AN ABSTRACT OF THE THESIS OF

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Title: Storage Time Effects on Quality of Fresh-Market Red Raspberries.

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To determine the effect of storage time on quality, five cultivars and two numbered selections of red raspberries (Rubus idaeus L.) were harvested six times per year (twice a week for three weeks) in 1984 and 1985. Harvested samples were cooled for 48 hr at 0°C, then stored at 4.4°C for 48 hr to simulate typical handling, transportation temperatures, and maximum time in transit for fresh marketing of red raspberries. Samples were then held at 20°C for up to 72 hr to simulate retail-display conditions.

Important fresh-market red raspberry quality characteristics--firmness (measured as cohesion), pH, percent soluble solids, percent titratable acidity, percentage of fruits with mold or defects, and color (measured by absorbance)--were tested at harvest and at 12 and 24 hr intervals during display-storage. Fruit temperature at harvest was not significantly correlated with fruit firmness at harvest. Fruit temperature in display-storage was significantly correlated ($r = -0.707$, $p < 0.01$, $n = 60$) with fruit firmness in display-storage.

All cultivars and selections decreased in firmness and percent titratable acidity, but increased in color intensity (darkening), defects, mold, and slightly in percent soluble solids with increased holding time in display-storage at 20°C. Cultivars and selections behaved differently when handled similarly, emphasizing the importance of choice of cultivar, proper handling, and good temperature management in fresh-marketing of red raspberries.

STORAGE TIME EFFECTS ON QUALITY OF FRESH-MARKET RED RASPBERRIES

by

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This thesis, and all that comes from it, is lovingly dedicated to my mother, Iris Mae Dennison Conway.

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REVIEW OF LITERATURE

Introduction

Literature concerning fresh marketing of red raspberries (*Rubus idaeus* L.) dates back to the early 1900s (63, 81). Raspberry production is an important horticultural industry in the Pacific Northwest of the U.S. The growth of the industry is largely dependent on the extension of the marketing zone for fresh-market red raspberries (19, 63), and this depends on the keeping qualities of the cultivars grown (63). Winter and Alderman (81) determined keeping qualities based on the length of time the fruits remain in a marketable and usable condition.

The Pacific Northwest is a major production area of red raspberries (18). The climate enables growers to produce high yields and top quality fruit demanded on the fresh market (57, 61). The percentage of raspberries marketed fresh, however, is relatively low: 5-20% (47, 57, 59). Lamonte and O'Rourke (47) consider the lack of aggressive marketing as a major factor in the slow growth of fresh-market sales. The potential expansion of both local and long distance sales of fresh-market red raspberries is considered untapped (13, 19, 57, 67). Thus raspberries, being one of the most perishable of all horticultural crops (42, 57, 61, 62, 73, 81), present a challenge to the industry: to produce high yields of good quality fruit and to develop methods of handling which maintain that level of quality.

Careful consideration for optimal quality maintenance and the factors which affect it (cultivar, maturity, production site, climate/season, and handling) (28, 32) must be done throughout the marketing process (34, 57).

Quality Characteristics Important in Fresh Marketing

Quality characteristics are those which make the fruit attractive as a food source (68). Color, taste, and texture are the most important quality characteristics concerning the acceptance of fresh-market red raspberries (12, 61, 68, 70, 79).

Color

Sistrunk and Moore (68) state that the primary basis of market acceptance of fresh fruits is color and appearance. Color, a very important quality characteristic (43, 47, 61, 70, 79), is variable in horticultural products (3). Color is primarily influenced by cultivar and maturity, but it can also be affected by climate, season, nutrition, cultural practices, and postharvest treatment (3). Because color is somewhat different depending on the cultivar, growers must choose cultivars best suited for the fresh market (3).

In red raspberries, the red color is primarily due to four major anthocyanin pigments: cyanidin 3-sophoroside (Cy 3-Sop), cyanidin 3-glucoside (Cy 3-Gl), cyanidin 3-rutinoside (Cy 3-Ru), and cyanidin 3-glucorutinoside (Cy 3-GlRu) (8, 66, 72, 78). All four pigments do not occur in every cultivar or selection and each can vary depending on the cultivar (72). Cy 3-Sop and Cy 3-Gl are the two pigments which make up the highest percentage of the total anthocyanin concentration (approximately 80% and 11%, respectively) (8, 72). The total anthocyanin concentration is in the range from approximately 20 to 60 mg/100g of fruit (expressed as Cy 3-Sop) (78). In a recent study in Oregon, Spanos (72) found the total anthocyanin concentration to range from approximately 68 to 101 mg/100 ml of fruit (expressed as Cy 3-Gl).

Taste

The quality characteristic of taste is directly related to the balance of sugars and acids (68). This "perceived sweetness" is used by consumers to judge quality (68) and thereby affects repetitive purchasing which is necessary for the stability and expansion of the fresh-market red raspberry industry (47). Titratable acidity, expressed as citric acid (the major acid of red raspberries [65, 74]), and soluble solids are affected by cultivar, fruit size, weather conditions, cultural practices, and time of harvest (68).

Texture

Texture is one of the most important quality characteristics regarding fresh-market red raspberries (3, 12). Sensations apprehended by the eyes, touch, or muscle senses of the mouth (mouth-feel) are all considered texture (3, 46). These include chewiness, fibrousness, mealiness, stickiness, juiciness, crispness, and firmness (3, 12, 68).

The texture of red raspberries depends primarily on the size and cohesion of the drupelets. The entanglement of epidermal hairs causes normal drupelets to cohere. When some drupelets on a fruit are large and others are small, a crumbly fruit results (3). Crumbly fruit, however, may also result from partial or poor pollenation, fungal or bacterial infections, or frost/freeze damage.

Red raspberries are a very delicate fruit due to their thin skins (42) and hollow core once harvested (3). The texture of red raspberries is greatly affected by maturity and cultivar (3). Because texture is important to consumer acceptance (68), every effort must be made to properly handle and deliver red raspberries with desirable texture (12).

Size

There are quality characteristics important with fresh-market red raspberries other than color, taste, and texture. Large-fruited cultivars are attractive and desirable to consumers in the pick-your-own market and command top prices in the retail marketplace (41, 68). Weight loss is a concern for the retailer and the consumer (34). Weight loss is often accompanied by shriveling.

Mold

The presence of mold is a primary reason for consumer rejection of fresh-market red raspberries (30, 33, 42) and short storage/shelf life (27, 61, 62, 73). Red raspberries have a characteristic fungal flora (7, 27), and there are differences among cultivars in their susceptibility to molds (25). Molds develop and are more easily spread in fruit that has been bruised or physically damaged (15, 35, 42, 75).

Gray mold, caused by Botrytis cinerea, is often responsible for the majority of postharvest rots (7, 15, 21, 22, 24, 25, 26, 42, 44, 45). Most gray mold infections begin in the field, where they penetrate flower parts and form latent infections, giving rise to postharvest rots (15, 36, 42). Gray mold is a dense, dusty, gray growth which spreads rapidly from fruit to fruit, causing a watery, soft rot (15, 25, 35).

Rhizopus rot, caused by Rhizopus stolonifera, is another common postharvest rot of red raspberries (15, 21, 26, 35, 42). Rhizopus spreads easily and attacks overripe or bruised fruit first, causing a watery, soft rot (15, 35).

Blue mold rot, caused by Penecillium spp., is another common postharvest rot that develops in storage (15, 42). Attacking overripe or bruised fruit first, it spreads rapidly.

Another common postharvest/storage rot is olive-green mold, caused by Cladosporium spp. (15, 35, 44). It is highly dependent on the season and weather conditions (44). Cladosporium rot is most commonly found in the central, hollow core of the fruit (15, 44).

Other fruit rots which occasionally cause postharvest problems are anthracnose, caused by Elsinoe veneta (15, 35), and Mucor spp. (15, 21). It is fairly common for one raspberry fruit to have greater than one mold species present at one time: gray mold on the outside and olive-green mold in the central core (44). Fungicide sprays during preharvest help to reduce fruit rots (15, 26).

Defects

Until consumed or cooked, fresh-market red raspberries are living organisms (33). As such, varying proportions of the fruit will deviate in terms of size, shape, color, texture, etc. from perfection (3). Arthey (3) defines defects as the presence of a mark or blemish, the lack of something essential, or both. Even after careful selection in the field or at packaging, perfection is rarely attained (3). Defects have been classified as genetic, entomological, physiological, pathological, mechanical/physical, or the presence of foreign material (3). A decision must be made as to how much deviation from perfection can be tolerated before the fruit will be downgraded from top quality (3). Defects play an important role in fresh-market red raspberries because even if the fruits are highly rated for all other aspects of quality, as little as one defective raspberry in the hallock can cause rejection from the consumer (3, 33, 48, 56).

Factors Influencing Fruit Quality

The principal factors that influence the condition of fresh-market red raspberries are: weather conditions during flowering through the ripening period; cultivar characteristics; maturity of harvested fruit; how the fruit is handled; and temperature management of fruit at harvest and throughout the marketing process (63, 81).

Weather Conditions

Losses from fruit rot can vary from year to year according to the prevailing weather conditions during flowering through harvest (50). Raspberries picked wet with dew or after a long period of rain or irrigation do not keep well (47, 63, 81). Rain or heavy dews can favor the development of many fruit rots (7, 15, 35, 42). Temperature can also influence fruit rot development, especially when combined with high-moisture conditions. Differences between seasons can affect many quality characteristics besides fruit rot. Temperature, sunlight, moisture, and relative humidity can affect soluble solids, size, color, and texture as well (68).

Cultivar Characteristics

Choice of red raspberry cultivars suitable for fresh market is important (47, 67, 81) and should be done early in the planning stages (before planting) as this will affect the quality of the delivered product (28, 32, 81). Cultivars which produce firmer fruit tend to have the longest shelf life (10). Several studies have found that raspberry cultivars selected for firmness might also confer resistance to molds, such as gray mold (9, 36, 44).

Increased focus on fresh marketing of red raspberries has brought about increased interest in fruit rot resistance (21, 24). Jennings and Carmichael (36) reported that cultivars having high soluble solids values tend to be softer and have a higher incidence of rots. Knight (44) found that cultivars producing large fruit tend to have a higher incidence of rot.

In 1979 Willamette and Meeker made up approximately 85% (70% and 15%, respectively) of the total acreage of red raspberries grown in Washington and Oregon (47). Despite the large acreage of the Willamette cultivar, it lacks certain quality characteristics necessary for fresh market (47, 67). The Meeker cultivar is considered acceptable for fresh market (67). Presently the majority of fresh-market red raspberries shipped from the Pacific Northwest are from the cultivars Willamette, Meeker (47), and Chilcotin (16, 20, 47). Amity, a fall-bearing cultivar, is also fresh marketed.

Studies agree on the dark color (8, 47, 61), sweet taste (8, 61), and medium to soft firmness (61) of Willamette. Willamette has a susceptibility or high incidence of fruit rot (24, 25, 61).

Meeker is considered to have a sweet taste (70), firm fruit (18) (Barritt & Torre [9] and Øydvin [61] say soft), and lighter color (61, 67), larger size, and higher yields than Willamette (18). Meeker's low incidence of fruit rot (7, 61) and its resistance to _Botrytis_ (7, 24, 36) enhance its suitability for the fresh market.

Daubeny (16, 19, 20) reported that Chilcotin is particularly well suited for fresh marketing. Chilcotin's fruit is large in size (18, 20) and has good color (67). Chilcotin is more uniformly colored, brighter, less apt to darken (16, 19, 20), and firmer than Willamette (18). It produces greater yields than Willamette (18) but has equal to or higher incidence of mold (16, 18). Chilcotin is highly susceptible to root rot, and thus the acreage is low.

Nootka is similar in color to Willamette at harvest, yet does not darken quite as much as Willamette because of storage time (17). Its fruit is very sweet (61), soft (9, 61), smaller (17, 18), and yields less than Willamette (18). Studies agree on Nootka's low mold incidence and high resistance to fruit rot (9, 17, 20, 44, 61).

Øydvin (61) found the selection OR-US 1836 to have firm fruit with good color, moderately sweet taste, and moderately low rot incidence. Because it is one of the latest June-bearing types of red raspberries, it could effectively extend the fresh-market red raspberry season (67).

Research indicates that there are differences among red raspberry cultivars with regard to the changes in quality with increased storage time (61, 70). No cultivar has proven itself to be "the overall best" with regard to all the quality characteristics necessary for fresh-market red raspberries. One cultivar may maintain good taste throughout increased time in storage, yet darken rapidly and/or become too soft (i.e., Nootka) (61). Sjulin and Robbins (70) found that the quality of a cultivar after time in storage is directly related to the quality of that cultivar at harvest. Choice of optimal quality fruit from best-suited cultivars is essential in the fresh marketing of red raspberries.

Maturity

Ripening is the composite of processes occurring from the later stages of growth and development through the early stages of senescence, which result in characteristic food quality, as evidenced by changes in color, texture, or other sensory attributes (80). Watada, et al. (80), in trying to minimize ambiguities and encourage standardized usage of terms, have defined horticultural maturity as "the stage of development when a plant or a plant part possesses the prerequisites for utilization by consumers for a particular purpose." Cultivar (32) and maturity (32, 77) are important factors affecting storage life and market quality. Most studies agree that red raspberries for the fresh market need to be of a maturity which will have a superior gloss, flavor, color, texture (70), resistance to damage and rotting (77), and a long shelf life (61, 77, 81).

Ramsey (63) states that raspberries should be harvested as soon as they attain a bright red color and separate from the receptacle without breaking. Spayd, et al. (73) chose raspberries with a bright red fruit color and called them "fresh-market ripe stage." Jolliffe (39) used the term "ripe" to describe fruit that is full bright red, easily picked, firm, and not bruised with gentle handling. Sjulin and Robbins (69, 70) described the optimal fresh-market maturity as the "red ripe stage", where the fruit's surface is 100% bright red but without the purple-red hues typical of processing fruit. Slightly immature (77), slightly under ripe (75), and red stage (61) have all been used to describe the stage of maturity which is superior for fresh market.

Raspberries at the light-red ripe stage of maturity are firmer than typical processing fruit (32, 39, 61, 69, 70, 77). As red raspberries mature, the pH (8, 51, 70) and soluble solids increase (54) and titratable acidity decreases (54, 70). These levels and the ratio of soluble solids to acids are a reliable indicator of ripeness (6).

Color continues to develop as the raspberries mature (69). Barritt and Torre (8) found that absorbance increases with maturity, but the relative proportion of major pigments does not change appreciably. Instead, minor pigments reach detectable levels as the anthocyanin concentration increases.

Picking and Handling

Red raspberries for the fresh market should be picked at least twice a week (2) and more often if the climatic conditions or season demands it. Raspberries should be picked in the early morning when they are the coolest (15, 81). Frequent, thorough pickings and careful handling can help to minimize fruit rot problems (15).

Fruit injuries during harvest are important factors in the keeping quality of red raspberries (81). Damage during picking and handling must be kept to a minimum (15, 42, 63, 75). Thorough picker training and supervision are necessary to reduce market losses (42). Adjusted pay scales and recruitment practices are advised in order to attract the skilled pickers necessary for attaining fresh-market quality raspberries (47). Bonus/penalty pay provisions are good ways to reinforce this message (42).

Raspberries should be discriminatingly picked; discarding all decayed, injured, or overripe fruit (2, 15, 42, 63, 71, 81). Only sound, firm fruit of optimal maturity should be picked (15). Because injury and decay (resulting from broken or bruised fruits as they are pulled away from the receptacle) are so common and serious, pickers should be instructed to use three fingers, instead of two, when picking, and to pull the fruit off straight rather than sideways (63). Raspberries should not be held in the hand after picking (2, 63). Fruit should be picked directly into the final containers (fresh-market hallocks) (42). Care should be exercised to keep the picked fruit in the hallocks off of the ground (42) and in the shade (2) until they are transported to the cold room.

As the season progresses, there are more ripe or overripe fruits (39, 76) which make it difficult to obtain the light-red ripe raspberries. Environmental factors (temperature, moisture, etc.) primarily cause seasonal effects on fruit quality (68). Appearance and color (70), size (70), berry weight (38), and texture (firmness) (37, 70) decline as the season progresses.

There are higher amounts of molds, more types of mold, or both on the fruit as the season progresses (26, 27, 43, 61, 75). This may be because the fungi sporulate on the greater amount and availability of overripe fruit in the field late in the season, thus providing plenty of inoculum for further infections (27). Dennis and Mountford (27) state that later-ripening fruit may be more susceptibility to attack by molds.

Proper packaging can aid in maintaining quality, increasing shelf life, and marketability. There are many different types of packages used for fresh marketing of red raspberries. Half-pint hallocks tend to provide good support yet minimize settling damage. Mesh lids (43) or film caps help to reduce waste from bruising, spilling, and pilfering (1). Proper packaging can aid in reducing moisture loss (5, 33, 49) and therefore weight loss and spoilage from shriveling (33).

A proper package for fresh-market red raspberries should: aim at retarding respiration and deterioration but without damaging quality (33); protect berries from mechanical damage, dirt, customer handling (33, 57); provide ventilation for cooling (33, 57); and be attractive and promote the raspberries (5, 47, 57). Film-capped packaging can reduce the respiration rate of red raspberries by creating a low oxygen/high carbon dioxide microenvironment. Refrigeration, however, is very important in reducing respiration. For this reason, packaging should be thought of as a supplement (not a substitute) for refrigeration in the fresh marketing of red raspberries (33).

Temperature Management

The reported storage life for fresh-market red raspberries is 2 to 3 days at temperatures of -0.5° to 0°C, at 90-95% relative humidity (49). However, both storage life at cold room temperatures and subsequent shelf life at ambient temperatures must be considered (43). The total life of fresh-market red raspberries is affected by whether the fruit is marketed in a partial or complete cold chain (under refrigeration throughout the marketing system) (43). A total cold chain is optimum; from the grower, through transport, and at the retail level (33, 40, 43). Kenny (43) states that it is most realistic to determine how long fruit can be cold stored, yet still have a residual shelf life at ambient temperatures for about 36 hr. This allows for unrefrigerated retail display and usage by the consumer (43).

Freshly picked red raspberries typically have temperatures greater than the surrounding air (81). The delay between harvest and cooling is very important (43, 63). Raspberries are known for their rapid deterioration after harvest (61, 63, 79) and therefore they should be handled carefully and promptly cooled after harvest to help increase shelf life (1, 40, 42, 43, 61, 63, 81).

Cooling and temperature management in fresh-market red raspberries is vital (5, 42, 47, 49, 70, 71, 73, 75, 79). Good temperature management begins in the field and continues throughout the marketing process. Refrigeration at optimal temperatures with optimal relative humidity directly affects fruit quality (49, 58, 81) and is the best method for extending shelf life (33, 40, 73). Refrigeration helps to retard respiration and ripening (4, 33, 42, 48, 49, 60, 63, 75, 79), textural and color changes, and moisture loss (49), and to retard and prevent spore germination and mold growth (4, 15, 33, 35, 40, 48, 49, 58, 63, 73, 79). Storage temperatures of greater than $0^{o}C$ but less than $2^{o}C$ can help prevent rot caused by Rhizopus but not rots caused by Botrytis or Mucor (26).

Because cooling red raspberries quickly after harvest is important, a cold room should be near or on the farm (40). The cold room should be cooled to the proper temperature before the fruit is put into it (43), and temperature-monitoring devices and air circulation are necessary to keep cooled fruit cool (15, 49).

Kenny (43) recommends that red raspberries be cooled to the optimal temperature within 2 to 3 hr. Because conventional cold rooms take longer than this to remove the field heat from the fruit, forcedair precooling is recommended (4, 33, 43, 63). It is important to allow enough time for precooling (43, 63) and fruit temperature should be checked to see that it is at least 2° to 4°C before moving the fruit into a conventional cold room or transportation vehicle (43). The recommended storage temperature for fresh-market red raspberries is -0.5° to 0°C with 90-95% relative humidity (15, 33, 49). Kenny (43) reported that storage temperatures of 2° to 4°C are realistic. Proper temperature management is essential in maintaining quality of fresh-market red raspberries yet good temperatures will not overcome bad handling (63).

The storage life of red raspberries decreases as the season progresses (26). Late season fruit often has heavier mold populations (27, 43) which may account for the shorter storage life. Lower storage temperatures (but above -0.6°C) may be justified (43).

Although the recommended transportation temperature for red raspberries is -0.5° to 2°C with 90-95% relative humidity (4), typical transportation temperatures for small fruits are approximately 4.4°C (1, 56). Most tractor-trailer refrigeration systems do not have the capacity to cool (precool) the fruit; they just keep cooled fruit cool (4, 33). The trailer should be cooled to 4.4°C <u>before</u> the cooled fruit is loaded (4). Typical time in transit is 24-48 hours (56). Brose (13) states that it would be beneficial for the red raspberry industry to establish shipping guidelines, for all transport modes, concerning technical aspects of fresh market shipping.

Typically, fresh-market small fruits are displayed without refrigeration (1, 43) at temperatures of 18.3° to 21.1°C at 50%

relative humidity (1, 34, 77). At 18.3°C, the typical shelf life is approximately 48 hr (77). Many times, deterioration in quality does not show up while in the continuous cold chain, but instead after one day at ambient temperatures (37, 43, 71, 77). The increase in temperature would result in an increase in respiration, thereby decreasing shelf life. Quality and shelf life could be maintained if sold under chilled display conditions (33, 43). The recommended display temperatures for fresh-market red raspberries are 0° to 10°C, with the best results at temperatures less than 4.4°C (48). Because produce coolers are designed just to keep cooled produce cool and they do not have the capacity to remove field heat (33), it's best if only cooled red raspberries are accepted. These raspberries should be put into the retailer's cold storage, at proper temperatures, as soon as they arrive (48).

The Influence of Storage Time on Quality

Product quality and product life are important to fresh-market small fruit consumers (34). Because consumers associate eye-appeal with quality (68), the attractiveness of the product often results in impulse buying (48). Raspberries should be usable longer than they are saleable (81). Direct or indirect losses, due to mold, defects, etc. (5), may be reflected back through each handler to the grower unless the retailer offers fresh red raspberries in a satisfactory condition (48).

Few studies have reported on the effect of increased storage time on quality of fresh-market red raspberries. Varseveld and Richardson

(79) found that soluble solids tend to increase during storage while quality is maintained, then gradually decline. Titratable acidity declines as red raspberries ripen (51, 52, 53, 55, 70). Titratable acidity appears to decrease with increased storage time (54, 73, 79). Spayd, et al. (73) found that pH increases with increased storage time.

Color (darkening) increases with maturity (8, 17). Many studies have reported an increase in color with increased storage time (61, 67, 69, 73, 79). Some cultivars (Willamette, Nootka) darken more rapidly than others (Chilcotin, Meeker) during storage (70).

Taste (the soluble solids to titratable acids ratio) decreases with increased storage time and more so in warmer storage temperatures (79). Weight loss, a major cause of deterioration with increased time in storage (49, 79), is also influenced by storage temperature. Mason (54) found that red raspberries lose more weight when stored at 22°C than at 5°C. Mold incidence, a primary factor limiting storage life (27), increased with increased storage time (61, 69, 73, 77). Varseveld and Richardson (79) found lower percentages of mold (and a longer shelf life) when the storage temperatures are 0°C versus 10° or 20°C.

Generally, fruit firmness decreases with increased storage time (61, 69, 79). Fruit firmness increases (79) or is maintained for the first few days in storage, then it declines sharply (69). Fruit firmness is temperature dependent, as it is best maintained in storage at -0.5° to 0°C temperatures (79).

STORAGE TIME EFFECTS ON QUALITY OF FRESH-MARKET RED RASPBERRIES

Abstract

To determine the effect of storage time on quality, five cultivars and two numbered selections of red raspberries (*Rubus idaeus* L.) were harvested six times per year (twice a week for three weeks) in 1984 and 1985. Harvested samples were cooled for 48 hr at 0°C, then stored at 4.4°C for 48 hr to simulate typical handling, transportation temperatures, and maximum time in transit for fresh marketing of red raspberries. Samples were then held at 20°C for up to 72 hr to simulate retail-display conditions.

Important fresh-market red raspberry quality characteristics--firmness (measured as cohesion), pH, percent soluble solids, percent titratable acidity, percentage of fruits with mold or defects, and color (measured by absorbance)--were tested at harvest and at 12 and 24 hr intervals during display-storage. Fruit temperature at harvest was not significantly correlated with fruit firmness at harvest. Fruit temperature in display-storage was significantly correlated ($r=-0.707$, $p<0.01$, $n=60$) with fruit firmness in display-storage.

All cultivars and selections decreased in firmness and percent titratable acidity, but increased in color intensity (darkening), defects, mold, and slightly in percent soluble solids with increased holding time in display-storage at 20°C. Cultivars and selections behaved differently when handled similarly, emphasizing the importance

of choice of cultivar, proper handling, and good temperature management in fresh-marketing of red raspberries.

Introduction

The climate in the Pacific Northwest combined with good management practices enables caneberry growers to produce high-quality red raspberries. Consumption of fresh fruits is increasing, and further development of the fresh red raspberry market has great potential (14, 57, 61, 67). Yet in the Pacific Northwest, only 5-20% of the total production of red raspberries is marketed fresh (47, 57, 59). This small percentage reflects the delicate nature of the fruit and its vulnerability to physical injury and quality loss (42, 79). Selection of suitable cultivars, picker training and supervision, proper handling, and good temperature management are essential to reduce market losses and aid in further market development.

Consumer perception of acceptability of fresh-market red raspberries depends on color, flavor, and texture (firmness) (12, 61, 68, 70, 79). For fruit to maintain high quality during storage and display, it must be picked in optimal condition and maturity.

A good fungicidal pest management program is essential in producing high quality red raspberries for the fresh market. The best methods for maintaining high quality, restricting mold growth and incidence (42, 70, 79), and extending shelf life of red raspberries are refrigeration at optimal temperature and relative humidity, proper packaging, and careful handling (5, 55, 81). Red raspberries have been shown to maintain good quality for up to one month in consistent, optimal, laboratory conditions (Sjulin, unpublished data). Typical fresh-marketing conditions and temperatures, however, are rarely optimal.

In this study, five cultivars and two numbered selections of red raspberries (Rubus idaeus L.) were handled similarly to simulate typical handling, transportation temperatures, and retail-display temperatures found in fresh marketing of red raspberries. The goal was to document the effect of storage time on the subsequent quality and shelf life of fresh-market red raspberries, and to compare and evaluate the cultivars and selections tested to their suitability for fresh market.

Materials and Methods

Red raspberry plots were located at the O.S.U. North Willamette Experiment Station in Aurora, Oregon. All plots were located in the eastern area of the experiment station, although not always adjacent to each other. All rows in the plots ran north-south. All plots were maintained similarly regarding insect pest management, disease control, and weed control. Fungicide applications were applied in the early spring (Polysol; 6 lbs/25 gal), late spring (Benlate; 0.5 lbs a.i./acre), and early summer (Captan; 2 lbs a.i./acre) both years.

Five named cultivars and two numbered selections of red raspberries were sampled on six dates (twice a week for three weeks) during the harvest seasons of 1984 and 1985. Six were June-bearing types: 'Willamette', 'Meeker', 'Chilcotin', 'Nootka', OR-US 520-48, and OR-US 1836; all were harvested and handled similarly on the same dates and at the same times. 'Amity', a fall-bearing (primocane fruiting) cultivar, was harvested and handled similarly later in the season (late August).

Six samples, each consisting of 25 hand-picked fruits, were harvested for each cultivar and selection at each harvest date. Fruit was picked in the light-red ripe stage of maturity, superior for the fresh market (61, 63, 70, 75, 77); fruit was firm and evenly, brightly colored. Fruit selected for samples was of high quality and uniformity. Fruit was harvested from the same side (eastern exposure) and area (middle 0.61 to 0.91 m of canopy) of the rows for each harvest. Fruit was picked directly into half-pint (0.069 l), pressed-paperboard hallocks. Once labeled, each hallock became a sample that was tested after a selected holding time.

Hallocks were put into plastic cannery flats in a random arrangement and stacked with a sheet of plastic loosely placed over each layer to minimize moisture loss in cold storage. Samples were stored at $0^{o} \pm 1^{o}C$ for 48 hr, then moved to $4.4^{o} \pm 1.1^{o}C$ for 48 hr to simulate typical transportation temperatures and maximum time in transit (43, 56). Samples were then held in a $20^{o} \pm 2^{o}C$ display-storage area for up to 72 hr to simulate the typically unrefrigerated display conditions of fresh-market red raspberries (34, 43). Temperatures were monitored in all storage areas with a recording thermograph.

One 25-berry sample from each cultivar or selection was tested at the following times: 1) harvest; 2) when the samples were moved from

4.4°C cold storage to 20°C display-storage (0 hr); and 3) after 12, 24, 48, and 72 hr in display-storage.

Several objective tests were used to measure quality in fresh-marketing of red raspberries. Tests on fresh fruit were berry weight, fruit temperature, percentage of fruits with mold or defects (shriveled, hard, or damaged drupelets), and fruit firmness (measured on the best 20 fruits of the 25-berry sample). Fruit firmness was measured with a Hunter springforce push-pull gauge, vertically mounted on a drill press (10), as modified by Robbins and Sjulin (64). Fruit firmness was measured as cohesion: the force needed to pull the raspberry apart. Samples were then frozen for laboratory analysis at a later date.

Thawed laboratory samples were macerated with a Waring Commercial laboratory blender into a puree. An Altex digital pH meter with a plastic electrode was used to measure pH. Percentage of soluble solids was measured with an Atago hand-held refractometer. Percentage of titratable acidity, figured as citric acid, was measured on a blend of 5 g of puree to 50 ml distilled water, titrated with 0.1 N NaOH to pH 8.2 $\pm$ 0.1 (65, 74).

Anthocyanin concentration was determined by a procedure similar to that recommended by Fuleki and Francis in 1968 (31) and Francis in 1982 (29). To 10 g of puree, 50 ml of a hydrochloric acid-ethanol extraction solvent (15 ml 1.5 N HCl:85 ml 95% EtOH) was added, stirred well, covered for 2 hr, and then centrifuged in an I.E.C. clinical centrifuge at 2575X g for 10 min. The liquid supernatant was decanted into a beaker. The pellet was resuspended in 50 ml of the extraction solvent, stirred for 15 min, and centrifuged at 2575X g for 10 min. This supernatant was added to the previous supernatant and thoroughly mixed. Three milliliters of this mixture was put into a 50-ml volumetric flask, brought up to 50 ml with the extraction solvent, and mixed; absorbance was read on a Varian DMS 80 digital, single-beam spectrophotometer at 533.5 nm (the wavelength of maximum absorption of the cyanidin 3-glucoside pigment) (78).

The determination of anthocyanin concentration was based on Lambert-Beer's law: $A = \varepsilon CL$. A = absorbance; ε = molar extinction coefficient (29,600 [11]); C = molar concentration; and L = pathlength (1 cm). The concentration in milligrams per liter was determined by multiplying by the molecular weight (MW) of cyanidin 3-glucoside (MW = 445.2) and 10^3.

$$C_{(mg/l)} = \frac{A}{\varepsilon L} \times MW \times 10^3$$

The concentration (C) was multiplied by the dilution factor (0.1667 l/g) to convert units to mg anthocyanin/g fruit (82). Results are reported as absorbance at 533.5 nm and in mg anthocyanin / 100 g fruit.

Data were analyzed as a randomized complete block with a 7 (cultivar) by 6 (harvest) by 6 (holding time) factorial arrangement of treatments. Analyses of variance were conducted both years for each variable. Main treatments and interactions were tested at 5% and 1% levels of significance. Means were separated by using LSD method.

Firmness, percentage of fruits with mold, and percentage of fruits with defects were analyzed for all cultivars and selections at all harvests and at all holding times. The remaining quality characteristics, percent soluble solids, pH, percent titratable acidity, and absorbance at 533.5 nm, were analyzed for a select harvest of each cultivar and selection at all holding times. These selective, representative harvests were determined based on previous records of approximate harvest dates when optimal yield, firmness, size, and quality could be obtained.

Results

There were differences among cultivars and selections regarding the quality characteristics tested. Cultivars and selections, when handled similarly, varied in fruit firmness (Fig. 1), percentage of fruits with mold (Fig. 2), and percentage of fruits with defects (Fig. 3).

There were significant ($p<0.01$) differences between harvests regarding fruit temperature at harvest in 1984 and 1985. The range in fruit temperature at harvest was 12.4° to 22.9°C in 1984 and 14.7° to 23.4°C in 1985. Regression analysis of the individual cultivars and selections indicated that the correlation between fruit temperature at harvest and fruit firmness at harvest was not significant. The relationship of fruit temperature with fruit firmness at 0 to 72 hr in display-storage (20°C) was significant ($r=-0.707$, $p<0.01$, $n=60$) (Willamette and Amity cultivars only).

Quality of fruit at harvest changed as the season progressed. There were significant ($p<0.01$) differences in mean berry weight at harvest between both harvests and cultivars. Mean berry weight decreased as the harvest season progressed (Fig. 4; Table 2, Appendix). Mean berry weight was significantly ($p < 0.01$), negatively correlated with harvest number (Table 1).

There were significant differences between cultivars ($p<0.01$), and harvest number ($p<0.05$), with regard to fruit firmness at picking time. In both years, the fruit appeared to be firmest at the third harvest, then decreased in firmness thereafter (Fig. 5). There were significant cultivar by harvest (C·H) and holding time by harvest (T·H) interactions ($p<0.01$, n=252), as well as significant ($p<0.01$) cultivar (C) and harvest (H) main effects (F values 10 times greater than the interactions).

In both years, the percentage of fruits with defects decreased between the first and third harvest, then increased after the third harvest (Fig. 6). There was a significant ($p<0.01$) C·H interaction. In 1985 only, there was a significant ($p<0.01$) T·H interaction and C main effect (F value 10 times greater than interactions). The percentage of fruits with defects was not significantly correlated with harvest number (Table 1).

Percentage of fruits with mold was highest at the last harvest of both years (Fig. 7), but was not significantly correlated with harvest number (Table 1).

There were generally significant ($p<0.05$) interactions between year and holding time (Y·T) with regard to fruit firmness, percentage of fruits with mold, and percentage of fruits with defects for Willamette, Meeker, Chilcotin (firmness only), Nootka (defects only), OR-US 520-48, OR-US 1836 (defects only), and Amity. The difference between years seemed to be especially evident concerning percentage of fruits with mold (Fig. 2, 7, and 11), with 1984 having higher percentage of moldy fruits.

There were significant ($p<0.01$) differences between cultivars regarding both soluble solids (%SS) and titratable acidity (%TA) at harvest. There also appeared to be differences between years regarding %SS (Table 3, Appendix) and %TA (Table 4, Appendix) content. In both years, Chilcotin had the highest %TA and OR-US 1836 had the lowest. There appeared to be a difference between years in cultivar ranking of the %SS to %TA ratio (Table 7, Appendix). Chilcotin had the lowest %SS:%TA ratio both years.

Holding time at 20°C affected many quality characteristics. Fruit firmness generally decreased with increased holding time at retail-display temperature (Fig. 8). Fruit firmness was significantly ($p<0.01$), negatively correlated with storage (holding) time (Table 1). There were significant differences between cultivars ($p<0.01$) and holding times ($p<0.01$), as well as a significant ($p<0.01$) C·T interaction regarding fruit firmness. OR-US 1836 was the firmest and Nootka was the least firm of June-bearing cultivars and selections tested both years. Amity, the fall-fruiting cultivar, was the firmest cultivar in 1984 but not in 1985 (Fig. 9).

Percentage of fruits with defects generally increased with increased holding time at 20°C (Fig. 10). In 1985 there were significant ($p<0.01$) differences between cultivars regarding percentage of fruits with defects. In both 1984 and 1985, there were significant differences ($p<0.01$) between holding times, and a significant ($p<0.01$) C·T interaction, regarding percentage of fruits with defects. Each cultivar or selection showed an increase in percentage of fruits with defects with increased holding time, yet some had a higher percentage of defects than others (Table 5, Appendix). Percentage of fruits with defects was significantly ($p<0.01$) correlated with holding time (Table 1).

Percentage of fruits with mold increased with increased holding time at 20°C (Fig. 11). There were significant ($p<0.01$) differences between cultivars or selections in percentage of fruits with mold in 1984. There was apparently more mold in 1984 than in 1985 (Fig. 2 and 11). In both years, there were significant ($p<0.01$) differences between holding times, and significant ($p<0.01$) C·T and T·H interactions, regarding percentage of fruits with mold. Each cultivar or selection had an increase in percentage of fruits with mold with increased holding time, yet some had a higher percentage of fruits with mold than others (Table 6, Appendix). For most cultivars and selections, mold incidence became noticeable after 12 hr holding time at 20°C (Table 6, Appendix).

Percentage of soluble solids tended to stay the same or increased slightly with increased holding time at 20°C (Fig. 14, Appendix). Although soluble solids were not affected by holding time, there were significant ($p<0.01$) differences between cultivars or selections regarding %SS (Table 3, Appendix). Nootka and Amity had high %SS values, whereas Chilcotin, OR-US 1836 and OR-US 520-48 had lower values.

Percentage of titratable acidity declined with increased holding time at $20^{o}C$ (Fig. 12). In both years, there were significant ($p<0.01$) differences in %TA between holding times, and cultivars. Chilcotin had the highest %TA and OR-US 1836 had the lowest (Table 4, Appendix). Titratable acidity was significantly ($p<0.01$), negatively correlated with storage time (Table 1).

In 1984, Amity had the highest %SS:%TA ratio, but in 1985, Nootka did. In both years, Chilcotin had the lowest (Table 7, Appendix).

There were significant ($p<0.01$) differences in pH between holding times, cultivars, and harvest number. For each cultivar and selection tested, pH generally increased with increased holding time. There was a significant ($p<0.01$) correlation of pH with holding time (Table 1).

Fruit color at picking time (measured by absorbance) was significantly ($p<0.05$) different between harvests. All cultivars and selections darkened with increased holding time at $20^{o}C$ (Fig. 13). OR-US 1836 appeared the least prone to darken throughout holding time at $20^{o}C$ compared to all other cultivars and selections. There were significant ($p<0.01$) differences between holding times, and cultivars, regarding absorbance at 533.5 nm. Willamette, Nootka, and Amity had the darkest fruit (the highest anthocyanin content [Table 8, Appendix]) as compared to OR-US 1836 or Chilcotin which appeared lighter and brighter. Absorbance at 533.5 nm was significantly ($p<0.01$) correlated with storage (holding) time (Table 1).

Discussion

Because cultivars behaved differently when handled identically in a simulated fresh-market situation, this study has documented the importance of choosing optimal cultivars for fresh market. Consideration for optimal quality, and the factors which affect it, is necessary throughout the marketing process.

Weather conditions at harvest play an important role in fresh-market quality (32, 63, 81). Results of this study indicated that fruit temperature at harvest was not significantly correlated with fruit firmness at harvest. Yet when fruit temperature at 0 to 72 hr in display-storage was correlated with fruit firmness in display-storage, the correlation was negative and significant. This negative correlation was not only because of the higher temperatures at display, but also because fruit with a higher temperature at harvest respires more rapidly (33, 42, 75) and therefore would have a shorter shelf life. Lewis (48) and Kenny (42) found that the temperature history of the fruit dictates subsequent shelf life.

The fungicidal pest management program was similar in both 1984 and 1985. The climate, however, in the 1984 and 1985 harvest seasons were very different (cool and wet in 1984; hot and dry in 1985). The effects of these climatic differences were especially evidenced in percentage of fruits with mold. The higher percentage of fruits with mold in the cool, wet 1984 harvest season are in agreement with previous studies reporting that cool, wet conditions favor plant infection (15, 35, 42, 50, 63, 81). Additional care in harvesting, handling, and temperature maintenance may be necessary in cool, wet harvest seasons.

Fruit quality generally decreases as the season progresses (68, 70). The results of this research are in agreement with other studies regarding a decline in berry weight (38, 70), fruit firmness (37, 70), and color (70), and an increase in percentage of fruits with mold (26, 27, 43, 61, 75) as the season progressed.

The peak harvest and duration of the fruit ripening season is dependent on which cultivar or selection is grown. Willamette was the earliest and OR-US 1836 was the latest of the June-bearing cultivars and selections. Although fruit generally appeared firmest at the third harvest, the differences among cultivars and selections changed as the harvest season progressed (C·H interaction, $p<0.01$). These differences were probably because of peak-season differences (Willamette vs. OR-US 1836) or similarities (Meeker, Chilcotin, Nootka) among cultivars and selections. This also may have resulted because of differences among cultivars and their ability to maintain firm fruit as the season progressed. Cultivars that maintain firmer fruit (OR-US 1836, Amity, Meeker) throughout the harvest season would be best suited for fresh market.

Generally, the percentage of fruits with defects increased after the third harvest. The differences between cultivars or selections were not consistent as the harvest season progressed (C·H interaction, $p<0.01$). This could have resulted because of peak-season differences. Regardless, cultivars and selections were different in their susceptibility to defects. At the third harvest, most cultivars and selections produced a high yield with a low percentage of defective fruits. Yet, as the season progressed and there had been more handling, differences in susceptibility to defects among cultivars and selections became more obvious.

The percentage of fruits with mold increased as the season progressed, agreeing with previous studies (26, 27, 43, 61). This could be because molds develop and are more easily spread in unsound fruit, which is more prevalent later in the season (15, 27, 35, 42, 75), providing plenty of inoculum for further infections (27). This could also be because of changes in the prevailing weather conditions as the harvest season progressed. Warmer temperatures and frequent irrigation can create an environment which favors fruit rot development (7, 35, 42).

Although recommended display temperatures for fresh-market red raspberries are 0° to 10°C (48), red raspberries are typically displayed without refrigeration (34, 43). The longer the fruit was held at retail-display temperature (20°C), the greater the loss of quality; demonstrating the deleterious effect of higher temperatures and storage time on quality of fresh-market red raspberries.

Fruit firmness is important to consumers for both texture (3, 12) and appearance (68); sunken, soft fruit is likely to be rejected. Varseveld and Richardson (79) found that red raspberries show an increase in fruit firmness in the beginning of cold storage, then decrease in fruit firmness with increased holding time. Our data showed the same trend. Fruit firmness generally decreased with increased holding time at 20°C, agreeing with previous studies (61, 69, 79). Fruit firmness was different among cultivars, and between holding times. However, the differences among cultivars changed with increased holding time at 20°C (C·T interaction, $p<0.01$). This change may have resulted because two cultivars, which at harvest were similarly firm (such as Meeker and OR-US 1836), did not maintain firmness similarly with increased holding time at 20°C (OR-US 1836 maintained greater firmness than Meeker). Thus the differences between the two cultivars became more pronounced with increased holding time. A similar but opposite change was observed with OR-US 520-48 and Meeker (Fig. 8).

All cultivars and selections showed an increase in percentage of fruits with defects with increased holding time at 20°C. However, because defects play such an important role in consumer rejection of fresh-market red raspberries (3, 33, 48), data indicating significant differences between cultivars are useful. The differences among cultivars changed over time in display-storage (C·T interaction, $p<0.01$). At harvest time and through 0 hr in display-storage, most cultivars did not differ greatly regarding defects. As time in display-storage increased, softer cultivars (such as Chilcotin and OR-US 520-48) had a higher percentage of defects, and increased at an apparent faster rate, than firm-fruited cultivars (such as OR-US 1836) (Table 5, Appendix).

The length of time fresh-market red raspberries can be stored is primarily limited by mold growth (27). All cultivars and selections tested showed no symptoms of mold at harvest, in cold storage, and through 12 hr in display-storage. In agreement with Johnson (37), Topping (77), Varseveld and Richardson (79), and Winter and Alderman (81), all cultivars and selections showed an increase in mold incidence with increased holding time at display-storage temperature. The significant differences among cultivars agreed with the work of Daubeny & Pepin (25). By 72 hr in display-storage, the difference between two firm cultivars, Amity and OR-US 1836, had increased (Table 6, Appendix). This difference may have been due to the cool and often damp harvest conditions in late August (for Amity), versus the hot, dry conditions in July (for OR-US 1836).

The stability or slight increase in %SS observed with increased time in display-storage was in agreement with observations of Varseveld and Richardson (79). The increase was probably moisture loss, producing an apparent increase in soluble solids.

Titratable acidity declines as raspberries ripen (51, 52, 53, 70). The same decrease occurred with increased holding time at 20°C, probably because of acids used during postharvest respiration. Mason (54) found that titratable acids were stable at 5°C, but decreased at 22°C. The same trend was apparent in this study, where most cultivars and selections showed the greatest decrease in titratable acidity at 20°C.

Sjulin and Robbins (70) and Mason (51) found that pH increases as raspberries ripen. An increase in pH occurred with increased holding time at 20°C in this study, with significant ($p<0.01$) differences between cultivars and between holding times.

Sistrunk and Moore (68) state that "perceived sweetness" is one way consumers judge quality of fruits. This property is based on the ratio of soluble solids to acids. In this study, Chilcotin and OR-US 1836 were similarly low in %SS (Table 3, Appendix). However, Chilcotin had higher %TA than OR-US 1836 (Table 4, Appendix), and thus a lower %SS:%TA ratio (Table 7, Appendix). Consequently, Chilcotin would not be perceived as sweet as OR-US 1836 by consumers.

Although all fruits in this study were harvested at the light-red ripe maturity stage, the actual color observed was dependent on the cultivar or selection sampled. As found in other studies (18, 67, 70), the cultivars Willamette and Nootka had darker fruit than Chilcotin or Meeker.

Fruit color is important in fresh-market red raspberries (43, 47, 61, 70, 79). All red raspberries darken during storage (61, 67, 69, 70, 73, 79), and darkening was observed in this study. Yet, there were significant ($p<0.01$) differences between cultivars, and between holding times, regarding absorbance at 533.5 nm. The results of this study agreed with the findings of Sjulin and Robbins (70) on the rapid darkening of Willamette and Nootka, which darkened apparently faster than Chilcotin or OR-US 1836. Cultivars and selections least prone to darken rapidly are best suited for the fresh market (18).

Conclusion

Five cultivars and two numbered selections of red raspberries were handled similarly to simulate typical handling, transportation temperatures, and retail-display temperatures found in fresh marketing of red raspberries. Storage time effects on the subsequent quality and shelf life were explored, and the cultivars and selections tested were compared. All cultivars and selections decreased in fruit firmness and %TA, but increased in color intensity, defects, mold incidence, and slightly in %SS with increased holding time at 20°C.

Considering the three most important quality characteristics in fresh-market red raspberries (color, taste, and firmness [61, 70, 79]), the results of this study indicated the cultivar Meeker, the selection OR-US 1836, and the cultivar Amity were the best suited, of all tested, for fresh-market sales. With proper harvesting, handling, and temperature management, the choice of these cultivars could provide an extensive season (June-September) of high quality fresh-market red raspberries.

Consumers in developed countries have established levels of food acceptability (12, 68) and have become accustomed to the availability of the highest quality fresh produce. To develop the Pacific Northwest fresh-market red raspberry industry, the industry must address problems such as consistency of supply (13, 47, 67), length of the season (67), cultivar suitability, and the changes in harvest and handling practices necessary to attain fresh-market quality. This study has addressed some of these problems. Further research will be needed on fresh-market red raspberry cultivar development, packaging and handling, and the advantage or necessity of refrigerated retail-display.

The potential expansion of both local and long distance sales of fresh red raspberries is considered untapped (14, 19, 57, 67). Proper handling and optimal temperature management of the best-suited fresh-market red raspberry cultivars are essential in meeting this potential.

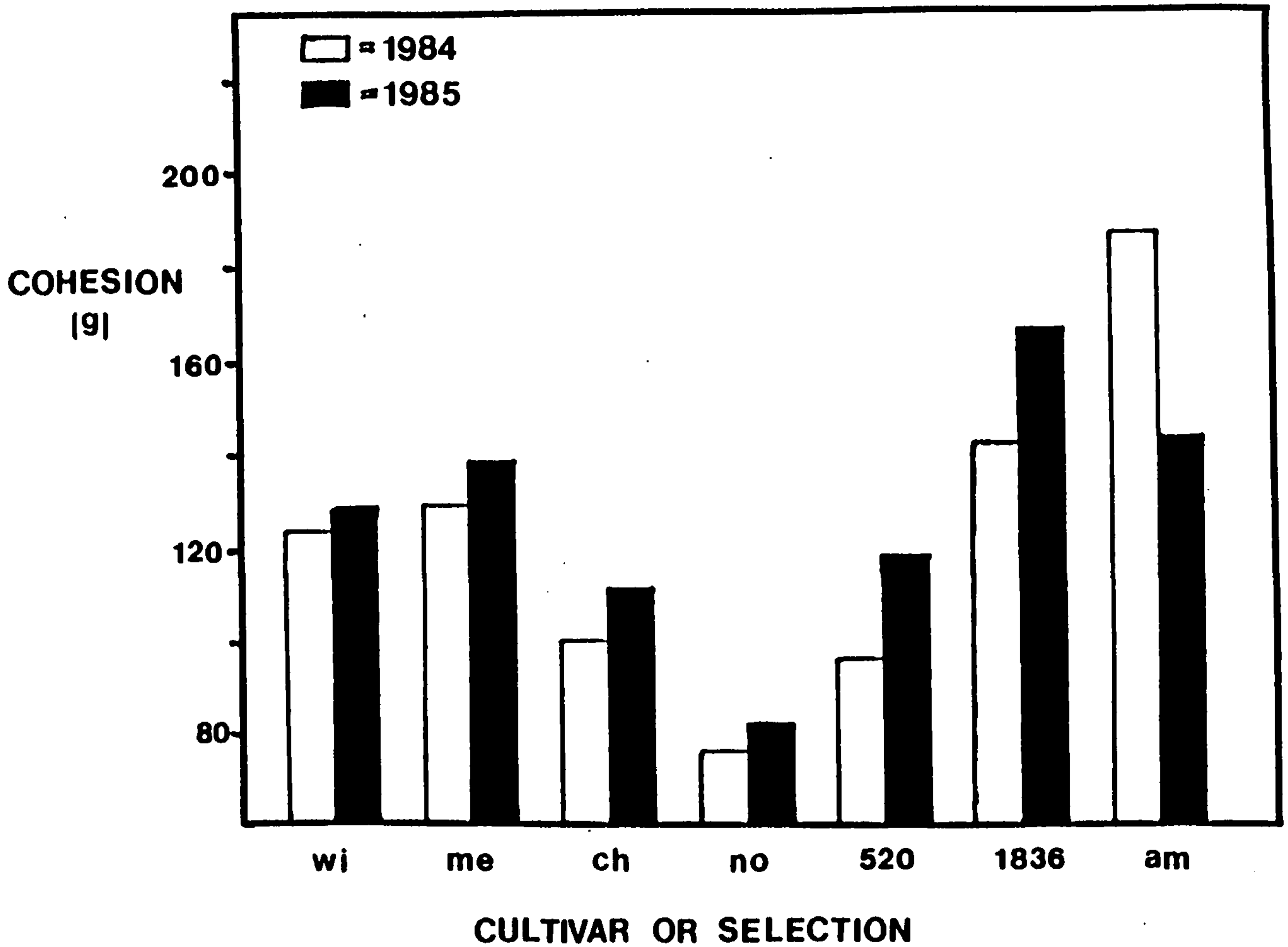


Figure 1. Fruit firmness (measured as cohesion) of five cultivars and two selections of red raspberries (averaged over all harvests and holding times). wi = Willamette, me = Meeker, ch = Chilcotin, no = Nootka, 520 = OR-US 520-48, 1836 = OR-US 1836, and am = Amity.

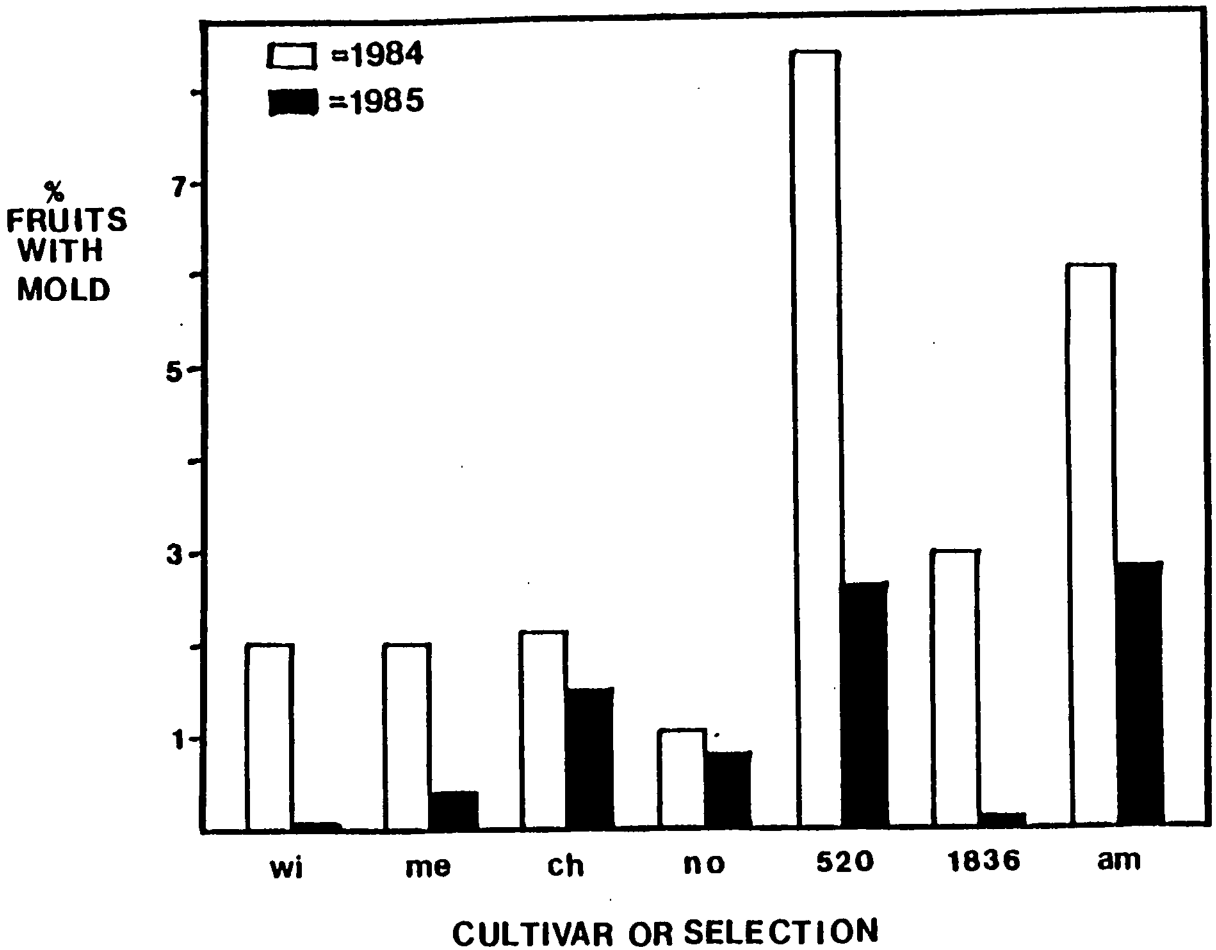


Figure 2. Percentage of fruits with mold of five cultivars and two selections of red raspberries (averaged over all harvests and all holding times). wi = Willamette, me = Meeker, ch = Chilcotin, no = Nootka, 520 = OR-US 520-48, 1836 = OR-US 1836, and am = Amity.

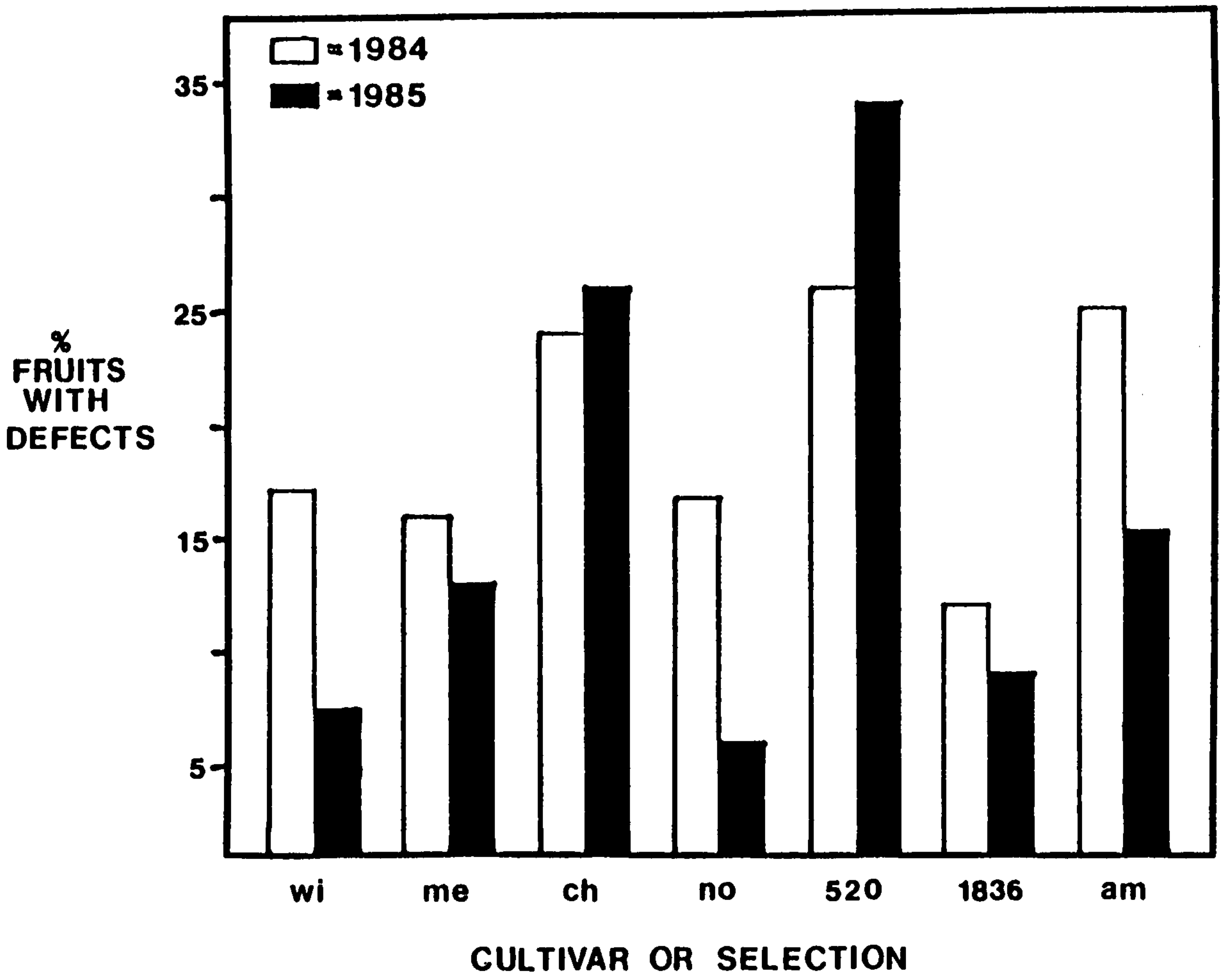


Figure 3. Percentage of fruits with defects of five cultivars and two selections of red raspberries (averaged over all harvests and all holding times). wi = Willamette, me = Meeker, ch = Chilcotin, no = Nootka, 520 = OR-US 520-48, 1836 = OR-US 1836, and am = Amity.

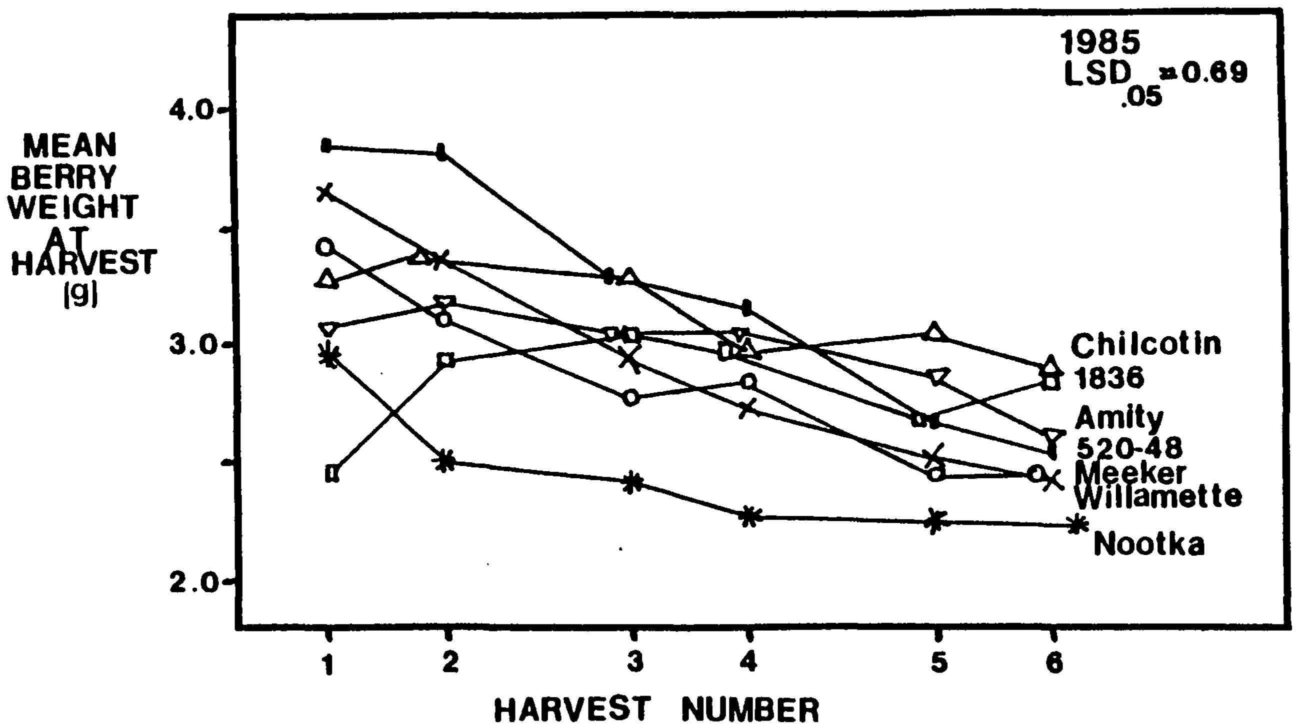


Figure 4. The change over the season in mean berry weight at harvest of five cultivars and two selections of red raspberries.

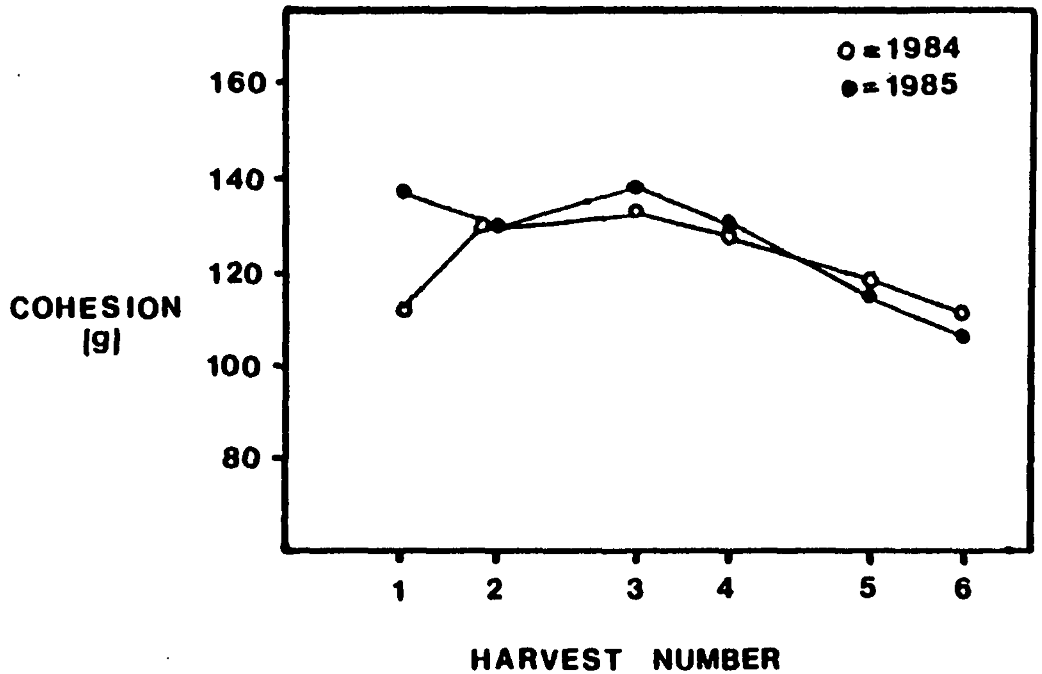


Figure 5. The change over the season in fruit firmness (measured as cohesion) of five cultivars and two selections of red raspberries (averaged together over all holding times).

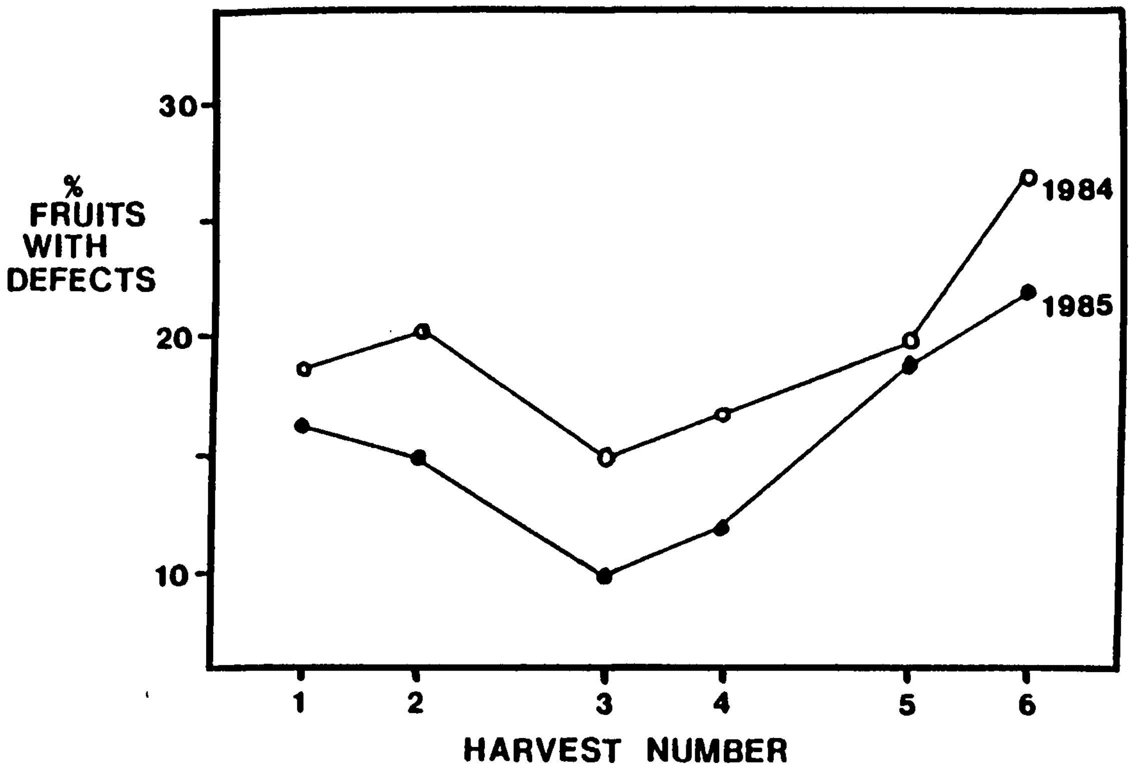


Figure 6. The change over the season in percentage of fruits with defects of five cultivars and two selections of red raspberries (averaged together over all holding times).

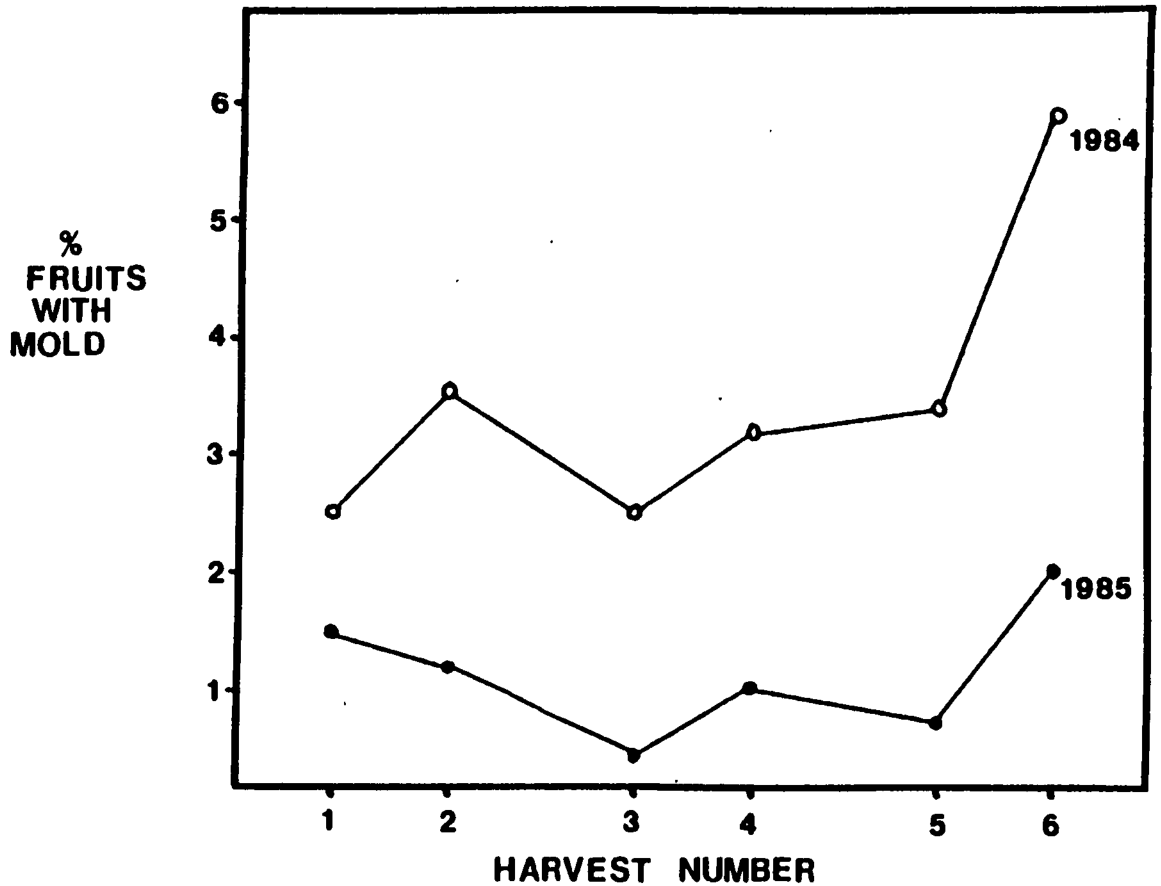
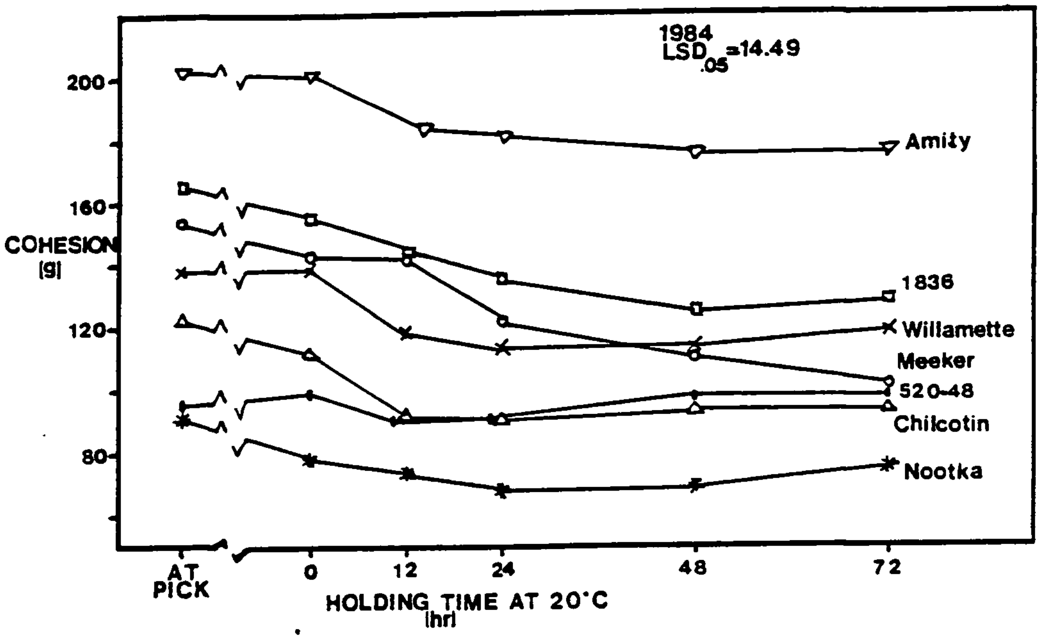


Figure 7. The change over the season in percentage of fruits with mold of five cultivars and two selections of red raspberries (averaged together over all holding times).



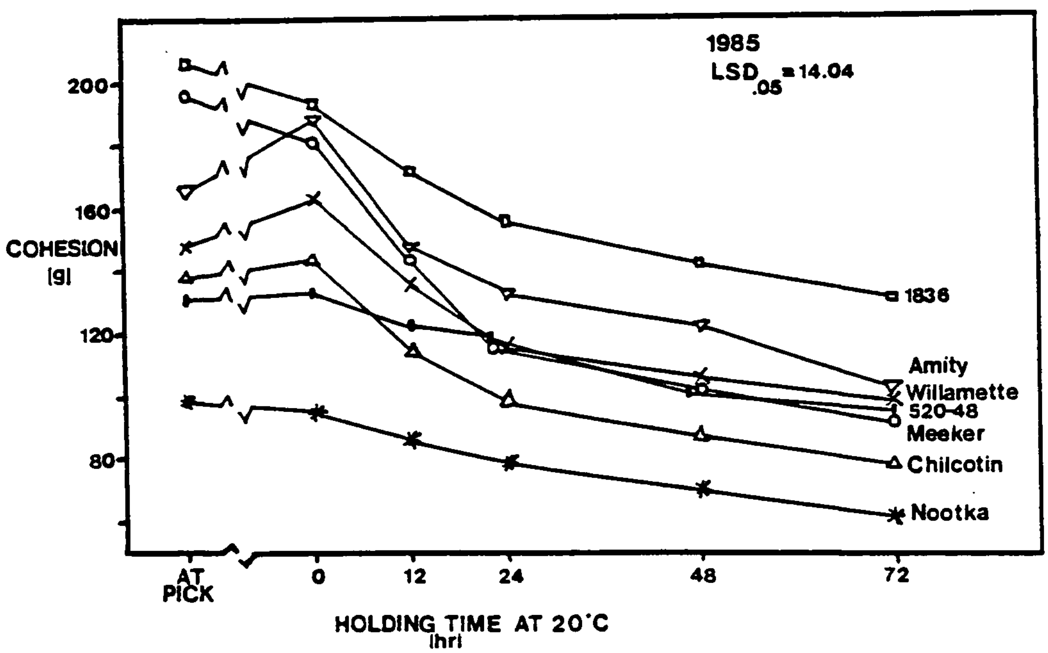


Figure 8. The effect of holding time at 20°C on the fruit firmness (measured as cohesion) of five cultivars and two selections of red raspberries (averaged over all harvests) in 1984 (top) and 1985 (bottom).

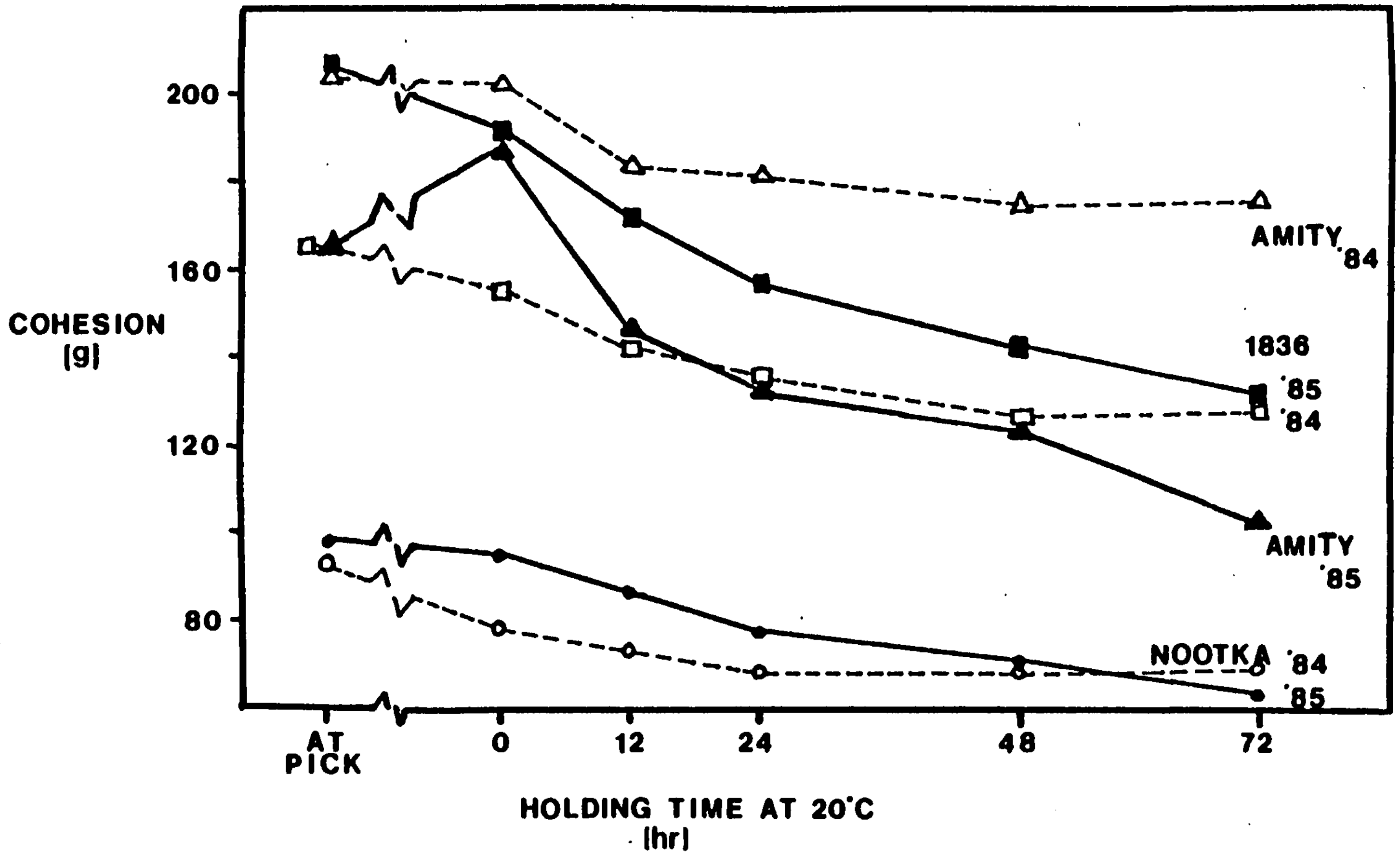


Figure 9. The effect of holding time at 20°C on the fruit firmness (measured as cohesion) of the least firm and the two firmest cultivars and selections of red raspberries tested (averaged over all harvests).

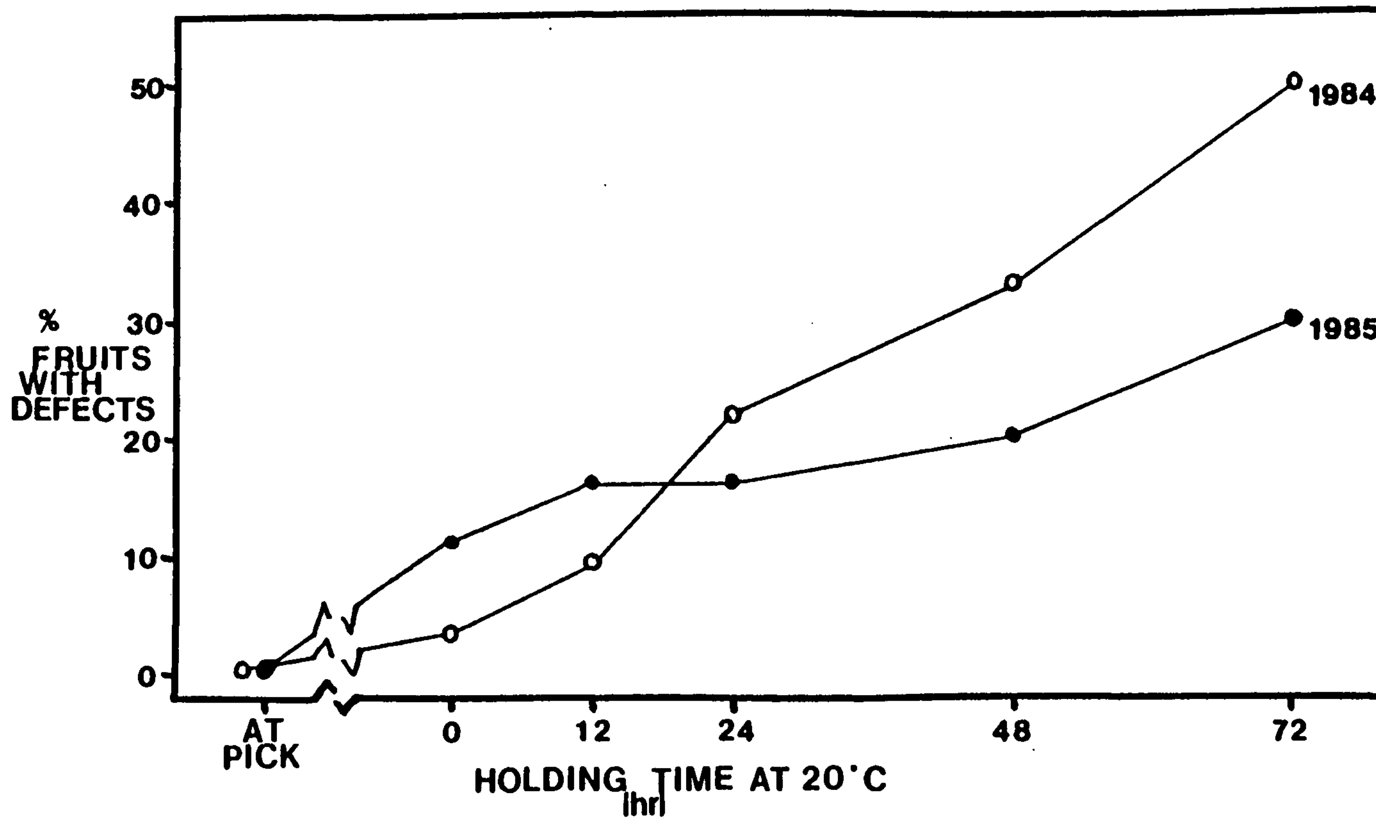


Figure 10. The effect of holding time at 20°C on the percentage of fruits with defects of five cultivars and two selections of red raspberries (averaged together over all harvests).

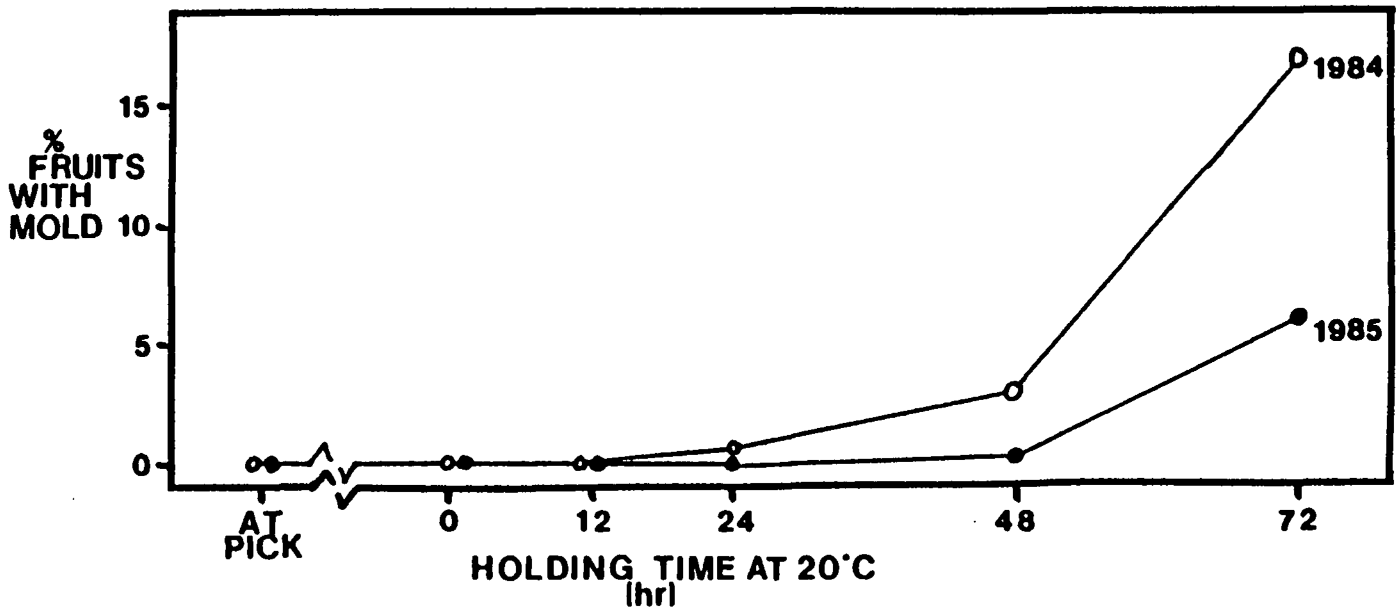


Figure 11. The effect of holding time at 20°C on the percentage of fruits with mold of five cultivars and two selections of red raspberries (averaged together over all harvests).

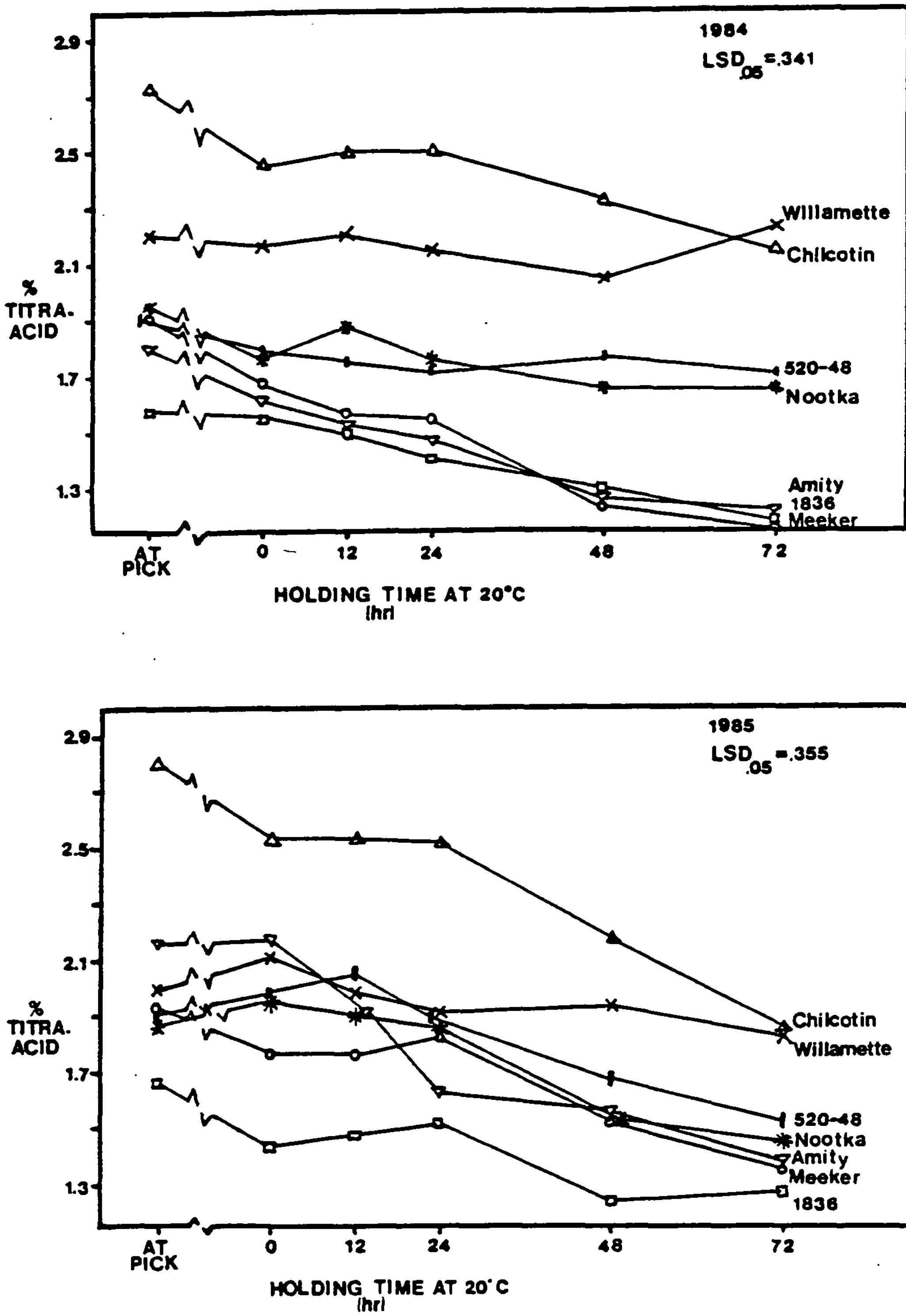


Figure 12. The effect of holding time at 20°C on the titratable acidity of a selective, representative harvest of five cultivars and two selections of red raspberries in 1984 (top) and 1985 (bottom).

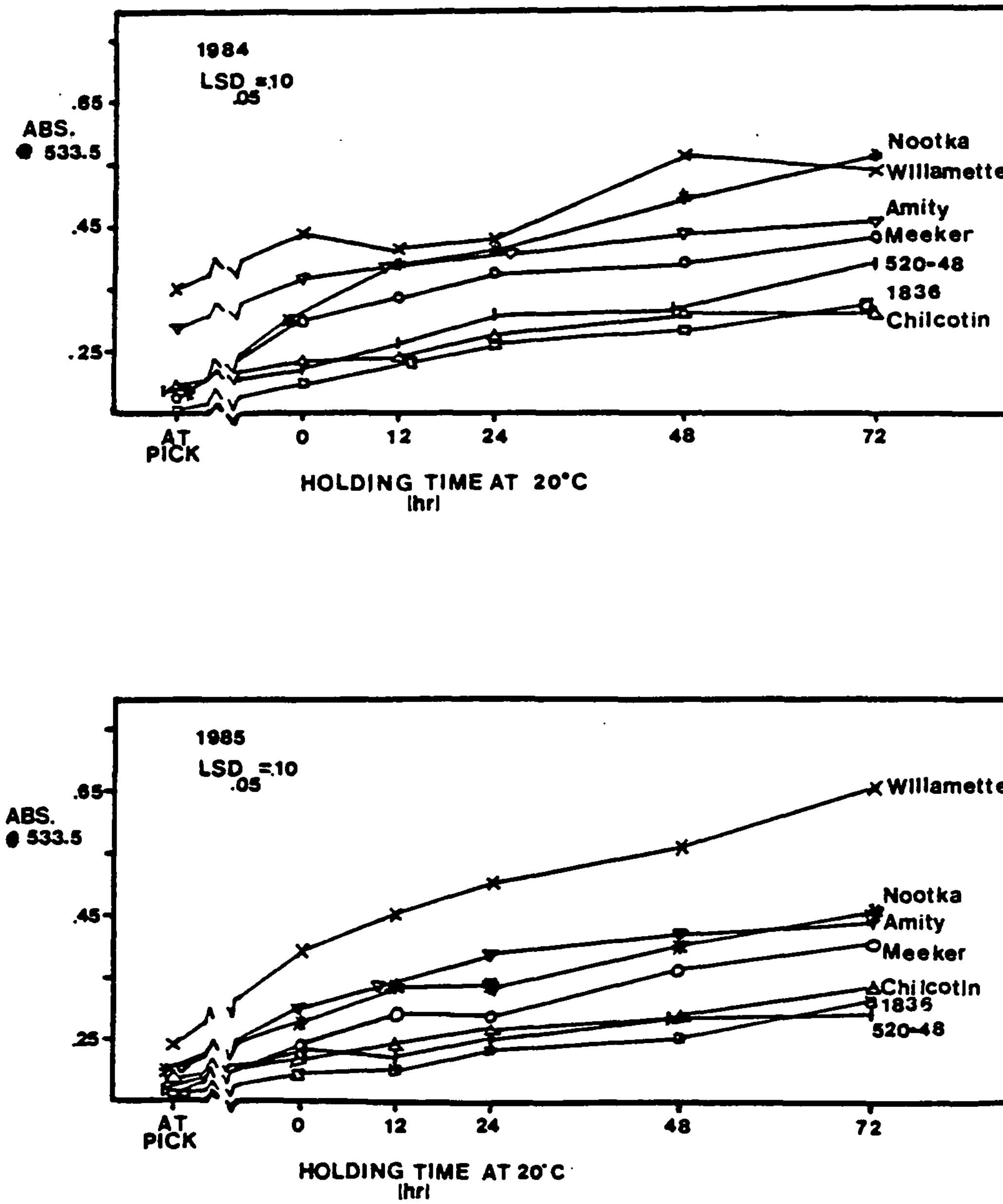


Figure 13. The effect of holding time at 20°C on the color (measured by absorbance at 533.5 nm) of a selective, representative harvest of five cultivars and two selections of red raspberries in 1984 (top) and 1985 (bottom).

Table 1. Regression analysis of the effect of harvest number or storage time on fresh-market quality in 1985.

	n	r	R^2	Regression Equation
Harvest Number vs.				
firmness	252	-0.25 **[3]	.06	y = 147.45 - 5.84x
% defects[1]	252	0.11 ns	.01	y = 11.87 + 1.18x
% mold[2]	252	0.02 ns	.01	y = 0.99 + 0.05x
fruit temperature	42	0.31 *	.09	y = 63.94 + 0.59x
mean berry weight	42	-0.63 **	.40	y = 3.43 - 0.15x
Storage Time vs.				
firmness	252	-0.57 **	.32	y = 160.60 - 13.43x
% defects	252	0.47 **	.22	y = 3.66 + 4.93x
% mold	252	0.38 **	.14	y = -1.29 + 0.99x
pH	42	0.76 **	.58	y = 3.04 + 0.06x
% T.A.	42	0.51 **	.26	y = 2.10 - 0.11x
Abs. @ 533.5	42	0.66 **	.44	y = 0.19 + 0.05x

[1] % defects = percentage of fruits with defects

[2] % mold = percentage of fruits with mold

[3] Significant differences at .05(*) or .01 (**) level.
ns = nonsignificant

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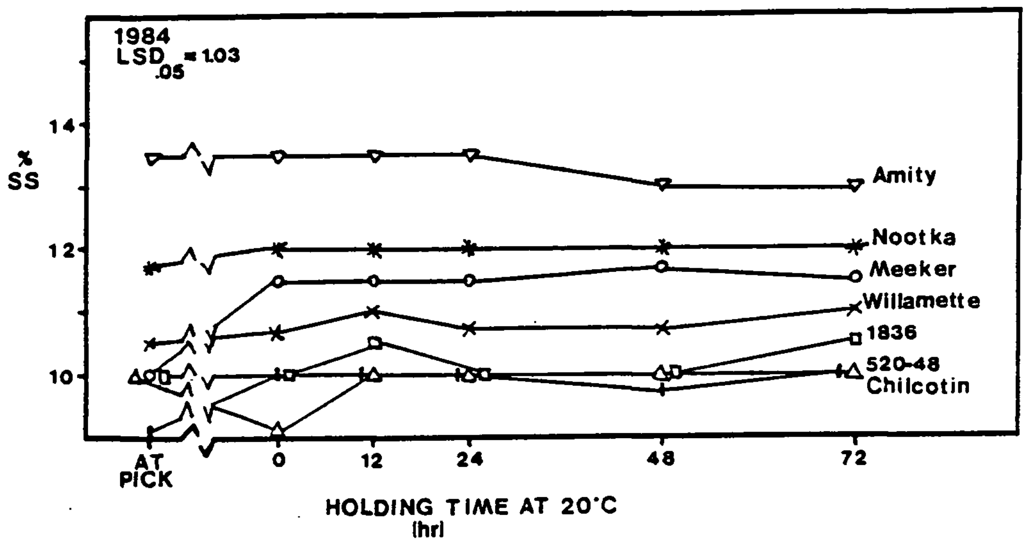
APPENDIX



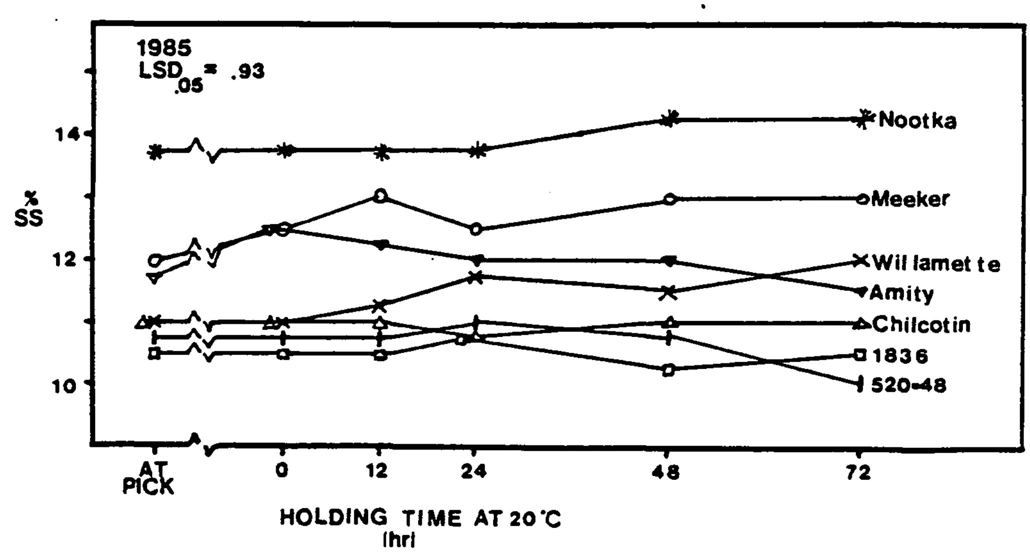


Figure 14. The effect of holding time at 20°C on the soluble solids of a selective, representative harvest of five cultivars and two selections of red raspberries in 1984 (top) and 1985 (bottom).

Table 2. Mean berry weight at harvest of five cultivars and two selections of red raspberries.

Cultivar or Selection	Year	Mean berry wt. in grams — Harvest Number 1	2	3	4	5	6
Willamette	1984[1]	3.92	2.66	3.14	2.94	2.60	2.75
	1985[2]	3.67	3.36	2.93	2.76	2.53	2.44
Meeker	1984	3.68	3.36	3.20	3.06	2.75	2.76
	1985	3.42	3.10	2.79	2.86	2.47	2.48
Chilcotin	1984	3.74	3.44	3.54	3.47	3.40	3.73
	1985	3.27	3.38	3.28	2.98	3.03	2.90
Nootka	1984	3.20	2.98	2.68	2.53	2.28	2.31
	1985	2.99	2.50	2.41	2.29	2.27	2.24
OR-US 520-48	1984	3.70	3.82	3.82	3.91	3.22	3.01
	1985	3.85	3.81	3.27	3.17	2.69	2.54
OR-US 1836	1984	2.92	2.58	3.24	3.23	3.24	3.26
	1985	2.46	2.91	3.02	2.93	2.69	2.83
Amity	1984	3.76	3.68	3.46	3.52	3.08	3.26
	1985	3.08	3.19	3.07	3.08	2.75	2.55

[1] 1984 $LSD_{.05}$ = 0.80

[2] 1985 $LSD_{.05}$ = 0.69

Table 3. Percentage of soluble solids of five cultivars and two selections of red raspberries at a selective, representative harvest in 1984 and 1985.

1984		1985	
Cultivar or Selection	% SS[1]	Cultivar or Selection	% SS
Amity	13.33 a[2]	Nootka	13.90 a[3]
Nootka	11.95 b	Meeker	12.67 b
Meeker	11.28 bc	Amity	12.00 bc
Willamette	10.76 bcd	Willamette	11.42 bcd
OR-US 1836	10.17 bcde	Chilcotin	10.95 bcde
Chilcotin	9.78 bcde	OR-US 520-48	10.63 bcde
OR-US 520-48	9.78 bcde	OR-US 1836	10.50 bcdef

[1] Values represent the average of 6 holding times

[2] 1984 Means separated using LSD at .05 level = 0.421

[3] 1985 Means separated using LSD at .05 level = 0.376

Table 4. Percentage of titratable acidity of five cultivars and two selections of red raspberries at a selective, representative harvest in 1984 and 1985.

1984		1985	
Cultivar or Selection	% TA[1]	Cultivar or Selection	% TA
Chilcotin	2.45 a[2]	Chilcotin	2.41 a[3]
Willamette	2.17 b	Willamette	1.96 b
OR-US 520-48	1.78 bc	OR-US 520-48	1.84 b
Nootka	1.78 bc	Amity	1.80 bc
Meeker	1.49 bcd	Nootka	1.76 bc
Amity	1.48 bcd	Meeker	1.70 bc
OR-US 1836	1.43 bcd	OR-US 1836	1.43 bcd

[1] Values represent the average of 6 holding times

[2] 1984 Means separated using LSD at .05 level = 0.139

[3] 1985 Means separated using LSD at .05 level = 0.145

Table 5. The percentage of fruits with defects of five cultivars and two selections of red raspberries at picking time and after 0 to 72 hr holding time at 20°C.

Cultivar or Selection	Year	Percentage of fruits with defects[1]					
		At Pick	Holding time at 20°C (hr) 0	12	24	48	72
Willamette	1984[2]	0.00	0.00	0.00	12.50	36.67	53.33
	1985[3]	0.00	4.67	4.67	8.00	11.33	16.67
Meeker	1984	0.00	0.00	0.00	18.33	32.50	46.67
	1985	0.00	13.33	13.33	14.67	16.00	23.33
Chilcotin	1984	0.00	5.00	15.00	32.67	38.33	56.67
	1985	4.00	16.67	29.33	31.33	31.33	43.33
Nootka	1984	0.00	8.33	11.67	18.00	25.83	36.67
	1985	0.00	4.67	6.00	6.67	8.67	9.33
OR-US 520-48	1984	0.00	5.00	14.67	32.00	44.17	61.67
	1985	1.33	31.33	44.00	30.67	37.67	62.66
OR-US 1836	1984	0.00	0.00	3.33	15.83	24.17	30.83
	1985	0.00	10.00	12.00	10.00	10.00	14.00
Amity	1984	0.00	6.67	15.83	25.83	34.17	67.50
	1985	0.00	2.67	7.33	14.67	26.00	42.00

[1] Values represent the average of 6 harvests

[2] 1984 $LSD_{.05}$ = 11.27

[3] 1985 $LSD_{.05}$ = 9.23

Table 6. The percentage of fruits with mold of five cultivars and two selections of red raspberries after 24, 48, and 72 hr holding time at 20°C.

Cultivar or Selection	Year	Percentage of fruits with mold[1] — Holding time at 20°C (hr.)[2] 24	48	72
Willamette	1984[3]	0.00	0.00	12.17
	1985[4]	0.00	0.00	0.00
Meeker	1984	0.00	0.00	12.17
	1985	0.00	0.00	2.67
Chilcotin	1984	0.00	3.33	10.00
	1985	0.00	0.00	9.33
Nootka	1984	0.00	0.00	6.67
	1985	0.00	0.67	4.00
OR-US 520-48	1984	2.50	9.17	38.33
	1985	0.00	0.67	15.33
OR-US 1836	1984	2.50	5.00	10.00
	1985	0.00	0.00	0.67
Amity	1984	0.00	5.33	30.83
	1985	0.67	0.67	15.33

[1] Values represent the average of 6 harvests

[2] There was no mold present each year until after 12 hour holding time at 20°C.

[3] 1984 $LSD_{.05}$ = 5.80

[4] 1985 $LSD_{.05}$ = 3.12

Table 7. The ratio of soluble solids to titratable acids (%SS:%TA) of five cultivars and two selections of red raspberries at a selective, representative harvest in 1984 and 1985.

1984		1985	
Cultivar or Selection	%SS : %TA[1]	Cultivar or Selection	%SS : %TA
Amity	9.01	Nootka	7.90
Meeker	7.57	Meeker	7.47
OR-US 1836	7.11	OR-US 1836	7.37
Nootka	6.71	Amity	6.71
OR-US 520-48	5.49	Willamette	5.83
Willamette	4.96	OR-US 520-48	5.78
Chilcotin	3.99	Chilcotin	4.54

[1] Values represent the average of 6 holding times

Table 8. Anthocyanin concentration, expressed as cyanidin 3-glucoside, of a selective, representative harvest of five cultivars and two selections of red raspberries at picking time and after 0 to 72 hr holding time at 20°C.

		Anthocyanin concentration in mg/100g fruit							
			Holding time at 20°C (hr.)						
Cultivar or Selection	Year	At Pick	0	12	24	48	72	% Change[1]	% Change[2]
Willamette	1984	87.75	110.07	100.54	108.31	142.16	134.64	53	22
	1985	61.68	99.79	113.08	126.87	141.66	167.23	171	68
Meeker	1984	42.62	77.47	82.74	90.76	97.78	110.82	160	43
	1985	32.34	61.18	71.71	70.45	91.77	102.05	216	67
Chilcotin	1984	48.64	60.42	60.93	69.20	77.97	78.23	61	29
	1985	44.63	55.41	61.18	65.19	70.20	83.74	88	51
Nootka	1984	44.88	74.72	96.28	104.30	125.86	141.91	216	90
	1985	48.39	69.45	83.74	86.25	101.54	115.33	138	66
OR-US 520-48	1984	43.38	56.41	65.44	75.96	79.48	99.04	128	76
	1985	36.36	56.91	56.41	63.43	71.21	76.72	111	35
OR-US 1836	1984	38.61	52.40	57.92	64.69	70.70	80.48	108	54
	1985	33.60	48.64	51.15	60.42	64.94	80.48	140	65
Amity	1984	71.96	91.01	94.77	104.05	112.33	113.33	57	25
	1985	50.90	73.21	86.50	96.28	104.55	111.82	120	53

[1] The percentage of change in anthocyanin concentration from "at pick" to 72 hour holding time at 20°C
[2] The percentage of change in anthocyanin concentration from 0 to 72 hour holding time at 20°C