MODIFICATION OF THE INCIDENCE OF SURFACE DAMAGE SYMPTOMS IN SWEET CHERRIES BY PRE- AND POSTHARVEST TREATMENTS

by

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ABSTRACT

The prevention of storage disorders in sweet cherries resulting from mechanical damage was investigated. Pre- and postharvest treatments were applied to modify fruit texture, fruit composition and fruit desiccation in storage. The effects of the treatments applied were related to fruit susceptibility to the incidence of fruit bruises, surface markings and surface pitting. The application of calcium in the form of preharvest sprays or postharvest dips decreased mechanical damage expression. Warm fruit was less susceptible to mechanical injury than cold fruit early in the storage period but fruit temperature had little effect after 8 days of cold storage. Similarly, high storage temperatures enhanced pitting development early in the storage life but storage temperatures had negligible effect after 8 days. A delay in $0^{o}C$ storage prior to bruising greatly reduced the susceptibility of cherries to mechanical injury. Fruit was most resistant to mechanical damage after 8 days in $0^{o}C$. The development of fruit symptoms in response to impact was enhanced by rough surfaces. Slowly applied compressive forces resulted in low incidences of injury symptoms. Fruit firmness and bioyield values were increased with mesocarp calcium from preharvest sprays and postharvest dips, but did not show consistent relationships to the susceptibility of fruit to mechanical damage. Weight loss enhanced by low relative humidity increased the rate of development of damage but did not influence the total damage incidence. Soaking fruit in water or fungicide solution increased damage expression in storage. Less

mature and intermediate maturity fruit were more susceptible to mechanical injury than were the most mature fruit. Fruit with relatively high alcohol insoluble solids content associated with preharvest gibberellic acid sprays or advanced maturity fruit had reduced susceptibility to mechanical damage. Large fruit was less susceptible to mechanical damage and had higher alcohol insoluble solids content than did small fruit. High levels of fruit nitrogen were associated with high susceptibility to mechanical damage.

A great many factors were found to modify fruit susceptibility to surface disorders resulting from mechanical damage. This provides a great flexibility to producers and marketing agents to minimize fruit losses due to the effects of rough handling.

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To my wife Carole and daughter Amanda

who have suffered.

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INTRODUCTION

Market Losses Due to Poor Fruit Quality

Claims by wholesalers and retailers against fresh cherries grown in British Columbia have risen to significant proportions in the last 5 years of cherry marketing. The claims have amounted to 1.55 million dollars over the last 5 crop years. Reductions of grower returns since 1974 due to claims resulting from poor fruit quality, have ranged from a low of 3.3% in 1977 to a high of 26.6% in 1976 (Table 1). These percentage claim figures are important when considered as increased production costs or reduced grower returns of 7.7, 10.7, 11.1, 1.9, and 7.3¢/kg through the crop years of 1974 to 1978. Continuing poor fruit quality will lower consumer confidence and increase the resistance of wholesalers to purchase cherries grown in British Columbia. In addition to direct losses due to damage claims the market dollar loss due to declining consumer preference for British Columbia cherries in incalculable. Also poor product quality early in a particular market year prevents price increases during mid and latter part of the season, further depressing returns to the grower. Continuing reductions in the annual 4 million dollar return from fresh cherries can be anticipated unless the causes of poor fruit quality are identified and remedied.

Factors Affecting Sweet Cherry Fruit Quality

Poor appearance of the fruit due to the high incidence of surface disorders apparently caused by mechanical damage is a major cause of market discontent. Symptoms of rough handling may be observed as surface pitting (Fig. 1) (66, 70) or flattened bruises (18). Surface pitting and bruising can be caused by mechanical damage and are associated with pressure or impact forces (18, 39, 61, 70, 71). Bruises are flattened surfaces on the cherry generally accompanied by tissue discoloration underlying the point of damage (61). Fruit bruises are apparent immediately after impact but surface pitting may not be visible externally for several days after damage has occurred and will develop readily in storage.

Surface pitting or dimpling appears as one or more irregular depressions on the surface of the fruit and often develops in cold storage (Fig. 1). Cellular examination of the depression reveals interior layers of injured cells while the cells in the cherry epiderm and hypoderm are unaffected but have collapsed inward (Fig. 2) (2, 70).

Cherry surface pitting appears after the fruit has been picked and placed in cold storage for a period of 3 to 21 days (M. Patterson, WSU, Pullman, Washington, unpublished results). The disorder appears in cold storage but incipient symptoms can be detected by microscopic examination in freshly harvested bruised fruit (N. Wade, CSIRO, Australia, unpublished data). Whereas damage to apple is apparent as discolored bruises, when cherries are injured pitting occurs but tissue

discoloration is masked by the red pigment. The injury which induces the pitting occurs at all stages of cherry handling (71). The damage sustained by the cherry will accumulate through the procedures of picking, sorting, packing and shipping. In years of high susceptibility to pitting, some fruit lots sorted and packed with mechanical aids have had greater than 60 percent severe pitting (26).

Factors Affecting Fruit Susceptibility to Surface Disorders Resulting From Mechanical Damage

The incidence of cherry pitting varies among crop years (Fig. 3) among cultivars and among trees (70). Fig. 3 indicates that yearly fluctuations in crop production are closely correlated with the estimated fruit susceptibility to surface pitting. The 1973 crop year was an outstanding exception to the general rule with a very high crop production but resistance to surface pitting. However, the weather conditions in 1973 were very favorable for cherry production and may have provided the cherry crop with a resistance to surface pitting. Fig. 3 suggests that some of the yearly fluctuations in pitting susceptibility may be associated with varying crop yields. This relationship may explain noticeable grower, tree, and lot variations where differences in crop production or percentage of the total crop is apparent.

There are a number of associated factors involved with high incidences of surface pitting in years of large crops. Trees heavily laden with fruit may produce cherries with lesser amounts of photosynthate per fruit than a tree with a lighter crop (3). The reduced input of photosynthate and minerals to the developing fruits may result in inherently weaker cellular structures and may predispose the fruit to mechanical damage. Also in heavy crop years the large volume of fruit to be marketed may result in additional delays between packing and marketing which allows greater expression of surface pitting. Growers with a large crop to harvest may begin harvesting fruit at an immature state to spread out their picking periods. The immature red fruit (No. 3 color comparator) (12, 13) is more susceptible to surface disorders than fruit harvested at No. 6 color maturity (red-mahogany) or greater (18). Large crops also require increased production on automated packing lines which may increase the damage to the fruit.

Cherry trees with heavy crops generally have small fruit (77). Cherries in a heavy crop year may attain the size of fruit in light crop years if the fruit is allowed to remain on the tree, but by this time may have passed optimum maturity resulting in the fruit texture becoming soft. Work by Proebsting (77) indicated that soft cherries are susceptible to surface disorders which may account for injury to fruit in heavy crop years.

Low soluble solids in Montmorency cherries were inversely related to tree vigor and varied from year to year (40). Low fruit soluble solids were associated with heavy crops (77) and were positively correlated with high mechanical damage susceptibility (98).

The incidence of surface disorders in sweet cherries does not appear to be related to storage relative humidities of 80-95% (70). Desiccation of cherries in cold storage with humidity of approximately 80% RH resulted in loss of fruit turgidity and lack of skin luster (S.W. Porritt, Agriculture Canada, Summerland, B.C., unpublished results) but did not affect the incidence of surface disorders due to mechanical damage. Examination of weather records indicate that years of high fruit damage incidence have no correlation with water stress while the fruit is on the tree. Simon (84) suggested, however, that disruption of cells within a fruit may promote localized drying which resulted in cell collapse and cell necrosis under storage conditions.

Cherry fruit is often enclosed in 1.5 ml (38 μm) perforated polyethylene bags which maintain relative humidity at approximately 94% without affecting carbon dioxide or oxygen levels. Research by Porritt (70) determined that polyethylene liners were ineffective in reducing the incidence of surface pitting and may even have increased the disorder slightly. However, a research trial in 1975 which examined 150 commercial packs of cherries determined that closed perforated polyethylene liners may have decreased the incidence of surface pitting slightly (S.W. Porritt, unpublished results). The evidence suggested that variations in storage relative humidity from 80 to 94% did not consistently modify surface pitting expression at $0^{o}C$.

Research has indicated a strong cultivar-surface disorder relationship (70, M.E. Patterson, unpublished results). Bings and Lamberts were the least susceptible to surface disorders resulting from cellular damage whereas the Van cultivar was susceptible.

As the Van cherry accounts for approximately one third of the cherries grown in British Columbia with an approximate value of $1.3 million per crop year the threat of mechanical damage to the local fruit industry is substantial.

The expression of surface pitting is not affected by controlled atmosphere storage or high carbon dioxide levels in storage (36, 69). Carbon dioxide levels as high as 20% failed to affect pitting incidence significantly. Lowering oxygen levels from 21 to 3% and raising CO_2 levels to as high as 13% also did not affect the incidence of surface defects.

The development of surface pitting is influenced by fruit temperature at the time of handling. Cherries are more susceptible to bruising and subsequent surface pitting when they were handled at $0^{o}C$ than at $10^{o}C$ or $24^{o}C$ (M.E. Patterson, unpublished results). This effect of greater surface pitting susceptibility when fruit is handled cold is most important at the packinghouse level where the fruit is often precooled prior to packing. Fruit in the orchard at the time of picking will not reach temperatures low enough to affect the incidence of surface pitting. Ogawa et al. (61) however have shown that flesh discoloration due to bruising was unaffected by fruit temperature.

Hydrocooling cherries has been shown to increase surface pitting (70). Patterson (unpublished data) however, has determined that hydrocooling subsequent to impact bruising did not modify the incidence of surface pitting. The increased incidence of surface pitting due to hydrocooling observed by Porritt et al. (70) may be

the result of increased susceptibility of cold fruit to surface pitting from mechanical damage.

Immature red cherries (No. 3 color comparator) are more susceptible to mechanical injury than are well matured mahogany (No. 6 to 33 cherry comparator) cherries (18, 72). The disadvantages of harvesting immature cherries are twofold: 1) increased susceptibility to pitting, and, 2) loss of fruit weight to the growers. Tukey (89) has observed sour cherries to gain approximately 3 to 4% of the total cherry weight per day in stage III of fruit development.

Porritt et al. (70) observed great variability of fruit susceptibility to surface disorders among trees. Similar observations of variability of fruit susceptibility to surface disorders have to be made among grower lots. The range of bruise susceptibility suggests variability in grower practices. Preliminary investigations of soil pH (P. Lidster, unpublished results) indicate that acidic soil conditions of pH below 4.5 are present in Okanagan cherry orchards. Low soil pH was found to decrease fruit yield in Montmorency cherries but to have no effect on fruit size (1, 9). Reduced crop yields would, however, be expected to result in fruit less susceptible to surface disorders. However, acidic soil conditions can restrict the availability of nitrogen, calcium and zinc to the tree (88) while rendering manganese or aluminum available in toxic levels (31, 83). The restriction of nitrogen and calcium may lead to reduced tree vigor and fruit low in nitrogen and calcium.

Proebsting (Research Center, Prosser, Washington, unpublished data) has observed fruit deficient in nitrogen to be more susceptible to bruising damage. Nitrogen added to a sweet cherry orchard which was nitrogen deficient increased yield and fruit size (62) and increased fruit nitrogen content (86). Applications of nitrogen or nitrogen plus phosphorus appeared to decrease the incidence of surface pitting (86). Stanberry and Clore (86) determined that soil nitrogen application of 270 lbs/acre imparted a resistance to surface pitting in cherries. In a preliminary sampling of Okanagan cherry orchards (P. Lidster, unpublished results), it was determined that many cherry growers are applying the equivalent of 800 lbs/acre or greater of nitrogen fertilizers (34-0-0 or 21-0-0). Compared to current recommendations in Oregon of 200 to 300 lbs/acre of nitrogen fertilizer (34-0-0), (T. Facteau, Experiment Station, Hood River, Oregon, unpublished results) the Okanagan applications are 4 times greater. Apparently cherry growers in the Okanagan try to increase fruit size through the application of nitrogen fertilizers alone. Added nitrogen increased the foliage surface area and subsequently increased the degree of fruit shading (74, 104). Fruit grown in the shade was delayed in maturity and lower in alcohol insoluble solids (80).

A high rate of nitrogen fertilizer application can lower soil pH levels dramatically (32, 79). Once soil pH becomes acidic soil calcium becomes unavailable or leached (27) and calcium deficiencies may be induced by high aluminum or manganese concentrations (27, 83). High levels of ammonium ions also may decrease calcium uptake by plants

(30). However, increased amounts of calcium available to the plant roots was achieved by liming of acidic soils (34). Similarly, calcium levels of Montmorency cherry leaves were found to increase in seasons of high moisture (1).

Calcium located within the fruit has a number of structural and physiological functions. Calcium may form bridges between adjacent cell wall pectins and serve to bind adjacent cell walls (30). Bangerth et al. (5) suggested that as the fruit matures, the calcium joining the pectate chains is released and the individual cells become uncoupled. The separation of the cells is associated with the decline of fruit flesh firmness. Increasing fruit calcium levels by the application of sprays or dips may maintain fruit firmness by preventing calcium - pectate bridges from being uncoupled (29, 68). However, approximately one half of the calcium found in pear fruit is not associated with binding of pectate chains (29).

Calcium is essential for the maintenance of the differential permeability and structural integrity of the cellular membranes (49, 51, 102). Cellular membranes are responsible for ion absorption and release selectivity of the cell (28, 50). The results of Van Stevenick (93) supported the hypothesis of Bennett and Rideal (9) in which the calcium adsorbed to the anionic moieties on the outside of the plasma membrane and not the structural calcium found within the membrane, was critical in maintaining selective permeability. The application of calcium to cellular structures can inhibit the progression of membrane leakage and can even reverse the process if it has not passed a critical stage (9, 90, 91). The decrease in the differential permeability of the

plasma membrane and tonoplast of fruit in a calcium deficient state will result in the loss of cellular compartmentalization and lead to mixing of cytoplasmic enzymes and vacuolar substrates (81). Loss of cellular membrane integrity resulting from mechanical damage will lead to increased respiration rates, accelerated ripening and an increase in the onset of damage disorders which may be reversed by the application of calcium (5, 78).

Pruning of cherry trees may directly affect the fruit susceptibility to mechanical damage. Pruning techniques may reduce crop loads which may indirectly provide cherries with a resistance to mechanical damage. Similarly, pruning may reduce the leaf surface area and allow fruit to receive more light. Ryugo and Intrieri (80) determined that fruit grown in shade contained lower amounts of alcohol insoluble solids than fruit which was exposed. Similar observations were made on cherry leaves (1). Fruit low in cell wall components is likely to be more susceptible to mechanical damage because weaker cell walls may be more prone to fracture under stress.

Handling Practices Which Influence The Incidence of Surface Disorders

Rough picking and handling procedures in the orchard will predispose cherries to surface pitting and bruises in storage. S.W. Porritt (unpublished data) found a direct relationship between the roughness of handling and the incidence of surface pitting. Fruit

picked by clipping stems gently developed less surface pitting than fruit picked by grasping the stems in the usual manner and twisting to remove fruit. Observations of commercial fruit lots (S.W. Porritt, unpublished data) showed that 31% and 53% total defects in Lambert and Van cultivars respectively were present in the fruit after dumping on the packing line. The total defects detected at this time were the accumulated defects from picking, transportation and dumping on to the packing line. Passage of the same fruit over the cluster cutter caused the total defects to increase to 61% for Lamberts and 89% for Vans.

The injury imparted to cherries may result from either surface abrasion or impact damage (60, 85). Drupe fruits were susceptible to vibrational injury when warm (85) but were more resistant to impact injury. Injury from surface abrasion appears to affect epidermal cells only, whereas impact bruising results in collapsed hypodermal cells (2, 70). Injury occurring in fruit passed over commercial sorting belts results from both surface abrasion and impact damage (S.W. Porritt, personal communication).

There is a great bruising potential inherent in automated cherry packing lines. Many existing lines have a total vertical drop of 3 to 4 feet over the packing line. Studies have shown (S.W. Porritt, unpublished data) that as little as one foot of vertical drop is sufficient to cause significant amounts of surface pitting in years of susceptible fruits. Consequently in such years, the vertical drop associated with commercial packing lines far exceeds that required to produce substantial damage.

Fruit can receive substantial damage during transit to market. O'Brien et al. (60) found the extent of damage to be a function of fruit location within a carton and the acceleration given the fruit by vibration. Fruit which was loose on the top layers within a box received the most damage during transport which could involve 15% of the fruit. Current Canadian regulations permit a maximum of 15% total defects on arrival at the market inclusive of mechanical damage symptoms. Mechanical damage to cherries from all sources constitutes a serious threat to the profitability of commercial production of sweet cherries.

Soft Cherry Fruit Problem

Softness of sweet cherries has been ascribed to over-maturity, excessive rainfall or irrigation immediately prior to harvest, excessive fruit set and damage during picking and handling (59). Calcium deficiency was also reported to reduce fruit firmness and to result in lower insoluble pectic substances in Montmorency cherries (19).

Softening of fruit was reported to be caused by solubilization of calcium ions from the galacturonic acid cross-linkages (4) which were responsible for the binding of cell walls by the middle lamella cementing structure (15, 33). Calcium was thought to interact with pectic compounds of cherries to increase fruit firmness (35, 58). Addition of calcium to Montmorency cherries increased firmness of the processed product after canning (7, 45).

The firmness of cherries may be important in determining acceptable eating quality and may be related to the susceptibility of cherry fruits to mechanical damage (E.L. Proebsting, M.E. Patterson, unpublished data). Hartman (37) and Hartman and Bullis (38) measured the force required to produce a constant deformation of cherries using a plunger. The resistance to deformation was found to decrease with advancing maturity. Hartman and Bullis (38) reported that the resistance to deformation of cherries harvested over the period from red to mahogany color decreased by 17.3 percent. The narrow firmness range for commercially mature cherries requires a sensitive firmness detection technique. Verner (94) used a similar method but compressed cherries between two flat plates and found this measurement unacceptable for predicting sweet cherry harvest dates. Couey and Wright (18) used a Durometer (Shore Instrument Co., Jamaica, N.Y.) to measure the surface resistance to compression in sweet cherries. Cherry texture as measured by the Durometer was directly related to the extent of impact bruising. However, this technique was subject to operator error as variations in the amount and rate of loading would greatly affect texture readings.

Whittenberger and Marshall (99) studied the compression of individual sweet cherry fruits subjected to 300g force between flat plates. Parker et al. (64) and Diener et al. (25) developed similar instruments to measure creep compliance of cherries under a constant load. Deformation of red tart cherries as an index of texture was related directly to the degree of bruising and other firming techniques.

LaBelle and Moyer (43) measured cherry texture as compliance under its own weight. The resistance to compression was found to increase in fruit that had been cold stored.

Objectives of Present Study

Previous research has indicated that the expression of surface damage symptoms can be modified by tree or storage treatments. The present study investigates the effects of various pre- and postharvest treatments on fruit texture and cherry susceptibility to mechanical damage. The research investigated the following areas:

1. The effect of fruit calcium supplements applied as preharvest sprays or postharvest dips on fruit texture and resistance to mechanical damage.
2. The effect of length of storage period prior to impact damage on the fruit susceptibility to mechanical damage. The effect of a delay prior to damage of fruit dipped in calcium chloride was also examined to determine whether the efficacy of a calcium dip could be improved.
3. The mechanism by which preharvest gibberellic acid sprays decrease fruit susceptibility to mechanical damage.
4. The effect of fruit maturity on cherry mineral and cell wall structure and the susceptibility to mechanical damage.
5. The moderating effect of temperature on the rate and total amount of surface damage resulting from impact bruising.

6. The elucidation of specific parameters of force and loading rate required to induce surface pitting and bruises.

7. The effects of storage temperature and widely differing storage relative humidities on fruit weight loss and the rate of development of surface damage. Dipping treatments which may modify fruit turgor, localized weight loss and the rate of surface disorder expression were also studied.

8. The effect of reducing crop load by hand thinning on fruit texture, contents and susceptibility to surface damage.

MATERIALS AND METHODS

Firmness Determination

The texture test consisted of forcing a 11 mm diameter Magness Taylor apple probe into the side of the fruit (Fig. 4) using the Ottawa Texture Measuring System (96). The cherry was supported in an indentation of 3 cm radius in an aluminum plate to align the fruit under the probe. The plate was arranged so that 3 fruits could be indexed under the probe in turn. The stem axis was at right angles to the direction of force application. The force transducer and strip chart recorder were adjusted to provide a full scale sensitivity of either 2 or 4 kg. A crosshead speed of 1.5 cm/min was chosen to give good sensitivity with a reasonable testing rate. A typical force deformation curve is shown in Fig. 5.

Fruit firmness was defined as the maximum slope (kg/cm) of the force-deformation curve. Fruit bioyield values were taken as the force at which there was a sudden decrease in the force sustained by the fruit due to tissue rupture. Deformation was the distance of probe travel from first contact with the cherry surface to the bioyield point. The fruit firmness, bioyield and deformation for each of 15 fruits tested were averaged to provide the textural attributes for a single replication.

Fruit Preparation and Mineral Analysis

Frozen fruit samples for calcium analysis were removed after 5 to 10 days at -37°C and peeled to provide flesh tissue only. The remaining fruit flesh was allowed to thaw and then homogenized in a "Waring blendor" for 5 min. to provide a mascerate of the parenchyma tissue. About 5 grams of homogenized cherry tissue was weighed into a dry, tared 50 ml beaker. The tissue was freeze dried and the beaker reweighed to obtain tissue dry weight. The cherry tissues were then ashed at 550°C for 3 hours. The ashed samples were then taken up in 25 ml of 0.5N HCl with 6500 ppm lanthanum added and the resultant solution analyzed for calcium, zinc and potassium by atomic absorption. Analyses for magnesium required a further dilution of 2:25 with 0.5N HCl plus 6500 ppm lanthanum prior to atomic absorption analysis.

Calcium-45 Determination

Experiment 1. Van cherries of No. 6 color maturity and of uniform size were dipped in solutions of: 1) 30g/l calcium chloride, 2) 30g/l calcium chloride plus 0.1% non-ionic surfactant, 3) 30g/l calcium chloride plus 2.5g/l thickener (Keltrol)[1] or 4) 30g/l calcium chloride plus 2.5g/l thickener plus 1 ml/l non-ionic surfactant. All solutions were labelled with 0.5 µCi calcium-45 per ml. The fruit was dipped by grasping 3 or 4

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1 Keltrol is the brand name for food grade xanthan gum produced by Kelco Division of Merck and Co., Inc., San Diego, California.

separate fruit at 21°C by the stem and immersing the fruit in 21°C dipping solution for 15 seconds. Fruit from each dip was divided randomly into 4 replications. All fruit was placed in corrugated paperboard boxes, surrounded by 38 µm perforated polyethylene liners and placed immediately in 0°C storage. Fruit samples were removed after 1, 2, 4, 8 and 16 days of cold storage and washed with running water. Ten fruit were removed per replication, the stem removed and the fruit sliced in half along the suture line. The pit was removed and a No. 5 cork borer was pushed from the pit side through the flesh to the epidermis. The tissue plug was then removed from the cork borer by pushing the plug along the length of the borer to prevent tissue contamination. The tissue plug containing the epidermis was peeled prior to drying. Tissue plugs from identical treatments were collected from each of 10 cherries, placed in 50 ml tared beakers and dried to constant weight in a forced air oven at 65°C for two days (Fig. 6). Tissue dry weights were determined by reweighing the beakers. The tissue was then ashed at 550°C for 3 hours, and the ash taken up in 3 ml of 0.5N HCl. The solution was then poured into liquid scintillation vials and an additional 15 ml of PCS[2] liquid scintillation cocktail added. The resulting mixture was analyzed by a Beckman LCS-100 liquid scintillation counter.

The quench correction curve (Fig. 7) was prepared using the channel ratios method. As the carbon-14 and calcium-45 energy spectrums overlapped (Fig. 8, 9), the entire calcium-45 energy spectrum was counted using a carbon-14 module. The initial one-third of the calcium spectrum

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2 PCS is brand name for liquid scintillation cocktail produced by Amersham Searle Co., Arlington Heights, Illinois.

was counted by setting a variable counter to measure the counts per minute within the 0-260 range of slit widths. The channel ratios and detection efficiencies were determined on a set of 20 calcium-45 solutions of known activity but which were quenched progressively with acetone. All samples of cherry tissues were analyzed, corrected for background, quench and decay and values expressed as mg/kg calcium uptake from the postharvest dip. This technique was similar to that used by Lidster et al. (47). The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Days, Log (Days), Surfactant, and Thickener.

Experiement 2. The penetration of calcium-45 into the cherry mesocarp was examined. Fruits were dipped in a solution of 30g/l $CaCl_2$ plus 2.5g/l thickener plus 1 ml/l non-ionic surfactant and placed immediately in $0^{o}C$ storage in 38 µm perforated polyethylene liners. Ten fruit per replication were removed at 1, 2, 4, 8 and 16 days after dipping and washed in deionized water. The fruit was cut in half along the suture line and the pit removed. A No. 5 cork borer was pushed through the half cherry from the pit side. The tissue plug was then sectioned into three tissue discs of approximately 3 mm thickness each. Tissue discs from various depths were collected from each of ten fruit and placed in dried, tared 50 ml beakers. The epidermis was removed prior to drying. Ashing and calcium-45 analysis was done using the procedure outlined in Experiment 1. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Days, Log (Days), and Depth.

Tissue Preparation for Microscopic Examination

Tissue sections as approximately 2 mm cubes were removed at 0-2, 2-4 and 4-6 mm below the epidermis in areas receiving impact damage. The tissue was then fixed in a solution of 5% glutaraldehyde in 0.1M phosphate buffer for 5-12 hours. The fixed tissues were then rinsed twice with 0.1M phosphate buffer and replaced with a solution of 1% osmium tetroxide in Palade's buffer (63) for 1 hour. The osmium tetroxide solution was replaced by ascending steps of alcohol solutions repeated 3 times for duration of 20 min each. The final 100% alcohol solution was replaced with 2 changes of 100% propylene oxide 15 min each. The tissue was then immersed in a 1:1 propylene oxide-Epon 812 solution under 750 Torr vacuum for 12 hours. The sections were then embedded in 100% Epon-812 and cured for 36 hr at 60°C. The embedded tissues were microtomed to 1500Å thickness and stained with 1% basic fuschin in 50% ethanol (21). All tissue sections prepared were examined by light microscopy.

Description of Damage Disorders

The disorders of cherry fruits resulting from mechanical damage were categorized as to the overt symptoms: 1) fruit with bruises which appeared as flattened surfaces on the cherry, 2) fruit with surface markings not deep or large enough to be considered pitting, 3) fruit with a small pit or pits with an aggregate pitting diameter less than

or equal to 5 mm, 4) fruit with large pits or aggregate pitting diameter greater than 5 mm, and 5) the number of pitted fruit per sample which included the summation of fruit exhibiting pit symptoms.

Tissue Fractionation and Analysis

Alcohol insoluble solids. The fractionation and analyses of cherry tissue components was adapted from the procedures of Wiley and Stembridge (101) Blumenkrantz and Asboe-Hansen (10) and Sapozhnikova et al. (82). A composite sample of 150 g of fresh cherries was obtained from 50-75 individual fruit. The cherry slices were boiled in 95% ethanol for 5 min and the ethanol decanted. The cherry slices were then homogenized in 375 ml of 95% ethanol in a "Waring blendor" for 5 min. The homogenate was then filtered through a tared No. 541 filter paper and dried in a forced air oven at 65°C for 2 days. The weight of the dried residue was recorded as the AIS content on a fresh weight basis.

Cellulose determination. A 0.5 g aliquot of dried AIS fraction was extracted with 30-35 ml of 10% KOH for 16 hours at 75°C to solubilize pectic substance and hemicelluloses. Antifoam-A was added during the extraction to prevent foaming. The remaining precipitate was filtered on a tared #1 filter paper and washed thoroughly with distilled water. The filtrate and filter paper were dried at 65°C for 2 days and the resulting weights recorded as percentage cellulose.

Soluble pectin determination. A 0.5 g aliquot of dried AIS fraction was brought to a boil in 50 ml of distilled water. The supernatant was collected and made up to 100 ml. To aliquots of 0.4 ml in an ice water bath, 4 ml of concentrated H_2SO_4 - tetraborate were added and the mixture shaken. The resulting solution was heated to 100°C for 5 min and recooled in ice water for 10 minutes. Aliquots of 0.1 ml orthohydroxydiphenyl were added to samples and 0.1 ml of 0.5% NaOH to the blanks and contents stirred in a cold water bath. After a 10 min delay to allow color development the absorbance of the solutions was read at 477 nm. The absorbance readings were corrected for the blank values and concentrations of galacturonic acid interpolated from a standard curve. The results were expressed as percentage soluble pectin per fresh and dry weights.

Total pectin determination. A 0.5 g aliquot of dried AIS sample was extracted with 30-35 ml of 0.25% ammonium oxalate and 0.25% oxalic acid at 75°C for 1.5 hr. The solution was filtered through nylon cloth and the filtrate extraction repeated twice. The supernatant from the three extractions was combined and the final volume determined. The pH of a 25 ml aliquot adjusted to 8.1 with 20% NaOH. To this solution, 2 ml of 10% HCl and 40 ml of 95% ethanol were added and the solution allowed to stand overnight. The resulting precipitate was centrifuged out at 15,000 rpm for 15 min and the supernatant decanted. The precipitate was redissolved in 10 ml of 0.2M Tris-HCl-EDTA (10). One ml of this solution was diluted 20 x with Tris-HCl-EDTA solution. Aliquots of 0.4 ml were analyzed for galacturonic acid as in soluble pectin determination.

Calcium Spray Experiments

1977 Study. A solution of 30 g $CaCl_2$ plus 1.0 ml/l non-ionic surfactant was applied to whole branches selected at random on each of 5 trees of similar age and growth habit. Three sprays were applied at 2 week intervals commencing 6 weeks prior to harvest while the single $CaCl_2$ spray was applied at 6 weeks prior to harvest. Fruits of uniform size were harvested at No. 6 color maturity. Texture tests and fruit composition determinations were made on samples of 15 and 50 fruit respectively, immediately after harvest and after storage. Flesh calcium was determined after harvest. Impact injury to the fruit was imposed by placing fruit on a fiber conveyor belt arranged so that fruit dropped 46 cm to another moving fiber belt. Belt speeds were such that fruit struck the surface of the belt and not other fruit. All fruit samples were bruised when the fruit temperature was $0^{o}C$. The data were analyzed as a 3 spray treatments x 5 replication factorial experiment using the Newman-Keuls multiple range test.

1978 Study. Branches picked at random in each of 4 tree (blocks) were sprayed with a solution of 30 g/l $CaCl_2$ plus 1.0 ml/l non-ionic surfactant. Sprays were applied so that one branch per tree received spray applications at: 1) 5 weeks prior to harvest, 2) 3 weeks prior to harvest, 3) 1 week prior to harvest, 4) 3 and 1 week prior to harvest and, 5) 5, 3, and 1 week prior to harvest. Fruit were harvested at No. 6 color maturity and

the texture tests done immediately on 15 fruit per sample at 21°C. The remaining fruit was impact damaged when fruit temperatures reached 0°C using the above method.

All fruit were placed in 38 µm perforated polyethylene liners to prevent desiccation and stored at 0°C. Fruit was removed for examination after 15 days of storage. The data were analyzed as a 5 treatment x 4 replication factorial experiements using the Newmans-Keuls multiple range test.

Calcium Dip Experiments

Calcium penetration study. 'Van' cherries of uniform size and No. 6 color maturity were harvested and divided at random into 4 replications of approximately 1,000 fruit each. The fruits were placed immediately in 0°C storage. A single sample of 50 untreated fruit was removed from each replication and prepared for Ca analysis by being washed, destemmed, pitted and frozen at -37°C. The remaining fruit was dipped for 15 sec in a solution of 30 g/l $CaCl_2$ plus 2.5 g/l Keltrol thickener plus 1.0 ml/l non-ionic surfactant plus 0.5 g/l Benlate[3] at 21°C. The fruit was allowed to drain and a second sample of 50 fruits was prepared for Ca analysis. The remaining fruits were placed in corrugated paperboard boxes lined with perforated 38 µm polyethylene to prevent desiccation. Fifty fruits were removed at intervals of 1, 2, 4, 7, 14 and 21 days after dipping,

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3 Benlate is the brand name for benomyl fungicide produced by E.I. DuPont de Nemours & Co., Wilmington, Delaware.

and prepared for Ca analysis according to the above procedure. The data were analyzed by forward stepwise multiple regression using the potential independent variables; Days, Log (Days), and Days x Log (Days).

Thickener effect on $CaCl_2$ dip. 'Van' cherries of uniform size were harvested at No. 6 color maturity and randomly divided into 12 treatments with 4 replications per treatment. Fruits were placed immediately in $0^{o}C$. One hundred fruits were dipped for 15 sec in solutions of 0, 15, 30 or 60 g/l $CaCl_2$ each at a thickener concentration of 0, 2.0, 4.0 g/l thickener. All dipping solutions contained 1.0 ml/l non-ionic surfactant and were maintained at $21^{o}C$. Dipped fruit was returned into polyethylene-lined boxes and $0^{o}C$ storage. The fruit was removed from storage after 21 days and 15 fruits were warmed to $21^{o}C$ for firmness determinations. The remaining 85 fruits were washed, destemmed, pitted and frozen at $-37^{o}C$ for Ca analysis. The data were analyzed by forward stepwise multiple regression using each and all possible combinations of the potential independent variables; Dip ($CaCl_2$), Dip $(CaCl_2)^2$, Thickener, and Thickener^2.

1977 Dipping duration study. 'Van' cherries of uniform size were harvested at No. 6 color maturity and randomly divided into 2 series of 5 treatments each with 4 replications of 100 fruit. The five treatments in the first series consisted of a control and 4 others that were dipped for 0.25, 10, 60 or 240 min in a solution of 30 g/l $CaCl_2$ plus

1.0 ml/l non-ionic surfactant plus 0.5 g/l Benlate. The second series was treated similarly to the first but with the addition of 2.5 g/l Keltrol to the dipping solution. Warm fruit (21°C) was dipped after harvest in a 21°C solution. All fruit were placed in boxes with perforated polyethylene liners and stored at 0°C for 21 days. Upon removal, 15 fruit were allowed to warm to 21°C and tested for firmness. The remaining 85 fruit were prepared and frozen for calcium analysis. The data were analyzed by forward stepwise multiple regression using each and all possible combinations of the potential independent variables; Dip Time, Log (Dip Time), and Thickener.

1978 Dipping duration study. 'Van' cherries were harvested from a single tree at No. 6 color maturity. The fruit was divided at random into 6 treatments of 4 replications of 50 fruit each. Warm fruit (21°C) was dipped in a solution containing 30 g/l $CaCl_2$ plus 0.5 g/l Benlate which was maintained at 21°C. The fruit was dipped for periods of 0.25, 1.0, 4.0, 16, 64 and 128 min. Immediately upon removal from the dipping solution, the fruit was rinsed under running water, allowed to dry, destemmed, pitted and frozen at -37°C for calcium analysis. The data were analyzed by forward stepwise multiple regression using the potential independent variables; Dip Time, Log (Dip Time), and Dip Time x Log (Dip Time).

Effects of pH of $CaCl_2$ dipping solution on calcium uptake and disorder incidence. 'Van' cherries were harvested from each of 4 trees (replications) and randomly divided into 2 series of 5 treatments each. Each of 4 replications of 250 fruit was dipped in one of the 2 solution series containing 30 g/l $CaCl_2$, plus 1.0 ml/l non-ionic surfactant plus 0.5 g/l Benlate with or without 2.5 g/l thickener added. For each solution series the pH was adjusted to 1, 4, 7, 10 or 12 with either HCl or NaOH. Warm fruit (21°C) was dipped in the appropriate solution for 15 sec and the excessive dip solution allowed to drain from the fruit. The treated fruit was then damaged by dropping the fruit 46 cm on to a fiber conveyor belt as described previously and then placed in paperboard boxes in a polyethylene liner and stored at 0°C. Fifty fruits which were dipped in the solution containing a thickener were removed from storage for each pH treatment, 1, 4, and 16 days after dipping. These fruits were washed, destemmed, pitted and frozen for calcium analysis. The remaining fruits were removed after 21 days of storage and examined for storage disorders. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; pH, Days, pH^2, and $Days^2$.

Effects of washing on effectiveness of postharvest dips. 'Van' cherries were harvested at No. 6 color maturity and randomly divided into 4 replications for each of 5 dipping solutions and three washing regimes.

The 5 dipping solutions consisted of: 1) water, 2) 2.5 g/l thickener, 3) 30 g/l $CaCl_2$, 4) 30 g/l $CaCl_2$ plus 2.5 g/l thickener and 5) 1:5 dilution of Mobileaf[4] antitranspirant. All dipping solutions contained 1.0 ml/l non-ionic surfactant plus 0.5 g/l Benlate. The washing schedules consisted of: 1) no wash, 2) washing prior to bruising, or 3) washing after bruising of the fruit.

Fruits were harvested and dipped immediately in 21°C dipping solution and placed in 0°C storage until fruit temperature reached 0°C. Fruit which required washing prior to bruising were rinsed in cold running water and returned to storage until the fruit reached 0°C. All fruit were then impact damaged by dropping the fruit 46 cm on a moving fiber belting. Fruit which required washing after bruising were rinsed in cold water. All fruit were placed in paperboard boxes in polyethylene liners and replaced in 0°C storage. Fruit was removed after 14 days of storage and examined for surface disorders. The data were analyzed as a 5 dip x 3 wash x 4 replication factorial experiment using the Newman-Keuls multiple range test.

Effects of soaking on surface disorders. 'Van' cherries were harvested at No. 6 color maturity with care to prevent damage to the fruit. The fruit was harvested from a single tree and randomly divided to give samples for 2 dipping series x 5 dipping sequences x 4 replications of 150 cherries each. All fruit was cooled to 0°C within 12 hr of harvest.

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4 Mobileaf is the brand name for wax emulsion antitranspirant produced by Mobil Chemical Co., Richmond, Va.

One series of fruit was dipped in a 21°C solution containing 0.5 g/l Benlate plus 1.0 ml/l non-ionic surfactant for periods 15 sec, 4, 16, 64, and 128 min after which the fruit was cooled to 0°C. All fruit was impact damaged by a free fall of 46 cm on to a moving fiber belt. The second series of fruit was then dipped in the identical solution for periods of 15 sec, 4, 16, 64 and 128 min. After treatment all fruit were replaced in perforated polyethylene liners and placed in 0°C cold storage for 14 days. Fruit were removed from storage and examined for surface disorder incidence. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Dip Sequence, Dip Duration, and Dip Duration^2.

Delay Versus Calcium Dip Experiments

1977 Study. 'Van' cherries were harvested carefully at No. 6 color maturity. Eight samples of 150 fruit each were selected from each of five tree-blocks. The fruit was cooled overnight to 0°C. Samples were then dipped in either a solution of 30 g/l $CaCl_2$, plus 2.5 g/l thickener, plus 1.0 ml/l non-ionic surfactant, plus 0.5 g/l Benlate fungicide or a solution of 1.0 ml/l non-ionic surfactant plus 0.5 g/l Benlate and allowed to dry in cold storage for 4 hr. All fruit samples were then placed in 38 μm perforated polyethylene lined corrugated paperboard boxes to prevent desiccation. Samples were impact damaged by dropping the fruit 46 cm on a fiber conveyor belt 0.5, 4, 8 or 12 days

after the dip treatment and then returned to 0°C storage in polyethylene liners. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Dip $CaCl_2$, Days Delay, and Log (Days Delay).

1978 Study. 'Van' cherries were harvested carefully at No. 6 color maturity from a single tree. The fruit was randomly divided into 4 replications of 16 samples to provide for 4 postharvest dips and 4 delay periods prior to bruising. The following dipping treatments were applied immediately after harvest: 1) water, 2) 30 g/l $CaCl_2$, 3) 2.5 g/l thickener, or 4) 30 g/l $CaCl_2$ plus 2.5 g/l thickener. All dipping solutions contained 1.0 ml/l non-ionic surfactant plus 0.5 g/l Benlate fungicide. The fruit samples were placed in 38 µm perforated polyethylene lined corrugated boxes and cooled to 0°C before folding the liner over the fruit to prevent desiccation. Samples were removed from storage and impact bruised at 1, 2, 4 or 8 days after harvest. The fruit was damaged by dropping 46 cm on to a moving fiber belt after which the fruit was returned to 0°C storage in polyethylene liners. Fruit was removed from storage 15 days from date of impacting and immediately examined for disorders. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Dip $CaCl_2$; Dip Thickener, Days Delay, and Log (Days Delay).

Gibberellic Acid Experiments

1977 Study. Two individual branches selected at random within each of 5 tree-blocks were sprayed by handgun with solutions of: 1) 20 ppm gibberellic acid (GA) and 2) 1:5 dilution of Mobileaf antitranspirant. Sprays were applied at green-straw fruit maturity approximately one month prior to harvest. One branch of the remaining unsprayed portion of each tree was selected as a control. Fruit was harvested at two maturities corresponding to No. 3 and 33 fruit color. Approximately 150 fruits were harvested per replication with care to prevent damage. All fruit was stored immediately at $0^{o}C$. The fruit was impacted by dropping 46 cm on a fiber belt and replaced in polyethylene liners in $0^{o}C$ storage. Fruit was examined for disorders after 21 days of cold storage. The data were analyzed as a 3 treatment x 2 maturity x 5 replication factorial experiment using the Newman-Keuls multiple range test.

1978 Study. Thirty parts per million gibberellic acid (GA) sprays were applied to branches selected at random in each of 4 tree-blocks. The spray was applied at straw color fruit maturity approximately 21 days prior to harvest. Control branches were selected at random from the remaining unsprayed portion of the tree. Approximately 250 fruit were harvested at each of two maturities corresponding to No. 3 and 33 fruit color. Immediately after harvest, 100 fruits were destemmed and fruit weight determined. Pits were removed from 50 of these fruits and 150 g of cherry slices prepared for determination of alcohol insoluble solids,

pectin and cellulose. The other 50 fruits were pitted and frozen for mineral analysis. The remaining 150 fruits per replication were cooled at 0°C then impact damaged as described previously and stored at 0°C in polyethylene liners. Fruit was examined after 21 days of cold storage. The data were analyzed as a 2 treatment x 2 maturity x 4 replication factorial experiment using forward stepwise multiple regression. The dependent variables were predicted using the potential independent variables; Maturity, Gibberellic Aid Spray, and Maturity x Gibberellic Acid Spray.

Fruit Maturity Experiments

1977 Study. 'Van' cherries were harvested at 3 maturities corresponding to No. 3, 6 and 33 fruit color. Fifteen fruits from each of 4 replications per maturity were selected for soluble solids, titratable acidity and mineral analysis determinations before and after 21 days of storage. Soluble solids were determined by refractive index of the juice sample. Titratable acidity measurements were determined by titrating 10 ml of juice with 0.1 N NaOH to pH 8.1 as the endpoint. Four samples of 150 fruit each were harvested at each of the three maturities. Fruit was picked carefully to avoid damage and randomly divided to give 4 replications for each of the 4 treatments. The fruit was cooled immediately to 0°C and impact damaged by dropping fruit of known weight sufficient distance to provide work equivalent to 0.0, 0.02, 0.04 and 0.08 joules (Fig. 9). The damaged fruit was placed in polyethylene

liners and replaced in 0°C storage for 21 days then examined for disorder incidence, soluble solids, titratable acidity and fruit texture. The data were analyzed as a 3 maturity x 4 work load x 4 replication factorial experiment by forward stepwise multiple regression using each and all combinations of the potential independent variables; Maturity, Work Done, and Work Done^2. The data analyses not involving variable amounts of work done to the fruit were accomplished using Newman-Keuls' multiple range test.

1978 Study. 'Van' cherries were harvested every 7 days commencing when fruit maturity corresponded to straw-green color. This maturity approximated the initiation of stage III of fruit development observed by Tukey (89). Approximately 250 fruit were harvested at each harvest. One hundred fruit were used prior to storage for texture, soluble solids, titratable acidity, mineral and alcohol insoluble solid determinations. Total fruit nitrogen content was determined on dry fruit tissue using a standard micro-Kjeldahl procedure. The remaining fruits were cooled rapidly to 0°C then bruised by dropping the fruit on a fiber belt from a height which corresponded to 0.04 joules of work (Fig. 9). The fruit was returned to 0°C storage in polyethylene liners for 15 days then examined for disorders. The data were analyzed by forward stepwise multiple regression using the potential independent variables; Days, and Days^2.

Effects of Fruit Size on Composition and Disorder Incidence

Maturity versus fruit size. 'Van' cherries were harvested at No. 3, 6, and 33 fruit color maturities from 5 tree-blocks. Fruit from each tree for each maturity was segregated into 2 sizes, small and large. All fruit was cooled to 0°C overnight and dropped 46 cm on to a fiber belt then returned to 0°C storage in polyethylene liners for 21 days. The fruit was then assessed for damage. The data were analyzed as a 3 maturity x 2 size x 5 replication factorial experiment using Newman-Keuls' multiple range test.

Drop height versus fruit size, 1977 study. 'Van' cherries were harvested at No. 6 color maturity from 5 tree-blocks. The fruit was segregated into 2 series of small and large sizes cooled to 0°C then one series was dropped 46 cm on to a moving fiber belt and the second series was dropped a height equivalent to 0.05 joules of work as determined by fruit weight. All fruit was stored in polyethylene liners at 0°C and assessed for the incidence of damage after 21 days. The data were analyzed as a 2 fruit weight x 2 treatment x 5 replication factorial design by forward stepwise multiple regression using the potential independent variables; Fruit Weight, Work Done, and Fruit Weight x Work Done.

Drop height versus fruit size, 1978 study. 'Van' cherries were harvested at No. 6 color maturity from 4 tree-blocks. Fruit from each tree was segregated into small and large fruit size categories and 100 fruits in each group were weighed to determined average fruit weight. These

fruits were then pitted and sliced to provide 150 g fruit tissue for alcohol insoluble solid determinations and the remainder used for soluble solids and titratable acidity determination. Two series of small and large fruit each were subdivided from the remaining fruit from the 4 tree-blocks and cooled to $0^{o}C$. One series each of small and large fruit was dropped on to a fiber belt at a constant height of 0.45 meters. The remaining series of fruit were dropped a height equivalent to 0.04 joules of work. The fruit was returned to $0^{o}C$ storage in polyethylene liners and after 15 days, 150 fruits in each replication were examined for disorders. The data were analyzed as a 2 x 2 x 5 replication factorial experiment by forward stepwise multiple regression using the potential independent variables; Fruit Weight, Work Done, and Fruit Weight x Work Done.

Effects of Bruising Surface and Rate of Deformation

Height of drop versus bruising surface. 'Van' cherries were carefully harvested at No. 6 color maturity from 5 tree-blocks. The fruit from each tree was randomized into 2 series of 4 treatments each. All fruit were cooled to $0^{o}C$. Each series of fruit was dropped distances of 13, 25, 51 and 102 cm on either a woven fiber belt or smooth plastic belting material. Care was taken to avoid fruit collisions at the belting surface. All fruits were stored at $0^{o}C$ in polyethylene liners and examined for surface disorders after 16 days. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Surface, Drop Height, and Drop Height^{2}.

Deformation rate versus bruising surface. 'Van' cherries of No. 6 color maturity were harvested carefully from a single tree and randomly divided into treatments of 2 bruising surfaces x 2 loading rates x 3 depths of deformation. The cherries were deformed to 2, 4 or 8 mm using either a smooth plastic or woven fiber belting material at loading rates of either 10 or 1000 mm/min. Each treatment consisted of 4 replications of 35 cherries each. Fruit was cooled to $0^{o}C$ prior to bruising. Fruit was bruised using an Instron Universal testing machine by placing individual fruits, with the suture parallel to the flat surface, and allowing the flat surface to deform the cherry, with appropriate belting material on the opposite side of the fruit. Fruit was replaced in polyethylene liners in $0^{o}C$ storage for 10 days and examined for surface disorders. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Bruising Surface, Deformation, $Deformation^{2}$, and Loading Rate.

Fruit and Storage Temperature Effects on Damage Incidence

Fruit temperature study, 1977. 'Van' cherries were gently harvested at No. 6 color maturity from several trees and the fruit divided at random into 5 treatments x 4 replications of 150 fruit each. Fruit was brought to temperatures of 0, 5, 10, 25 and $38^{o}C$ then damaged by dropping a distance of 46 cm on to a moving fiber belt. All fruit was then placed in polyethylene liners in $0^{o}C$ storage. After 21 days the

fruit was removed from storage and examined for surface disorders. The data were analyzed by forward stepwise multiple regression using the potential independent variables; Fruit Temperature, and Fruit Temperature^2.

Storage temperature study, 1977. The 'Van' cherries were harvested carefully at No. 6 color maturity from several trees and the fruit divided at random into 3 treatments x 4 replications of 150 fruit each. Fruit was cooled to 0°C prior to bruising. Subsequent to impact damage, two lots of fruit were placed in 0°C storage while the remaining fruit was placed in 25°C storage. Fruit from 0 and 25°C storage was removed after 5 days and examined for surface disorders. The remaining 0°C treatment was removed from storage after 15 days and examined for surface disorders. The data were analyzed using the Newman-Keuls multiple range test.

Fruit temperature study, 1978. 'Van' cherries were harvested carefully at No. 6 color maturity from a single tree and randomly divided into 4 periods in storage x 4 bruise temperatures x 4 replications of 150 cherries each. Fruit temperatures of 0, 5, 10 and 20°C were achieved within 12 hours of harvest at which time fruit was impact damaged by dropping 46 cm on to a moving fiber belt then stored in polyethylene liners at 0°C. After 1, 2, 4 and 8 days storage the fruit was examined for surface disorders. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Days, Log (Days), and Temperature.

Storage temperature study, 1978. 'Van' cherries were harvested carefully at No. 6 color maturity from a single tree and randomly divided into 5 periods in storage x 4 storage temperatures x 4 replications of 150 cherries each. Fruit cooled to $0^{o}C$ was impact damaged by a distance of 46 cm free fall on to a moving fiber belt. Five samples of 4 replications each were stored in polyethylene liners at 0, 5, 10 and $20^{o}C$. Fruit was removed at intervals of 1, 2, 4, 8 and 16 days after bruising and examined for surface disorders. The data were analyzed by forward stepwise multiple regression using each and all combinations of the potential independent variables; Days, Log (Days), and Temperature.

Effects of Storage Temperature and Humidity on the Incidence of Surface Disorders

'Van' cherries of No. 6 color maturity were harvested from several trees and the fruit randomly divided into 2 storage temperatures x 5 removal dates x 2 storage relative humidities x 4 replications of 150 cherries each. Fruit were enclosed in polyethylene and cooled to $0^{o}C$ within 12 hours of harvest and impact damaged by dropping 46 cm free fall on to a moving fiber belt. Five samples of 4 replications each were placed in storage at: 1) $0^{o}C$ 95-100% RH, 2) $0^{o}C$ 40% RH, 3) $20^{o}C$ 95-100% RH, and 4) $20^{o}C$ 40% RH. The fruit was examined for weight lost and surface disorders after periods of 1, 2, 4, 8 and 16 days. The data were analyzed by forward stepwise multiple regression using

each and all combinations of the potential independent variables; Humidity, Days, Log (Days), and Temperature.

Effects of Thinning on Fruit Characteristics and Resistance to Impact Damage

Five 'Van' cherry tree blocks in each of two commercial orchards were selected on the basis of heavy fruit set. Three weeks after full bloom, the cherries on a branch selected at random from each tree were thinned by hand to one fruit per cluster. The fruit was harvested at No. 6 color maturity and 100 fruits were weighed to determine average fruit weight. Samples of 15 and 50 fruit were used for prestorage determinations of texture and fruit analysis respectively. A further set of fruit samples of 15 and 50 fruit per replication were stored in polyethylene at $0^{o}C$ for 21 days for texture, soluble solids and titratable acidity determinations. A sample of 150 fruit per replication cooled to $0^{o}C$ were impact bruised by free fall of 46 cm on to a moving fiber belt. The fruit was replaced in polyethylene liners and stored at $0^{o}C$ for 21 days after which fruit was examined for surface disorders. The data were analyzed as a 2 treatment x 2 location x 4 replication factorial experiment by forward stepwise multiple regression using the potential independent variables; Thinning, Orchard, and Thinning x Orchard.

Microscopic Examinations

'Van' cherries were harvested at No. 3 and 6 color maturities and cooled to 0°C immediately after harvest. Twenty fruits of each maturity were bruised by dropping a 16 g centrifuge tube with a rounded bottom a distance of 30 cm on to the cheek of the fruit. The impact area was circled for later identification. The fruit was placed in polyethylene liners in 0°C storage. Twenty undamaged fruit served as controls. Ten control fruit and 10 damaged fruit were sectioned immediately. The remaining 10 control and 10 damaged fruit were sectioned after 9 days of storage.

RESULTS AND DISCUSSION

Calcium Study

Rate of calcium penetration. Calcium penetrated into the fruit rapidly (Fig. 11) and approached an asymptotic maximum level 7 days after a post harvest $CaCl_2$ dip. The cherry cuticle and epidermis were very permeable (Fig. 11) to calcium movement allowing a 100 ppm increase from an undipped control level of 545 ppm in mesocarp calcium concentration even when fruit were washed immediately after dipping. Calcium moved rapidly into cherry fruit mesocarp during prolonged dipping periods (Table 3). Flesh calcium levels increased to 266 ppm when fruit was exposed to the dipping solution for 128 min. These observations were consistent with those which show that water could move rapidly into cherry fruit to cause cracking (95). The rate of calcium uptake by the cherry fruit declined after the first day until after 7 days in storage when only small increases in calcium uptake were evident. The high calcium concentration in fruit tissues at 7 days or later corresponded to the high efficiency of $CaCl_2$ dips to reduce surface disorders (Tables 4, 5). Apparently, the calcium concentration in the fruit flesh equilibrated with the residual calcium within 7 days of dipping.

Radiotracer studies showed that calcium from a postharvest dip moved readily into cherry fruit flesh (Fig. 12). Significant amounts of calcium-45 were detected in the 6-9 mm depth of flesh 2 days after the dip. Calcium uptake at all flesh depths increased progressively with

increased time in storage. The results in Fig. 12 indicate that the calcium penetration into cherry flesh approaches an upper asymptotic level approximately 8-16 days after dipping. The decreased rate of calcium uptake with storage time agrees with the previous results as determined by atomic absorption (Fig. 11). The results using calcium-45 however, indicate that the flesh calcium levels continue to increase after 8 days but at a reduced rate.

Factors affecting calcium uptake. Flesh calcium concentration determined by atomic absorption was increased by raising calcium chloride concentration in the postharvest dipping solution (Fig. 13). Addition of a thickener to the calcium chloride dip further increased calcium uptake by the fruit. A dipping solution containing 8% calcium chloride and 0.4% Keltrol resulted in a 4-fold increase in fruit calcium levels from 450 ppm in the control to 2260 ppm. The addition of thickener to the calcium chloride dipping solution was previously found to enhance calcium uptake in apples (48, 54). Mason et al. (54) concluded that a thickener added to the dipping solution caused more dip to adhere to the surface of the fruit which resulted in greater calcium uptake by the fruit.

Calcium uptake, as determined by radiotracer techniques, was also greatly modified by the inclusion of surfactants and thickeners in the dipping solution (Fig. 14). Addition of a non-ionic surfactant to the calcium chloride dipping solution decreased calcium uptake from that obtained from a solution not containing a surfactant. These results agree with the data of Mason et al. (54) on apples. The

addition of 0.25% thickener to the calcium chloride dipping solution greatly increased calcium uptake by the cherry flesh. The addition of a surfactant to the dipping solution containing a thickener initially reduced calcium penetration into the cherry flesh, but after 5 days, calcium absorption in fruit dipped in a solution of thickener and surfactant exceeded the calcium uptake of that without surfactant. These results are in contrast to those of De Villiers and Hanekom (24) which showed that initial uptake of calcium by Golden Delicious apples was enhanced by the inclusion of a surfactant in a calcium chloride plus thickener solution, but ultimately more calcium was absorbed by fruit when the surfactant was omitted. The differences in the rates of calcium uptake may be due to the innate differences between fruits of cherries and apples. Cherries appear to be much more permeable to calcium penetration than apples (53, 54). This may be because cherries have a larger surface/volume ratio than apples. Large droplets which remain on the cherry surface when dipped may influence a greater portion of the cherry than is the case for a much larger apple fruit.

Dipping cherry fruits for 0.25 min increased fruit calcium content by 170 and 440 ppm for calcium chloride solutions without and with 2.5 g/l thickener, respectively. The mesocarp calcium levels were increased by prolonging the contact time with the dipping solution as determined immediately after the dip (Table 3) and after 21 days of $0^{o}C$ storage (Fig. 15). Adjusting the pH of the $CaCl_2$ dipping solution to 7.0 resulted in maximum calcium uptake (Table 6). Basic or acidic dipping solutions greatly decreased the efficacy of calcium chloride dips. Normal pH of a 4% $CaCl_2$ solution with thickener is usually near

pH 10. Therefore increased calcium penetration may be achieved by lowering the dipping solution pH with hydrochloric acid to pH 7. Basic $CaCl_2$ dipping solutions may form insoluble carbonates and result in ionic calcium being unavailable for fruit penetration. On the other hand, acidic solutions have been shown to extract calcium from fruit tissues (67). Highly acidic $CaCl_2$ solutions may dislocate fruit calcium bound to exchange sites (8, 73) and make fruit calcium more mobile. A reduced amount of bound calcium on fruit surfaces when removed from the dip may result in decreased calcium influx into the fruit.

A single preharvest $CaCl_2$ spray six weeks prior to harvest did not raise flesh calcium levels significantly. However, 3 preharvest $CaCl_2$ sprays were effective in raising cherry flesh calcium levels by 100 ppm (Table 7). Mason (52) observed preharvest $CaCl_2$ sprays increased fruit calcium levels in Spartan apples. No significant effect on fruit Mg, K or Zn levels were observed as a result of $CaCl_2$ sprays.

Effects of $CaCl_2$ spray and postharvest dips on fruit texture. Fruit firmness and bioyield showed similar positive correlations with flesh calcium concentration following a calcium chloride dip (Fig. 16, 17). Fruit deformation to bioyield, however, was not significantly correlated ($p > 0.05$) with flesh calcium concentration. Higher calcium levels resulted in increased flesh firmness and bioyield determined after 21 days storage. Increased flesh calcium levels caused by raising $CaCl_2$ or thickener concentration in the dipping solution resulted in

proportionately higher fruit firmness and bioyield readings. This phenomenon of increasing firmness is different from the calcium effect in retarding the loss of firmness in stored apples (53).

The data in Figs. 16 and 17 indicate that mesocarp calcium levels were increased, and corresponding increases in fruit firmness and bioyield occurred, as a result of prolonging the contact time of the fruit with the dipping solution. The actual fruit firmness and bioyield values (Tables 8, 9) show a general relationship to the values predicted from the mesocarp calcium levels in Figs. 16 and 17. However, fruit firmness appeared to be greater than the values predicted from calcium levels for the 4 hr dip (Tables 8, 9). This suggests that prolonged soaking may increase fruit firmness irrespective of the effect of calcium. The firming effect of prolonged soaking has been previously documented (7, 14, 44).

The infusion of calcium into mesocarp tissues may have increased bioyield and fruit firmness by preventing the disruption of calcium bonds and by the formation of additional calcium cross-linkages between polygalacturonic acid chains (4) which are largely responsible for the cementing features of the middle lamella (33). McCready and McComb (58) suggested that calcium could form a calcium pectate gel within cherries. A greater resistance to cell rupture and shearing between adjacent cells would result from a calcium fortified middle lamella thereby providing increased bioyield and firmness values.

A single $CaCl_2$ spray 6 weeks prior to harvest had no effect on fruit calcium content or textural attributes ($p > 0.05$) (Tables 7, 10), but cherry fruits which received 3 $CaCl_2$ sprays had higher mesocarp

calcium levels and were firmer than the unsprayed controls at harvest. These results agree with those of Bedford and Robertson (7) which show that $CaCl_2$ applications result in firmer canned Montmorency cherries. However, the firming effect of $CaCl_2$ sprays was not apparent after 21 days of storage.

Effects of $CaCl_2$ application and delay in storage on damage disorder incidence. The incidence of bruised fruit was negatively correlated with the length of storage period prior to impact damage (Tables 4, 5). A 12-day delay decreased the incidence of bruised fruit by approximately 50% in 1977 and an 8-day delay decreased the incidence of bruised fruit by approximately 66% in 1978. Postharvest $CaCl_2$ dips had no effect on the incidence of bruising at any delay period. The preharvest $CaCl_2$ sprays decreased the incidence of fruit pitting and increased the incidence of bruises (Tables 11, 12). Pitting appears to result from cell rupture and tissue collapse (Figs. 18, 19, 20), while bruises are considered to be in expression of mechanical damage which causes distortion of the fruit parenchyma cells without cell rupture (Figs. 22, 23). Cold storage prior to impact damage apparently increases the resistance of the fruit to cellular distortion caused by impact. The infusion of calcium into the fruit flesh may strengthen cell walls and thus prevent cell rupture due to mechanical damage.

The term surface marking is used in these studies to describe small miscellaneous indentations in the skin and outer cell layers adjacent to the epidermis. In this area, the cells have been damaged

by localized pressure such as that imposed by cherry stems, particularly stem ends. Storage periods of up to 12 days prior to bruising did not affect the amount of surface marking but a postharvest $CaCl_2$ dip was effective in reducing the incidence of surface markings in both years studied. Preharvest $CaCl_2$ sprays however had no significant effect on the incidence of surface markings (Tables 9, 10). Increased tissue calcium from the postharvest dip may strengthen cell structure sufficiently to reduce surface markings even in fruit damaged 12 hours after dipping.

The incidence of pitting declined with increasing time in $0^{o}C$ storage prior to impact damaging the fruit. Fruit dipped in $CaCl_2$ plus Keltrol solutions showed reductions in the incidence of small, large and total pitting for all storage periods. The calcium content of cherry tissue increases rapidly following a dip in $CaCl_2$. Calcium concentrations in 'Van' cherries increased by several hundred ppm within 2 days of dipping (Figs. 11, 12).

The $CaCl_2$ was highly effective in preventing the occurrence of large pits and in reducing the total number of pits in cherries damaged immediately after dipping or in those which were damaged after various periods of cold storage. In the 1978 study, however, dipping fruit in $CaCl_2$ without thickener had no effect on the incidence of pitting. This suggests that high fruit calcium levels resulting from calcium dips with thickener (Fig. 13) are required to impart fruit resistance to mechanical damage. Increased fruit calcium levels resulting from preharvest $CaCl_2$ sprays were negatively correlated with the incidence

of large and total surface pitting. Calcium may react with free carboxyl groups of polygalacturonic acid molecules to increase the strength of intercellular bonds (4, 15, 34, 41, 86) thus increasing the resistance of the tissue to damage. Increasing the calcium content of 'Van' cherries by postharvest $CaCl_2$ dips was shown to increase fruit firmness and resistance to cell rupture as measured by bioyield (Fig. 16, 17).

The reason a delay in storage reduced surface disorders due to mechanical damage is not clear. Couey and Wright (18) found that cold fruit was more susceptible to bruises than warm fruit. Porritt et al. (70) reported that hydrocooled fruit was even more susceptible to pitting than aircooled fruit at $0^{o}C$. The immediate effect of cooling may be to reduce tissue resilience so that it is more susceptible to mechanical damage. Whittenberger (100) suggested that postharvest aging of Montmorency cherries may strengthen intercellular cement which may impart a resistance to cell rupture when the fruit is damaged. Gee and McCready (35) observed a similar toughening of frozen Montmorency cherries and suggested that the texture changes were the result of enzymic de-esterification and the formation of a calcium pectinate gel. During extended cold storage, however, it appears that changes occur which are not attributable to water loss from the fruit but which result in increased resistance to impact damage.

Factors affecting the efficacy of postharvest dips in preventing surface damage of fruit. The pH of $CaCl_2$ dipping solutions was shown to modify greatly calcium penetration into the cherry flesh (Table 6), and to have a significant effect on the incidence of surface disorders due to mechanical damage (Table 13). The incidences of bruises, surface markings and small surface pitting showed positive correlation with the pH of the dipping solution. However, the incidence of fruit with large and total surface pitting was a minimum when dipped in a $CaCl_2$ solution with a pH 4. The optimum efficacy of a $CaCl_2$ dip in preventing surface disorders corresponds very closely to the pH optimum for maximum calcium uptake. The positive correlation of surface markings, bruises and small surface pitting with dipping solution pH is as yet unexplained.

Commercial handling of the fresh cherry crop requires that fruit be picked, packed and shipped to market within 3 days in most instances. Therefore, the time allowed for calcium to penetrate the fruit flesh from a postharvest $CaCl_2$ dip prior to washing and packing may be as little as several hours. The incidence of surface damage in fruit dipped in water prior to impact damage was not significantly different from non-dipped fruit (Table 14). This suggests that water on the surface of the fruit is ineffective in lubricating the fruit to lessen the degree of damage. Similarly the lubricating effects of a thickener solution on the fruit surface to lessen the magnitude of damage were insignificant. However, the thickener solution when allowed to remain on the fruit surface after damage decreased the incidence of

large and total pits. This effect may be due to restriction of water loss due to the thickener coating preventing formation of sunken pits. Calcium chloride applied without thickener and not washed off prior to storage and $CaCl_2$ applied with thickener significantly decreased the incidence of fruit bruises and surface pitting. However, dipping fruit in $CaCl_2$ with thickener was most effective in reducing surface damage when the fruit remained unwashed. Washing the dipping solution from the surface of the fruit might be expected to decrease the surface supply of calcium for penetration and hence reduce the efficiency of a $CaCl_2$ dip. Substantial reductions in the incidence of bruises and surface pitting however, resulted from $CaCl_2$ plus thickener dips even when washed immediately after dipping. This suggests that dipping fruit may have commercial application in reducing surface disorders. The fruit may be dumped into a $CaCl_2$ plus thickener solution prior to the cluster cutter in a commercial packing line. The $CaCl_2$ plus thickener dip may then be washed off the fruit by water jets prior to sorting. This procedure could result in 30% reductions in the incidence of surface pitting.

Effects of Storage Humidity and Water Loss on Surface Disorder Expression

Low storage humidity of 40% RH increased water loss (Fig.24) and the rate of formation of large pits (Table 14). Storage temperatures interacted with storage humidity to modify the rate of surface pitting

formation. A temperature of 20°C and low storage humidity of 40% RH resulted in most rapid rate development of surface pitting. Fruit stored at 0°C storage, however, developed a slightly higher incidence of pitted fruit than at 20°C storage after 16 days. Porritt et al. (70) suggested that surface pitting development was independent of weight loss. The present results indicate, however, that the rate of surface pitting development can be enhanced by storage conditions that promote weight loss. Other evidence in this study (Table 15) indicated that dipping fruit in an antitranspirant film to restrict water loss (20) significantly reduced the expression of surface pitting.

Histological examination (Fig. 20) indicate that cell rupture results immediately upon impact damage. Fracture of cell membranes and walls will lead to mixing of vacuolar and cytoplasmic contents and weakening of the 3-dimensional cellular matrix. Surface pitting does not occur immediately after impact damage because the contents of the ruptured cells are still present. Water loss may be necessary for the disorder to appear. The present results support this hypothesis because storage conditions which increased water loss also reduced the time for appearance of surface pitting.

'Van' cherries dipped in water prior and subsequent to impact damage showed substantial increases in the incidences of bruised and pitted fruit. The incidence of surface markings and surface pitting was significantly increased by a dip in water prior to impact damage. The water dipping procedure was designed to increase water content which hypothetically should have decreased the incidence of surface depressions.

However, soaking fruit prior and subsequent to bruising enhanced the development of surface damage disorders. Soaking fruit prior to impact damage may increase fruit turgor and fruit firmness (65) and result in increased cell fracture upon impact damage. Considine and Kriedman (17) observed a similar effect for rupture of grapes. Wade and Dewey (97) also found that internal browning of 'Schmidt' cherries resulting from bruising damage was increased by presoaking the fruit in water prior to bruising (Table 16). The increase in fruit damage associated with soaking fruit subsequent to impact is in direct contrast with the results of Wade and Dewey (97). Soaking cherries in water has been found to increase fruit turgor (95) and result in tissue rupture (16, 41, 95). Thus, cherry parenchyma cells which have been weakened by impact damage may rupture in response to increased fruit turgor caused by soaking after the injury occurred. Subsequently, due to cellular disruption, the cells will collapse, in storage, and could result in normal pitting symptoms. The present results would indicate that the maintenance of high fruit turgor by placing fruit in direct contact with water could increase the expression of surface pitting symptoms.

The incidence of fruit with surface markings and bruises was unaffected by storage humidity at $0^{o}C$ or $20^{o}C$. Fruit stored at $20^{o}C$ showed a marked reduction in the incidence surface markings and bruised fruit. Warm storage temperatures may allow damaged fruit tissues to recover.

Effects of Fruit and Storage Temperature on Surface Disorder Incidence

Fruit temperature at the time of impact damage affected the rate of occurrence damage symptoms (Tables 17, 18). Fruit which was impact bruised when cold developed surface pitting symptoms much sooner than fruit which was bruised warm. However, the incidence of large surface pitting among fruit temperature treatments was not significantly different after 8 days at $0^{o}C$. Fruit temperature at the time of impact showed a slight negative correlation to the incidence of surface markings in the 1977 study but fruit temperatures were not significantly related to the incidence of surface marking in the 1978 study. The incidence of all surface markings, large and total surface pitting increased consistently with storage duration. The incidence of small pitting reached a maximum level at 4 days in storage. The apparent decreases in small surface pitting symptoms after 4 days of storage is likely due to small pits increasing in size and number and being classed as large pits.

The influence of storage temperature on rate of development of damage disorders following impact was opposite to the effects of fruit temperature at time of impact (Tables 19, 20). Fruit which was impact damaged at $0^{o}C$ in 1977 and placed in 0^{o} or $25^{o}C$ storage developed lower incidence of surface pitting in $0^{o}C$ after 5 days in storage. However, no significant differences in the incidence of surface pitting existed after 15 days of storage at $0^{o}C$. Fruit in the 1978 study showed that warm storage temperatures accelerated the development of surface pitting disorders, but storage temperatures were negatively correlated

to the incidence of fruit bruises after 16 days of storage which suggests that the tissues distorted in the formation of bruises may have either recovered their original shape or developed into surface pitting in warm storage temperatures. The incidence of all surface disorders except fruit bruises increased with storage time. This evidence suggests that time is required for water loss from the region of damaged or collapsed cells for surface marking or pitting symptoms to develop. Warm storage temperatures would facilitate rapid water loss and account for the rapid occurrence of surface damage symptoms.

Couey and Wright (18) and Porritt et al. (70) observed fruit temperatures to be negatively correlated to the incidence of cherry surface disorders after storage periods of 11 and 12 days respectively. The previous results do agree with the results in this study but the present data shows surface pitting disorders will develop to the same extent for all fruit and storage temperatures in prolonged storage. The effects of fruits temperature in modifying the incidence of surface pitting may be due to greater elasticity of warm fruit tissues.

Storage temperatures affect the rate of surface pitting development but do not markedly affect the total incidence of damage after prolonged storage. The impact received by the fruit is likely to cause a specific amount of cellular damage. Storage temperatures modify the rate at which symptoms appear but not the total amount of damage. Storage temperatures may modify the rate of pit development by influencing water loss from the damaged cell zone. Also when the enzymes of the cytoplasm and vacuolar substrates are mixed in ruptured cells, temperature

influences respiratory activity (55). Increased and uncontrolled enzymatic activity may attack nearby cells causing further cellular disruption. If the formation of surface pits is dependent upon additional cellular disruption after impact, then warm temperatures would facilitate enzymatic attack on cells adjacent to the damaged tissues thus increasing the amount of surface pitting.

Effects of Maturity on Fruit Composition

Fruit weight and soluble solids content increased with advancing fruit maturity (Tables 21, 22). These observations agree with those of Hartman (37) and Proebsting (77). At harvest, titratable acidity was highest in the least mature fruit in 1977 but showed no significant correlation with fruit maturity in the 1978 study. The fruit soluble solids levels increased with advanced fruit maturity. Fruit of intermediate maturity (No. 6) was softest in both years. Bioyield values were, however, unrelated to fruit maturity. The drop in fruit firmness after No. 3 maturity corresponds to the time of rapid fruit swell in the stage III of growth (89). The lowest levels of alcohol insoluble solids (Table 22) expressed on a fresh weight basis were correlated with minimum fruit firmness. Low values for firmness likely are attributable to rapid cell expansion with a slow rate of photosynthate accumulation as evidenced by low alcohol insoluble solids level. Cell structure would be weakened at this point in fruit development.

The percent dry matter increased linearly with advancing fruit maturity (Table 23). The differences observed in accumulation of dry matter and alcohol insoluble solids is likely due to the rapid accumulation of fruit sugars which are removed in the alcohol insoluble solids determination. The levels of soluble solids would not contribute to cell wall rigidity or the cellular 3-dimensional network strength. Mesocarp calcium, potassium and magnesium levels decreased with advancing fruit maturity when expressed on a dry weight basis (Table 24). However, only potassium and magnesium showed significant positive relationship to fruit maturity in 1977 when expressed on a fresh weight basis (Table 23). In the 1978 study, calcium, magnesium, and potassium all showed significant negative correlations with advancing fruit maturity when expressed on a dry weight basis (Table 25). Because dry weight increased linearly with advancing maturity the apparent decreases in mineral content may have resulted from a dilution effect. Expressed on a fresh weight basis fruit nitrogen decreased linearly with fruit maturity (Table 26). Concentrations of mesocarp calcium, magnesium, zinc and potassium reached minimum at intermediate maturities and appeared to increase with advancing maturity. The mineral accumulation and nitrogen dilution appear to be consistent with the hypothesis of accumulation of photosynthate and cell wall material with advancing maturity. Cell walls and the middle lamella reinforced by accumulated alcohol insoluble solids would provide greater resistance to cell fracture and decreased incidences of damage disorders.

Water soluble and total pectin on a dry weight basis (Table 25) reached a maximum about 7 days after the beginning of the stage III growth phase but decreased linearly on a fresh weight basis (Table 26). Cellulose content expressed on an alcohol insoluble solids basis was not significantly related to maturity. The maximum values recorded for total and water soluble pectin approximated the maturity at which minimum fruit firmness occurred.

Histological Examinations of Disorder Incidence

Microscopic examinations of impact damaged tissue indicated that fruit of No. 3 color maturity was susceptible to cell fracture (Fig. 18, 19). Cell rupture in No. 3 color maturities was evident immediately after impact even though surface dimpling had not occurred. The expression of surface pitting after 9 days of storage was evidenced by collapse and sunken appearance of the cells (Fig. 20). The present results agree with those of Porritt et al. (70) which indicated that surface pitting resulted from the collapse of cells 8-10 cell layers beneath the epidermis. Surface pitting appears to develop in storage as a result of volume loss from the region of fractured cells allowing the outer cell layers to collapse inwards.

Cherries of No. 33 color maturity did not develop surface pitting. Fruit parenchyma cells, however, appeared to be distorted and form a flattened surface in response to impact damage (Fig. 21, 22). The flattened surface (bruise) was evident immediately upon impact

damage and no progression of the disorder with storage was evident (Fig. 23). Mature cherry parenchyma cells did not rupture and hence cellular collapse to form surface pitting symptoms did not occur.

Fruit tissue of No. 33 color cherries appears to have strengthened cell walls resistance to impact damage. Cellular distortion may result from disruption of the middle lamella complex which would allow individual cells to shift in a distorted 3 dimensional cell matrix. However, in fruit of No. 3 color maturity, the middle lamella complex may be stronger than the individual cell walls so that on impact, the cell walls fracture and the cells collapse rather than the middle lamella yielding to form a distorted cellular structure.

Effects of Maturity on Impact Damage Expression

The amount of surface markings and surface pitting due to mechanical damage decreased with maturity in the 1977 study (Table 27). The incidence of fruit bruises, however, increased with increased fruit maturity. The increase in the incidence of fruit bruises with maturity may be a consequence of the fruit cells distorting but not collapsing in response to impact. A similar observation was made in the 1978 study (Table 28) where the maximum level of fruit with surface markings occurred at 14 days and surface pitting occurred at 7 days into stage III of fruit growth. At 7 days into stage III a minimum incidence of fruit bruises was recorded. This inverse relationship between fruit bruises and surface pitting may describe cell resistance to fracture. Cells which fracture and collapse result in surface pitting. Cells which distort but are resistant to fracture result in fruit bruises.

The maximum level of surface markings and surface pitting occurred in the initial part of stage III of fruit, associated with rapid cell enlargement (89). Cell weakening caused by rapid fruit enlargement apparently predisposes fruit to surface pitting. High proportions of nitrogen, total pectin and soluble pectin and low alcohol insoluble solids may contribute to cell fracture rather than cell distortion. High levels of fruit nitrogen have been shown to result in fruit cells which are relatively unstable in storage (30, 56, 57). High levels of pectin would result in a firm middle lamella creating a rigid 3 dimensional structure which would absorb energy on impact without damage. Low levels of alcohol insoluble solids would indicate limited concentration of cell wall components. As cellulose appears to be unaffected by maturity, the fluctuation in alcohol insoluble solids with maturity appears to be attributable to the hemicellulose fraction (32, 100). Cell wall structures weakened by limited hemicellulose content would tend to fracture readily under stress. Accumulation of cell wall components with advancing maturity would strengthen cell walls and provide cellular resistance to fracture. Potassium accumulation on a fresh weight basis may also contribute to increased cell turgor, due to osmotic effects. Increased cell turgor may result in firmer fruit tissue and may provide resistance to cellular fracture and collapse.

Effects of Work, Deformation and Loading Rate on Fruit Damage Incidence

Increasing the work done on the fruit from free fall increased the incidence of fruit bruises and surface pitting but decreased the

incidence of surface markings (Table 29, 30) for 3 fruit maturities. Surface markings appear to result from compression forces such as a fruit being forced onto a stem. Bruises and surface pitting increase with increased work imparted to the fruit by impact. The inverse relationship of surface markings to impact force may be due to the formation of bruises and surface pitting which mask smaller surface marks.

Impact as measured by work done by free fall did not significantly affect the soluble solids levels at three maturities (Table 29) after 21 days storage. However, increasing the amount of impact work resulted in a significant decrease in the titratable acidity in the fruit after storage. Increased levels of work done on the fruit resulted in increased tissue damage as evident by increased incidences of surface pitting. Increased amounts of tissue damage may be positively correlated with respiration rates (55) which may utilize a greater portion of acid substrate thus accounting for decreased titratable acidity. The impact work on the fruit did not affect firmness or bioyield after storage for No. 3 or 33 color maturity but was positively correlated with fruit firmness and bioyield after storage in fruit of No. 6 maturity. The firming effect of increased impact loads may be similar to that observed by Parker et al. (65), Labelle et al. (44) in Montmorency cherries. Repeated bruising of sour cherries was found to result in callus formation (27) which strengthened the fruit tissue in storage.

Height of free fall was positively correlated with the incidences of bruises as well as large and total pitting in a 1978 study (Table 30). Fruit dropped on to a rough fiber belt developed higher incidences of surface markings and surface pitting than fruit dropped on to a smooth plastic belt while the development of bruises was unaffected by the type of belting material.

The incidence of surface markings decreased as the drop distance to a rough belt increased. This evidence supports the hypothesis that surface markings result from compression of the fruit on to a rough or small object. Impact pressures and fruit collision with smooth surfaces do not aggravate this marking disorder. However, rough surfaces and increased impact energies enhance the expression of surface pitting. Rough surfaces would provide many individual pressure points of impact with a cherry. The result would be that impact pressures would be concentrated on specific locations within the cherry fruit. This phenomenon would be conducive to cell rupture because greatly increased impact pressures would be exerted on specific cell tissue. Fruit contacting a smooth surface would have the energy of impact distributed more evenly across the fruit surface and internal tissues which would cause less cell fracture and decreased incidence of surface pitting.

The development of damage disorders appears to be a function of the bruising surface texture, the degree of fruit deformation and the loading rate (Table 31). Surface pitting showed a positive relationship to the amount of deformation of the fruit and the loading rate of a flat plate. Fridley et al. (34) indicated that maximum shear stress would correspond to the observed areas of cell collapse (Figs. 21, 22) which

result in surface pitting symptoms. The model of the cherry fruit when subjected to deformation may be described as a series dashpot arrangement (34). Cherry fruit will exhibit viscoelastic properties when deformed. Slow loading rates applied to cherry fruits will allow the cherry matrix to distort and flow in response to pressures exerted. However, large deformations of 4 to 8 mm may compress the parenchyma cells against the pit causing cell fracture. Similarly fruit tissue subjected to very fast loading rates (1000 mm/min) is not able to flow and distort fast enough in response to the pressure applied. Consequently, very fast loading rates may readily cause cell fracture at all deformations studied.

The incidence of bruised fruit is unaffected by the loading rate or texture of the bruising surface. Fruit bruises result from permanent cellular distortion. The amount of cellular deformation therefore appears to be critical in determining whether the cells are to remain permanently distorted. The distortion of fruit cells must exceed a yield point with applied pressure beyond which the cells are unable to resume their original formation. A yield point may correspond to rupture of the middle lamella complex which is largely responsible for maintenance of the cellular 3-dimensional structure (32).

Effects of Fruit Size on Fruit Composition and Damage Disorder Incidence

Large fruit at all maturities showed significant reductions in the incidence of large and total pitting (Tables 32, 33). Cherry fruit subjected to a free fall with height adjusted to fruit weight to result in a constant work done on the fruit, showed similarly that large fruit

was resistant to surface pitting (Tables 32, 33).

The incidence of fruit bruises were inversely related to fruit size in 1977, but incidence of fruit bruises and surface markings were unaffected by fruit size and drop height in the 1978 study (Table 33).

The effect of fruit size on surface damage does not appear to be related to factors such as alcohol insoluble solids, total or water soluble pectin, calcium, magnesium, potassium or zinc content when expressed on a fresh weight basis (Table 34). However, when fruit mineral content is expressed on a dry weight basis (Table 35) large fruit had significant lower levels of calcium, magnesium, potassium and zinc. Fruit nitrogen content on a fresh or dry weight basis was significantly lower in larger fruit than in smaller fruit.

The tendency of smaller fruit to be more susceptible to cell fracture and surface pitting may be attributable to high fruit nitrogen. Fruit high in nitrogen has been found to be of low quality and are subject to cellular breakdown and loss of firmness (30, 56, 57). Stanberry and Clore (86) observed decreased incidence of surface pitting in 'Bing' cherries when fertilized with ground applications of nitrogen. Proebsting (77) also indicated that increased susceptibility to surface pitting may result from nitrogen deficiency. In this study, however, fruit nitrogen decreased with advancing maturity, and resistance to surface pitting disorders increased. Fertilization practices in the Okanagan indicate the use of 4 times are nitrogen than was used by Stanberry and Clore (86). This degree of nitrogen excess may predispose fruit to impact damage.

The incidence of surface markings (Tables 32, 36) was not related significantly to fruit weight. Surface markings appear to be superficial damage which is unlikely to be influenced by fruit nitrogen. The incidence of bruises, however, was less in small than in large fruit in the 1977 study (Table 36). This may be attributable to the greater incidence of large pits found in small fruit. Fewer bruises but higher incidence of surface pits in small fruit may result from a greater tendency of cells to fracture in response to impact pressures, whereas in large fruit the cells tend to distort and form bruises.

Effects of Preharvest Sprays on Fruit Composition and Incidence of Damage Disorders

Preharvest sprays of gibberellic acid (GA) significantly reduced the incidence of large and total surface pitting in 1977 and 1978 (Tables 37, 38). Gibberellic acid concentration in range of 20 to 30 ppm significantly reduced the incidence of surface pitting in fruit of No. 3 and 6 color maturities which agrees with results of Proebsting (77). GA sprays significantly increased alcohol insoluble solids and significantly decreased total nitrogen from control values (Tables 39, 40). Increased alcohol insoluble solids may impart greater cell wall strength and resistance to fracture and may provide increased fruit firmness detected by Proebsting *et al.* (76). A decrease in fruit nitrogen on fresh and dry weight bases is similar to that observed in large fruit which also

is resistant to surface pitting. GA sprays had no significant effect on superficial surface markings or incidence of bruising in No. 3 color maturity fruit, but reduced bruising in the more mature No. 33 fruit color maturity in the 1977 study.

Mobileaf sprays applied preharvest significantly increased fruit susceptibility to bruises, and surface markings in the second harvest and large and total pitting in the first harvest (Table 37). Langer and Fisher (46) reported that antitranspirant films applied to fruit as a preharvest spray significantly decreased dry matter. Susceptibility of cherries to mechanical damage was found in the current study to be negatively related to the alcohol insoluble solids content of the fruit. Decreased dry matter resulting from a Mobileaf spray could therefore account for increased susceptibility to mechanical damage.

Effects of Reducing Crop Load on Fruit Characteristics and Susceptibility to Mechanical Damage

Reducing crop load in two orchards gave variable results (Tables 41, 42). Fruit thinning on individual branches had no significant effect on soluble solids, bioyield, fruit firmness or titratable acidity of the fruit. Fruit weight, and alcohol insoluble solids content were significantly increased in fruit from branches which had been thinned in Orchard 1. Thinning had no effect on fruit composition in Orchard 0.

However, after the thinning was completed in Orchard 0, an extensive spontaneous fruit drop occurred which also reduced the crop on control branches. The results indicate that thinning may be beneficial only when a full crop or overcropping occurs.

Where thinning failed to affect fruit chemical and physical characteristics there was also no effect on resistance to impact damage. Thus thinning in Orchard 0 had no influence on the incidence of fruit bruises (Table 42). Thinning treatments showed significant reductions in the incidence of surface markings, large and total surface pitting. Resistance of fruit to surface pitting associated with reduced crop loads agrees with the general observations shown in Fig. 3. Crop reductions may impart fruit resistance to mechanical damage by increasing fruit size and alcohol insoluble solids content. Large fruit, mature fruit with high alcohol insoluble solids and fruit sprayed with GA have been shown to be resistant to surface pitting. Reducing crop loads contributes to the development of this type of fruit by providing for greater photosynthate accumulation per fruit. Greater amounts of cell wall material would provide stronger fruit cells which would resist cell fracture. Stronger parenchyma cells resulting from photosynthate fortification also would account for the increased fruit firmness associated with the crop reduction.

SUMMARY AND RECOMMENDATIONS

The amount and severity of impact collisions to the fruit were found to be the primary determinant of surface damage. However, previous results have shown that fruit damage will occur even with the minimum of fruit handling. The present study has described the pre- and postharvest treatments that are able to affect the expression of surface disorders in cherry fruit.

The results provide the following conclusions and recommendations which when applied could minimize surface disorders resulting from mechanical damage in sweet cherries.

1. The application of preharvest sprays of 0.5% calcium chloride was effective in reducing susceptibility of fruit to mechanical damage. Sprays closest to harvest and multiple sprays were most effective in providing fruit resistance to surface pitting and bruises.

2. Postharvest calcium chloride dips were effective in increasing fruit firmness and bioyield values and in imparting resistance to mechanical damage to fruit. Firming of the fruit and decreasing fruit susceptibility to mechanical damage are not cause and effect but rather, coincidental factors resulting from dipping.

Calcium uptake from a postharvest dip is best fitted by a logarithmic equation. Fruit uptake of calcium is enhanced by the addition of a thickener to the dipping solution, prolonged contact of fruit with dipping solution and the adjustment of the pH to 7.

3. Fruit susceptibility to surface damage is greatly decreased by a delay in $0^{o}C$ storage for periods of 2-8 days before impact bruising of fruit. A delay in storage prior to impact damage enhanced the effect of a postharvest calcium chloride dip in prevention of damage symptoms.

4. Gibberellic acid sprays prior to harvest were effective in preventing mechanical damage to fruit. Preharvest gibberellic acid sprays resulted in fruit with higher alcohol insoluble content and lower nitrogen content.

5. The susceptibility of fruit to mechanical damage reached a maximum value between No. 3 to No. 6 color maturity. Mature mahogany fruit (color maturity No. 33) were the least susceptible to mechanical damage. As fruit developed it became most suceptibility to mechanical damage at the time of initial fruit swell in stage III of development. Lower levels of alcohol insoluble solids and higher nitrogen levels were associated with fruit of high predisposition to surface damage.

6. Large fruit was less susceptible to mechanical damage than small fruit. This effect was not related to maturity or alcohol insoluble solids content. However, large fruit had lower nitrogen values than did the smaller fruit.

7. Fruit which was bruised when cold developed more surface disorders earlier in storage than did fruit which was damaged when warm. Damaged fruit developed surface symptoms at a greater rate when stored in warm temperatures than in cold storage. The total amount of surface damage after 8-12 days of storage, however, was unaffected by fruit or storage temperatures.

8. Surface pitting develops as a result of a combination of loading rate and total force exerted on the fruit. Rapid loading rates will produce damage at very low forces. Slow loading rates, however, require much higher forces to cause surface pitting. Cell disruption at time of impact appears to be necessary for disorders to develop in storage.

9. Low relative humidity in storage (40%) increased the rate of disorder development. However, storage humidity had no effect on the incidence of surface disorders after 16 days of storage. High temperature interacted with low storage humidity to give the most rapid development of surface disorders. The development of surface pitting and bruises are a function of weight loss and may be the result of localized water loss from the fruit. Fruit dipped in an antitranspirant (Mobileaf) designed to restrict water loss, reduced the expression of surface disorders. Soaking treatments prior to storage designed to increase fruit turgor, however, increased disorder incidence.

10. Reducing crop load on trees by hand thinning had variable results in benefiting fruit texture and decreasing fruit susceptibility to mechanical damage. However, hand thinning of trees which were heavily set did reduce susceptibility to mechanical damage.

11. Microscopic examinations revealed that cell fracture was apparent immediately after mechanical damage. The development of surface pitting requires time for redistribution of cell contents or loss of water from the region of cellular damage. Micrographs confirmed that impact forces caused tissue damage that resulted in surface pitting.

The possible handling and storage procedures which could be used by the commercial fruit industry to minimize losses due to mechanical damage in 'Van' cherries would be as follows:

One spray of 30 ppm gibberellic acid or three sprays containing calcium chloride should be applied with the final spray applied within one week of harvest. Crop load should be limited by restricting amount of insect pollination, hand or chemical thinning or by more detailed pruning. It is most preferable to have large fruits without high nitrogen levels. Excessive fertilizing with nitrogenous compounds is, therefore, undesirable. Urea sprays should be avoided. Fruit should be harvested with care when mature, at least No. 6 color. Fruit received at the packing-house could be dipped in a solution of 4% calcium chloride plus 0.25% thickener plus 0.1% surfactant with pH adjusted to between pH 4 to 7. The fruit then may be either:

1) packed immediately when the fruit is still warm, cooled to below 5°C immediately and then shipped to arrive and be sold at the market within 4-6 days of packing, or,

2) the fruit which cannot be handled in this time frame may be cooled immediately to 0°C and packed after 4-8 days in cold storage at which time susceptibility to damage is reduced.

With proper handling and 0°C storage cherries retain premium dessert condition for 3 to 4 weeks after harvest. Under no circumstances should fruit be in contact with surface water for prolonged periods as this will increase disorder incidences. In all cases, the fruit should be kept at temperatures below 5°C and at storage relative humidities of greater than 85% RH.

These procedures make it possible to reduce the incidence of surface disorder from greater than 70% to less than 10%. An improvement in condition of this magnitude combined with proper fungicide applications to restrict decay will ensure the arrival of cherries on the most distant markets with less than the 15% allowable defects.

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Table 1. Yearly cherry claims and returns.[z]

Year	Total fresh volume sold (cases[y])	Total fresh return ($)	Total fresh claim ($)	Average claim (¢/kg)	Average grower return (¢/kg)	Expected grower return without claims (¢/kg)	Percent reduction of grower return by claims (%)
1974	348,922	2,934,318	257,151	7.94	56.10	64.04	12.3
1975	469,749	3,678,564	461,787	10.55	34.12	44.67	23.7
1976	511,059	3,707,977	529,589	11.23	31.02	42.25	26.6
1977	484,562	3,991,791	79,159	1.69	51.26	52.95	3.3
1978	333,985	4,015,386	225,000	7.26	86.88	94.14	7.7

z B.C. Tree Fruits Ltd. production figures

y One case = 9.3 kg

Table 2. Approximate cherry production handled by B.C. Tree Fruits Ltd.[z]

Cultivar	1975 No.of cases[y]	1975 % of yearly total	1976 No.of cases	1976 % of yearly total	1977 No.of cases	1977 % of yearly total	1978 No.of cases	1978 % of yearly total
Van	151,361	32.9	163,664	32.5	117,116	25.3	117,380	36.0
Bing	90,425	19.7	72,739	14.4	87,895	19.0	60,907	18.7
Lambert	213,885	46.5	263,564	52.3	258,273	55.8	147,999	45.4

z B.C. Tree Fruits Ltd. production figures

y One case = 9.3 kg

Table 3. Effect of contact time with postharvest dip on calcium uptake by 'Van' cherries, 1978 crop.

Time in dip (min)	Mesocarp calcium (mg/kg)
0.25	666[z]
1.0	667
4.0	671
16.0	688
64.0	755
128.0	844

z Values fitted from regression equation:
Mesocarp calcium = 665.7 + 1.39 Time
(r^2 = 0.76, p = 0.01). Flesh Calcium of undipped control = 578 ppm

Table 4. Effects of fruit delay in storage and a $CaCl_2$ dip containing thickener on disorder incidence in 'Van' cherries, 1977 crop.

Delay prior to impact damage (days)	$CaCl_2$ plus thickener dip	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
0.5	0	27.4[z]	35.6[y]	10.1[x]	40.1[w]	52.5[v]
4	0	27.4	35.6	6.1	17.0	21.4
8	0	27.4	35.6	4.8	9.3	14.6
12	0	27.4	35.6	4.0	4.8	9.1
0.5	1	11.4	39.8	10.1	21.8	29.7
4	1	11.4	27.3	6.1	13.2	13.5
8	1	11.4	23.1	4.8	3.8	8.1
12	1	11.4	20.7	4.0	1.2	5.0

z Values fitted from regression equation: Fruit with surface marks = 27.4 - 16.0 Dip (r^2 = 0.60, p = 0.01).

y Values fitted from regression equation: Bruised fruit= 35.6 - 13.8 Dip x Log (days delay) (r^2 = 0.34, p = 0.01).

x Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = 8.8 - 4.42 Log (days delay) (r^2 = 0.42, p = 0.01).

w Values fitted from regression equation: Fruit with > 5 mm diam pitting = 32.4 - 15.1 Dip - 25.6 Log (days delay) + 10.7 Dip x Log (days delay) (R^2 = 0.95, p = 0.01).

v Values fitted from regression equation: Pitted fruit = 43.0 - 18.7 Dip - 31.4 Log (days delay) + 13.5 Dip x Log (days delay) (R^2 = 0.93, p = 0.01).

Table 5. Effects of fruit delay in storage, $CaCl_2$ and thickener dip on disorder incidence in 'Van' cherries, 1978 crop.

Days prior to impact damage (days)	$CaCl_2$ dip	Thickener dip	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
1.0	0	0	7.4[z]	7.7[y]	14.4[x]	30.4[w]	48.3[v]
2.0	0	0	7.4	5.8	14.0	21.2	41.5
4.0	0	0	7.4	4.0	13.3	16.6	30.2
8.0	0	0	7.4	2.1	11.9	8.2	18.7
16.0	0	0	7.4	0.0	9.1	13.4	24.8
1.0	1	0	7.4	7.7	14.4	30.4	48.3
2.0	1	0	7.2	5.8	14.0	21.2	41.5
4.0	1	0	6.7	4.0	13.0	16.6	30.2
8.0	1	0	5.2	2.1	11.9	8.2	18.7
16.0	1	0	1.4	0.0	9.1	13.4	24.8
1.0	0	1	7.4	7.7	9.4	30.4	42.8
2.0	0	1	7.4	5.8	9.0	21.2	36.0
4.0	0	1	7.4	4.0	8.0	16.6	24.7
8.0	0	1	7.4	2.1	7.9	8.2	13.2
16.0	0	1	7.4	0.0	5.1	13.4	19.3
1.0	1	1	7.4	7.7	9.4	22.7	28.3
2.0	1	1	7.2	5.8	9.0	13.5	22.4
4.0	1	1	6.7	4.0	8.0	8.9	13.1
8.0	1	1	5.2	2.1	7.9	0.5	5.5
16.0	1	1	1.4	0.0	5.1	5.7	19.3

z Values fitted from regression equation: Fruit with surface marks = 7.4 - 0.31 Log (day delay) x $CaCl_2$ x Days delay (r^2 = 0.16, p = 0.01)

y Values fitted from regression equation: Bruised fruit = 7.7 - 6.2 Log (day delay) (r^2 = 0.31, p = 0.01)

x Values fitted from regression equation: Fruit with less 5 mm diam pitting = 14.7 - 0.35 Day delay - 5.0 Thickener (R^2 = 0.39, p = 0.01)

w Values fitted from regression equation: Fruit with greater 5 mm diam pitting = 47.2 - 16.8 Days delay - 7.68 $CaCl_2$ x Thickener + 16.0 Log (day delay) + 11.2 Log (day delay) x day delay (R^2 = 0.78, p = 0.01)

v Values fitted from regression equation: Pitted fruit = 70.8 - 22.5 Day delay - 5.53 Thickener + 0.97 Day delay x $CaCl_2$ x Thickener - 15.5 $CaCl_2$ x Thickener + 22.4 Log (day delay) + 14.9 Log (day delay) x day delay (R^2 = 0.87, p = 0.01).

Table 6. Effect of pH of postharvest calcium chloride dip on calcium uptake by 'Van' cherries, 1978 crop.

	Mesocarp Ca content (mg/kg)				
	pH of dipping solution				
Days from dip	1	4	7	10	12
1	864[z]	910	920	894	857
4	934	1120	1160	1050	905
16	1210	1940	2100	1690	1090

z Values fitted from regression equation:

Mesocarp calcium = 841.2 + 25.2 pH x Days - 1.99 pH^2 x Days

(R^2 = 0.82, p = 0.01).

Table 7. Effects of preharvest $CaCl_2$ tree sprays on cherry mineral content, 1977 crop.

Treatment	Mesocarp Ca (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp K (mg/kg)	Mesocarp Zn (mg/kg)
No tree spray	762 b[z]	653 a	9309 a	6.0 a
1 tree spray 0.5% $CaCl_2$	760 b	653 a	10450 a	6.9 a
3 tree sprays 0.5% $CaCl_2$	853 a	666 a	10140 a	5.7 a

z Mean separation within a column by Newman-Keuls test, 5% level.

Table 8. Effects of dipping 'Van' cherries in a $CaCl_2$ dip solution[z] on fruit bioyield and fruit firmness. No thickener in dip, 1977 crop.

Dip Time (min)	Mesocarp Ca (mg/kg)	Predicted[y] bioyield (kg)	Actual bioyield (kg)	Predicted[x] firmness (kg/cm)	Actual firmness (kg/cm)
No dip	511	0.76	0.80	1.66	1.67
0.25	695	0.88	0.85	1.91	1.77
10	865	0.99	0.88	2.18	2.05
60	957	1.05	1.00	2.32	2.41
120	1003	1.08	1.04	2.37	2.46
240	1126	1.16	1.13	2.56	2.73

z Dip solution contained 30 g/l $CaCl_2$, 1 g/l nonionic surfactant, 0.5 g/l Benlate.

y Values fitted from regression equation: Bioyield = 0.428 + 0.00065 Ca (r^2 = 0.86, p = 0.01).

x Values fitted from regression equation: Firmness = 0.877 + 0.0015 Ca (r^2 = 0.88, p = 0.01).

Table 9. Effects of dipping 'Van' cherries in a $CaCl_2$ dip solution[z] on fruit bioyield and fruit firmness. Thickener in dip, 1977 crop.

Dip Time (min)	Mesocarp Ca (mg/kg)	Predicted[y] bioyield (kg)	Actual bioyield (kg)	Predicted[x] firmness (kg/cm)	Actual firmness (kg/cm)
No Dip	511	0.76	0.85	1.66	1.73
0.25	957	1.05	1.00	2.32	2.11
10	972	1.06	0.98	2.34	2.25
60	1080	1.13	1.10	2.49	2.67
120	1188	1.20	1.18	2.67	2.66
240	1295	1.27	1.32	2.82	3.50

z Dip solution contained 30 g/l $CaCl_2$, 1 g/l nonionic surfactant, 0.5 g/l Benlate.

y Values fitted from regression equation: Bioyield = 0.428 + 0.00065 Ca (r^2 = 0.86, p = 0.01).

x Values fitted from regression equation: Firmness = 0.877 + 0.0015 Ca (r^2 = 0.88, p = 0.01).

Table 10. Effects of $CaCl_2$ tree sprays on cherry fruit firmness, 1977 crop.

Treatment	Bioyield at harvest (kg)	Bioyield after storage (kg)	Mesocarp firmness at harvest (kg/cm)	Mesocarp firmness after storage (kg/cm)
No tree spray	0.81 a[z]	0.83 a	1.29 b	1.52 a
1 tree spray 0.5% $CaCl_2$	0.79 a	0.78 a	1.35 b	1.37 a
3 tree sprays 0.5% $CaCl_2$	0.90 a	0.91 a	1.69 a	1.53 a

z Mean separation within a column by Newman-Keuls test, 5% level.

Table 11. Effects of preharvest $CaCl_2$ tree sprays on the incidence of cherry fruit disorders, 1977 crop.

Treatment	Fruit with bruises (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pit (%)	Fruit with > 5 mm diameter pit (%)	Fruit with pitting (%)
No tree spray	33.9 b[z]	30.5 a	3.5 a	60.6 a	64.1 a
1 tree spray 0.5% $CaCl_2$	57.3 a	32.7 a	1.1 a	37.3 b	38.4 b
3 tree sprays 0.5% $CaCl_2$	50.6 a	35.4 a	2.6 a	41.0 b	43.2 b

z Mean separation within a column by Newman Keuls test, 5% level.

Table 12. Effects of preharvest $CaCl_2$ tree sprays on the incidence of cherry fruit disorders, 1978 crop.

Treatment			Fruit characteristics						
0.35% $CaCl_2$ spray 5 wks prior to harvest	0.35% $CaCl_2$ spray 3 wks prior to harvest	0.35% $CaCl_2$ spray 1 wk prior to harvest	Bruised fruit (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)	Fruit firmness (kg/cm)	Bioyield (kg)
-	-	-	4.0a[z]	4.8a	9.8a	70.5a	80.3a	2.25b	1.78a
+	-	-	5.3a	12.0a	11.8a	59.8b	71.5a	2.74ab	1.80a
-	+	-	4.3a	7.5a	15.3a	57.3b	72.5a	2.41b	2.04a
-	-	+	5.3a	10.3a	13.0a	51.5b	67.0ab	2.84ab	1.69a
-	+	+	3.5a	6.5a	10.0a	48.0b	58.0b	3.09a	1.96a
+	+	+	5.3a	10.5a	17.3a	21.8c	39.0c	3.29a	2.09a

z Mean separation within a column by Newman-Keuls test, 5% level.

Table 13. Effects of pH and $CaCl_2$ postharvest dip on disorder incidence in 'Van' cherries, 1978 crop.

pH of solution	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted Fruit (%)
1	4.0[z]	5.9[y]	6.5[x]	16.6[w]	27.9[v]
4	5.7	10.2	12.1	22.8	18.4
7	7.3	13.6	17.6	27.5	22.8
10	9.0	16.9	23.1	32.2	34.8
12	10.0	19.1	26.8	35.0	44.1

z Values fitted from regression equation: Surface marks = 3.5 + 0.545 pH (r^2 = 0.19, p = 0.01).

y Values fitted from regression equation: Bruised fruit = 5.8 + 1.11 pH (r^2 = 0.61, p = 0.01).

x Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = 4.7 + 1.84 pH (r^2 = 0.55, p = 0.01).

w Values fitted from regression equation: Fruit with > 5 mm diam pitting = 16.6 + 1.56 pH (r^2 = 0.27, p = 0.01)

v Values fitted from regression equation: Pitted fruit = 35.2 - 8.47 pH + 1.22 pH^2 - 0.0377 pH^3 (R^2 = 0.82, p = 0.01).

Table 14. Effects of storage temperature and humidity on weight loss and disorder development in 'Van' cherry, 1978 crop.

Storage temperature (°C)	Days in storage	Storage relative humidity	Weight lost (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)	Bruised fruit (%)
0	1	0[z]	0.103[y]	10.8[x]	15.0[w]	1.2[v]	1.8[u]	14.8[t]
	2	0	0.103	10.8	15.0	5.5	15.2	14.8
	4	0	0.103	10.8	15.0	12.6	29.5	14.8
	8	0	0.103	10.8	15.0	24.8	45.6	14.8
	16	0	0.103	10.8	15.0	47.6	66.3	14.8
0	1	1	1.945	10.8	15.0	0.0	14.6	14.8
	2	1	1.945	10.8	15.0	12.8	27.7	14.8
	4	1	1.945	10.8	15.0	27.1	40.7	14.8
	8	1	1.945	10.8	15.0	41.4	53.8	14.8
	16	1	1.945	10.8	15.0	55.7	66.9	14.8
20	1	0	0.103	10.8	15.0	11.4	21.0	14.8
	2	0	0.103	10.6	15.0	13.8	32.8	14.5
	4	0	0.103	9.9	15.0	24.9	43.7	13.5
	8	0	0.103	8.0	15.0	41.5	50.2	12.1
	16	0	0.103	3.2	15.0	75.3	60.8	10.4
20	1	1	1.945	10.8	15.0	9.2	33.8	14.8
	2	1	1.945	10.6	15.0	23.2	45.2	14.3
	4	1	1.945	9.9	15.0	37.3	55.0	13.5
	8	1	1.945	8.0	15.0	51.2	61.4	12.1
	16	1	1.945	3.2	15.0	65.2	61.4	10.4

z Relative humidity values coded as: 0 = 95-100%RH, 1 = 40%RH.

y Values fitted from regression equation: Weight lost = 1.945 - 1.842 Humidity (r^2 = 0.28, p = 0.01)

x Values fitted from regression equation: Surface markings = 10.8 - 0.0196 Log (day) x day x temperature (r^2 = 0.20, p = 0.01)

w Fruit with ≤ 5 mm diam pitting = 15.0 (regression equation not significant p = 0.01)

v Values fitted from regression equation: Fruit with > 5 mm diam pitting =-1.47 + 0.535 Temperature + 2.62 Humidity x day + 47.5 Log (day) - 41.6 Log (day) x humidity - 0.0508 Log (day) x day x temperature + 0.0474 Log (day) x humidity x temperature x day (R^2 = 0.90, p = 0.01)

u Values fitted from regression equation: Pitted fruit = 14.6 - 12.8 $Humidity_2$ + 1.04 Temperature - 0.0822 Day x temperature + 43.4 Log (day) + 0.635 Log (day) x humidity x day (R^2 = 0.85, p = 0.01)

t Values fitted from regression equation: Bruised fruit = 14.8 - 0.0270 Log (day) x day x temperature (r^2 = 0.22, p = 0.01).

Table 15. Effects of washing on effectiveness of postharvest dips in preventing damage disorders in 'Van' cherries, 1978 crop.

Dipping solution	Wash time	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
Water	None	11.3 a[z]	4.8 c	16.8 abc	45.8 ab	62.5 a
	before bruising	12.5 a	4.5 c	18.0 ab	44.3 abc	62.3 a
	after bruising	15.0 a	3.0 c	14.0 bcd	48.5 a	62.5 a
2.5 g/l Keltrol	None	15.8 a	4.3 c	12.3 bcd	30.5 d	42.8 c
	before bruising	14.3 a	2.5 c	21.5 a	36.0 cd	57.5 a
	after bruising	17.0 a	10.0 a	11.5 bcd	42.3 abc	53.8 ab
40 g/l $CaCl_2$	None	6.5 a	3.0 c	9.5 cd	31.8 d	41.3 c
	before bruising	7.5 a	2.3 c	16.5 abc	44.3 abc	60.8 a
	after bruising	14.5 a	5.5 bc	14.8 abc	45.3 abc	60.0 a
40 g/l $CaCl_2$ 2.5 g/l Keltrol	None	9.8 a	3.2 c	8.3 d	21.3 e	29.5 d
	before bruising	10.8 a	6.0 bc	14.8 abcd	30.8 d	45.5 c
	after bruising	7.8 a	5.3 bc	15.0 abcd	27.3 de	42.3 c
1/5 (v:v) Mobileaf	None	7.0 a	2.5 c	8.3 d	20.0 e	28.3 d
	before bruising	14.0 a	4.5 c	11.8 bcd	36.5 bcd	48.3 bc
	after bruising	9.5 a	9.5 ab	13.3 bcd	29.3 d	42.5 c

z Mean separation, within columns, Newman-Keuls test, 5% level.

Table 16. Effects of dipping duration on disorder incidence in 'Van' cherry, 1978 crop.

Dipping duration (min)	Dipping sequence	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
0.25	before impact (0)	16.3[z]	7.8[y]	11.9[x]	13.3[w]	24.6[v]
4.0	" "	16.3	7.5	13.6	14.4	26.1
16.0	" "	16.3	6.7	16.5	17.8	29.9
64.0	" "	16.3	5.3	41.3	26.3	40.8
128.0	" "	16.3	8.1	70.8	25.3	42.5
0.25	after impact (1)	12.3	10.7	11.9	22.9	34.8
4.0	" "	12.3	10.4	13.6	24.1	36.2
16.0	" "	12.3	9.6	16.5	27.4	40.0
64.0	" "	12.3	8.2	41.3	35.9	50.9
128.0	" "	12.3	11.0	70.8	34.9	52.6

z Values fitted from regression equation: Fruit with surface marks = 16.3 - 3.98 Sequence (r^2 = 0.07, p = 0.01)

y Values fitted from regression equation: Bruised fruit = 7.8 - 0.0795 Duration + 2.94 Sequence + 0.000640 Duration^2 (R^2 = 0.16, p = 0.01).

x Values fitted from regression equation: Fruit with ≤ 5 mm pitting = 11.8 + 0.461 Duration (r^2 = 0.14, p = 0.01).

w Values fitted from regression equation: Fruit with > 5 mm pitting = 13.2 + 0.315 Duration + 9.63 Sequence - 0.00172 Duration^2 (r^2 = 0.49, p = 0.01).

v Values fitted from regression equation: Pitted fruit = 24.6 + 0.365 Duration + 10.1 Sequence - 0.00176 Duration^2 (R^2 = 0.54, p = 0.01)

Table 17. Effects of handling temperature of fruit on disorder incidence in 'Van' cherries, 1977 crop.

Handing temperature (°C)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
0	40.1[z]	28.7[y]	14.1[x]	42.5[w]
5	38.8	27.0	12.5	39.4
10	37.5	25.2	11.0	36.2
25	33.5	20.1	6.2	26.8
38	30.0	15.6	2.1	18.6

z Values fitted from regression equation: Fruit with surface marking = 40.1 - 0.265 Handling temp (r^2 = 0.16, p = 0.01).

y Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = 28.7 - 0.346 Handling temp (r^2 = 0.27, p = 0.01).

x Values fitted from regression equation: Fruit with > 5 mm diam pitting = 14.1 - 0.315 Handling temp (r^2 = 0.31, p = 0.01).

w Values fitted from regression equation: Pitted fruit = 42.5 - 0.630 Handling temp (r^2 = 0.34, p = 0.01).

Table 18. Effects of fruit temperature at time of impact on disorder development in 'Van' cherries, 1978 crop.

Days in storage	Fruit temperature at impact (°C)	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
1	0	2.6[z]	7.0[y]	3.6[x]	1.0[w]	7.2[v]
2	0	7.1	7.0	12.8	1.6	17.3
4	0	9.4	7.0	18.0	10.0	31.2
8	0	6.1	7.0	13.5	37.9	54.3
1	5	2.6	7.0	3.6	1.0	5.7
2	5	7.1	7.0	12.8	1.6	15.8
4	5	9.4	7.0	18.0	10.0	29.6
8	5	6.1	7.0	13.5	37.9	52.7
1	10	2.6	7.0	3.6	1.0	4.1
2	10	7.1	7.0	12.8	1.6	14.3
4	10	9.4	7.0	18.0	10.0	28.1
8	10	6.1	7.0	13.5	37.9	51.2
1	20	2.6	7.0	3.6	1.0	1.0
2	20	7.1	7.0	12.8	1.6	11.2
4	20	9.4	7.0	18.0	10.0	25.0
8	20	6.1	7.0	13.5	37.9	48.1

z Values fitted from regression equation: Surface marks = 2.6 + 18.8 Log (Day) - 1.86 Log(Day) x day (R^2 = 0.41, p = 0.01)

y Regression equation not significant (p = 0.01) Bruised fruit = 7.0 (p > 0.01)

x Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = 3.6 + 37.0 Log (Day) - 3.25 Log (Day) x day (R^2 = 0.59, p = 0.01)

w Values fitted from regression equation: Fruit with > 5 mm diam pitting = 1.0 - 10.9 Log (Day) + 6.47 Log (Day) x day (R^2 = 0.96, p = 0.01)

v Values fitted from regression equation: Pitted fruit = 7.2 - 0.308 Temp + 27.5 Log (Day)+ 3.08 Log (Day) x day (R^2 = 0.94, p = 0.01)

Table 19. Effects of storage temperature and time on incidence of storage disorders in 'Van' cherries, 1977 crop.

Storage temp. (°C)	Time in storage (d)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
0	5	34.3 a[z]	18.8 b	7.5 c	26.3 b
25	5	39.2 a	25.2 a	31.0 b	56.2 a
0	15	30.9 a	13.0 b	40.9 a	53.9 a

z Mean separation within a column by Newman-Keuls test, 5% level.

Table 20. Effects of storage temperature of 'Van' cherries on disorder development, 1978 crop.

Days in storage	Storage temperature (°C)	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
1	0	5.8[z]	6.7[y]	8.8[x]	0.0[w]	2.1[v]
2	0	9.1	9.8	12.3	8.1	13.4
4	0	11.9	11.9	15.2	18.6	27.6
8	0	13.6	11.8	16.7	30.7	45.8
16	0	13.2	7.4	14.8	43.3	67.9
1	5	5.8	10.0	8.8	3.0	9.3
2	5	9.1	12.8	12.3	12.1	20.1
4	5	11.9	14.1	15.2	22.6	33.4
8	5	13.6	12.9	16.7	34.7	49.6
16	5	13.2	6.6	14.8	47.3	67.8
1	10	5.8	13.3	8.8	7.1	16.5
2	10	9.1	15.8	12.3	16.1	26.8
4	10	11.9	16.4	15.2	26.7	39.1
8	10	13.6	14.0	16.7	38.8	53.3
16	10	13.2	6.0	14.8	51.4	67.7
1	20	5.8	19.9	8.8	15.1	30.8
2	20	9.1	21.5	12.3	24.2	40.2
4	20	11.9	20.9	15.2	34.7	50.5
8	20	13.6	16.3	16.7	46.8	60.9
16	20	13.2	4.4	14.8	59.5	67.6

z Values fitted from regression equation: Surface marks = 6.3 - 0.529 Day + 12.8 Log (Day) (R^2 = 0.65, p = 0.01)

y Values fitted from regression equation: Bruised fruit = 7.8 - 1.07 Day + 0.758 Temp - 0.0971 Temp x day + 13.9 Log (Day) + 0.0336 Log (Day) x day x temp (R^2 = 0.56, p = 0.01)

x Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = 8.8 + 12.6 Log (Day) - 0.476 Log (Day) x day (R^2 = 0.49, p = 0.01)

w Values fitted from regression equation: Fruit with > 5 mm diam pitting = -5.1 + 4.07 Day + 0.808 Temp + 21.0 Log (Day) - 2.18 Log (Day) x day (R^2 = 0.77, p = 0.01)

v Values fitted from regression equation: Pitted fruit = -4.6 + 6.74 Day + 1.53 Temp - 0.0965 Temp x day + 21.5 Log (Day) - 3.18 Log (Day) x day (R^2 = 0.81, p = 0.01)

Table 21. Effects of maturity and storage of 'Van' cherries on soluble solids, weight, titratable acidity and firmness, 1977 crop.

Maturity	Fruit weight (g)	Soluble solids at harvest (%)	Titratable acidity at harvest (mgMalic/100ml)	Soluble solids after storage (%)	Titratable acid after storage (mgMalic/100ml)	Bioyield at harvest (kg)	Fruit firmness (kg/cm)	Bioyield after storage (kg)	Fruit firmness (kg/cm)
3[z]	8.25c[y]	15.3c	1009a	13.0c	868a	0.83a	1.55a	0.98a	1.64a
6	9.19b	16.1b	836b	15.3b	820a	0.83a	1.26c	0.79b	1.10b
33	10.0a	17.9a	837b	18.1a	844a	0.78a	1.47b	0.92a	1.75a

z Color comparator qualitative indices of maturity.

y Mean separation within a column by Newman-Keuls test, 5% level.

Table 22. Effects of maturity on fruit characteristics in 'Van' cherries, 1978 crop.

Days of stage III of fruit development	Fruit weight (g)	Soluble solids (%)	Titratable acidity (mgMalic/100ml)	Firmness (kg/cm)	Bioyield (kg)	Alcohol insoluble solids (% fresh wt)
0[z]	4.49[y]	10.0[x]	818[w]	6.02[v]	1.96[u]	2.505[t]
7	6.11	11.3	818	3.02	1.96	1.908
14	7.20	12.6	818	2.28	1.96	1.730
21	7.75	13.9	818	2.78	1.96	1.972
28	7.76	15.2	818	3.51	1.96	2.052

z Fruit development corresponds to color comparator qualitative indices of: Day 7 (No. 3), Day 14 (No. 6), and Day 28 (No. 33)

y Values fitted from regression equation: Fruit wt = 4.488 + 0.2705 Days - 0.005485 Day^2 (R^2 = 0.87, p = 0.01)

x Values fitted from regression equation: Soluble solids = 10.0 + 0.184 Days (r^2 = 0.71, p = 0.01)

w Regression equation not significant. Titratable acidity = 818 (p > 0.01)

v Values fitted from regression equation: Firmness = 6.02 - 0.637 Days + 0.0333 Day^2 - 0.000491 $Days^3$ (R^2 = 0.95, p = 0.01)

u Regression equation not significant. Bioyield = 1.96 (p = 0.01)

t Values fitted from regression equation: AIS = 2.505 - 0.1777 Days + 0.01171 $Days^2$ - 0.0002122 $Days^3$ (R^2 = 0.85, p = 0.01)

Table 23. Effects of maturity of 'Van' cherries on dry weight and mesocarp mineral content on a fresh weight basis. 1977 crop.

Maturity	Dry matter (%)	Flesh Ca (mg/kg)	Flesh K (mg/kg)	Flesh Mg (mg/kg)	Flesh Zn (mg/kg)
3[z]	15.7c[y]	139.8 a	1623 a	82.7 c	1.17 a
6	17.7 b	136.4 a	1693 a	106.6 b	0.84 a
33	20.9 a	138.0 a	1830 b	122.7 a	1.43 a

z Color comparator qualitative indices of maturity.

y Mean separation within a column by Newman-Keuls test, 5% level.

Table 24. Effects of maturity of 'Van' cherries on mineral content of fruit mesocarp on a dry weight basis, 1977 crop.

Maturity	Mesocarp Ca (mg/kg)	Mesocarp K (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp Zn (mg/kg)
3[z]	836 a[y]	10290 a	698 a	7.78 a
6	762 b	9309 ab	653 b	5.98 a
33	625 c	8680 b	592 c	7.20 a

z Color comparator qualitative indices of maturity.

y Mean separation within a column by Newman-Keuls test, 5% level.

Table 25. Effects of maturity on fruit composition on a dry weight basis, 1978 crop.

Days of stage III growth	Total pectin (% AIS)	Water soluble pectin (% AIS)	Cellulose (% AIS)	Total mesocarp N (%)	Mesocarp Ca (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp Zn (mg/kg)	Mesocarp K (mg/kg)
0[z]	25.5[y]	15.0[x]	0.419[w]	7.25[v]	1865[u]	1178[t]	7.9[s]	15480[r]
7	28.5	16.0	0.419	6.23	1565	1035	7.9	12456
14	27.6	14.9	0.419	5.22	1264	891	7.9	11175
21	22.9	11.6	0.419	4.21	964	748	7.9	10548
28	14.2	6.3	0.419	3.19	664	604	7.9	10940

z Fruit development corresponds to color comparator qualitative indices of: Day 7 (No. 3), Day 14 (No. 6), and Day 28 (No. 33).

y Values fitted from regression equation: Total pectin = 25.5 + 0.709 Days - 0.0397 Day^2 (R^2 = 0.66, p = 0.01)

x Values fitted from regression equation: Water soluble pectin = 15.0 + 0.293 Days - 0.0216 Day^2 (R^2 = 0.76, p = 0.01)

w Regression equation not significant. Cellulose = 0.419 ($p > 0.01$)

v Values fitted from regression equation: Total mesocarp nitrogen = 7.25 - 0.145 Day^2 (r^2 = 0.63, p = 0.01)

u Values fitted from regression equation: Mesocarp calcium = 1865 - 42.9 Days (r^2 = 0.68, p = 0.01)

t Values fitted from regression equation: Mesocarp magnesium = 1178 - 20.5 Days (r^2 = 0.68, p = 0.01)

s Regression equation not significant. Mesocarp zinc = 7.9 ($p > 0.01$)

r Values fitted from regression equation. Mesocarp potassium = 15480 - 452.8 Days + 10.38 $Days^2$ (R^2 = 0.70, p = 0.01)

Table 26. Effects of fruit maturity on fruit composition on fresh weight basis, 1978 crop.

Days of stage III growth	Total pectin (%)	Water soluble pectin (%)	Total mesocarp N (%)	Mesocarp Ca (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp Zn (mg/kg)	Mesocarp K (mg/kg)	Dry Weight (%)
0[z]	0.613[y]	0.356[x]	1.317[w]	230[v]	128[u]	1.43[t]	2015[s]	15.9[r]
7	0.684	0.409	1.170	158	128	0.87	1736	17.1
14	0.756	0.461	1.036	135	128	0.83	1643	18.3
21	0.827	0.514	0.895	131	128	0.98	1736	19.5
28	0.899	0.567	0.754	156	128	1.44	2015	20.7

z Fruit development corresponds to color comparator qualitative indices of: Day 7 (No. 3), Day 14 (No. 6), and Day 28 (No. 33)

y Values fitted from regression equation: Total pectin = 0.613 - 0.0102 Days (r^2 = 0.74, p = 0.01)

x Values fitted from regression equation: Water soluble pectin = 0.356 - 0.00752 Days (r^2 = 0.90, p = 0.01)

w Values fitted from regression equation: Total mesocarp nitrogen = 1.317 - 0.0201 Days (r^2 = 0.52, p = 0.01)

v Values fitted from regression equation: Mesocarp calcium = 230 - 10.9 Days + 0.295 Days^2 (R^2 = 0.67, p = 0.01)

u Regression equation not significant. Mesocarp magnesium = 128 (p > 0.01)

t Values fitted from regression equation: Mesocarp zinc = 1.43 - 0.0866 Days + 0.00310 Days^2 (R^2 = 0.44, p = 0.01)

s Values fitted from regression equation: Mesocarp potassium = 2015 - 53.11 Days + 1.897 Days^2 (R^2 = 0.73, p = 0.01)

r Values fitted from regression equation: Dry weight = 15.9 + 0.170 Day (r^2 = 0.53, p = 0.01)

Table 27. Effects of maturity and work done on cherry fruit on the incidence of surface disorders, 1977 crop.

Maturity	Work done (joules)	Fruit with Bruises (%)	Fruit with surface marks (%)	Fruit with pitting (%)
3[z]	0.00	5.4[y]	30.9[x]	8.4[w]
3	0.02	12.2	28.6	50.8
3	0.04	17.4	26.4	76.5
3	0.08	23.1	21.8	77.8
6	0.00	5.4	31.0	8.4
6	0.00	28.6	28.7	35.3
6	0.04	44.7	26.5	48.2
6	0.06	55.2	21.9	31.9
33	0.00	5.4	13.9	8.4
33	0.02	50.7	11.6	20.5
33	0.04	77.7	9.4	26.8
33	0.08	76.3	4.8	22.1

z Color comparator qualitative indices of maturity. Color maturity of fruit coded as: Three = (1-0); Six = (0-1), Thirty-three (0-0).

y Values fitted from equation: Bruised fruit = $5.28 + 2730\ \text{Work} - 2349\ \text{Three} \times \text{work}^2 + 21100\ \text{Three} \times \text{Work}^2 - 1389\ \text{Six} \times \text{Work} + 14100\ \text{Six} \times \text{Work}^2 - 23000\ \text{Work}^2$ ($R^2 = 0.89$, $p = 0.01$).

x Values fitted from equation: Fruit with surface marking = $13.9 + 17.1\ \text{Three} - 113.7\ \text{Work} + 17.0\ \text{Six}$ ($R^2 = 0.62$, $p = 0.01$).

w Values fitted from equation: Fruit with pitting = $8.38 + 750\ \text{Work} + 1788\ \text{Three} \times \text{Work} - 13600\ \text{Three} \times \text{Work}^2 + 944\ \text{Six} \times \text{Work} - 10300\ \text{Six} \times \text{Work}^2 - 7240\ \text{Work}^2$ ($R^2 = 0.95$, $p = 0.01$).

Table 28. Effects of maturity of 'Van' cherries on disorder incidence, 1978 crop.

Days of stage III of fruit development	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
0[z]	2.9[y]	21.6[x]	16.9[w]	17.6[v]	32.0[u]
7	7.0	5.4	14.1	58.3	74.8
14	8.3	16.3	11.3	47.2	60.8
21	7.0	27.1	8.5	18.0	26.4
28	2.9	10.8	5.7	4.1	8.2

z Fruit development corresponds to color comparator qualitative indices of: Day 7 (No. 3), Day 14 (No. 6), and Day 28 (No. 33)

y Values fitted from regression equation: Surface marks = $2.9 + 0.776 \text{ Days} - 0.0277 \text{ Days}^2$ ($R^2 = 0.37$, $p = 0.01$)

x Values fitted from regression equation: Bruised fruit = $21.6 - 5.55 \text{ Days} + 0.554 \text{ Days}^2 - 0.0132 \text{ Days}^3$ ($R^2 = 0.76$, $p = 0.01$)

w Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = $16.9 - 0.400 \text{ Days}$ ($r^2 = 0.45$, $p = 0.01$)

v Values fitted from regression equation: Fruit with > 5 mm diam pitting = $17.6 + 11.1 \text{ Days} - 0.870 \text{ Days}^2 + 0.0163 \text{ Days}^3$ ($R^2 = 0.89$, $p = 0.01$)

u Values fitted from regression equation: Pitted fruit = $32.0 + 11.9 \text{ Day} - 0.951 \text{ Days}^2 + 0.0177 \text{ Days}^3$ ($R^2 = 0.96$, $p = 0.01$)

Table 29. Effect of maturity and work done on fruit on soluble solids, titratable acids, firmness and bioyield in 'Van' cherries, 1977 crop.

Maturity	Work done (joules)	Soluble solids (%)	Titratable acids (mgmalic/100ml)	Bioyield (kg)	Firmness (kg/cm)
3[z]	0.00	13.1[y]	840[x]	2.19[w]	3.55[v]
3	0.02	13.1	834	2.19	3.55
3	0.04	13.1	817	2.19	3.55
3	0.08	13.1	747	2.19	3.55
6	0.00	15.8	840	1.75	2.44
6	0.02	15.8	834	1.81	3.07
6	0.04	15.8	817	1.87	3.43
6	0.08	15.8	747	1.99	3.31
33	0.00	18.1	840	2.05	3.87
33	0.02	18.1	834	2.05	3.87
33	0.04	18.1	817	2.05	3.87
33	0.08	18.1	747	2.05	3.87

z Color comparator qualitative indices of maturity. Color maturity of fruit coded as: Three = (1-0); Six = (0-1); Thirty-three = (0-0).

y Values fitted from equation: Soluble solids = 18.1 - 4.98 Three - 2.35 Six (R^2 = 0.85, p = 0.01).

x Values fitted from equation: Titratable acids = 840 - 14600 $Work^2$ (r^2 = 0.38, p = 0.01).

w Values fitted from equation: Bioyield = 2.05 + 0.137 Three - 0.298 Six - 3.04 Six x Work (R^2 = 0.50, p = 0.01).

v Values fitted from equation: Firmness = 3.87 - 0.324 Three - 1.43 Six + 38.6 Six x Work - 346 Six x $Work^2$ (R^2 = 0.70, p = 0.01).

Table 30. Effects of height of drop of cherry and impact surface on disorder incidence in 'Van' cherries, 1978 crop.

Height of drop (cm)	Impact surface	Fruit with surface marks (%)	Bruised fruit (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
13	smooth[z]	10.9[y]	2.3[x]	14.0[w]	5.6[v]	15.4[u]
25	smooth	10.9	3.7	14.0	13.0	24.4
51	smooth	10.9	6.6	14.0	27.9	42.5
102	smooth	10.9	12.4	14.0	57.7	78.7
13	rough	23.3	2.3	14.0	22.3	38.3
25	rough	22.0	3.7	14.0	29.7	46.6
51	rough	19.3	6.6	14.0	44.6	61.5
102	rough	14.0	12.4	14.0	74.4	85.3

z Impact surface coded as: Smooth = 0; Rough = 1.

y Values fitted from regression equation: Fruits with surface marks = 10.9 + 13.7 Surface - 0.104 Surface x height (R^2 = 0.53, p = 0.01)

x Values fitted from regression equation: Bruised fruit = 0.8 + 0.114 Height (r^2 = 0.68, p = 0.01)

w Regression equation not significant. Fruit with ≤ 5 mm diam pitting = 14.0 (p > 0.01)

v Values fitted from regression equation: Fruit with > 5 mm diam pitting = -1.9 + 16.7 Surface + 0.587 Height (R^2 = 0.94, p = 0.01)

u Values fitted from regression equation: Pitted fruit = 6.3 + 23.2 Surface x height - 0.00161 Surface x height^2 (R^2 = 0.96, p = 0.01)

Table 31. Effects of deformation, loading rate and loading surface on the incidence of surface disorders in 'Van' cherries, 1978 crop.

Loading surface	Deformation (mm)	Loading rate (mm/min)	Bruised fruit (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
Smooth[z]	2	10	2.4[y]	5.5[x]	5.5[w]	0.0[v]	0.0[u]
Smooth	4	10	12.0	5.5	5.5	1.0	5.6
Smooth	8	10	50.6	5.5	5.5	10.6	18.2
Rough	2	10	2.4	5.5	3.9	0.0	1.2
Rough	4	10	12.0	5.5	16.1	1.0	13.1
Rough	8	10	50.6	5.5	64.9	10.6	48.2
Smooth	2	1000	2.4	5.5	5.5	5.1	7.4
Smooth	4	1000	12.0	5.5	5.5	18.9	16.4
Smooth	8	1000	50.6	5.5	5.5	46.6	50.8
Rough	2	1000	2.4	8.1	3.9	5.1	9.3
Rough	4	1000	12.0	10.5	16.1	18.9	29.4
Rough	8	1000	50.6	15.7	64.9	46.6	80.7

z Loading surface coded as: Smooth = 0; Rough = 1

y Values fitted from regression equation: Bruised fruit = 0.800 + 0.803 Deformation^2 (r^2 = 0.92, p = 0.01)

x Values fitted from regression equation: Fruit with surface marks = 5.5 + 0.00128 Deformation x Loading surface x Loading rate (R^2 = 0.36, p = 0.01)

w Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = 5.5 - 5.65 Bruising surface + 1.017 Deformation^2 x Loading surface (R^2 = 0.63, p = 0.01)

v Values fitted from regression equation: Fruit with > 5 mm diam pitting = -8.8 + 2.38 Deformation + 0.00455 Deformation x Loading rate (R^2 = 0.84, p = 0.01)

u Values fitted from regression equation: Pitted fruit = -7.0 + 3.11 Deformation + 0.00411 Deformation x Loading rate + 0.468 Deformation^2 x Loading surface (R^2 = 0.93, p = 0.01)

Table 32. Effects of cherry fruit weight and work done on fruit on the incidence of surface disorders, 1977 crop.

Fruit weight (g)	Work done on fruit (joules)	Bruised fruit (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
7.11	0.050	13.8[y]	18.4[x]	2.2[w]	94.3[v]	95.8[u]
9.19	0.050	30.9	18.4	2.2	77.0	83.7
7.11	0.032[z]	13.8	18.4	2.2	70.7	73.4
9.19	0.045[z]	30.9	18.4	2.2	72.1	77.5

z Drop height constant at 0.45 m.

y Values fitted from regression equation: Bruised fruit = -44.9 + 8.25 Fruit weight (r^2 = 0.70, p = 0.01).

x Regression equation not significant. Fruit with surface marks = 18.4 (p > 0.01).

w Regression equation not significant. Fruit with ≤ 5 mm diam pitting = 2.2 (p > 0.01)

v Values fitted from regression equation: Fruit with > 5 mm diam pitting = 28.7 + 2500 Work done - 167 Fruit weight x Work done, (R^2 = 0.85, p = 0.01)

u Values fitted from regression equation: Pitted fruit = 75.0 + 1240 Work done - 5.80 Fruit weight (R^2 = 0.85, p = 0.01).

Table 33. Effects of cherry fruit weight and work done on fruit on the incidence of surface disorders, 1978 crop.

Fruit weight (g)	Work done on fruit (joules)	Bruised fruit (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
5.70	0.04	5.2[y]	13.0[x]	13.4[w]	83.5[v]	51.2[u]
7.20	0.04	5.2	13.0	13.4	53.9	23.2
5.70	0.025[z]	5.2	13.0	13.4	68.1	57.7
7.20	0.034[z]	5.2	13.0	13.4	45.8	22.4

z Drop height constant at 0.45 m.

y Regression equation not significant. Bruised fruit = 5.2 ($p > 0.01$)

x Regression equation not significant. Fruit with surface markings = 13.0 ($p > 0.01$)

w Regression equation not significant. Fruit with ≤ 5 mm diam pitting = 13.4 ($p > 0.01$)

v Values fitted from regression equation: Fruit with > 5 mm diam pitting = 162.0 − 21.0 Fruit weight + 1030 Work ($R^2 = 0.93$, $p = 0.01$)

u Values fitted from regression equation: Pitted fruit = 196 − 24.7 Fruit weight + 17.5 Fruit weight x Work ($R^2 = 0.87$, $p = 0.01$)

Table 34. Effects of fruit size on mesocarp composition of 'Van' cherries on fresh weight basis, 1978 crop.

Fruit size (g)	Total pectin (%)	Water soluble pectin (%)	AIS (%)	Total mesocarp N (%)	Mesocarp Ca (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp K (mg/kg)	Mesocarp Zn (mg/kg)
6.52b[z]	0.524a	0.204a	2.202a	0.939a	26.8a	20.8a	261a	0.18a
7.99a	0.504a	0.226a	2.181a	0.837b	22.5a	18.5a	244a	0.14a

z Mean separation within a column by Student's-t test, 5% level.

Table 35. Effects of fruit size on mesocarp composition of 'Van' cherries on dry weight basis, 1978 crop.

Fruit Weight (g)	Soluble solids (%)	Titratable acidity (mgMalic/100ml)	Total pectin (%)	Water soluble pectin (%)	Cellulose (%)	Total mesocarp N (%)	Mesocarp Ca (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp K (mg/kg)	Mesocarp Zn (mg/kg)
6.52b[z]	13.0a	807a	24.4a	9.29a	0.357a	6.26a	1051a	753a	10940a	7.0a
7.99a	13.9a	811a	23.5a	10.26a	0.398a	5.08b	924b	699b	10220b	6.2b

z Mean separation within a column by Student's-t test, 5% level.

Table 36. Effect of cherry fruit weight and maturity on storage disorders, 1977 crop.

Maturity	Fruit weight (g)	Fruit with surface marks (%)	Fruit with bruises (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Fruit with pitting (%)
3[z]	6.21	17.9a[y]	12.9d	2.9a	79.7a	82.6a
6	7.04	42.4a	13.8d	2.5a	78.5a	81.0a
33	8.08	19.8a	38.8b	7.7a	40.0d	47.7d
3	8.04	18.8a	31.8c	1.5a	60.8b	62.3b
6	9.04	35.0a	40.7b	3.9a	47.2c	51.1c
33	10.50	19.8a	53.5a	8.5a	17.8e	26.3e

z Color comparator qualitative indices of maturity.

y Mean separation within a column by Newman-Keuls test, 5% level.

Table 37. Effects of gibberellic acid and mobileaf sprays on cherry fruit disorders, 1977 crop.

Spray	Harvest	Fruit with bruises (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Fruit with pitting (%)
No spray	1	13.1c[z]	16.8b	12.9a	42.3b	55.1b
20 ppm GA	1	11.4c	19.8b	15.4a	22.6c	38.1c
20% Mobileaf	1	9.4c	16.5b	18.0a	52.2a	70.2a
No spray	2	43.1a	27.6b	5.5a	6.3d	11.9de
20 ppm GA	2	28.6b	27.9b	3.8a	5.6d	9.6de
20% Mobileaf	2	33.7ab	44.9a	6.9a	7.5d	14.4d

z Mean separation, within a column, Newman-Keuls test, 5% level.

Table 38. Effects of fruit maturity and preharvest gibberellic acid spray on the incidence of surface disorders in 'Van' cherries, 1978 crop.

Maturity	Gibberellic acid spray	Bruised fruit (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
0[z]	0	9.4[y]	12.1[x]	15.5[w]	52.5[v]	70.8[u]
0	1	9.4	12.1	15.5	15.0	28.3
1	0	9.4	12.1	15.5	7.5	22.5
1	1	9.4	12.1	4.5	1.0	7.5

z Coded for qualitative indices of color maturity: 0 = No. 3, 1 = No. 33.

y Regression equation not significant. Bruised fruit = 9.4 ($p > 0.01$)

x Regression equation not significant. Fruit with surface marks = 12.1 ($p > 0.01$)

w Values fitted from regression equation: Fruit with ≤ 5 mm diam pitting = 15.5 - 9.0 Maturity x Gibberellic spray ($r^2 = 0.61$, $p = 0.01$)

v Values fitted from regression equation: Fruit with > 5 mm diam pitting = 52.5 - 45.0 Maturity - 37.5 Gibberellic spray + 31.0 Maturity x gibberellic spray ($R^2 = 0.96$, $p = 0.01$)

u Values fitted from regression equation: Pitted fruit = 70.8 - 48.3 Maturity - 42.5 Gibberellic spray + 27.5 Maturity x gibberellic spray ($R^2 = 0.96$, $p = 0.01$)

Table 39. Effects of preharvest gibberellic acid spray on 'Van' cherry mesocarp composition on a fresh weight basis, 1978 crop.

Treatment	Total pectin (%)	Water soluble pectin (%)	Alcohol insoluble solids (%)	Total mesocarp N (%)	Dry Weight (%)	Mesocarp Ca (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp Zn (mg/kg)	Mesocarp K (mg/kg)	Mesocarp Mn (mg/kg)
No spray	0.509a[z]	0.264a	1.807b	0.896a	16.5b	176a	126a	1.2a	1843a	0.72a
30 ppm GA	0.503a	0.326a	2.044a	0.741b	18.0a	183a	132a	1.3a	1812a	0.78a

z Mean separation within columns by Student's-t test, 5% level.

Table 40. Effects of preharvest gibberellic acid spray on 'Van' cherry mesocarp composition on a dry weight basis, 1978 crop.

Treatment	Total pectin (%)	Water soluble pectin (%)	Cellulose (%)	Total mesocarp N (%)	Mesocarp Ca (mg/kg)	Mesocarp Mg (mg/kg)	Mesocarp Zn (mg/kg)	Mesocarp K (mg/kg)	Mesocarp Mn (mg/kg)
No spray	27.8a[z]	14.4a	0.553a	5.43a	982a	742a	7.1a	11170a	4.4a
30 ppm GA	25.1a	16.6a	0.526a	4.36b	1043a	727a	7.1a	10660b	3.8a

z Mean separation within columns by Student's-t test, 5% level.

Table 41. Effects of fruit thinning on soluble solids, titratable acidity, fruit weight and texture of 'Van' cherry fruit, 1977 crop.

Orchard	Fruit thinned	Soluble solids (%)	Titratable acidity (mgMalic/100ml)	Alcohol insoluble solids (%)	Fruit weight (g)	Bioyield (kg)	Fruit Firmness (kg/cm)
0	0	17.6[z]	909[y]	1.912[x]	8.08[w]	1.764[v]	2.878[u]
0	1	17.6	909	1.912	8.08	1.764	2.878
1	0	17.6	909	1.912	8.08	1.764	2.878
1	1	17.6	909	2.350	9.24	1.764	2.878

z Regression equation not significant. Soluble solids = 17.6 ($p > 0.01$)

y Regression equation not significant. Titratable acidity = 909 ($p > 0.01$)

x Values fitted from regression equation: AIS = 1.912 + 0.438 Orchard x thinned ($r^2 = 0.56$, $p = 0.01$)

w Values fitted from regression equation: Fruit weight = 8.08 + 1.16 Orchard x thinned ($r^2 = 0.45$, $p = 0.01$)

v Regression equation not significant. Bioyield = 1.764 ($p > 0.01$)

u Regression equation not significant. Fruit firmness = 2.878 ($p > 0.01$)

Table 42. Effects of fruit thinning on the incidence of surface disorders in 'Van' cherries, 1977 crop.

Orchard	Fruit thinned	Bruised fruit (%)	Fruit with surface marks (%)	Fruit with ≤ 5 mm diameter pitting (%)	Fruit with > 5 mm diameter pitting (%)	Pitted fruit (%)
0	0	20.0[z]	26.0[y]	13.9[x]	42.7[w]	59.9[v]
0	1	20.0	26.0	13.9	23.7	39.4
1	0	20.0	26.0	13.9	42.7	59.9
1	1	20.0	17.7	13.9	23.7	39.4

z Regression equation not significant. Bruised fruit = 20.0 ($p > 0.01$)

y Values fitted from regression equation: Fruit with surface markings = 26.0 - 8.28 Orchard x thinned ($r^2 = 0.39$, $p = 0.01$)

x Regression equation not significant. Fruit with ≤ 5 mm diam pitting = 13.9 ($p > 0.01$)

w Values fitted from regression equation: Fruit with > 5 mm diam pitting = 42.7 - 19.0 Thinned ($r^2 = 0.49$, $p = 0.01$)

v Values fitted from regression equation: Pitted fruit = 59.9 - 20.5 Thinned ($r^2 = 0.51$, $p = 0.01$)

Fig. 1. Typical surface pitting and surface markings in 'Van' cherry.

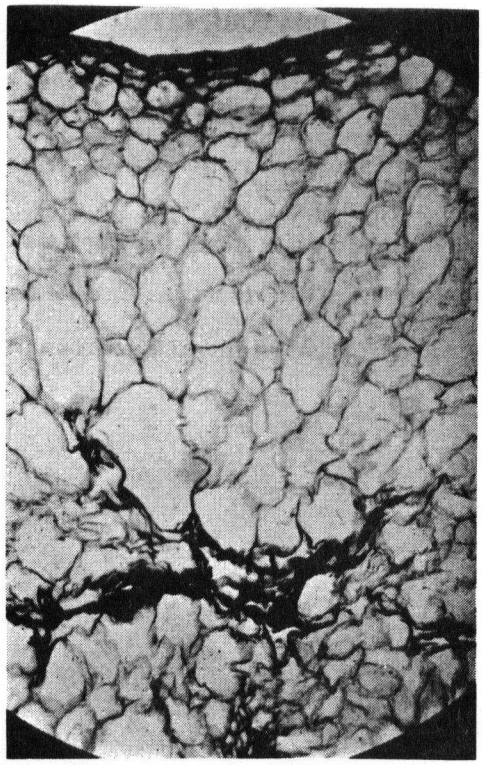

Fig. 2. Radial section of 'Van' cherry (slight injury), showing surface pitting and injured zone in the lower hypodermal cells (from reference 70).

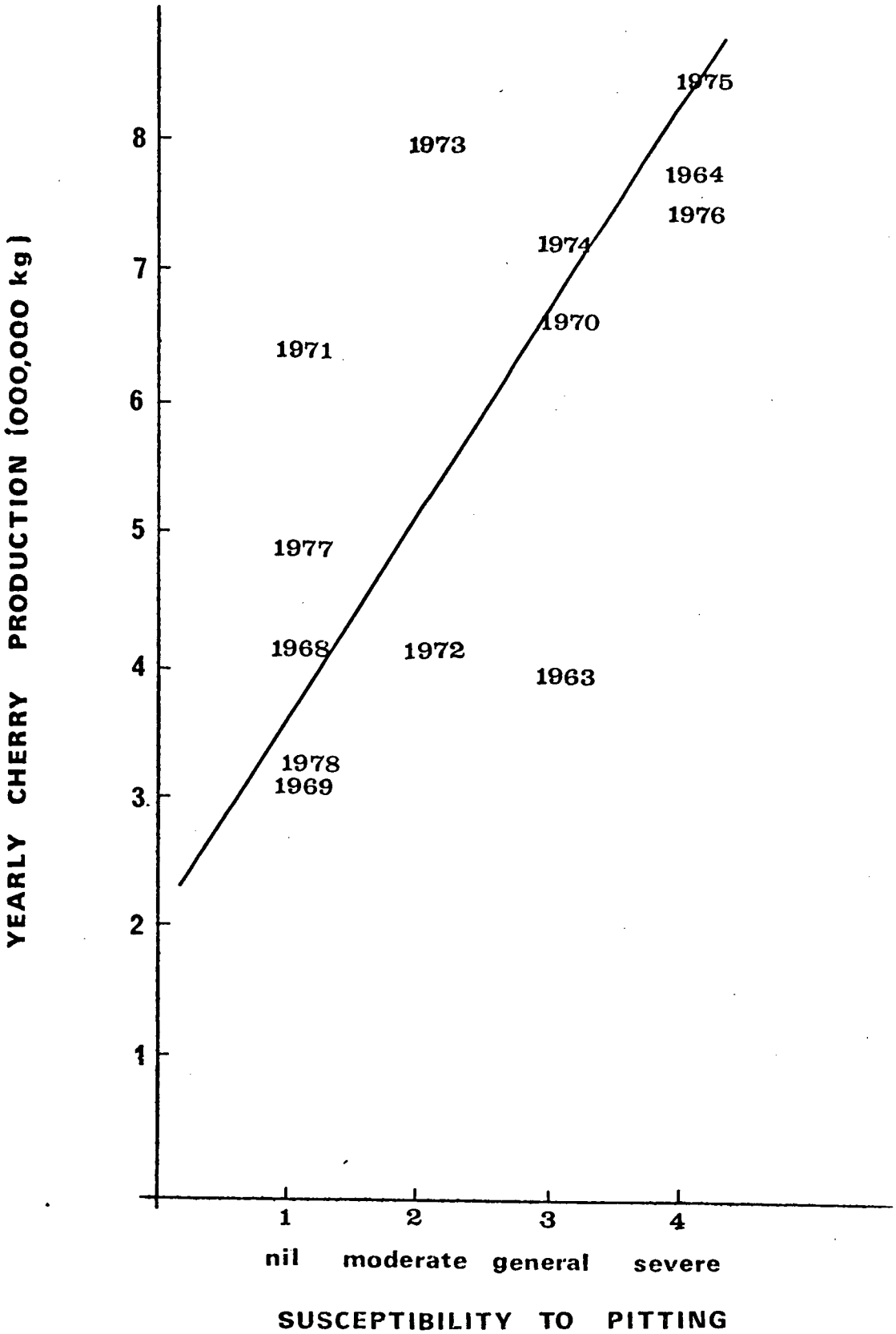

Fig. 3. Effect of cherry production on estimated susceptibility to pitting.

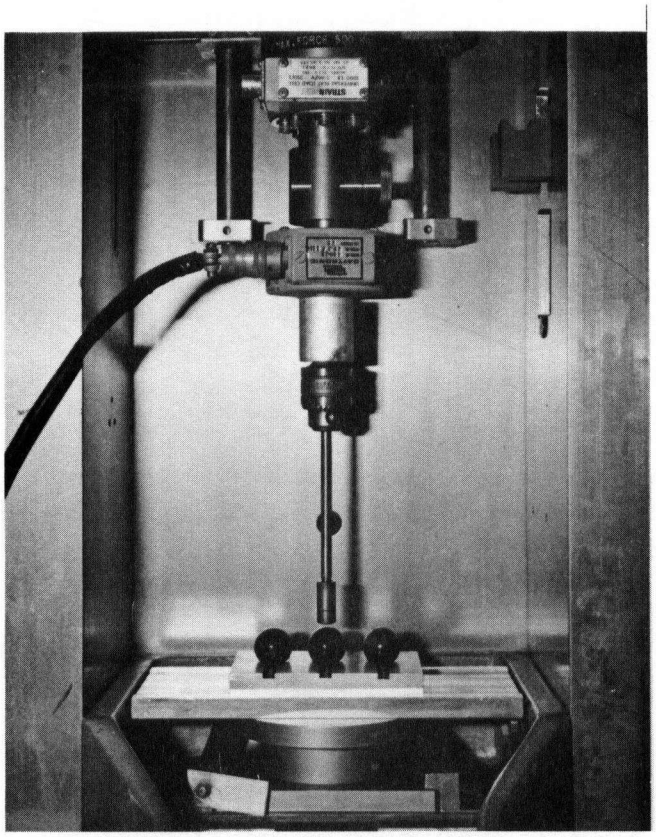

Fig. 4. Probe attachment to Ottawa Texture Measuring System.

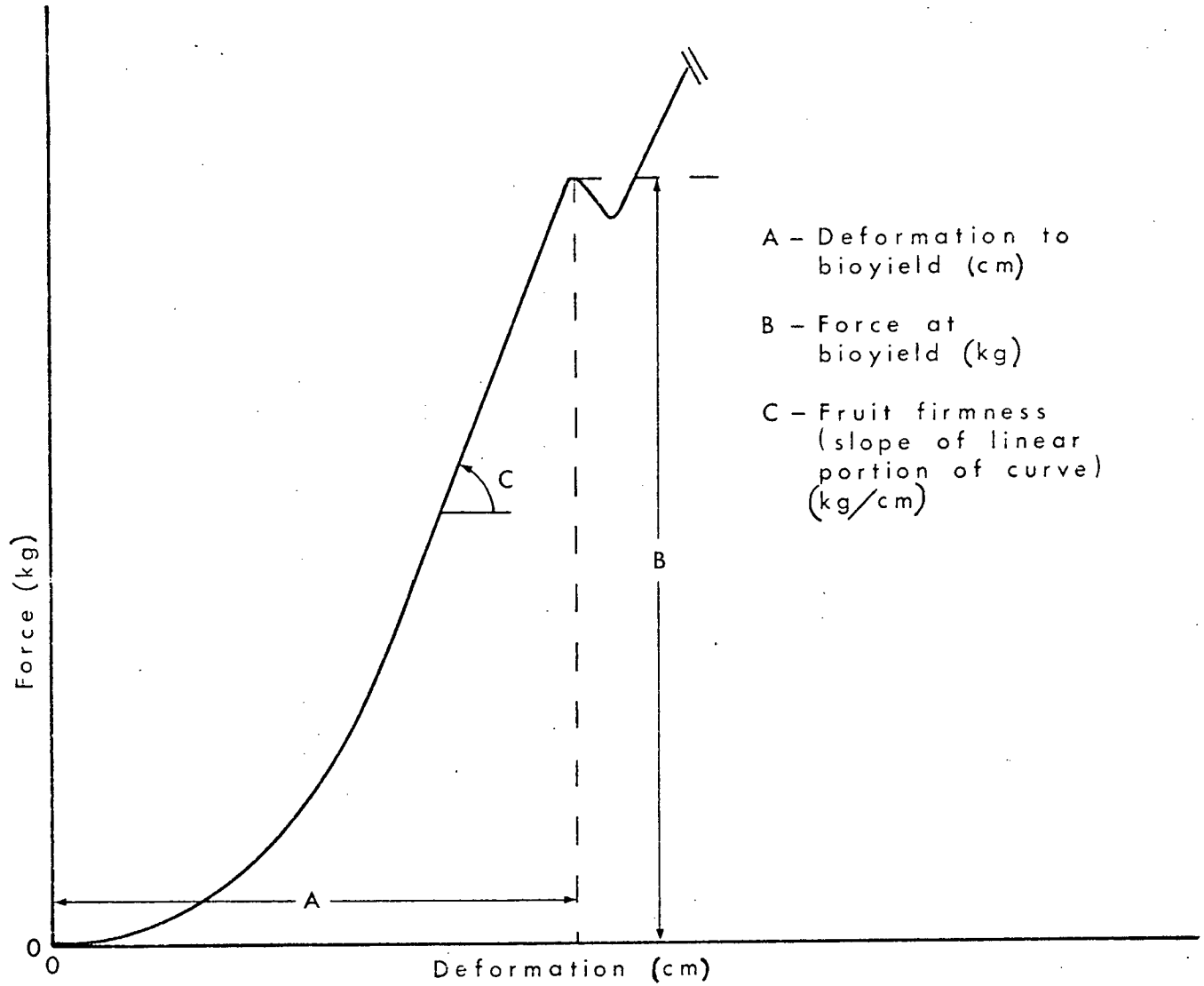

Fig. 5. Typical force-deformation curve of individual cherry pressure test.

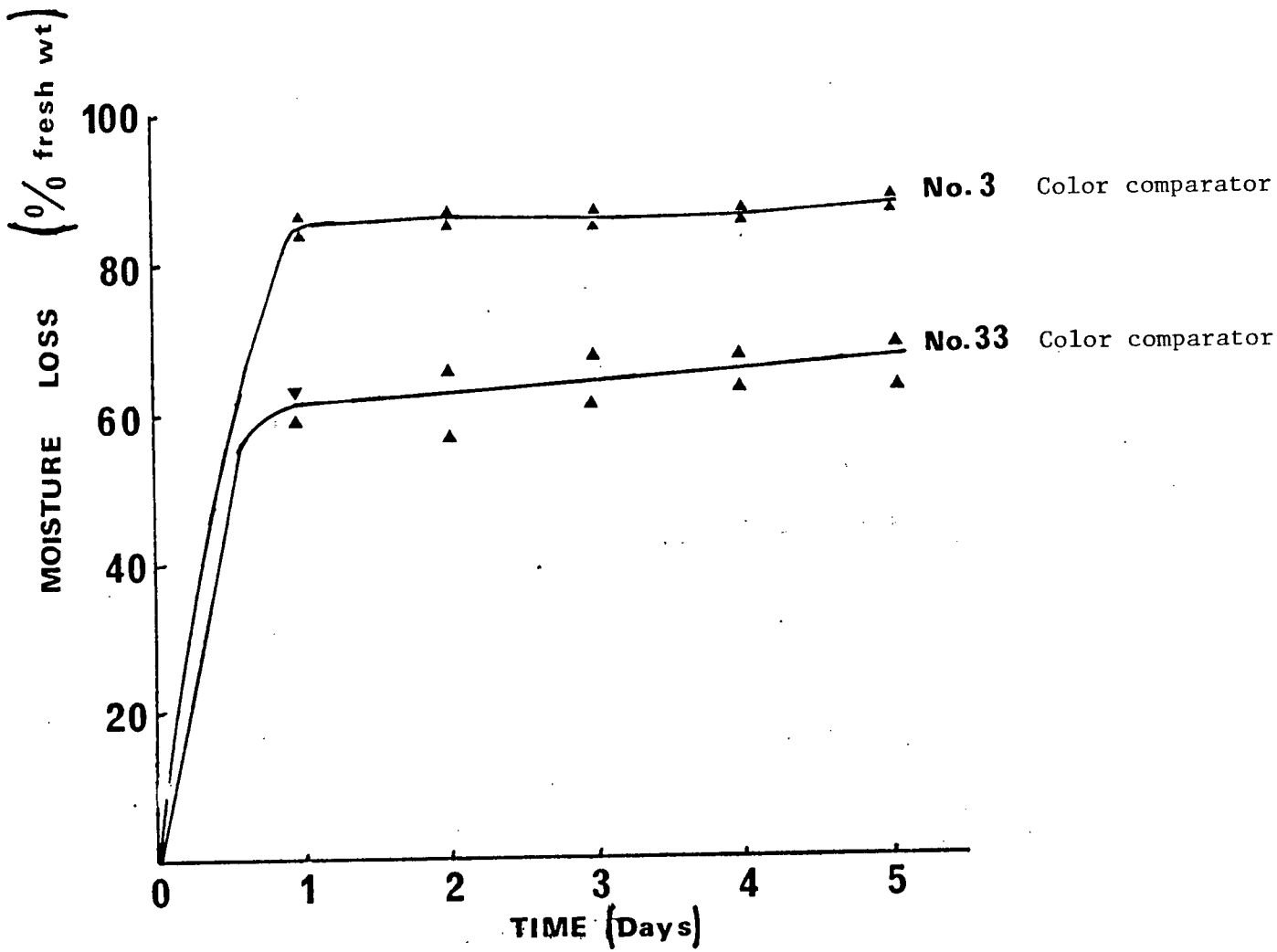

Fig. 6. Moisture loss of sweet cherry flesh stored at 65°C.

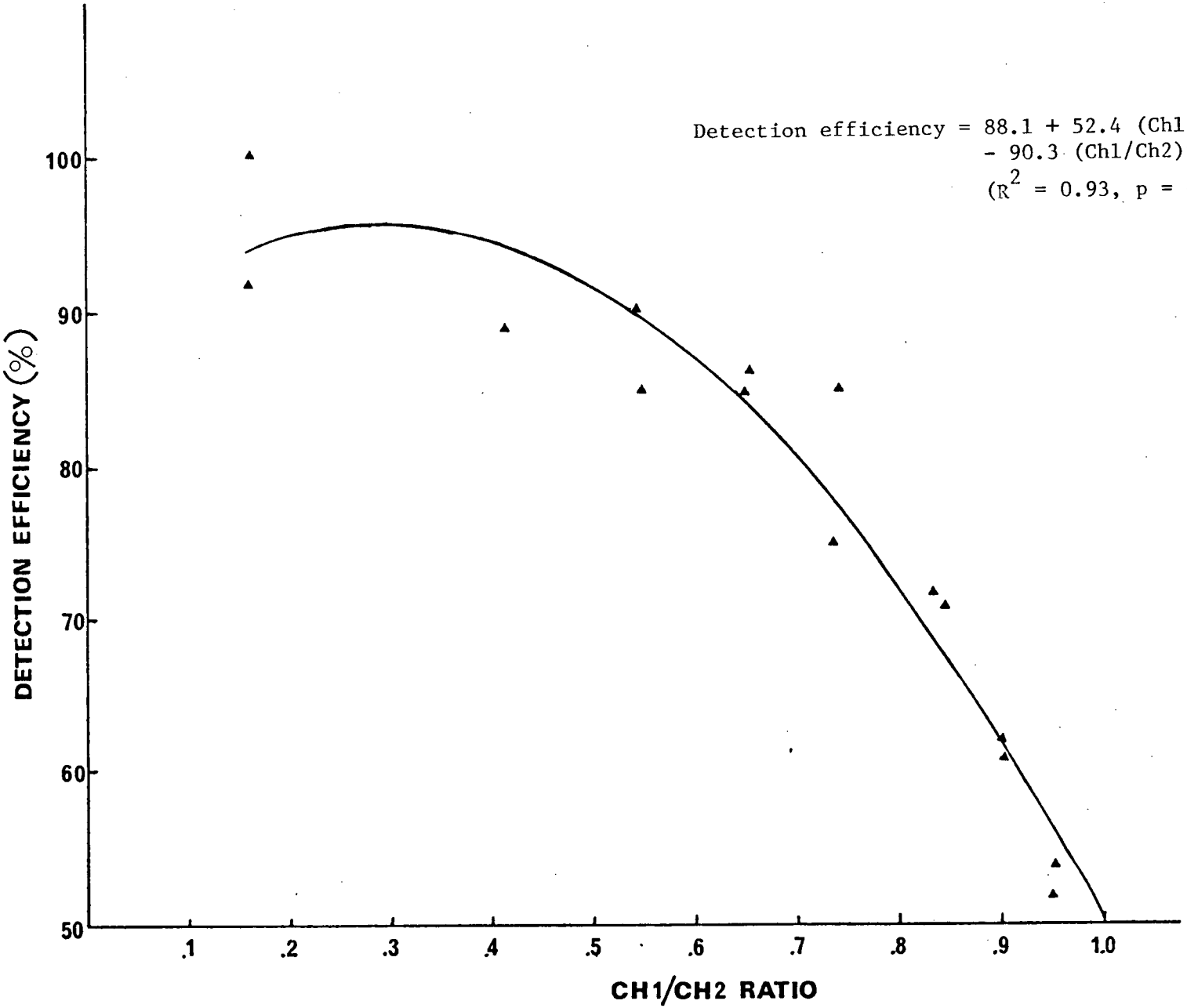

Fig. 7. Calcium-45 Quench Correction Curve.

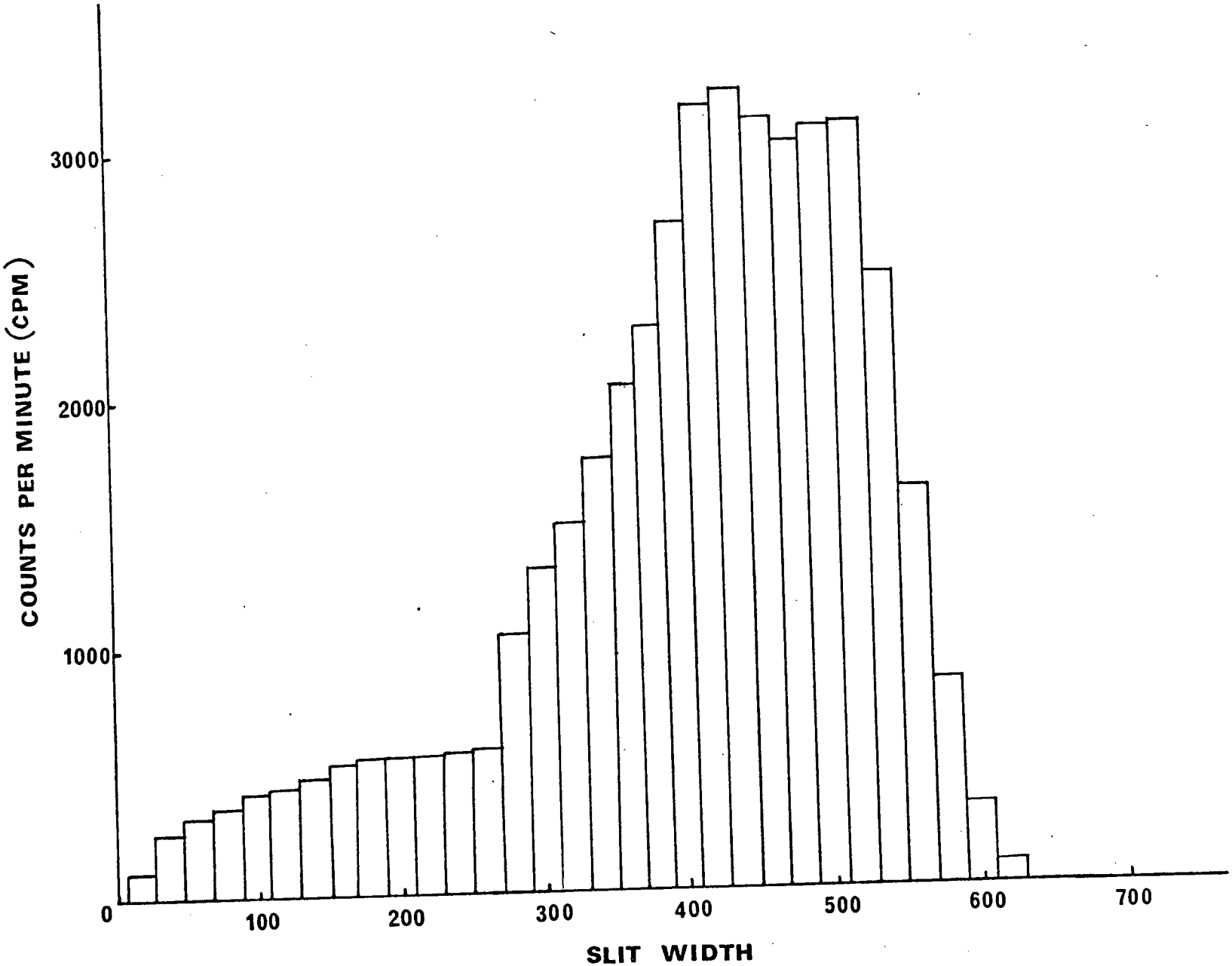

Fig. 8. Carbon-14 Energy Spectrum.

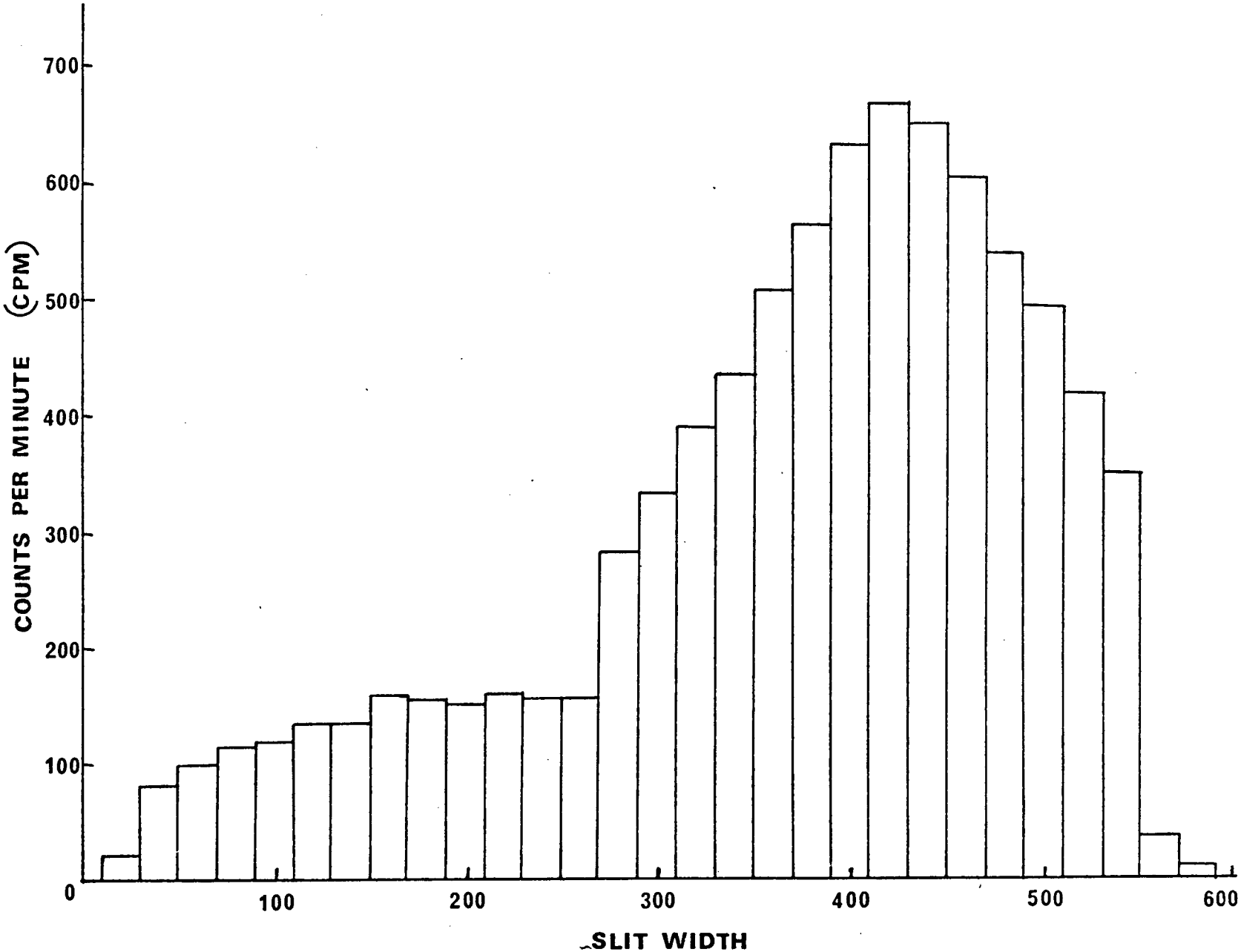

Fig. 9. Calcium-45 Energy Spectrum.

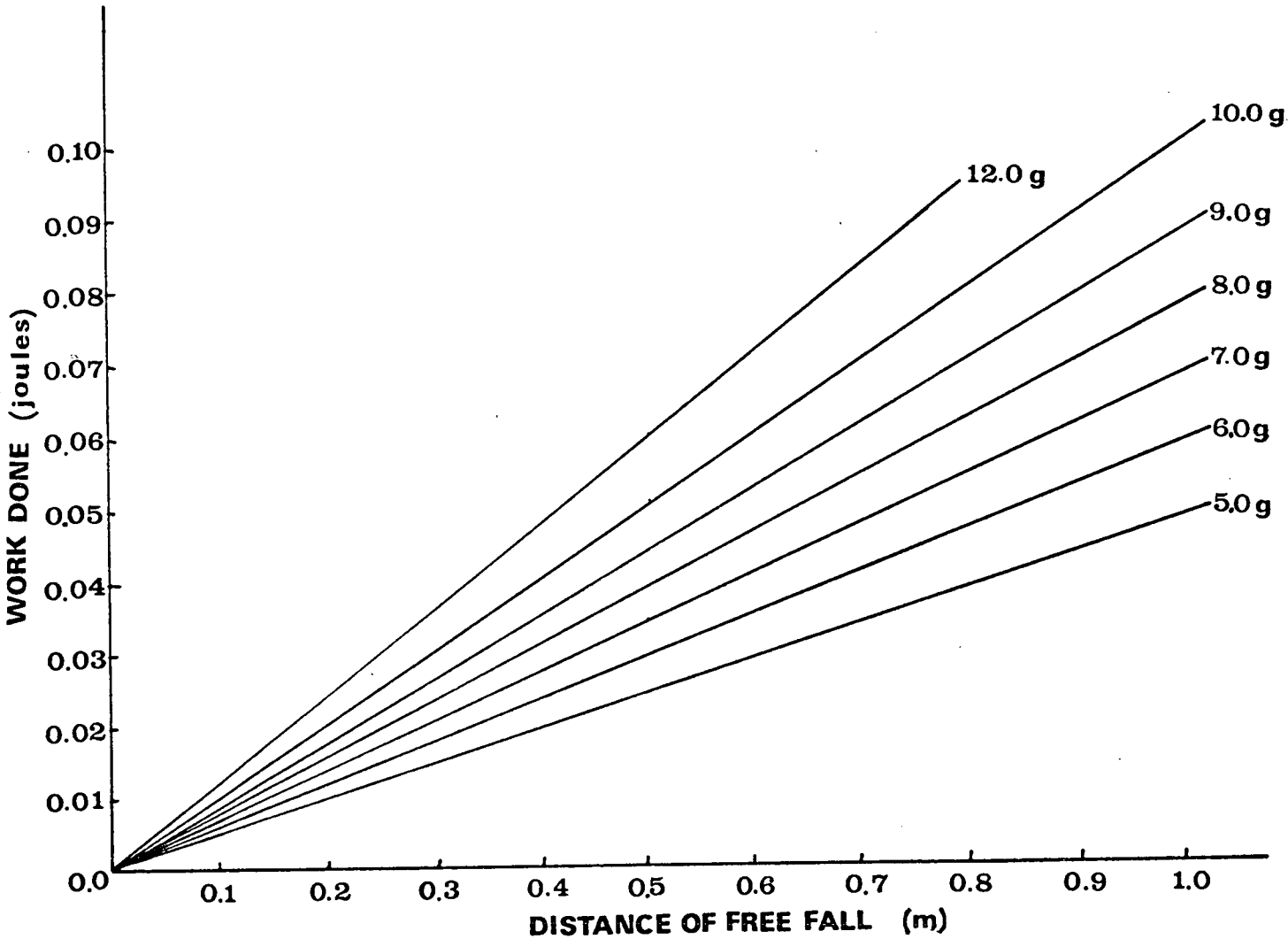

Fig. 10. Work done on cherry versus distance of free fall and fruit weight.

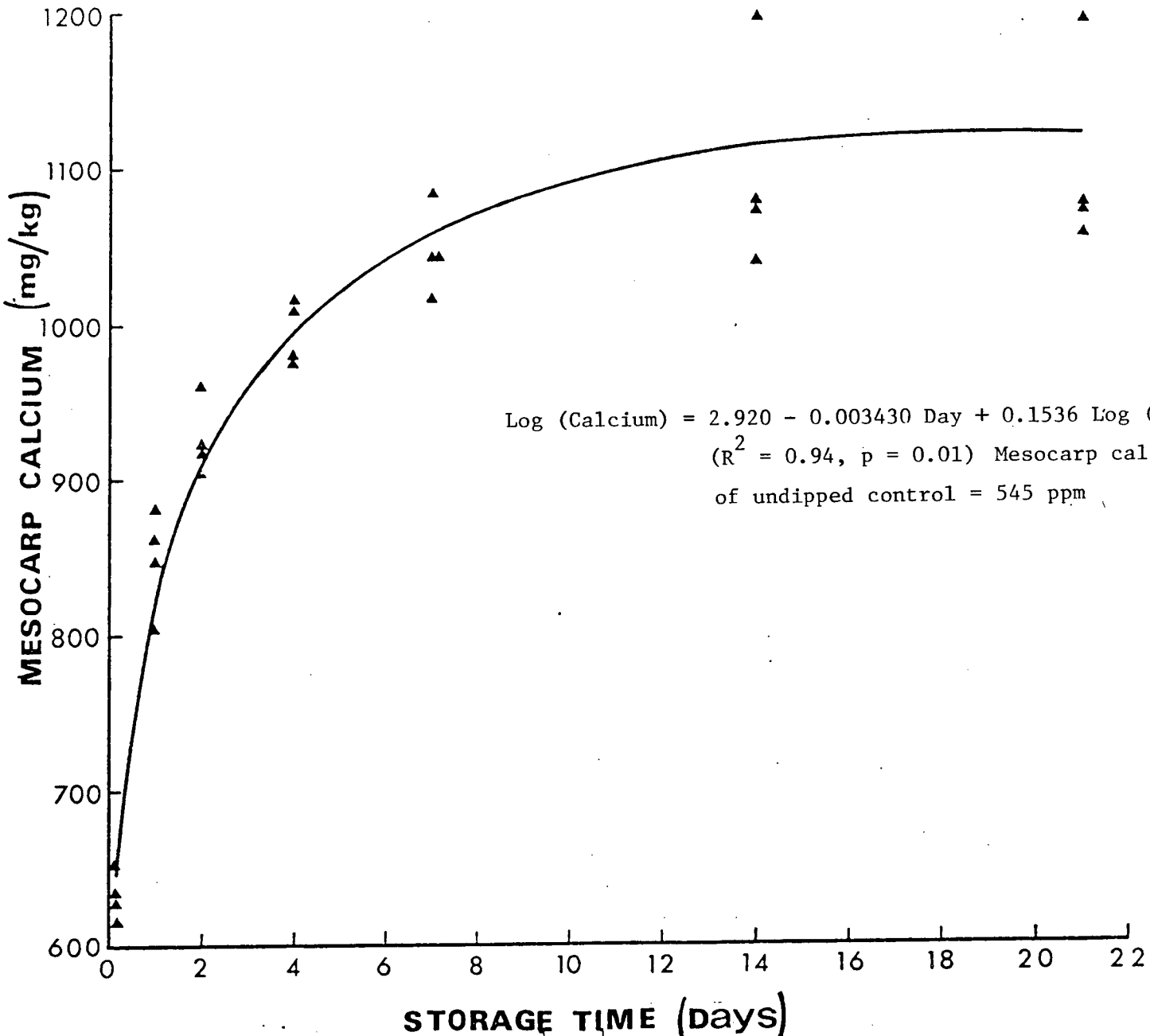

Fig. 11. Calcium uptake by 'Van' cherry.

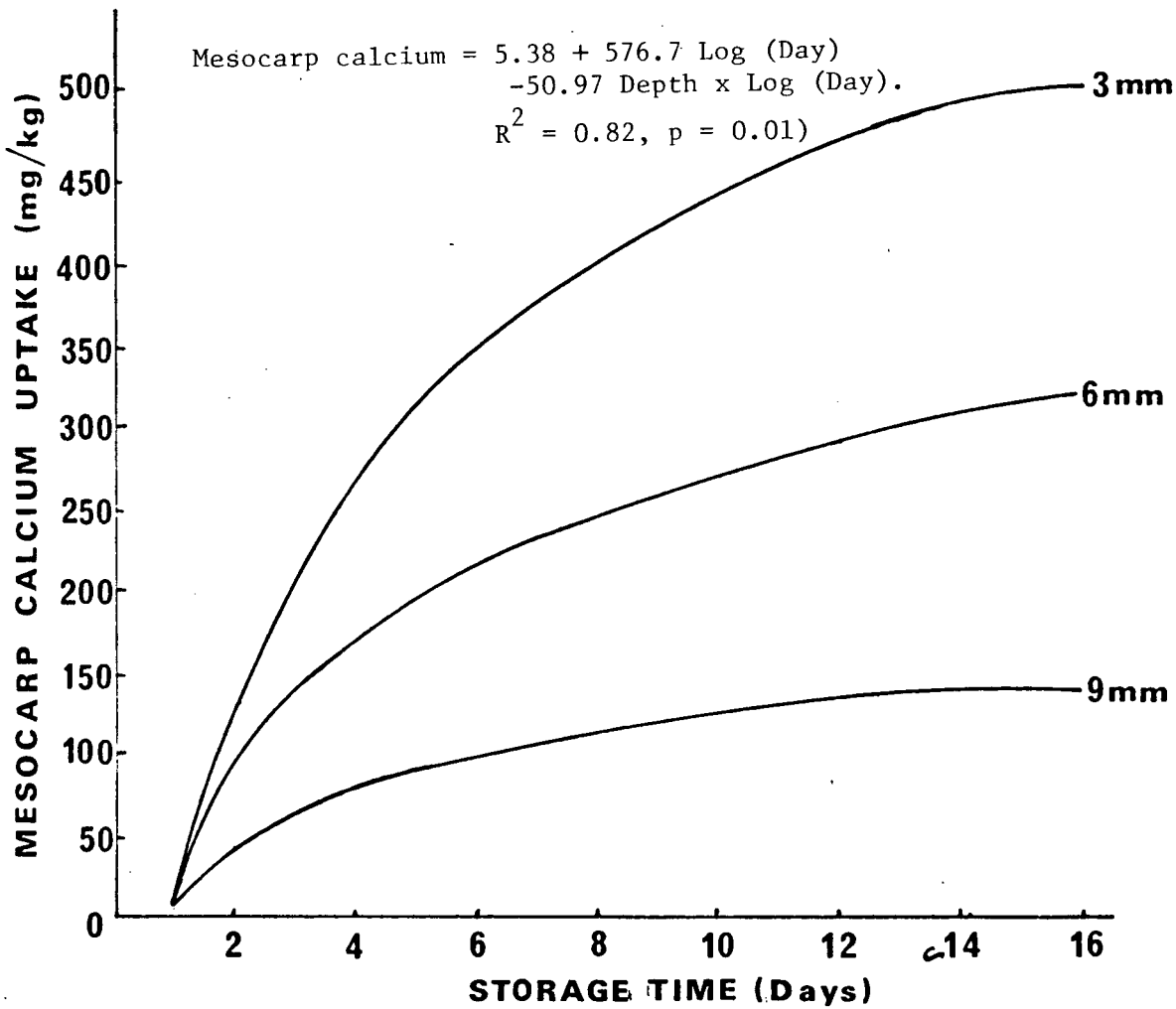

Figure 12. Calcium penetration into 'Van' cherries.

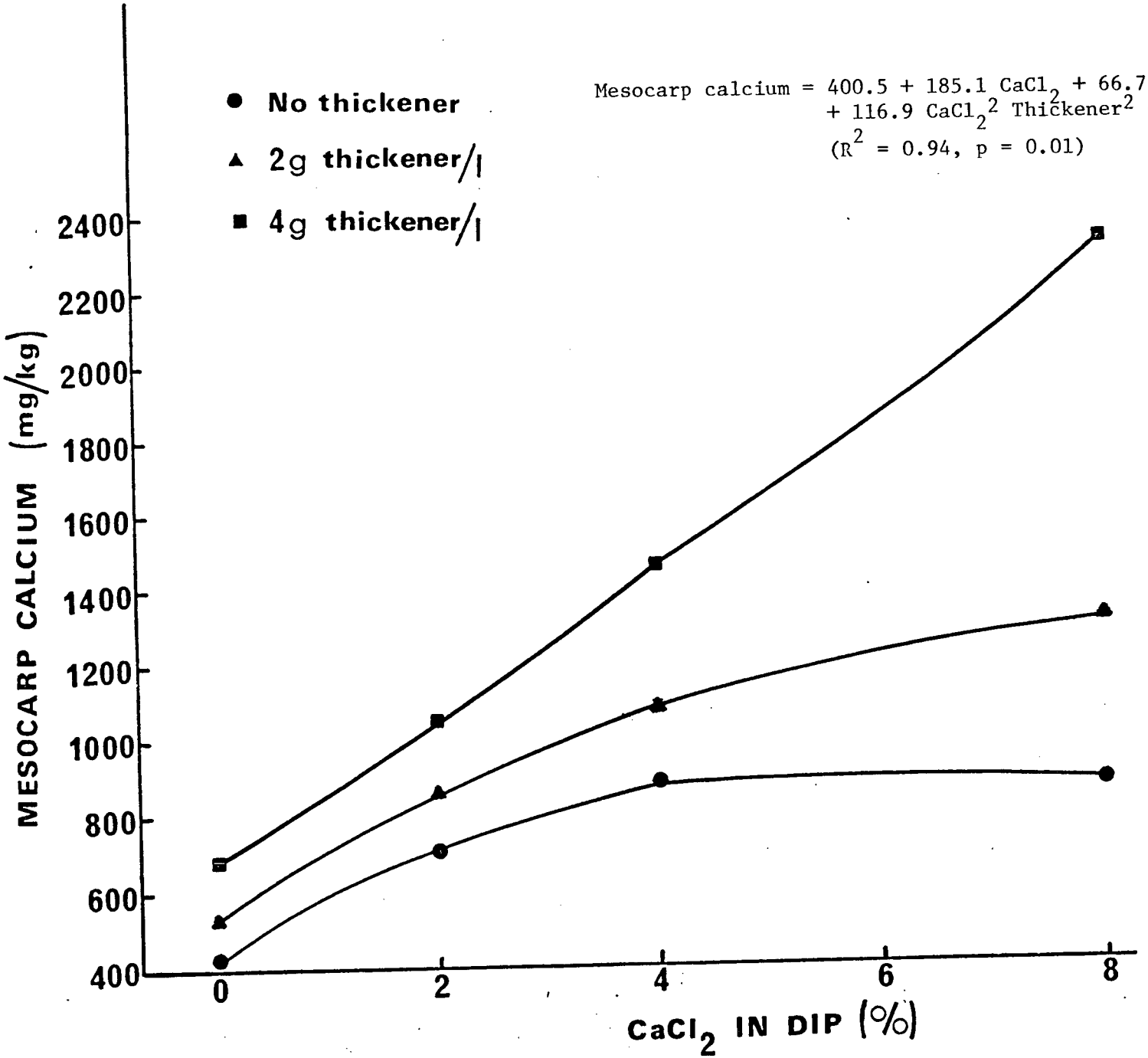

Fig. 13. Calcium uptake by cherries from postharvest calcium chloride dips modified by thickener.

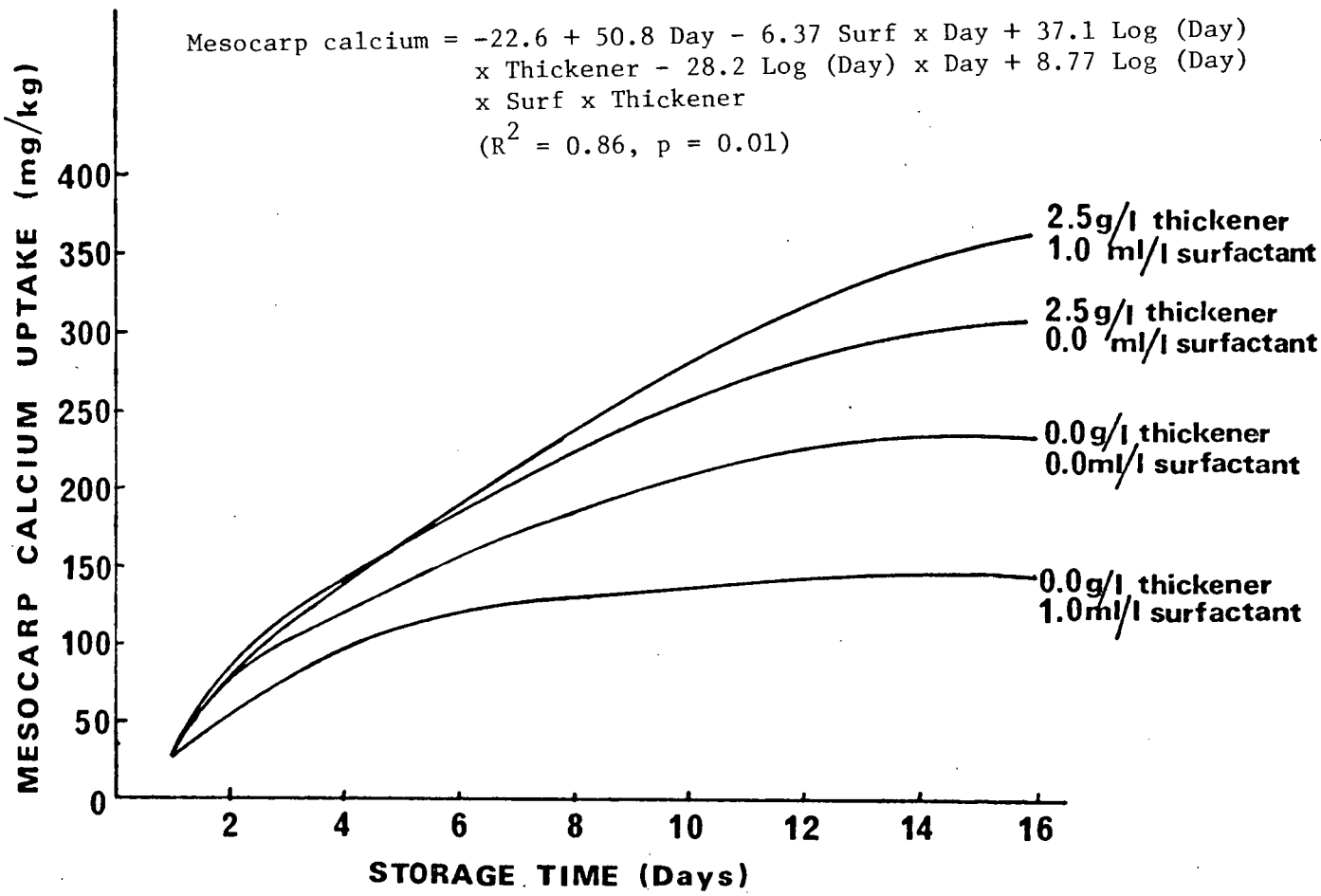

Figure 14. Mesocarp calcium uptake by 'Van' cherries from a postharvest dip modified by surfactant and thickener.

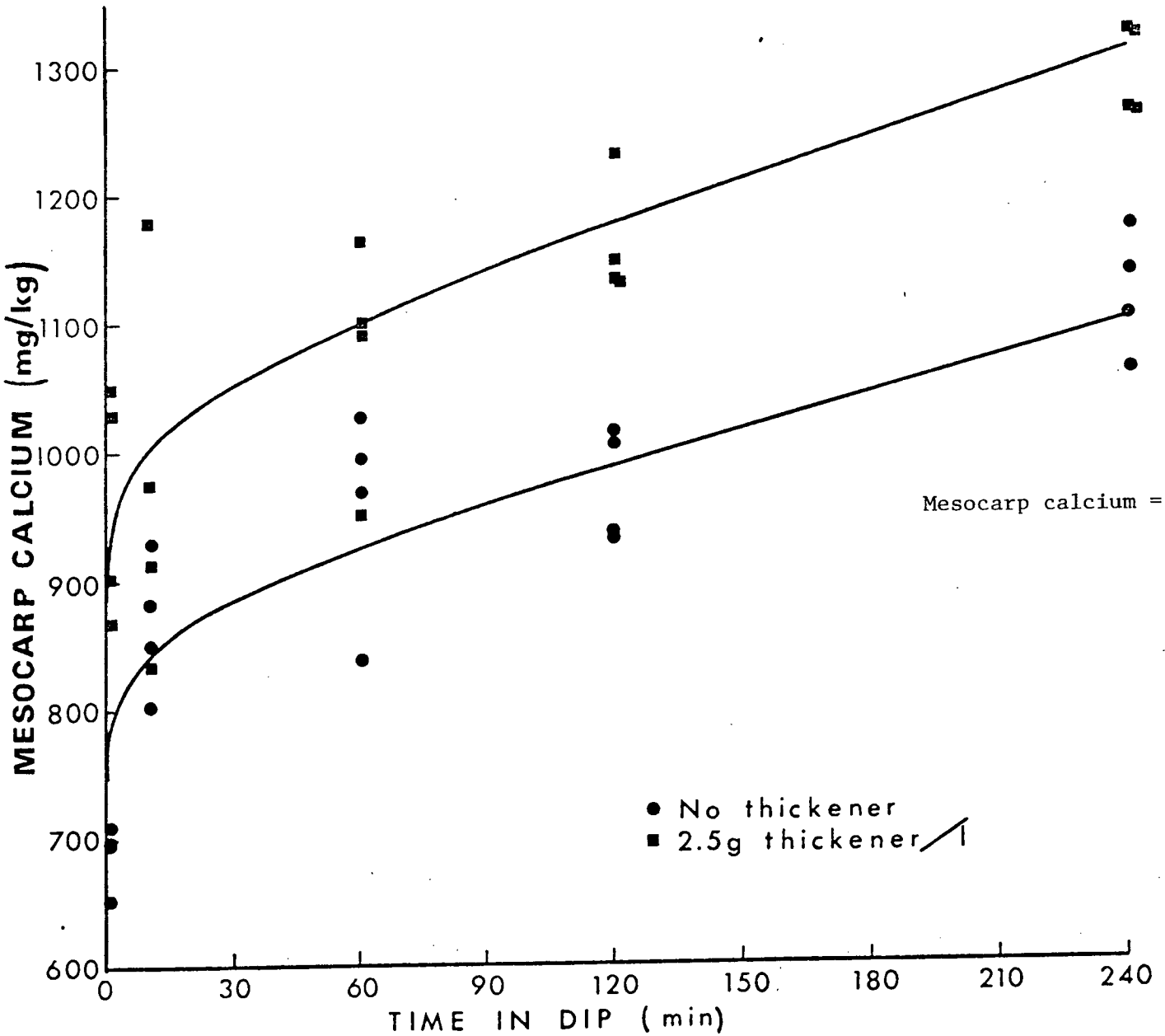

Fig. 15. Effect of calcium chloride postharvest dip on flesh calcium uptake in 'Van' cherry.

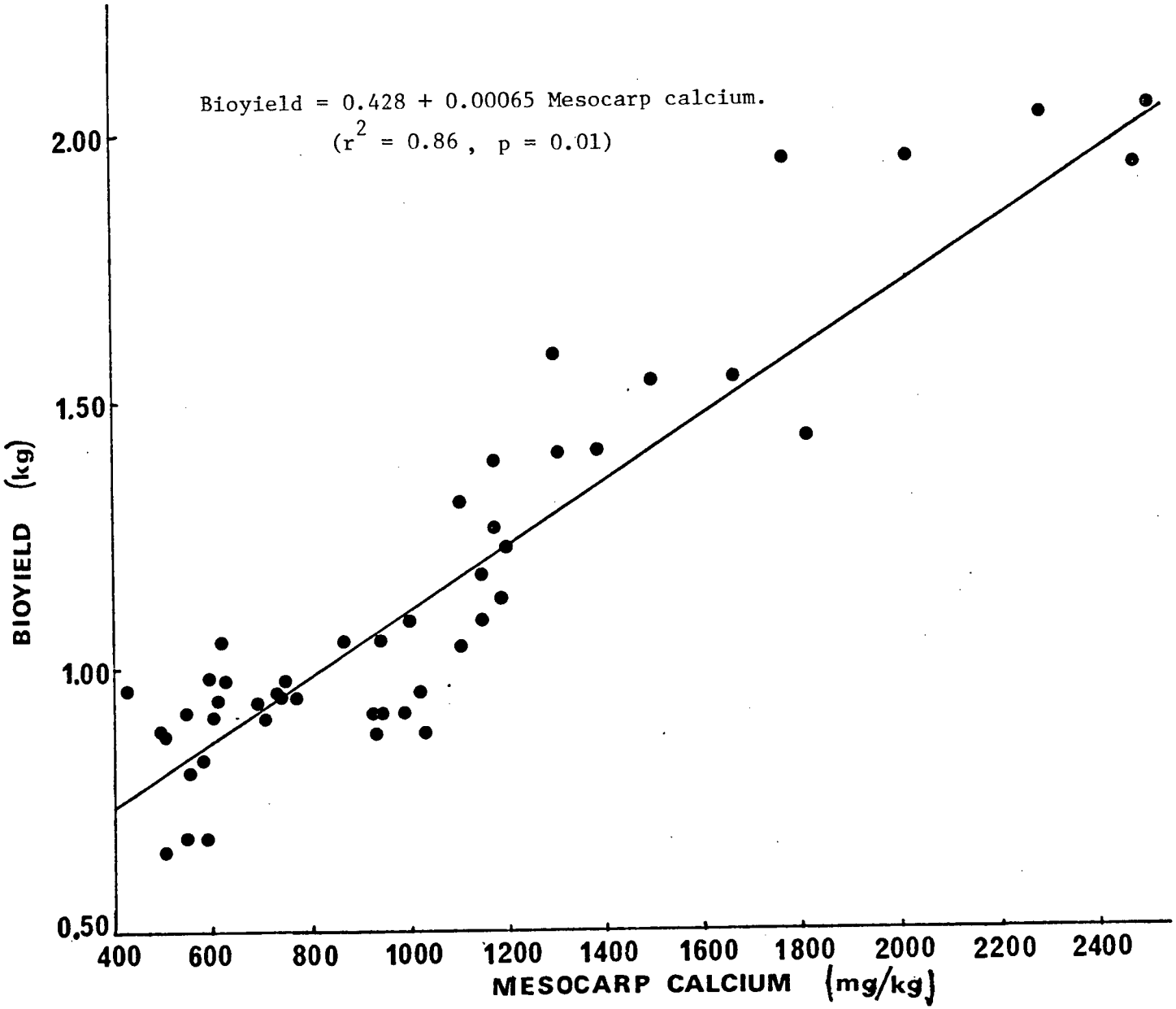

Fig. 16. Mesocarp calcium versus bioyield in 'Van' cherries.

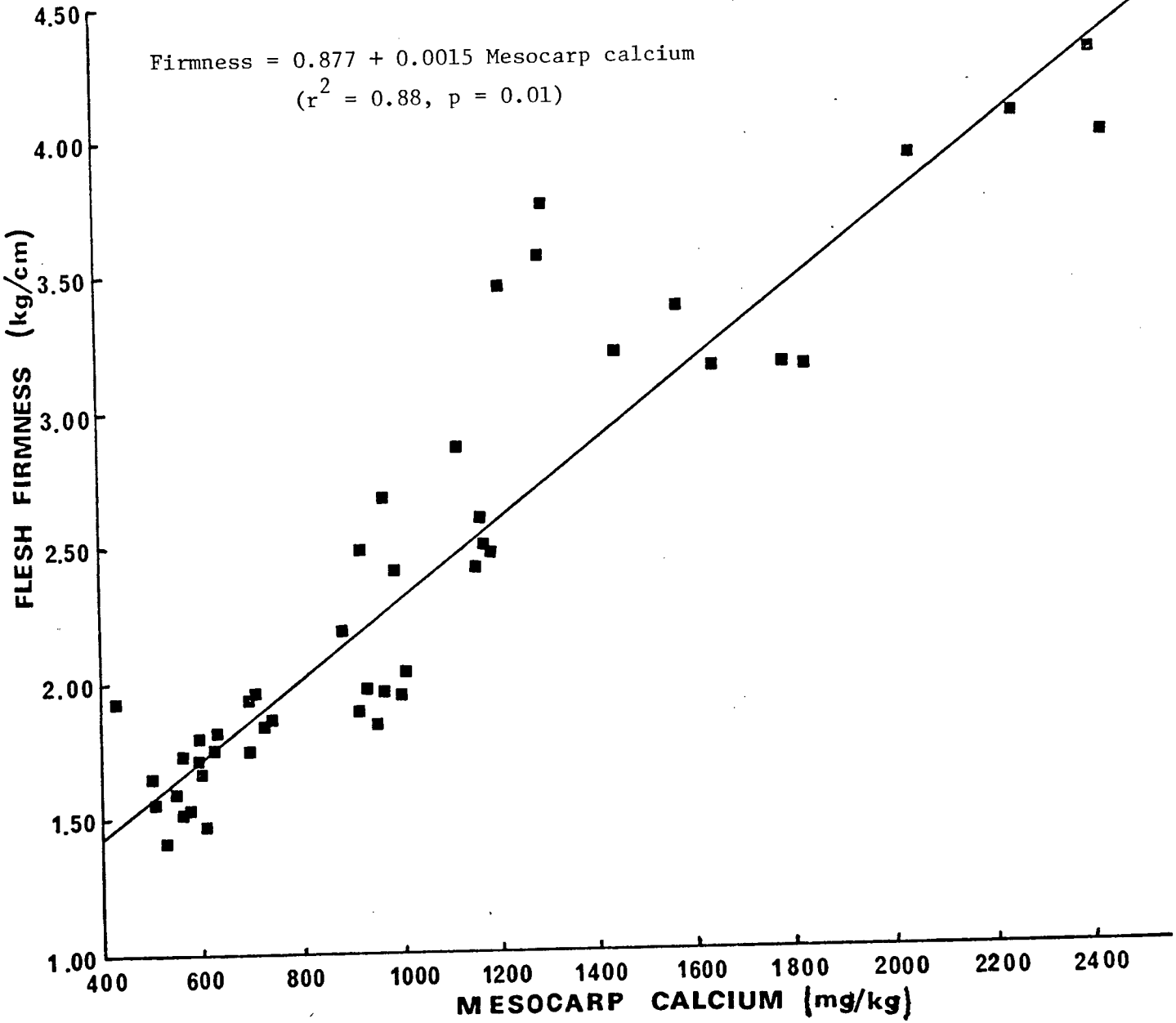

Fig. 17. Mesocarp calcium versus fruit firmness in 'Van' cherries.

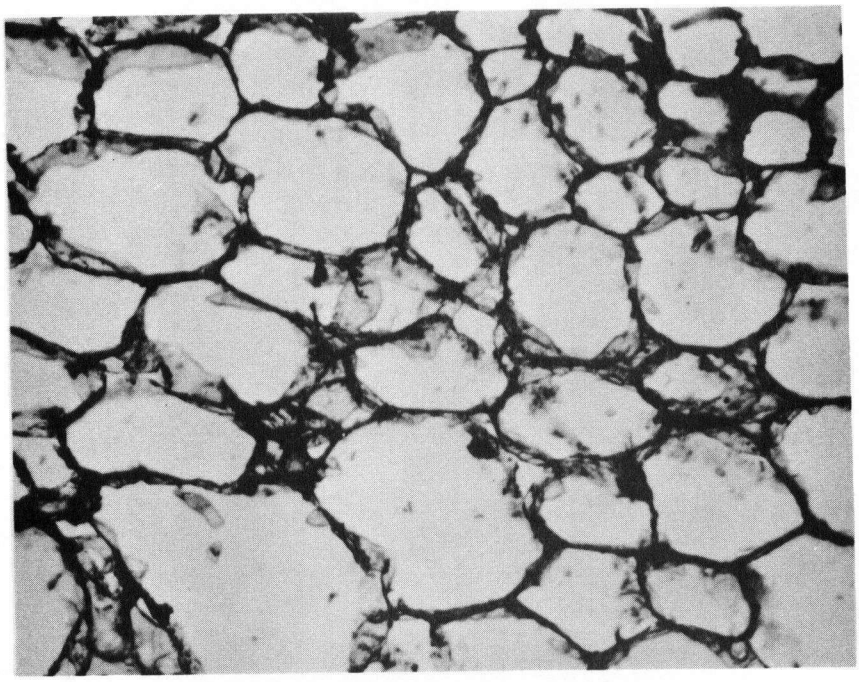

Fig. 18. Micrograph of non-damaged No. 3 color maturity cherry tissue (x60).

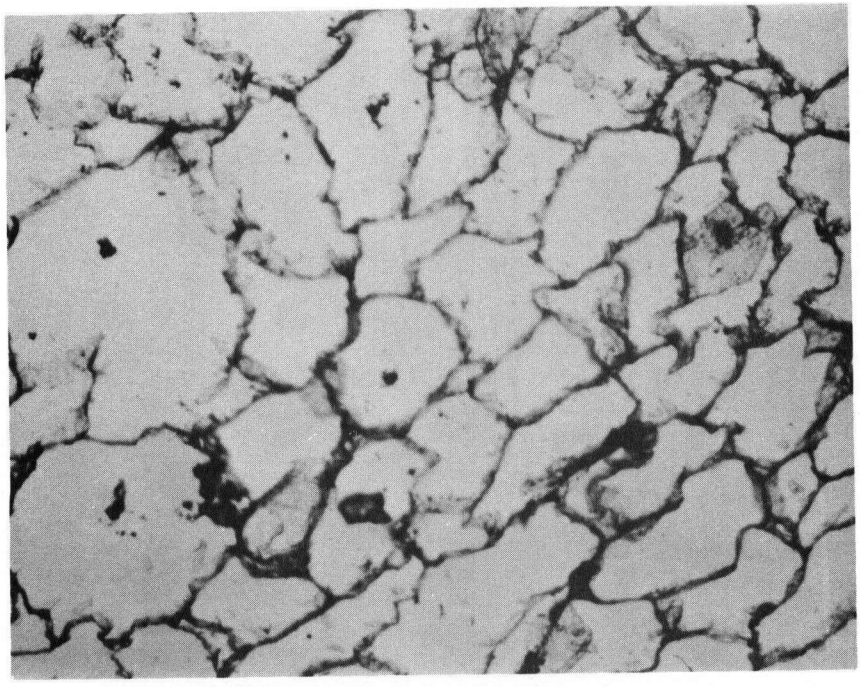

Fig. 19. Micrograph of No. 3 color maturity cherry tissue immediately after impact (x60).

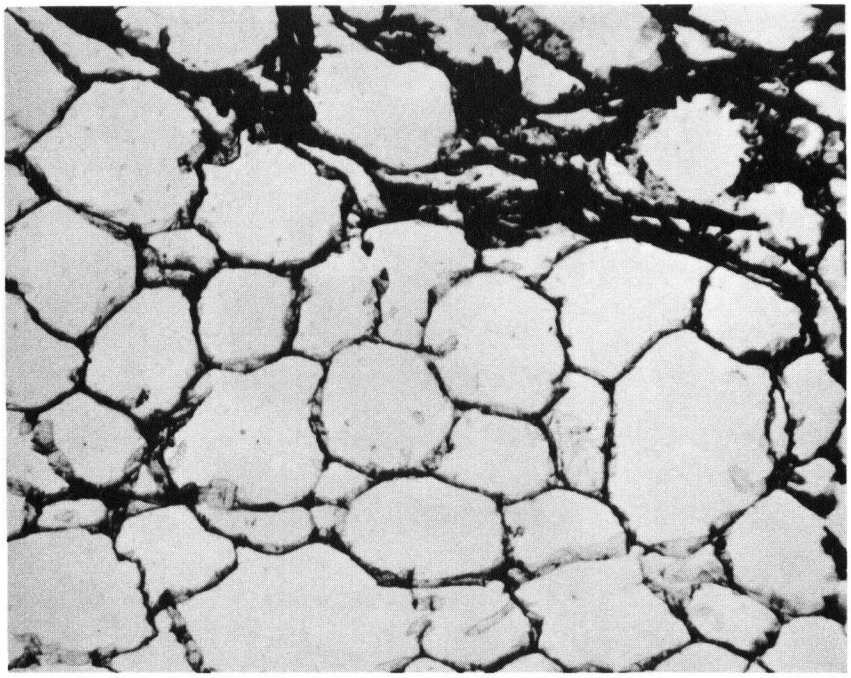

Fig. 20. Micrograph of No. 3 color maturity cherry tissue showing damage 9 days after impact (x60).

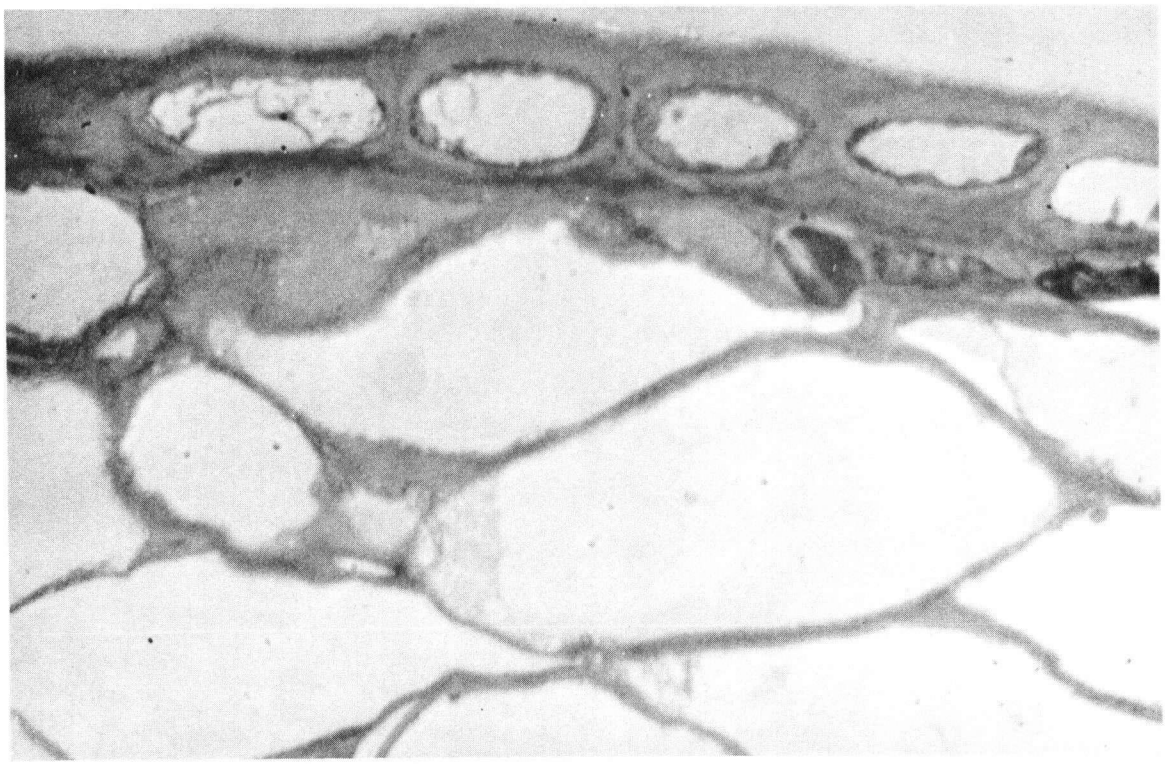

Fig. 21. Micrograph of non-damaged No. 33 color maturity cherry tissue (x750).

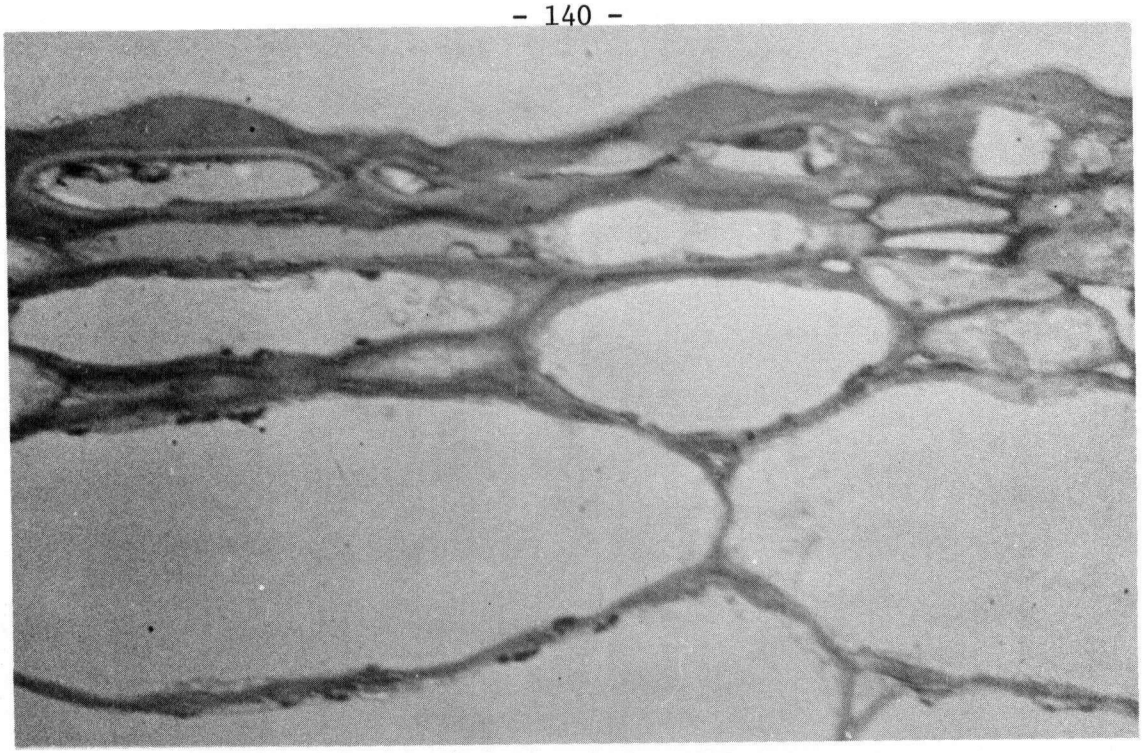

Fig. 22. Micrograph of No. 33 color maturity cherry tissue immediately after impact (x750).

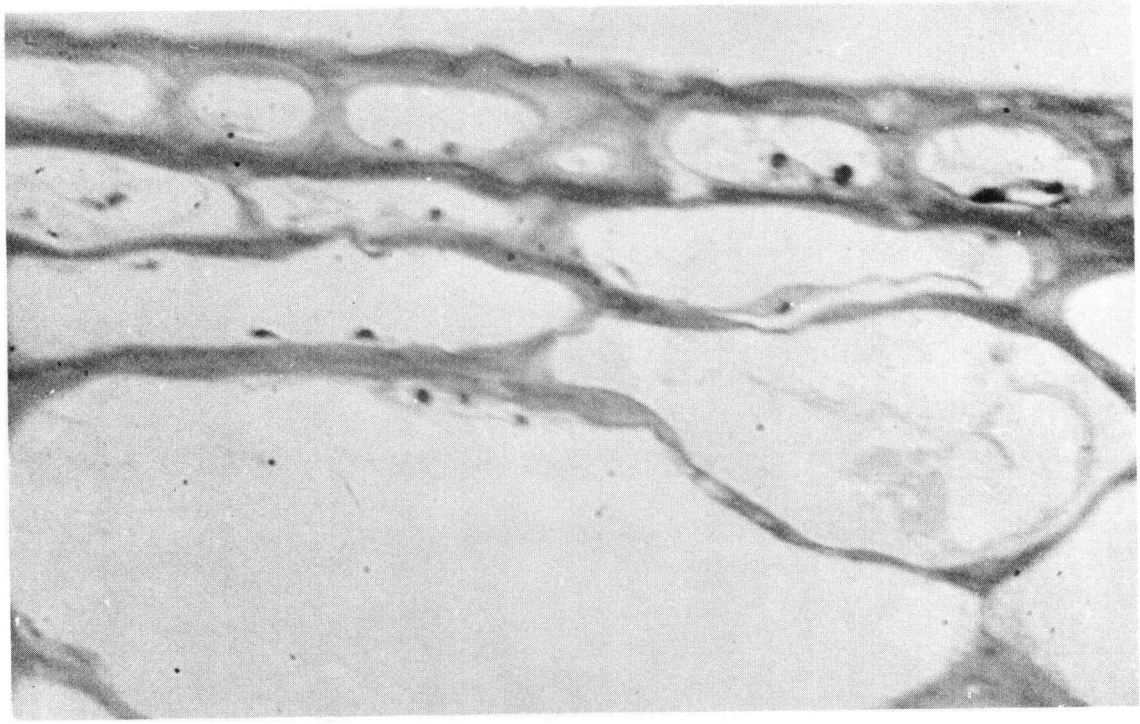

Fig. 23. Micrograph of No. 33 color maturity cherry tissue showing damage 9 days after impact (x750).

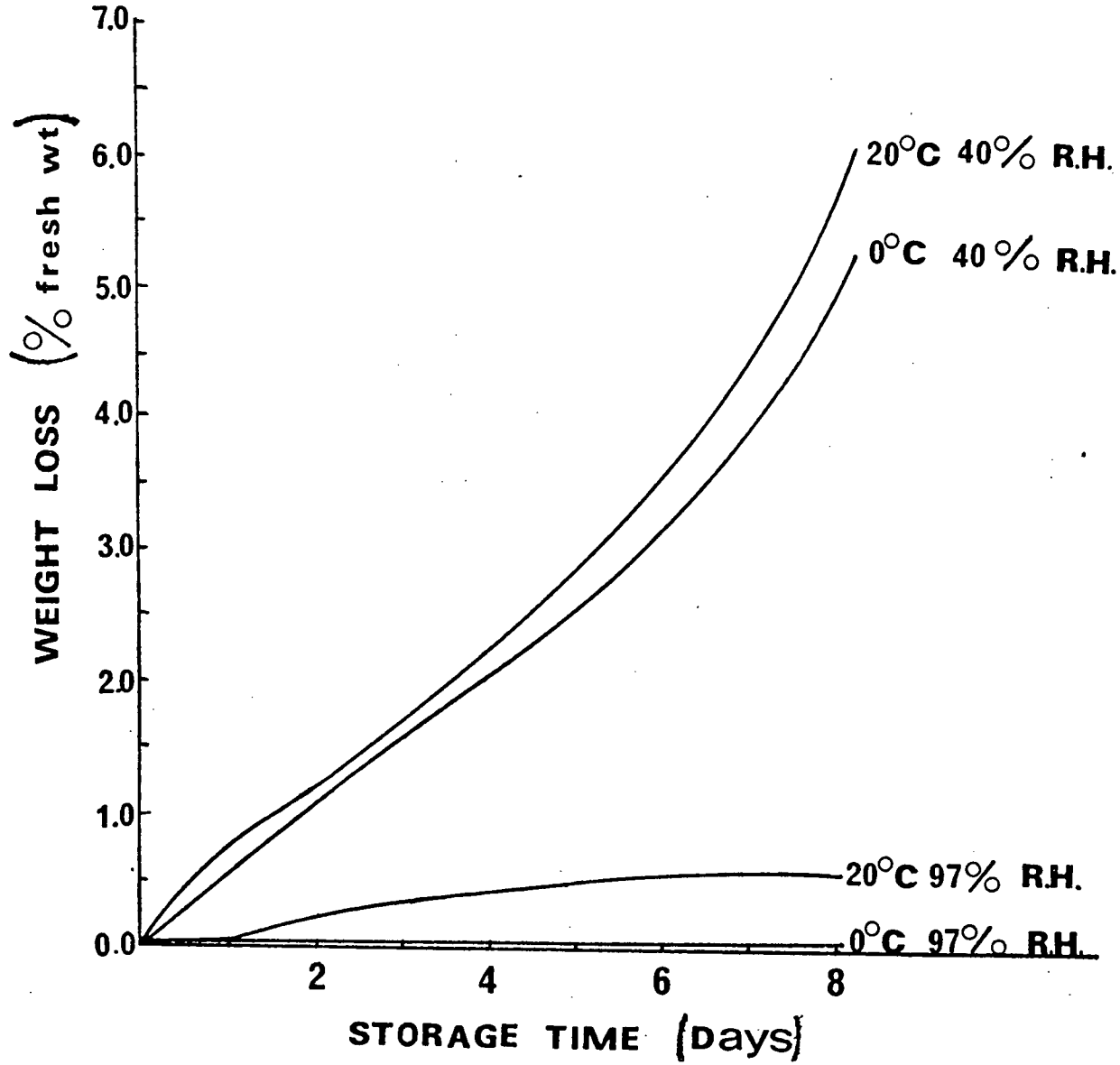

Fig. 24. Weight loss in 'Van' cherries due to relative humidity in storage (n = 4).