***	7.48 ***	7.43 ***	4.95 ***	3.84 **	n.s.
STxRIPE	4	5.08 ***	13.89 ***	18.17 ***	6.83 ***	3.17 *	n.s.
HDxSTxRIPE	20	4.33 ***	4.82 ***	6.79 ***	4.37 ***	1.74 *	n.s.

n.s., *, **, ***: non significant, or significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 3.5. Analysis of variance of 'Braeburn' fruit characteristics, sampled at 7 harvest dates (HD), stored for 5 durations (ST) and held one and 7 days at 20C for ripening (RIPE).

		F value and significance					
Sources of Variation	df	Firmness	SSC	pH	TA	Hue ground	Hue surface
HD	6	67.66 ***	58.84 ***	404.75 ***	280.92 ***	111.94 ***	293.01 ***
ST	4	554.78 ***	197.91 ***	2055.48 ***	1211.40 ***	89.47 ***	7.98 ***
HDxST	24	2.24 ***	16.91 ***	18.52 ***	2.90 ***	3.62 ***	1.71 *
RIPE	1	222.74 ***	51.77 ***	312.56 ***	206.04 ***	76.36 ***	9.13 **
HDxRIPE	6	4.39 ***	3.46 ***	4.45 ***	5.07 ***	n.s.	n.s.
STxRIPE	4	11.47 ***	30.45 ***	27.49 ***	4.14 **	2.45 *	n.s.
HDxSTxRIPE	24	2.77 ***	3.40 ***	6.86 ***	1.88 **	1.85 **	n.s.

n.s., *, **, ***: non significant, or significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 3.6. Analysis of variance of 'Fuji' fruit characteristics, sampled at 7 harvest dates (HD), stored for 5 durations (ST) and held one and 7 days at 20C for ripening (RIPE).

		F value and significance					
Sources of Variation	df	Firmness	SSC	pH	TA	Hue ground	Hue surface
HD	6	100.60 ***	62.63 ***	407.86 ***	211.08 ***	80.56 ***	212.45 ***
ST	4	133.89 ***	13.18 ***	2444.70 ***	1383.41 ***	33.31 ***	7.32 ***
HDxST	24	3.69 ***	13.45 ***	19.31 ***	7.03 ***	6.59 ***	n.s.
RIPE	1	56.14 ***	11.04 ***	105.94 ***	107.63 ***	14.61 ***	n.s.
HDxRIPE	6	n.s.	3.01 **	6.97 **	5.99 ***	n.s.	4.03 ***
STxRIPE	4	5.92 ***	24.72 ***	8.20 ***	6.59 ***	n.s.	n.s.
HDxSTxRIPE	24	1.76 *	1.54 *	3.48 ***	2.42 ***	n.s.	n.s.

n.s., *, **, ***: non significant, or significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 3.7. 'Gala' fruit firmness at harvest and after 4 storage durations, one and 7 days of ripening at 20C. Means (± SE) of 20 (harvest) and 15 (storage) fruits are reported.

Weeks in storage (0C), and days at 20C.	Firmness (N)					
	DAFB					
	108	115	122	129	136	143
Harvest						
1	103.30 (1.29)	100.00 (1.50)	92.83 (1.66)	85.89 (2.34)	77.75 (1.76)	69.08 (1.14)
7	104.40 (1.91)	87.94 (1.53)	89.18 (1.62)	70.50 (1.04)	70.28 (1.29)	67.61 (1.14)
6 wks						
1	100.30 (2.85)	92.47 (3.11)	87.49 (1.77)	74.46 (1.36)	75.22 (1.92)	71.84 (1.60)
7	89.89 (2.86)	80.02 (1.94)	86.87 (2.16)	69.34 (1.16)	66.10 (1.63)	60.09 (1.75)
12 wks						
1	86.91 (2.35)	89.00 (2.30)	88.11 (1.58)	68.59 (1.51)	70.41 (1.30)	61.60 (1.61)
7	80.64 (1.97)	77.44 (2.82)	74.28 (1.70)	65.12 (1.09)	64.32 (1.440	61.43 (1.39)
18 wks						
1	84.60 (1.98)	83.62 (2.31)	76.19 (3.23)	59.60 (1.71)	59.96 (1.36)	52.26 (0.80)
7	81.40 (1.91)	76.82 (1.97)	71.17 (2.15)	65.47 (2.42)	52.35 (1.08)	51.51 (1.01)
24 wks						
1	72.86 (1.54)	77.88 (1.52)	62.76 (1.41)	56.09 (1.24)	54.00 (1.25)	47.59 (1.17)
7	83.40 (1.93)	63.12 (1.20)	62.49 (2.06)	51.51 (1.02)	49.19 (1.43)	44.12 (1.73)

Table 3.8. 'Braeburn' fruit firmness at harvest and after 4 storage durations, one and 7 days of ripening at 20C. Means (± SE) of 20 (harvest) and 15 (storage) fruits are reported.

Weeks in storage (0C), and days at 20C.	Firmness (N) DAFB 147	154	161	168	175	182	186
Harvest							
1	96.79 (1.26)	95.59 (1.12)	95.32 (1.07)	91.41 (0.96)	96.43 (1.42)	90.07 (0.94)	84.33 (0.88)
7	93.41 (1.37)	93.76 (1.05)	91.36 (1.60)	89.85 (1.08)	85.62 (1.08)	82.78 (1.09)	80.64 (1.27)
8 wks							
1	92.65 (1.23)	94.39 (1.23)	92.83 (1.69)	92.96 (2.10)	88.60 (1.35)	85.27 (1.13)	85.22 (1.39)
7	88.03 (1.79)	81.62 (2.02)	78.77 (1.62)	77.84 (1.89)	79.26 (1.73)	75.84 (1.47)	75.13 (1.32)
16 wks							
1	87.54 (0.96)	83.18 (1.25)	79.75 (1.67)	80.60 (1.94)	85.09 (1.22)	75.75 (1.21)	72.86 (1.53)
7	80.51 (0.87)	79.53 (1.17)	76.95 (1.90)	84.82 (1.66)	68.68 (0.83)	73.17 (2.90)	68.45 (1.46)
24 wks							
1	80.46 (1.25)	76.02 (1.41)	79.71 (1.32)	74.50 (2.06)	73.44 (1.51)	75.39 (1.07)	74.50 (2.29)
7	79.09 (1.94)	73.39 (1.17)	73.17 (2.45)	69.66 (1.65)	67.43 (2.73)	67.48 (1.95)	65.12 (1.99)
32 wks							
1	74.99 (1.01)	65.52 (1.12)	66.72 (2.10)	64.63 (1.42)	65.52 (1.78)	61.56 (2.11)	59.56 (3.91)
7	69.57 (1.77)	67.52 (1.80)	65.39 (2.51)	63.78 (2.38)	58.98 (2.40)	55.56 (2.17)	55.96 (2.62)

Table 3.9. 'Fuji' fruit firmness at harvest and after 4 storage durations, one and 7 days of ripening at 20C. Means (± SE) of 20 (harvest) and 15 (storage) fruits are reported.

Weeks in storage (0C), and days at 20C.	Firmness (N)						
	DAFB						
	145	152	159	166	173	180	187
Harvest							
1	86.29 (1.28)	87.63 (1.04)	79.13 (0.89)	83.80 (1.54)	75.44 (1.12)	77.22 (1.24)	76.02 (1.20)
7	85.98 (1.16)	84.87 (1.22)	83.36 (1.69)	80.51 (1.45)	78.28 (1.14)	77.35 (1.67)	76.46 (1.17)
8 wks							
1	87.80 (1.85)	84.69 (1.09)	82.11 (2.42)	79.93 (1.76)	75.79 (1.52)	75.57 (1.81)	75.48 (1.00)
7	85.67 (1.22)	81.31 (1.53)	81.13 (2.39)	74.59 (1.60)	74.82 (1.76)	72.95 (1.87)	72.41 (2.38)
16 wks							
1	84.82 (1.50)	81.31 (2.27)	79.22 (1.35)	74.99 (1.78)	73.88 (1.86)	66.72 (1.53)	63.87 (2.15)
7	78.33 (2.25)	80.60 (1.65)	75.75 (1.91)	76.68 (1.70)	64.27 (1.70)	65.87 (1.63)	59.43 (1.24)
24 wks							
1	79.71 (1.33)	80.42 (2.26)	78.11 (2.12)	77.66 (2.14)	70.41 (1.87)	68.45 (1.63)	59.65 (2.29)
7	77.22 (1.90)	76.15 (1.43)	74.86 (2.04)	65.79 (2.28)	67.30 (2.91)	59.43 (1.66)	58.54 (1.57)
32 wks							
1	77.80 (1.77)	72.68 (1.89)	71.88 (1.57)	71.52 (1.93)	65.87 (1.79)	67.83 (1.94)	64.54 (3.15)
7	75.70 (2.06)	69.08 (2.04)	68.94 (2.48)	59.02 (2.29)	56.85 (1.61)	63.12 (2.12)	63.78 (3.21)

Table 3.10. Analysis of variance of 'Gala' sensory ratings for overall quality in a randomized block design, with harvest date (HD) as the main effect and panelist (PAN) as the blocking effect. The untrained panel was different for each testing session.

Taste Test Date	Sources of Variation	df	F value and significance
7 Oct.	HD	5	5.85 ***
	PAN	57	2.16 ***
11 Nov.	HD	5	2.56 *
	PAN	58	4.17 ***
7 Dec.	HD	5	3.70 **
	PAN	48	2.82 ***
21 Jan.	HD	5	2.36 *
	PAN	59	3.46 ***

*, **, ***: significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 3.11. Analysis of variance of 'Braeburn' sensory ratings for overall quality in a randomized block design, with harvest date (HD) as the main effect and panelist (PAN) as the blocking effect. The untrained panel was different for each testing session.

Taste Test Date	Sources of Variation	df	F value and significance
7 Nov.	HD	5	2.11 *
	PAN	57	2.10 ***
7 Jan.	HD	5	2.84 **
	PAN	56	2.63 ***
18 Feb.	HD	5	n.s.
	PAN	55	1.98 ***
14 Apr.	HD	5	3.73 **
	PAN	53	1.75 **
26 May	HD	5	5.01 ***
	PAN	58	2.71 ***

n.s., *, **, ***: non significant, or significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 3.12. Analysis of variance of 'Fuji' sensory ratings for overall quality in a randomized block design, with harvest date (HD) as the main effect and panelist (PAN) as the blocking effect. The untrained panel was different for each testing session.

Taste Test Date	Sources of Variation	df	F value and significance
12 Nov.	HD	5	4.98 ***
	PAN	58	3.11 ***
14 Jan.	HD	5	5.07 ***
	PAN	57	3.24 ***
25 Feb.	HD	5	2.29 *
	PAN	56	2.88 ***
25 Apr.	HD	5	n.s.
	PAN	59	2.81 ***
2 June	HD	5	n.s.
	PAN	56	3.05 ***

n.s., *, **, ***: non significant, or significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 4.1. Wilk's Lambda and F approximations for the hypothesis of no overall harvest date (HD) and panelist (PAN) effect for the sensory ratings of 'Gala' apples on 4 taste tests.

Taste test date	Source of variation	df	Wilk's Lambda	F	Pr>F
7 Oct.	HD	5	0.518	7.90	0.0001
	PAN	56	0.051	3.98	0.0001
11 Nov.	HD	5	0.699	4.07	0.0001
	PAN	56	0.041	4.33	0.0001
7 Dec.	HD	5	0.582	5.51	0.0001
	PAN	48	0.062	3.69	0.0001
21 Jan.	HD	5	0.610	6.17	0.0001
	PAN	59	0.053	3.95	0.0001

Table 4.2. Wilk's Lambda and F approximations for the hypothesis of no overall harvest date (HD) and panelist (PAN) effect for the sensory ratings of 'Braeburn' apples on 5 taste tests.

Taste test date	Source of variation	df	Wilk's Lambda	F	Pr>F
7 Nov.	HD	5	0.722	3.61	0.0001
	PAN	53	0.073	3.38	0.0001
7 Jan.	HD	5	0.806	2.40	0.0001
	PAN	55	0.043	4.32	0.0001
18 Feb.	HD	5	0.780	2.76	0.0001
	PAN	54	0.059	3.72	0.0001
14 Apr.	HD	5	0.468	8.70	0.0001
	PAN	50	0.123	2.55	0.0001
26 May	HD	5	0.643	5.23	0.0001
	PAN	54	0.077	3.29	0.0001

Table 4.3. Wilk's Lambda and F approximations for the hypothesis of no overall harvest date (HD) and panelist (PAN) effect for the sensory ratings of 'Fuji' apples on 5 taste tests.

Taste test date	Source of variation	df	Wilk's Lambda	F	Pr>F
12 Nov.	HD	5	0.785	2.81	0.0001
	PAN	57	0.030	4.99	0.0001
14 Jan.	HD	5	0.755	3.12	0.0001
	PAN	54	0.037	4.64	0.0001
25 Feb.	HD	5	0.710	3.89	0.0001
	PAN	55	0.051	4.04	0.0001
25 Apr.	HD	5	0.689	4.57	0.0001
	PAN	59	0.064	3.64	0.0001
2 June	HD	5	0.699	4.09	0.0001
	PAN	55	0.047	4.16	0.0001

Table 4.4. Partial correlation coefficients between the sensory attributes of 'Gala' apples, from the Error Sum of Squares and Cross Product matrix.

Taste test date	df	Sensory attribute	Sweetness	Tartness	Firmness	Flavor
7 Oct.	277	Overall	0.55***	0.31***	0.44***	0.69***
11 Nov.	273	liking	0.49***	0.13*	0.39***	0.76***
7 Dec.	239		0.58***	0.39***	0.54***	0.75***
21 Jan.	294		0.56***	0.15**	0.36***	0.75***
7 Oct.	277	Sweetness		n.s.	0.23***	0.54***
11 Nov.	273			-0.24***	n.s.	0.50***
7 Dec.	239			n.s.	0.29***	0.55***
21 Jan.	294			-0.12*	n.s.	0.56***
7 Oct.	277	Tartness			0.35***	0.22***
11 Nov.	273				0.36***	0.14*
7 Dec.	239				0.42***	0.41***
21 Jan.	294				0.45***	0.12*
7 Oct.	277	Firmness				0.38***
11 Nov.	273					0.35***
7 Dec.	239					0.41***
21 Jan.	294					0.29***

n.s., *, **, ***: non significant, or significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

Table 4.5. Partial correlation coefficients between sensory attributes of 'Braeburn' apples, from the Error Sum of Squares and Cross Product matrix.

Taste test date	df	Sensory attribute	Sweetness	Tartness	Firmness	Flavor
7 Nov.	268	Overall	0.57***	0.12*	0.44***	0.68***
7 Jan.	274	liking	0.51***	n.s.	0.24***	0.73***
18 Feb.	271		0.48***	0.19**	0.40***	0.77***
14 Apr.	261		0.50***	0.33***	0.45***	0.70***
26 May	281		0.56***	0.161**	0.58***	0.70***
7 Nov.	268	Sweetness		-0.19**	n.s.	0.53***
7 Jan.	274			-0.44***	n.s.	0.38***
18 Feb.	271			-0.17**	n.s.	0.50***
14 Apr.	261			n.s.	n.s.	0.49***
26 May	281			n.s.	0.30***	0.57***
7 Nov.	268	Tartness			0.42***	0.12*
7 Jan.	274				0.25***	0.12*
18 Feb.	271				0.38***	0.18*
14 Apr.	261				0.27***	0.39***
26 May	281				0.40***	0.19**
7 Nov.	268	Firmness				0.36***
7 Jan.	274					0.24***
18 Feb.	271					0.32***
14 Apr.	261					0.34***
26 May	281					0.50***

n.s., *, **, ***: non significant, or significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

Table 4.6. Partial correlation coefficients between sensory attributes of 'Fuji' apples, from the Error Sum of Squares and Cross Product matrix.

Taste test date	df	Sensory attribute	Sweetness	Tartness	Firmness	Flavor
12 Nov.	283	Overall liking	0.57***	0.21***	0.22***	0.72***
14 Jan.	269		0.61***	n.s.	0.29***	0.78***
25 Feb.	274		0.56***	0.32***	0.43***	0.70***
25 Apr.	294		0.48***	0.23***	0.39***	0.77***
2 June	274		0.59***	0.46***	0.45***	0.78***
12 Nov.	283	Sweetness		n.s.	0.18**	0.62***
14 Jan.	269			-0.24***	n.s.	0.60***
25 Feb.	274			n.s.	0.22***	0.51***
25 Apr.	294			-0.19***	0.14*	0.49***
2 June	274			0.15*	0.27***	0.63***
12 Nov.	283	Tartness			0.18***	0.24***
14 Jan.	269				0.26***	n.s.
25 Feb.	274				0.26***	0.21***
25 Apr.	294				0.14*	0.25***
2 June	274				0.30***	0.44***
12 Nov.	283	Firmness				0.24***
14 Jan.	269					0.24***
25 Feb.	274					0.41***
25 Apr.	294					0.28***
2 June	274					0.41***

n.s., *, **, ***: non significant, or significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

Table 4.7. Stepwise regression of sensory attributes intensities over overall liking ratings given on the taste panels of 'Gala', 'Braeburn' and 'Fuji' apples.

Cultivar	Taste test date	Model R^2	Variable entered and partial R^2			
Gala	7 Oct.	0.57	Flavor (0.50)	Sweet. (0.05)	Firm. (0.02)	Tart. (0.01)
	11 Nov.	0.61	Flavor (0.55)	Firm. (0.05)	Sweet. (0.02)	-
	7 Dec.	0.69	Flavor (0.63)	Sweet. (0.03)	Firm. (0.02)	-
	21 Jan.	0.62	Flavor (0.54)	Sweet. (0.05)	Firm. (0.04)	-
Braeburn	7 Nov.	0.56	Flavor (0.49)	Sweet. (0.04)	Firm. (0.04)	-
	7 Jan.	0.63	Flavor (0.55)	Sweet. (0.07)	Firm. (0.02)	-
	18 Feb.	0.57	Flavor (0.54)	Firm. (0.02)	Sweet. (0.01)	Tart. (0.01)
	14 Apr.	0.62	Flavor (0.55)	Sweet. (0.03)	Sweet. (0.03)	-
	26 May	0.67	Flavor (0.60)	Firm. (0.05)	Firm. (0.05)	-
Fuji	12 Nov.	0.59	Flavor (0.55)	Sweet. (0.04)	-	-
	14 Jan.	0.70	Flavor (0.65)	Sweet. (0.05)	Firm. (0.01)	-
	25 Feb.	0.61	Flavor (0.51)	Sweet. (0.07)	Tart. (0.02)	-
	25 Apr.	0.67	Flavor (0.63)	Firm. (0.02)	Sweet. (0.02)	-
	2 June	0.65	Flavor (0.62)	Firm. (0.01)	Sweet. (0.01)	Tart. (0.01)

Table 4.8. Factor loadings, communalities and variance explained by each factor for 'Gala' apples after two factors extraction and rotation, per taste test session. Factor analysis was performed on the covariance matrix of the residuals of the GLM-MANOVA (model: OL, sweetness, tartness, firmness, flavor = harvest date, panelist).

Taste test date	Sensory attribute	Factor 1	Factor 2	Communality
7 Oct.	Overall liking	**0.82**	0.38	0.81
	Flavor	**0.82**	0.26	0.73
	Sweetness	**0.86**	-0.13	0.75
	Tartness	-0.02	**0.96**	0.91
	Firmness	0.39	**0.54**	0.44
	Variance	3.64	2.57	
11 Nov.	Overall liking	**0.86**	0.26	0.81
	Flavor	**0.88**	0.24	0.83
	Sweetness	**0.78**	-0.33	0.72
	Tartness	-0.10	**0.87**	0.76
	Firmness	0.32	**0.73**	0.64
	Variance	3.70	2.50	
7 Dec.	Overall liking	**0.82**	0.43	0.85
	Flavor	**0.78**	0.39	0.76
	Sweetness	**0.87**	-0.06	0.76
	Tartness	0.03	**0.91**	0.83
	Firmness	0.36	**0.69**	0.60
	Variance	3.45	2.72	
21 Jan.	Overall liking	**0.87**	0.27	0.84
	Flavor	**0.86**	0.20	0.79
	Sweetness	**0.84**	-0.19	0.73
	Tartness	-0.07	**0.90**	0.81
	Firmness	0.23	**0.76**	0.63
	Variance	4.47	2.52	

Table 4.9. Factor loadings, communalities and variance explained by each factor for 'Braeburn' apples after two factors extraction and rotation, per taste test session. Factor analysis was performed on the covariance matrix of the residuals of the GLM-MANOVA (model: OL, sweetness, tartness, firmness, flavor = harvest date, panelist).

Taste test date	Sensory attribute	Factor 1	Factor 2	Communality
7 Nov.	Overall liking	**0.87**	0.25	0.81
	Flavor	**0.85**	0.23	0.78
	Sweetness	**0.81**	-0.22	0.70
	Tartness	-0.12	**0.93**	0.88
	Firmness	0.33	**0.70**	0.60
	Variance	4.00	2.75	
7 Jan.	Overall liking	**0.93**	0.00	0.87
	Flavor	**0.89**	0.19	0.83
	Sweetness	**0.62**	**-0.63**	0.78
	Tartness	-0.01	**0.93**	0.87
	Firmness	0.27	0.41	0.24
	Variance	3.77	2.39	
18 Feb.	Overall liking	**0.85**	0.33	0.83
	Flavor	**0.87**	0.27	0.83
	Sweetness	**0.81**	-0.28	0.73
	Tartness	-0.06	**0.86**	0.74
	Firmness	0.26	**0.73**	0.60
	Variance	4.87	2.91	
14 Apr.	Overall liking	**0.76**	0.47	0.80
	Flavor	**0.74**	0.49	0.79
	Sweetness	**0.88**	-0.13	0.79
	Tartness	-0.02	**0.89**	0.79
	Firmness	0.23	**0.58**	0.39
	Variance	4.19	3.30	

Table 4.9 (continued)

Taste test date	Sensory attribute	Factor 1	Factor 2	Communality
26 May	Overall liking	**0.87**	0.28	0.84
	Flavor	**0.86**	0.24	0.80
	Sweetness	**0.83**	-0.16	0.71
	Tartness	-0.07	**0.86**	0.74
	Firmness	0.48	**0.73**	0.77
	Variance	5.41	2.81	

Table 4.10. Factor loadings, communalities and variance explained by each factor for 'Fuji' apples after two factors extraction and rotation, per taste test session. Factor analysis was performed on the covariance matrix of the residuals of the GLM-MANOVA (model: OL, sweetness, tartness, firmness, flavor = harvest date, panelist)

Taste test date	Sensory attribute	Factor 1	Factor 2	Communality
12 Nov.	Overall liking	**0.85**	0.24	0.78
	Flavor	**0.86**	0.27	0.81
	Sweetness	**0.87**	-0.12	0.77
	Tartness	0.02	**0.98**	0.96
	Firmness	0.25	0.24	0.12
	Variance	3.63	1.84	
14 Jan.	Overall liking	**0.89**	0.21	0.85
	Flavor	**0.88**	0.25	0.83
	Sweetness	**0.85**	-0.25	0.79
	Tartness	-0.14	**0.92**	0.87
	Firmness	0.25	0.53	0.35
	Variance	3.91	1.76	
25 Feb.	Overall liking	**0.83**	0.36	0.82
	Flavor	**0.84**	0.24	0.76
	Sweetness	**0.83**	-0.16	0.71
	Tartness	0.02	**0.95**	0.89
	Firmness	0.44	0.44	0.38
	Variance	3.74	1.99	
25 Apr.	Overall liking	**0.92**	0.05	0.86
	Flavor	**0.91**	0.03	0.83
	Sweetness	**0.63**	**-0.61**	0.77
	Tartness	0.27	**0.88**	0.84
	Firmness	0.46	0.20	0.25
	Variance	4.86	1.99	

Table 4.10 (continued)

Taste test date	Sensory attribute	Factor 1	Factor 2	Communality
2 June	Overall liking	**0.72**	0.55	0.83
	Flavor	**0.79**	0.48	0.86
	Sweetness	**0.93**	-0.02	0.86
	Tartness	0.08	**0.82**	0.68
	Firmness	0.21	**0.68**	0.51
	Variance	4.50	2.95	