FRUIT BRUISING IN SOLO PAPAYA: QUALITY, RIPENING AND DISINFESTATION

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Abstract

Carica papaya L. cv. Solo fruit were taken off different points in a commercial postharvest handling system to determine where in the handling chain mechanical injury occurred and what caused it. "Green islands" (GI) apparently induced by mechanical injury were seen in all fruit and the occurrence increased as fruit moved through the handling system. This type of injury was only seen in fruit taken from the sides but not in fruit taken from the center of the field bins. To duplicate the GI seen in fruit from the handling system, fruit at different stages of ripeness (5 to 50% yellow) were dropped from different heights (0 to 100 cm) onto a smooth steel plate. Injury seen did not resemble the GI seen in fruit from the handling system. Fruit (10 to 15% yellow) were then dropped on different grades of sandpaper (220 mesh to 36 mesh) from a height of 10 cm. GI similar to those seen on fruit from the handling system were observed in fruit dropped on all grades of sandpaper. Fruit dropped on fine sandpaper had a higher severity of GI than those dropped on coarse sandpaper. A lesser severity of GI was seen in 40 to 50% yellow fruit dropped onto 150 mesh sandpaper from a height of 10 cm compared to greener fruit. These results suggest that abrasion damage was more important than impact damage in Solo papaya fruit.

Respiration rate and ethylene production did not significantly increase when fruit were dropped onto a smooth steel plate or sandpaper from a height of 10 cm. Similar results were seen even when the number of drops were increased to eight.

Washing off the latex did not affect the severity of GI. Heating fruit at 48°C for ~6 hours or until fruit core temperature (FCT) reached 47.5°C aggravated the

severity of GI. Delaying the time of heating from the time of dropping did not significantly lower the severity of GI, except for fruit heated 24 hours after dropping. Heating also resulted in fruit that had a rubbery texture. Waxing fruit alleviated the severity of GI and it did not matter whether waxing was done before or after the heat treatment.

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Literature Review

Introduction

Papaya (*Carica papaya* L.) production in the United States is mostly in Hawaii where it is a $15 million industry (Souza, 1991). In 1990, fresh production totalled about 58 million pounds (Souza, 1991). This fruit is a relatively recent commercial introduction to the mainland U.S., especially on the East Coast, which also receives papaya shipments from Central and South America and the Carribean (Capellini et al., 1988). Shipments of fresh papayas from Hawaii totalled about 42 million pounds in 1990 (Souza, 1991).

Inspection of papaya shipments on the New York market revealed quite a number of disorders which included mechanical injury, physiological disorders and postharvest disease (Cappellini et al., 1988). Shipments from Hawaii had bruise damage as the only mechanical injury reported, but this occurred in 14.8% of the shipments.

Bruise damage in papaya manifests itself on a ripe fruit as a sunken area which fails to degreen. In the present study, these green areas are referred to as "Green islands" (GI). It has been observed to be associated with broken skin, however, its occurence does not seem to be affected or aggravated by the presence of latex. It is not known at what point in the postharvest handling system of papayas that fruit get bruised and these areas develop into GI. It is being surmised that the quarantine treatments the fruit undergo before shipment aggravate this condition. Except for the research of Wang and Chang (1970) on deformation of Solo papaya fruit and of Kumar and Wang (1971) on the response of papaya fruit to dynamic loading, there have been no other published works on mechanical injury in papaya. This work was undertaken to rectify this deficiency.

Papaya fruit handling and physiology

Papaya fruit exported from Hawaii to the U.S. mainland and Japan are disinfested by approved quarantine treatments (Akamine, 1966). The fruit require postharvest quarantine treatment for disinfestation of Mediterranean fruit fly (*Ceratitis capitata* Wiedemann), melon fly (*Dacus cucurbitae* Coquillett) and Oriental fruit fly (*Dacus dorsalis* Hendel.). In 1984, the U.S. Environmental Protection Agency discontinued the registration of ethylene dibromide (EDB) for use as a postharvest fumigation treatment (Anonymous, 1984). Alternatives had to be rapidly developed and heat treatments were the logical choice.

Current papaya quarantine treatments include a double-dip treatment that involves a hot water treatment of 42°C for 40 minutes, later reduced to 30 minutes, followed by 49°C for 20 minutes (Couey and Hayes, 1986), an extended dry heat treatment which involves bringing the fruit center temperature (FCT) to 47.2°C and immediately hydrocooling the fruits until the FCTs are 30°C or below (Armstrong et al., 1989) and vapor heat treatment (Balock and Kozuma, 1954; Esguerra et al., 1987). All these treatments can cause thermal injury in fruit. Prolonged heat treatment causes the fruit to ripen externally, retaining a 1- to 1.5-cm thick layer of hard tissue surrounding the seed cavity (Chan et al., 1981). Esguerra et al. (1987)

reported that the major manifestation of heat injury in Kapoho Solo due to vapor heat treatment was the reduction in the intensity of pulp color and pulp separation.

For most agricultural products, the mechanical behavior is time dependent (Wang and Chang, 1970). The deformation experienced by a loaded fruit (fruit experiencing a force) depends not only on the magnitude of the applied load but also on the time period over which the load is applied. This time dependency of the mechanical behavior of fruit under stress is associated to fruit ripening with time. Therefore, those physical properties which are dependent on the stage of maturity will also change with time. Wang and Chang (1970) reported that as Solo papaya fruit ripen, less deformation is required to initiate internal flesh damage. Their results also showed that the deformation rate of the fruit at which damage occurs decreases continuously under constant plate loading. Furthermore, the authors were able to establish a limit on the deformation a fruit may undergo without suffering internal damage. It is not known at what point in the papaya postharvest handling system that fruit get mechanically injured and these areas develop into "green islands." Likewise, the time frame during which the stress/force acts on the fruit to cause the bruise is also not known.

Failure and Description of Injury in Fruits and Vegetables

Failure in solid horticultural materials is classified as cleavage, slip or bruising (Holt and Schoorl, 1982). Cleavage (sometimes referred to as cracking or splitting) is a normal stress phenomenon. In their review, Holt and Schoorl (1982) cited several authors (Mohsenin, 1977; Sherif, 1976; Brown, 1979; Aspinall, 1980) who observed cracking in potatoes, tomatoes, cabbages, watermelons and apples. The tearing apart of tissue is due to the presence of tensile stresses. The tensile stresses responsible for cleavage failure of potatoes and tomatoes under compressive loading are often induced stresses, for example hoop stresses.

Like cleavage failure, slip in horticultural produce is characterized by cell rupture or separation along defined surfaces, the tissue on either side of the fracture remaining relatively undamaged (Holt and Schoorl, 1982). This has been observed in apple, potato, ripe and unripe plantains, pineapple, unripe papaya, unripe pears (Diehl et al., 1980; Miles and Rehkugler, 1973; Diehl and Hamann, 1980; Peleg and Brito, 1977; Peleg et al., 1976; Brown, 1979 as cited by Holt and Schoorl, 1982). In these various materials, failure has occurred under compression loading but the actual failure takes place by shearing, with two parts of the specimen sliding past each other, that is the pieces "slip" or slide relative to each other, usually along planes at approximately 45° to the compressive load.

Mohsenin (1986) defined bruising as damage to plant tissue by external forces causing physical change in texture and/or eventual chemical alteration of color, flavor and texture. Bruising does not break the skin. Diehl et al. (1980) used scanning electron micrographs to confirm that failure occurred through the cell walls in apples. Peleg et al. (1976) reported the release of liquids (i.e. cell bursting) in ripe mango, papaya, pineapple and watermelon.

The mechanical state of a material can be defined in terms of its current cleavage strength, slip strength and current bruising strength (Holt and Schoorl, 1982). However, the strength values should not be thought of as constant, since it differs with the stage of maturity of the fruit. Slip failure occurs in unripe mango and papaya while bruising occurs in the ripe fruit (Peleg et al., 1976).

Vibration and impacts to deciduous fruits of shipping maturity typically produced widely varying injury. Sommer (1957a,b) has shown that vibration injury to 'Bartlett' pears is usually limited to the epidermis and few underlying cell layers. Tissue browning can be detected a few minutes after injury. By contrast, impact bruises may be restricted only to the internal flesh tissue. Drops of two to three feet generally result in an interior bruise of pears detectable only on peeling. Initially, bruised areas appear slightly water-soaked, eventually producing a typical "brown spot" condition and finally becomes dessicated. Mohsenin (1986) states that browning of tissues in fruits such as apples, pears, peaches, apricots, cherries, grapes and bananas is enzymatic in nature. The rupture of plant cells exposes the cell contents to the intercellular air and results in enzymatic oxidation and discoloration of plant tissues.

Causes of Fruit Bruising

Damage to horticultural produce occurs at every point in the distribution chain, from harvest to the consumer.

According to Sommer and his co-workers (1960) the two important types of injury are surface abrasion and impact bruises. Surface abrasion may result from fruit rolling against the container, grading belts, or each other. 'Bartlett' and 'd'Anjou' pears (*Pyrus communis* L.) were bruised when passed through several brush rollers during washing, rinsing, waxing and drying sequences of a simulated packing process (Mellenthin et al., 1982). The bruising observed, which was due to brush friction, resulted in peel discoloration.

Damage is also observed when fruit jiggle or roll from transit vibrations. On the other hand, impact bruises may occur at any time during and after harvest if the fruit drops more than a few inches. Likewise, injury is also possible if the content of rail cars are subjected to severe longitudinal impacts, incurred in starting or stopping, or from slack in the coupling system as long trains go up or down grades. On transport trucks, damage occurs in the top layers of fruit in containers (O'Brien et al., 1963). There is direct relationship between the amount of bruising and the magnitude of vibration accelerations in the top levels of fruit. Accelerations may be as much as four times as great in the top layers as in the bottom layers of fruit. Furthermore, depth-of-bin studies showed an optimum depth of 24 inches. This is attributed to accelerations in the top layers of fruit and the per cent of total fruit in the bin that is free to move (O'Brien et al., 1963).

Effects of Bruising on the Ripening Process

Numerous studies have shown that wounding in various fruits enhances physiological processes which lead to faster ripening and decay.

Respiration rate

Carbon dioxide evolution has been recognized as an indicator of bruise damage to fruit, however, its application has not been widespread. Fruits such as citrus, cranberries, tomatoes, cherries and apples, when impact bruised, show an immediate increase in the evolution of CO_2 (Eaks, 1961; MacLeod et al., 1976; Marks and Varner, 1957; Massey et al, 1982; Parker et al, 1984; Robitaille and Janick, 1973; Burton and Schulte-Pason, 1987) and pears by vibration injury (Sommer et al., 1960).

The amount of bruise damage is proportional to the CO_2 produced (Massey et al., 1982; Parker et al., 1984). Burton and Schulte-Pason (1987) measured CO_2 as an indicator of impact damage in blueberries, sweet cherries and tart cherries. Respiration rate increased significantly in blueberries and sweet cherries with increasing number of impacts (1 to 3). There was no further effect of four and five impacts on 'Schmidt' sweet cherry. Tart cherry respiration increased slightly with the 1 meter impact over that of the control, but additional impacts lead to a significant decrease in CO_2 evolution. Furthermore, the authors reported that CO_2 evolution reached a maximum within 1 hour after the bruising and generally remained at this level for 6 hours.

The increase in CO_2 evolution after bruising is possibly not due to enhanced normal respiratory activity, but to the decarboxylation of malic acid spilled from the damaged cells at the site of the bruise (Pollack and Hills, 1956; Marks and Varner, 1957). This increased respiration in wounded tissue is referred to as wound respiration and differs from infection-induced respiration seen in fungal infected tissues (Uritani and Asahi, 1980). The increased respiration may be attributed to wound-healing reactions involving the formation of lignin and suberin (Kahl, 1974) or callus formation, differentiation (Mitsuhashi-Kato et al., 1978).

Ethylene production

Most plant tissues produce ethylene following trauma caused by chemicals, temperature extremes, waterlogging, drought, radiation, insect damage, disease or mechanical wounding (Abeles, 1973; Yang and Pratt, 1978). Ethylene produced under such conditions is referred to as wound or stress ethylene. The rate of ethylene production begins to rise immediately after injury, increases 10- to 100-fold in 1 to 10 hours, and then declines (McGlasson and Pratt, 1964; Imaseki et al., 1968; Jackson and Osborne, 1970; Herner and Sink, 1973; Kende and Hanson, 1976). It has been suggested that stress ethylene may enable the plant to cope successfully with trauma. For instance, drought causes leaves or fruit to increase ethylene production, which in turn promotes abscission and thereby reduces water loss (McMichael et al., 1972).

Wound ethylene is synthesized from carbon atoms 3 and 4 of methionine (Hanson and Kende, 1976). Wounding induces the synthesis of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase, the rate-controlling enzyme in the pathway of ethylene biosynthesis (Yu and Yang, 1980; Wang and Yang, 1987; Hyodo et al., 1989). This leads to an accummulation of ACC, the ethylene precursor and an increase in ethylene production.

Wound ethylene formation is dependent on the degree of injury. In soybean leaves showing electrolyte leakage not higher than 40%, the promotion of ethylene formation was observed (Kacperska and Kubacka-Zebalska, 1989). Internal levels of ACC and 1-(malonylo)-cyclopropane-1-carboxylic acid (MACC) also increased.

However, in tissues showing a relatively higher level of injury, about 50%, the formation of MACC prevailed over the ACC accumulation and no further synthesis of ethylene was observed. Furthermore, stress-promoted ethylene formation was correlated with lipoxygenase activity (Kacperska and Kubacka-Zebalska, 1989). The enzyme was stimulated in tissues showing small injury (leakage lower than 40%) and inhibited in tissues showing injury higher than 40%. Two prerequisites for effective stress ethylene synthesis have been proposed in vivo: promotion of the ACC synthesis and activation of free radical-generating system which is responsible for the chemical conversion of ACC to ethylene (Kacperska and Kubacka-Zebalska, 1989).

Little is known about the subcellular localization of ethylene formation. Pech and his co-workers (1989) reported that in osmoticum sensitive cells of a suspension culture of *Vitis vinifera*, ethylene-forming activity is mainly located at the plasmalemma with small activity inside the cell. On the other hand, in osmoticum insensitive cells, the bulk of ethylene production is intracellular. Furthermore, their results indicated that MACC is synthesized in the cytosol, transported through the tonoplast and accumulates in the vacuole.

Sweet potato root tissue produce ethylene in response to cut injury (Imaseki et al., 1968) and breaking (Randle and Woodson, 1986). There is a direct relationship between the cut surface area and the amount of ethylene produced (Imaseki et al., 1968). Furthermore, the amount of ethylene produced is proportional to the logarithm of the surface area. The presence of living cells is necessary for wound ethylene production. Maximum ethylene production occurred 2 to 4 days after wounding (Randle and Woodson, 1986). Impact-bruised, mature-green tomatoes (*Lycopersicum esculentum* Mill. cvs. Cal Ace and Tropic), exhibited an increase in ethylene production within one hour after injury. These same fruits exhibited sustained increases in rate of ethylene and carbon dioxide production. The magnitude of ethylene production increased with number of impacts (MacLeod et al., 1976). Dropping cucumbers four times from a height of 1 m and then rolling them for 1 min between a benchtop and a 30-cm square board supporting a 10 kg mass stimulated ethylene production after 8 hr storage at 0°C (Miller et al., 1987). Furthermore, stressed and unstressed fruits exhibited increased ethylene production when stored for 48 hr at 0°C. Increases in ethylene production after mechanical injury was also observed in cantaloupe (McGlasson and Pratt, 1964; Hoffman and Yang, 1982), citrus fruit (Hyodo, 1978), squash (Hyodo et al., 1989), actively growing regions of etiolated barley, cucumber, maize, oat, pea, tomato, and wheat seedlings (Saltveit and Dilley, 1978).

Contrasting results have been reported regarding the ethylene evolution in apples following bruising. Robitaille and Janick (1973) postulated that bruise injury might be associated with increased level of ethylene production yet their research to test this hypothesis showed the reverse to be true in 'Golden Delicious' apples. The authors concluded that bruising decreases ethylene production in apples by destroying the production region under the skin. Lougheed and Franklin (1974) findings do not support the findings of the earlier study. They report that bruising increased ethylene production of 'Red Snow' and 'Northern Spy' apples. In former studies, the apples were stored for six weeks at 1°C before injured (Robitaille and Janick, 1973), while in the later study, freshly harvested apples were used (Lougheed and Franklin, 1974). To reconcile these difference, Lougheed and Franklin (1974) proposed that bruising apples before major endogenous ethylene production begins, induces non-ethylene producing tissue to begin producing ethylene. Bruising apples with a high rate of ethylene production lowers production by destroying productive tissue (Robitaille and Janick, 1973).

Zauberman and Fuchs (1981) reported that no wound ethylene could be detected immediately upon wounding mature 'Fuerte' avocado fruit (*Persea americana* Mill.). Ethylene production was similar in wounded and unwounded fruit. In wounded fruit stored at 14°C, ethylene peak was observed on the 10th day after wounding, whereas for wounded fruit stored at 20°C, it was observed on the 4th day after wounding. Wade and Bain (1980) reported that impact bruising in sweet cherry fruit did not significantly affect ethylene evolution, but respiration rate increased in proportion to the height of the fall.

Fruit softening

Fruit softening as affected by bruising has been reported in cranberries (Patterson et al., 1967) and avocado (Zauberman and Fuchs, 1981). Cranberry (*Vaccinium macrocarpon* Ait.) softening can be induced by impact bruising, and appears identical to that commonly observed in commercial cold storage. The percentage of softened berries increased linearly with increasing impact force up to a plateau (Patterson et al., 1967). In avocados, softening was accelerated by wounding. There were no differences between sound and wounded fruit in softening rates when fruit were stored at 5°C for 10 days before being transferred to either 14° or 20°C. However, both sound and wounded fruit, become soft 7 days after it was transferred to 14°C and after only 4 days at 20°C (Zauberman and Fuchs, 1981).

Polygalacturonase activity has been reported in bruised fruits. Wounded avocado fruits show greater polygalacturonase activity than non-wounded ones (Zauberman and Fuchs, 1981). Polygalacturonase activity was found in the soft tissues of bruised cranberries but not in sound berries or parts of berries (Patterson et al., 1967). It appears that softening results in part from endogenous enzymatic degradation of cell wall pectin leading to loss of structural integrity and resulting in physiological softening.

Discoloration

Adverse color changes are observed in bruised cranberries (Patterson et al., 1967). Overall degradation of anthocyanin pigment results in adverse color changes in the injured tissue which do not occur at 32°F. Fruit stored at 45°F had 20% adverse color changes and 62% in fruit at 68°F. Absence of color changes at 32°F suggests that the discoloration is due to enzymatic destruction of anthocyanin with activity increasing with temperature.

Ingle and Hyde (1968) reported that at least 50% of the browning in bruised apples occurred within 30 minutes. All browning was completed in about two hours. Furthermore, browning was less rapid at 2°C than at 22°C, but the magnitude of the effect varied between cultivars, being greater in 'Red Delicious' than 'Golden

Delicious' and 'Rome'. The authors reported that chlorogenic acid and flavonols are involved in the browning of apple tissue following bruising. Both chlorogenic acid and flavonols decreased, but the decrease after bruising was greater in the latter. In some cases bruised tissue is essentially devoid of flavonols.

The extent of discoloration depends not only on the severity of bruising, but also on the inherent browning potential of the fruits (Kader and Chordas, 1984). Browning potential depends on the total amount of phenolic compounds and level polyphenol oxidase (PPO) activity. Normally, phenolic compounds are separated from PPO enzyme in the intact tissue. Cell damage leads to a mixing of PPO and phenolic compounds leading to browning. These browning reactions involve the oxidation of phenolic compounds to formation of highly unstable quinones, and polymerize quickly to form brown-colored products. Kader and Chordas (1984) found large differences in browning potential, total phenolics content and PPO activity among peach cultivars and within a given cultivar in relation to environmental conditions and cultural practices.

Black, purple and tan discolorations have been found within red-pigmented areas of peach skin fruit several hours after the fruit has been packed (Denny et al., 1986). This peach skin discoloration (PSD) is restricted to the skin and does not affect the flesh. Denny et al. (1986) hypothesized that structure changes in cyanidin-3-glucoside, the only appreciable red pigment reported in peach (Hsia et al., 1965; Van Blaricom and Senn, 1967) result in the change in color associated with PSD.

The anthocyanin cyanidin-3-glucoside color is dependent on cellular pH (Van Buren et al., 1974) and/or metallic ions binding (Jurd and Asen, 1966).

Postharvest disease

The mechanism by which phytopathogenic fungi penetrate the cuticular barrier of plant tissues has long been debated (Martin, 1964). The cogent theory was that fungal pathogens invade through natural openings in the cuticle such as stomata or through punctures or wounds caused by mechanical force. It has also been acknowledged that penetration involves enzymatic degradation of the cuticle by the fungus (McKeen, 1974; Van den Ende and Linskens, 1974; Dickman and Patil, 1984). In papaya, *Colletotrichum gloeosporioides* can penetrate the cuticular layer of the fruits by secreting a cutinase (Dickman et al., 1982).

Wound infections frequently provide sites for pathogen entry. This was believed to be the case in papaya anthracnose (*C. gloeosporioides*). However, results suggest that infection occurs at early stages of fruit maturity in the field while fruit are still attached to the trees (Alvarez et al., 1977). The fungus remained quiescent until the fruit reached the climacteric phase (Dickman and Alvarez, 1983) when symptoms will be expressed as anthracnose or chocolate spot lesions.

Fungal activity and physiological breakdown are not only directly related to bruising injury (Graham et al., 1967), but that bruising during harvesting and handling may be a primary factor associated with poor keeping quality of cranberries. Studies on apricots, peaches, nectarines and plums by Sommer et al. (1960) show that surface abrasion injury from vibration provides a convenient infection court for certain decay saprophytic fungi (i.e. *Rhizopus stolonifer*, *Penicillium expansum*, *Botrytis cinerea*). Burton and Schulte-Pason (1987) reported that there is a positve correlation between impact damage and decay in blueberries, sweet cherries and tart cherries.

Physiological effects of injury

Mechanically damaged fruits have been reported to have an accelerated ripening rate. These observations have been made in mature green tomatoes (MacLeod et al., 1976), mature 'Fuerte' avocados (Zauberman and Fuchs, 1981), and bananas (Peacock, 1973) and pears (Sommer et al., 1960). Injury also accelerates weight loss. Sommer et al. (1960) reported that vibration injured fruits (peach, plum, apricot and nectarines) lost weight faster than non-injured control fruit in simulated transit tests.

Mild injuries occasioned by dropping, scratching or cutting, shortened the green-life of banana fruit (Peacock, 1973). Green-life of climacteric-type fruit is defined as the time that elapses from harvest until the onset of the respiratory climacteric rise under any defined conditions (Peacock and Blake, 1970). In the matter of shelf-life, it has been reported that impact-induced breakdown in 'Howes' cranberries (Massey et al., 1981) and vibration injured 'Bartlett' pears (Sommer et al., 1960) resulted in shortened shelf-life.

Mechanical injury of sweet cherry fruit causes the disorder 'surface pitting', in which skin depressions overlie necrotic lesions in the fleshy mesocarp (Wade and Bain, 1980). Furthermore, surface pitting induced by impact-treatment was not visible immediately after dropping but appeared after about 9 days or longer at 1.5°C.

A similar observation was made by Massey et al. (1981) for 'Howes' cranberries. The development of visible defects from impacted berries frequently involves a lag period of several hours and significant breakdown can occur in impacted berries showing no visible defects as long as 24 hours following impacts.

Ingle and Hyde (1968) reported that bruising in apples reduced the concentration of total phenols, flavanols and chlorogenic acid. The authors further noted that there was some relation between rate of browning and tissue content of phenolic compounds. Aworh et al. (1983) reported that compared to undamaged controls, damaged fresh ripe tomatoes had lower reduced ascorbic acid, higher dehydroascorbic acid concentration, higher pH, lower total soluble solids, and titratable acidity.

Factors Influencing Sensitivity and Susceptibility of Fruits to Bruising

Environmental

Temperature. Schoorl and Holt (1977) reported that fruit temperature had no significant effect on the bruise volume with a 1.25 joules impact energy on 'Jonathan', 'Delicious' and 'Granny Smith' apples. Apple pulp temperatures ranged from 2° to 30°C. On the other hand, Saltveit (1984) reported that the volume of bruises produced in 'Starkrimson Delicious' and 'Golden Delicious' by mechanical impact injury increased with increasing temperatures (0°, 10°, 20° and 30°C) and with increasing holding temperature (0°, 10°, 20° and 30°C) during bruise development. Increased bruise volume at higher bruising and holding temperatures probably resulted from increased enzyme activity, especially those responsible for the browning of the injured tissue. Since flesh firmness did not change significantly with temperature, changes in bruise volume with temperature cannot be accounted for by changes in tissue firmness. In sweet cherries (*Prunus avium* L.), warm fruit were less susceptible to impact bruising than cold fruit (Couey and Wright, 1974; Lidster and Tung, 1980). Warm storage temperature accelerated the development of bruise symptoms (Lidster and Tung, 1980).

Biotic

Cultivar. Bruise size in apples was affected by cultivar (Hyde and Ingle, 1968). 'McIntosh' and 'Red Delicious' developed the largest bruises while 'Jonathan' and 'Golden Delicious' the smallest. Furthermore, the rate of increase in tissue damage in apples is cultivar-dependent (Topping and Luton, 1986). In Asian pears, the 'Chojuro' varieties is the most firm and most resistant to mechanical damage compared to 'Twentieth Century', 'Tsu Li' and 'Ya Li' varieties when subjected to impact and compression tests (Chen et al., 1987).

Harvest date. Susceptibility of apples (*Malus domestica* Borkh. 'Gala' and 'Granny Smith') to impact damage was influenced by the harvest date, a relative indicator of fruit ripeness (Klein, 1987). Susceptibility to impact damage increased from early to late harvest time and decreased during storage at 1°C.

Maturity and Stage of Fruit Ripeness. Bruise size increased with advancing maturity in apples (Hyde and Ingle, 1968). Ripening leads to a significant decrease in bioyield (peak force just prior to a sudden decrease in force sustained by the fruit due to tissue rupture), toughness and fruit firmness and an increase in compliance (reciprocal of fruit firmness) in tomato fruit (Olorunda and Tung, 1985).

The incidence of bruises in sweet cherries was highest in more mature fruit. Fruit weights, soluble solids and dry matter generally increased and fruit firmness generally decreased with maturity (Lidster et al., 1980). On the other hand, Couey and Wright (1974) reported that mahogany-colored cherries were less susceptible to impact damage than the red-colored, less ripe cherries. In 'Red Globe' peaches, Hung and Prussia (1989) reported that mature peaches were the most susceptible and had larger bruise volumes than the immature peaches.

Investigation of numerous impact parameters in relation to ripeness of pears and apples revealed that impact duration and time to maximum force were strongly related to ripeness (Garcia et al., 1988), whereas, maximum deformation, permanent deformation, bruise size and impulse were all least related to ripeness. Furthermore, maximum impact force, rebound velocity and elastic rebound energy had intermediate correlation with ripeness.

Crop load. 'Bing' cherries from lightly cropped (LC) trees were firmer (higher bioyield) and riper, as indicated by higher soluble solids and total anthocyanin concentrations (TAcy) than those from heavily cropped (HC) trees (Spayd et al., 1986). At a given color (TAcy) within the range of commercial shipping maturity, cherries from HC trees were more susceptible to bruising, were softer, and had lower concentrations of soluble solids, acid, and dry matter than cherries from LC trees.

Methods Used to Produce Mechanical Damage in Fruits

A number of studies have been conducted to define the resistance of fruit and vegetables to impact damage and/or to evaluate the response of fruit to mechanical damage. Commodities such as apples (Green, 1962; Dedolph and Austin, 1962), cranberries (Massey et al., 1982; Patterson et al., 1967), sweet cherries (Wade and Bain, 1980; Lidster and Tung, 1980; Burton and Schulte-Pason, 1987), onions (Isenberg, 1955) or potatoes (Green, 1956) were simply dropped from a specified height onto a hard surface and the resulting damage was then evaluated. Oftentimes, a piezoelectric impact force transducer is used (Delwiche et al., 1987; Brusewitz and Bartsch, 1989). In an alternative technique, the product was fixed and a solid weight of known mass was dropped onto it from a predetermined height (Saltveit, 1984; Couey and Wright, 1974; Chen et al., 1987; Hung and Prussia, 1989).

Impact forces experienced by fruit in a packing line can be measured. Timm and Brown (1989, 1991) measured impact forces experienced by avocado, papaya and pineapple in the packing line using an Instrumented Sphere (IS). When placed with fruit in the handling system, the IS could record impacts exceeding 15 g's (1 g = 9.81 m/s^2 [32.2 ft/s^2]).

The amount of bruise on a fruit can be quantified. Brusewitz and Bartsch (1989) measured the bruise volume in apples taking into account the bruise depth, bruise diameter and fruit diameter with the assumption that the bruise is spherical in shape.

Currently, problems seen in shipped papaya fruit include injury from mechanical damage that cause losses to the industry. This information led to the development of the present study's objectives.

Objectives

1. Determine where most damage to papaya fruit occurs in postharvest handling.
2. Simulate the bruising incurred by fruit in the commercial postharvest handling system and determine the effect of injury on papaya fruit ripening and shelf life.
3. Determine the effect of injury on papaya fruit ripening as influenced by fruit stage of ripeness at time of injury.
4. Determine the effect of injury on papaya fruit ripening and shelf life as modified by disinfestation treatments.

Materials and Methods

Papaya fruit, *Carica papaya* cv. Kapoho Solo and Sunset Solo, were obtained from Hilo, Hawaii and Poamoho Experiment Farm on central Oahu, Hawaii, respectively. Kapoho Solo fruit were used in the evaluation of a commercial postharvest handling system while Sunset Solo fruit were used in subsequent experiments. The stage of fruit ripeness used depended on objectives of individual experiments. In most experiments, ten fruit were used for each treatment. Unless otherwise stated, after each treatment, fruit were dipped in Thiabendazole (TBZ, 650 ppm a.i.) for 5 sec. to control fungal decay (Couey and Farias, 1979). Fruit were air dried before ripening at 25°C. Dropping experiments were done by using an apparatus that held the fruit by vacuum cup at the desired orientation and height (Figure 1). Fruit were dropped on its equatorial plane onto a solid steel plate and were caught after one bounce.

Fruit evaluation

Observations depended on the objectives of individual experiments. Fruit were evaluated for the following parameters:

1) Initial and final peel color (iPC and fPC) estimated and expressed as percentage of yellow peel of the whole surface area;
2) Peel color determined objectively using a Minolta Chromameter (CR-110) with a 50 mm head, measured in terms of the brightness (C.I.E. *L* value), the green to red component (C.I.E. *a* value), and the blue to yellow component (C.I.E. *b* value);

3) Flesh color estimated and expressed as percentage of full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh;

4) Firmness expressed in kg; measured with a AccuForce Cadet Force Gage registering the force required to push a 1.5 cm-diameter plunger 2 mm into the flesh;

5) Shrivelling was subjectively estimated on a scale of 0 = no shrivelling, 1 = slight shrivelling, 2 = moderate shrivelling, 3 = severe shrivelling;

6) Peel Green islands (GI) expressed as percentage of fruit surface area affected; severity of GI was subjectively estimated on a scale from 0 = no GI, 1 = light green, 2 = medium green, 3 = dark green;

7) Peel Scald;

8) Internal abnormality (i.e. water-soaked areas, lumpy areas, discolored areas);

9) External abnormality;

10) Disease severity; and

11) Disease incidence was evaluated using 0 = disease absent, 1 = disease present.

Scald, internal and external abnormalities and disease severity were evaluated using the following scale based on one-fifth of the angular transformation from 0^{o} to 90^{o}: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, 6 = 100%. This system was designed for more comfortable visual discrimination with less error in estimation. The raw data was evaluated on the rating, not the percentage (Hills et al., 1980).

Fruit damage in a commercial postharvest handling system

A commercial papaya postharvest handling system on the island of Hawaii was observed twice (September 1989 and 1990) during operation (Figure 2). Fruit damage was determined by removing fruit off the handling system at different points. Fruit were removed at six points:

1) at harvest;
2) upon arrival at the packinghouse when fruits were unloaded by floating in water (before culling);
3) dropped into 4 x 4 ft x 2 ft deep bins (after culling);
4) floated in water out of bin (before waxing);
5) dropped onto packing tables (after waxing); and
6) onto conveyor (after packing in carton boxes).

The last sampling point was added during the second trial. Thirty (30) fruit were removed at each point and divided into three lots. Ten fruits were ripened at 25°C, another lot inoculated with spores and hyphae of *Rhizopus stolonifer* then ripened at 25°C. The remaining 10 fruits were stored at 10°C for two weeks before ripening at 25°C. Fruit were individually wrapped in styrofoam sheets and packed with crumpled newspaper in cardboard boxes for the return to the laboratory in Honolulu by air. In the second trial, fruit were rinsed with tap water after removal from the chlorinated water in the dump tanks. This was done to remove chlorine from the fruit.

Bruising effects

Impact Injury

Fruit were carefully harvested and selected for various stages of ripeness: 5 to 10%, 25 to 30%, and 40 to 50% peel yellowing. Fruit were dropped onto a half-inch thick smooth steel plate from heights that varied from 0 to 100 cm. This experiment was done in three parts, with a different stage of fruit ripeness being done in each part.

Abrasion Injury

Fruit in this series of experiments were carefully harvested and individually wrapped in styrofoam protective sleeves. The protective sleeves were removed before fruit were dropped from a height of 10 cm onto a steel plate covered with sandpaper. Sandpaper was used to cause abrasion injury as it is available in different degrees of grittiness in uniform sheets. The grades of sandpaper initially tested were: 220 mesh - very fine, 150 mesh - fine, 100 mesh - medium, 50 mesh - coarse, and 36 mesh - very coarse. In subsequent experiments, 150 mesh sandpaper was used routinely as it inflicted a more uniform injury in fruit. Fruit at different stages of ripeness (5 to 10%, 10 to 15%, 25 to 30%, and 40 to 50% yellow) were dropped from a height of 10 cm onto steel plate covered with 150 mesh sandpaper. Fruit with 10 to 15% peel yellowing were normally used in other experiments.

Role of latex and abrasion injury

Abrasion injury leads to breaking of papaya skin laticifers and latex exuding onto the peel. Fruit that were not dropped were wiped with recently collected latex, while for fruit that were dropped, the latex was left to dry or washed off immediately or one hour after dropping with copious amounts of tap water.

Duration between dropping and heating

Fruit were heated at 48°C for ~6 hours or until the fruit core temperature (FCT) reached 47.5°C at various times after dropping. Relative humidity was held between 50 to 60% during heating to avoid fruit scald damage. After the heat treatment, the fruit were immediately cooled by a cold water shower until FCTs reached ~30°C (Ca. 45 minutes) then ripened at 25°C. Fruit heating was started 0, 6, 12, 24, 36, and 48 hours after dropping. Heating was initiated in all treatments at the same time.

Fruit waxing and heat

After dropping, fruit were waxed then heated at 48°C for ~6 hours or until FCTs reached 47.5°C then cooled as above. Two waxes were used: FMC-819, a carnauba-based wax used on lemons and FMC-820, a polyethylene paraffin wax (FMC Corp. Riverside CA). A wax: water ratio of 1: 3 was used, resulting in a solution with 2 to 3% solids. In a supplementary experiment, fruit were waxed with FMC-819 (1:3) only either before or after the heat treatment.

Respiration rate and Ethylene production

Impact and abrasion injury

The effects of impact and abrasion injuries on respiration rate and ethylene production of fruit were determined. Eighteen fruits at 10% yellow were used. Fruit were dropped from a height of 10 cm onto a smooth steel plate and onto a steel plate covered with sandpaper. Individual fruit were immediately sealed daily for 1 hour in ~2500 ml containers. The headspace gas was homogenized by using a 10 cc syringe before taking two 1 ml gas samples from each container. Carbon dioxide produced was measured using an infrared CO_2 gas analyzer (Clegg et al., 1978) and ethylene production with a gas chromatograph fitted with an Alumina column and photoionization detector (Bassi and Spencer, 1985).

Multiple drops

Respiration rate and ethylene production of fruit that received 0, 1, 2, 4, and 8 drops was determined. Dropping was done on a smooth steel plate from a height of 10 cm. The same procedure as described above was followed.

Results

Fruit damage in a commercial postharvest handling system

Mechanical injury in papaya fruit taken from different points along the handling system and ripened at 25°C is manifested as green islands (GI). GI are characterized as sunken areas on a ripe yellow fruit that do not degreen. GI in fruit increased as the fruit moved along the handling system (Table 1). The amount of disease-induced internal abnormality decreased as fruit moved along the handling system (Table 1). In fruit that were stored at 10°C for two weeks before ripening at 25°C, no significant difference was seen in GI (Table 3).

Disease incidence and severity decreased in fruit removed from the handling system, with no disease seen in fruit removed from the last two sampling points (Table 1). Inoculating fruit, within hours of removal from the handling system, with *Rhizopus stolonifer* did not significantly affect GI, disease incidence and severity (Table 2). Disease incidence and severity decreased significantly in fruit removed from the handling system then stored at 10°C for two weeks before ripening at 25°C (Table 3).

Fruit taken off the handling system showed GI only in fruit taken from the side but not in fruit taken from the center of the field bin (Figure 3).

Bruising effects

Impact injury

Injury was seen in fruit at different stages of ripeness dropped onto steel plate from different heights (Table 4), however, it did not resemble the injury seen in fruit taken off the postharvest handling system. No definite trend was seen in the external abnormality as drop height was increased within each stage of fruit ripeness. Internal abnormality was only seen in fruit that were 40 to 50% yellow at the time of dropping from 100 cm (Table 5). The abnormality was a mushy, water-soaked area in the mesocarp adjacent to the area of impact (Figure 4).

Dropping fruit from different heights did not significantly affect the ripening of the fruit in terms of fruit firmness, except for fruit that were dropped at 40 to 50% yellow stage (Table 6). Fruit dropped when 40 to 50% yellow softened faster compared to non-dropped fruit at the same stage of ripeness.

Abrasion injury

To simulate abrasion injury fruit were dropped onto various grades of sandpaper on top of a steel plate (Table 7). The injury was similar to that seen in fruit taken off the postharvest handling system; green islands. The severity of GI was significantly different (Table 7). The severity of GI was higher in fruit dropped on finer sandpaper. The difference in appearance between skin injury incurred using fine sandpaper and coarse sandpaper is shown in Figure 5.

Subjective peel color and objective C.I.E. color were used to indicate fruit ripeness. Fruit at different stages of fruit ripeness dropped from 10 cm onto 150 mesh sandpaper softened faster and was significantly different between fruit 5 to 10% and 40 to 50% yellow at the time of dropping (Table 8). The severity of GI was significantly lower in fruit dropped when 40 to 50% yellow (Table 9).

Role of latex and abrasion injury

The removal of exuded latex after dropping onto sandpaper did not significantly affect the severity of GI (Table 10). Wiping or washing the impact zone with tap water did not reduce the severity of GI.

Duration between dropping and heating

Fruit were dropped various times before heating at 48°C. Heating of all fruit was done at one time. Peel color at time of dropping and at time of heating were significantly different (Table 11). No significant difference was seen in final peel color (Table 11). A significant difference was seen in the change of peel color between the time of dropping and time of heating in fruit heated 24, 36 and 48 hours after dropping (Table 12). Heating significantly intensified the severity of GI (Figure 6), except in fruit heated 24 hours after dropping (Table 14).

Fruit waxing and heat

Waxing resulted in significantly firmer fruit (Tables 15 and 17), lower weight loss (Tables 16 and 17), and with a lesser severity of GI (Tables 16 and 17, Figure 7), compared to the unwaxed controls. Fruit waxed with FMC-819 had significantly lower weight loss compared to fruit waxed with FMC-820, hence the former wax was used in a subsequent experiment. Scald injury was seen in fruit that were heated at 48°C for ~6 hours or until FCT reached 47.5°C (Table 18).

Where the time of waxing on fruit bruising was determined, dropping the fruit significantly hastened ripening in terms of final peel color (Table 20). Dropping resulted in GI on the fruit (Table 20). Waxing either before or after the heat treatment did not significantly affect the severity of GI on dropped fruit (Appendix Table 34).

Heating and waxing on fruit ripening

Heating fruit various times after dropping resulted in significantly firmer fruit except for those fruit heated 24 hours after dropping (Table 13). Flesh color changes were not influenced by heating (Table 13). Heating significantly affected the ripening of waxed fruit in terms of final peel color, flesh color and firmness (Tables 15 and 18). Normal peel color and flesh color development of waxed fruit was retarded by heating (Table 18). Heating also resulted in firmer fruit (Table 18). Heating resulted in more shrivelled fruit, retardation of normal flesh color development, firmer fruit and higher weight loss (Table 21). Waxing the fruit before the heat treatment resulted in lower final peel color, flesh color, firmer fruit and lower weight loss compared to fruit waxed after the heat treatment (Table 22).

Respiration rate and Ethylene production

Impact and abrasion injury

Dropping fruit from a height of 10 cm onto a smooth steel plate or a steel plate covered with 150 mesh sandpaper did not significantly increase respiration rate (Figure 8) or ethylene production (Figure 9) during ripening at 25°C.

Multiple drops

Dropping fruit from one to eight times onto a smooth steel plate from a height of 10 cm did not significantly increase the respiration rate (Figure 10) or ethylene production (Figure 11) during ripening at 25°C.

Table 1. Green islands, internal abnormality, disease incidence and severity in papaya fruit taken off different points in the postharvest handling system.[a] Fruit were ripened at 25°C.

Points in the handling system	Green islands[b]	Internal abnormality[c]	Disease incidence[d]	Disease severity[c]
At harvest	7.8 c	0.7 a	0.7 a	1.5 a
Before culling	11.0 c	0.6 a	0.5 a	0.6 b
After culling	18.0 bc	0.3 ab	0.4 ab	0.4 b
Before waxing	33.0 ab	0.1 b	0.1 bc	0.1 b
After waxing	30.0 ab	0 b	0 c	0 b
After packing	40.0 a	0 b	0 c	0 b
Analysis of variance				
Linear	***	***	***	***
Quadratic	ns	ns	ns	*
Cubic	ns	ns	ns	ns
R-Square	0.28***	0.27***	0.35***	0.30***

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % fruit surface area affected.

[c] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

[d] Evaluated using the following scale: 0 = disease absent, 1 = disease present.

*, **, *** Significant at 5%, 1% and 0.1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 2. Green islands, disease incidence and severity of papaya fruit taken off different points in the postharvest handling system.[a] Fruit were inoculated with *Rhizopus stolonifer* then ripened at 25°C.

Points in the handling system	Green islands[b]	Disease incidence[c]	Disease severity[d]
At harvest	5.6 a	0.7 ab	1.9 a
Before culling	9.0 a	0.8 ab	1.9 a
After culling	6.7 a	0.9 a	2.5 a
Before waxing	11.0 a	0.9 a	2.4 a
After waxing	7.0 a	0.4 b	0.9 a
After packing	10.0 a	0.6 ab	1.3 a
Analysis of variance			
Linear	ns	ns	ns
Quadratic	ns	ns	ns
Cubic	ns	ns	ns
R-Square	0.08ns	0.09ns	0.08ns

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % fruit surface area affected.

[c] Evaluated using the following scale: 0 = disease absent, 1 = disease present.

[d] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 3. Green islands, disease incidence and severity in papaya fruit taken off different points in the postharvest handling system.[a] Fruit were stored at 10°C for two weeks then ripened at 25°C.

Points in the handling system	Green islands[b]	Disease incidence[c]	Disease severity[d]
At harvest	10.0 a	1.0 a	3.9 a
Before culling	22.0 a	1.0 a	3.8 a
After culling	38.6 a	1.0 a	2.7 b
Before waxing	14.0 a	0.4 b	0.8 c
After waxing	19.0 a	0 c	0 c
After packing	26.0 a	0 c	0 c
Analysis of variance			
Linear	ns	***	***
Quadratic	ns	ns	ns
Cubic	*	***	*
R-Square	0.11ns	0.78***	0.56***

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % fruit surface area affected.

[c] Evaluated using the following scale: 0 = disease absent, 1 = disease present.

[d] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

*, **, *** Significant at 5%, 1% and 0.1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 4. External abnormality of papaya fruit at different stages of ripeness (% yellow) dropped onto a smooth steel plate from different heights.[a] Fruit were ripened at 25°C.

Drop Height (cm)	External abnormality[b]					
	Extabn_o[c]			Extabn_e[d]		
	5-10%Y	25-30%Y	40-50%Y	5-10%Y	25-30%Y	40-50%Y
0	1.2 a	0.9 a	0.7 a	---	---	---
10	0.5 b	1.2 a	1.2 a	0 c	0.1 a	0.1 b
25	1.2 a	1.2 a	0.8 a	0.5 ab	0.4 a	0.2 ab
50	0.6 b	0.9 a	1.1 a	0.1 c	0.3 a	0.2 ab
75	0.6 b	1.0 a	0.7 a	0.2 bc	0.2 a	0.1 b
100	1.2 a	1.0 a	1.3 a	0.6 a	0.1 a	0.6 a
Analysis of variance	**	ns	ns	**	ns	*

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

[c] Extabn_o is the external abnormality evaluated from the whole fruit.

[d] Extabn_e is the external abnormality evaluated from the equatorial area on which the fruit was dropped.

*, ** Significant at 5% and 1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 5. Internal abnormality of papaya fruit at different stages of ripeness (% yellow) dropped onto a smooth steel plate from different heights.[a] Fruit were ripened at 25°C.

Drop Height	Internal abnormality[b]		
(cm)	5 to 10% yellow	25 to 30% yellow	40 to 50% yellow
0	0 a	0 a	0 b
10	0 a	0 a	0 b
25	0 a	0 a	0 b
50	0 a	0 a	0 b
75	0 a	0 a	0 b
100	0 a	0 a	0.6 a
Analysis of variance	***	***	***

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

*** Significant at 0.1% level.

Table 6. Firmness of fruit at different stages of ripeness (% yellow) dropped onto a smooth steel plate from different heights.[a] Fruit were ripened at 25°C.

Drop Height	Firmness (kg)		
(cm)	5 to 10% yellow	25 to 30% yellow	40 to 50% yellow
0	3.3 ab	3.4 a	5.2 a
10	5.2 ab	5.2 a	4.0 b
25	2.8 b	3.0 a	4.0 b
50	5.7 ab	3.7 a	3.9 b
75	7.9 a	3.3 a	3.8 b
100	4.8 ab	3.1 a	3.2 b
Analysis of variance	ns	ns	**

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

** Significant at 1% level.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 7. Severity of green islands in 10 to 15% yellow papaya fruit dropped onto a smooth steel plate covered with different grades of sandpaper from a height of 10 cm.[a] Fruit were ripened at 25°C.

Grade of sandpaper	Severity of green islands[b]
Control (TBZ dip only)	0 c
mesh 220 (very fine)	1.8 a
mesh 150	2.0 a
mesh 100	1.4 b
mesh 50	1.4 b
mesh 36 (very coarse)	1.2 b
Analysis of variance	***

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means followed by the same letter are not significantly different at the 5% level (n=10).

[b] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

*** Significant at 0.1% level.

Table 8. Initial and final peel color, C.I.E. L, a, b values and firmness in papaya fruit at different stages of ripeness dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were ripened at 25°C.

Peel color	initial Peel Color[b]	final Peel Color[b]	C.I.E. L^c	C.I.E. a^c	C.I.E. b^c	Firmness (kg)
5 to 10%	6.0 d	88.5 b	46.46 b	-17.20 c	29.16 b	3.9 a
10 to 15%	11.0 c	89.0 b	43.53 b	-15.04 b	26.12 b	3.4 ab
25 to 30%	28.5 b	100.0 a	44.42 b	-13.59 ab	27.87 b	2.3 ab
40 to 50%	45.0 a	100.0 a	53.89 a	-12.10 a	40.22 a	1.7 b
Analysis of variance	***	**	***	***	***	ns

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of the whole surface area.

[c] Determined objectively using a Minolta Chromameter (CR-110) with a 50 mm head. C.I.E. L measures brightness; C.I.E. a measures green to red component; C.I.E. b measures blue to yellow component.

, * Significant at 1% and 0.1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 9. Severity of green islands in papaya fruit at different stages of fruit ripeness dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were ripened at 25°C.

Peel color	Severity of green islands[b]
5 to 10%	2.5 a
10 to 15%	2.1 ab
25 to 30%	1.8 ab
40 to 50%	1.6 b
Analysis of variance	ns

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means followed by the same letter are not significantly different at the 5% level (n=10).

[b] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 10. Effect of latex on the severity of green islands on papaya fruit.[a] Fruit were dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm then allowed to ripen at 25°C.

Treatment	Severity of green islands[b]
Control - no drop	0 b
No drop - wipe with latex	0 b
Drop - leave latex on	1.8 a
Drop - wash off latex immediately	1.9 a
Drop - wash off latex 1 hour later	2.0 a
Analysis of variance	
Handling	***
Latex	ns

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

*** Significant at 0.1% level.

ns Nonsignificant at 5%, 1% or 0.1% level.

Table 11. Peel color of papaya fruit heated different times after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until the FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Treatment	iPC[b]	hPC[c]	fPC[d]
Control (dropped without heat)	19.5 a	---	90.0 a
0 hr (dropped, immediately heated)	15.0 b	15.0 cd	77.0 a
6.0 hrs	18.0 ab	18.0 abc	79.0 a
12.0 hrs	11.0 c	13.5 d	82.0 a
24.0 hrs	11.5 c	16.5 bcd	79.0 a
36.0 hrs	11.5 c	21.5 a	81.0 a
48.0 hrs	11.0 c	20.0 ab	80.0 a
Analysis of variance			
Linear	***	**	ns
Quadratic	ns	ns	ns
Cubic	ns	ns	ns
R-Square	0.37***	0.15*	0.08ns

[a] Peel color was expressed as % yellow peel of the whole surface area. Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Initial peel color taken at the time of dropping.

[c] Peel color taken at the time of heating.

[d] Final peel color taken at the time of fruit evaluation.

*, **, *** Significant at 5%, 1% and 0.1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 12. Change in peel color between dropping and heating in papaya fruit heated at different times after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for~ 6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Time peel color was measured	Peel color[b]					
	Number of hours between dropping and heating					
	0 hr	6.0 hrs	12.0 hrs	24.0 hrs	36.0 hrs	48.0 hrs
At dropping	15.0 a	18.0 a	11.0 a	11.5 b	11.5 b	11.0 b
At heating	15.0 a	18.0 a	13.5 a	16.5 a	21.5 a	20.0 a
Analysis of variance	ns	ns	ns	**	***	***

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of whole surface area.

, * Significant at 1% and 0.1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 13. Firmness and flesh color of papaya fruit heated different times after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until the FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Treatment	Firmness (kg)	Flesh color[b]
Control (dropped without heat)	3.4 d	98.0 a
0 hr (dropped, immediately heated)	14.9 a	86.0 b
6.0 hrs	8.6 bc	86.0 b
12.0 hrs	10.1 bc	91.0 ab
24.0 hrs	7.1 cd	86.0 b
36.0 hrs	11.6 ab	92.0 ab
48.0 hrs	11.3 ab	90.0 ab
Analysis of variance		
Linear	ns	ns
Quadratic	ns	*
Cubic	**	*
R-Square	0.19**	0.14*

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

*, ** Significant at 5% and 1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 14. Severity of green islands in papaya fruit heated different times after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Treatment	Severity of green islands[b]
Control (dropped without heat)	1.3 b
0 hr (dropped, immediately heated)	2.2 a
6.0 hrs	2.3 a
12.0 hrs	2.5 a
24.0 hrs	1.6 b
36.0 hrs	2.5 a
48.0 hrs	2.2 a
Analysis of variance	
Linear	*
Quadratic	*
Cubic	**
R-Square	0.22***

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

*, **, *** Significant at 5%, 1% and 0.1% level, respectively.

Table 15. Final peel color, firmness and flesh color in waxed and heated papaya fruit dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm. Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Handling	Wax	Temperature (°C)	final Peel Color[a]	Firmness (kg)	Flesh color[b]
No drop	none	25	75.6	3.7	97.2
		47.5	76.7	7.3	92.8
	FMC-819	25	82.8	5.2	99.4
		47.5	80.6	13.2	92.2
	FMC-820	25	88.3	4.5	97.8
		47.5	72.8	18.8	81.1
Drop	none	25	79.4	3.7	97.2
		47.5	80.6	8.2	95.6
	FMC-819	25	83.3	5.0	95.0
		47.5	72.2	14.8	81.1
	FMC-820	25	85.6	5.1	97.8
		47.5	83.3	8.7	95.6
Analysis of variance					
Wax			ns	***	ns
Handling			ns	ns	ns
Temperature			*	***	***
Wax x Handling			ns	**	***
Wax x Temperature			ns	**	ns
Handling x Temperature			ns	ns	ns
Wax x Handling x Temperature			ns	***	*

[a] Expressed as % yellow peel of whole surface area.

[b] Expressed as % full-ripened color with normal color development (0 to 10%) and overripe scale (101 to 140%) with water-soaked flesh.

Table 15. (Continued) Final peel color, firmness and flesh color in waxed and heated papaya fruit dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm. Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

*, **, *** Significant at 5%, 1% and 0.1% level, respectively.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 16. Severity of green islands, scald, % weight loss and shrivelling of waxed and heated papaya fruit dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm. Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Handling	Wax	Temperature (°C)	Severity of green islands[a]	Scald[b]	% Weight loss	Shrivelling[c]
No drop	none	25	0	0	7.5	1.8
		47.5	0	2.9	9.0	2.2
	FMC-819	25	0	0	3.2	0
		47.5	0	3.0	3.1	0
	FMC-820	25	0	0	3.2	0
		47.5	0	2.1	4.0	0
Drop	none	25	2.4	0	7.6	1.7
		47.5	3.0	3.7	9.3	2.6
	FMC-819	25	1.6	0	3.6	0.2
		47.5	1.6	3.4	3.4	0
	FMC-820	25	1.0	0	3.4	0
		47.5	1.4	3.3	4.9	0.2
Analysis of variance						
Wax			***	*	***	***
Handling			***	***	*	ns
Temperature			ns	***	***	**
Wax x Handling			***	ns	ns	ns
Wax x Temperature			ns	*	***	***
Handling x Temperature			ns	***	ns	ns
Wax x Handling x Temperature			ns	ns	ns	ns

[a] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

Table 16. (Continued) Severity of green islands, scald, % weight loss and shrivelling of waxed and heated papaya fruit dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm. Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

[b] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

[c] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

*, **, ***, ns Significant at 5%, 1% and 0.1% level and nonsignificant, respectively.

Table 17. Wax effect on shrivelling, firmness, severity of green islands and % weight loss in papaya fruit waxed and heated after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Wax	Shrivelling[b]	Firmness (kg)	Severity of green islands[c]	% Weight loss
none	2.1 a	5.7 b	1.4 a	8.3 a
FMC-819	0.1 b	9.5 a	0.8 b	3.3 c
FMC-820	0.1 b	9.3 a	0.6 b	3.9 b
Analysis of variance	***	**	*	***

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=36).

[b] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[c] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

*, **, *** Significant at 5%, 1% and 0.1% level, respectively.

Table 18. Temperature effect on final peel color, flesh color, firmness and scald in papaya fruit waxed and heated after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Temperature (°C)	final Peel Color[b]	Flesh color[c]	Firmness (kg)	Scald[d]
25	82.5 a	97.4 a	4.5 b	0 b
47.5	77.7 b	89.7 b	11.8 a	3.1 a
Analysis of variance	ns	***	***	***

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=54).

[b] Expressed as % yellow peel of whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 10%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

*** Significant at 0.1% level.

ns Nonsignificant at either 5%, 1% or 0.1% level.

Table 19. Handling effect on severity of green islands in papaya fruit waxed and heated after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Handling	Severity of green islands[b]
No drop	0 b
Drop	1.8 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=54).

[b] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

Table 20. Handling effect on final peel color and severity of green islands in papaya fruit waxed before and after heating.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Handling	final Peel Color[b]	Severity of green islands[c]
No drop	70.4 b	0 b
Drop	78.0 a	1.3 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=50).

[b] Expressed as % yellow peel of whole surface area.

[c] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

Table 21. Effect of temperature on shrivelling, flesh color, firmness and % weight loss in papaya fruit waxed before or after heating.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Temperature (°C)	Shrivelling[b]	Flesh color[c]	Firmness (kg)	%Weight loss
25	0 b	92.0 a	6.7 b	2.6 b
47.5	0.2 a	82.5 b	14.6 a	3.2 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=50).

[b] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[c] Expressed as % full-ripened color with normal color development (0 to 10%) and overripe scale (101 to 140%) with water-soaked flesh.

Table 22. Time of waxing effect on final peel color, flesh color, firmness and % weight loss in papaya fruit waxed before or after heating.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Time of waxing	final Peel Color[b]	Flesh color[c]	Firmness (kg)	%Weight loss
waxed before heating	69.5 b	80.5 b	19.3 a	1.7 b
waxed after heating	83.0 a	87.5 a	8.1 b	2.6a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=50).

[b] Expressed as % yellow peel of whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 10%) and overripe scale (101 to 140%) with water-soaked flesh.

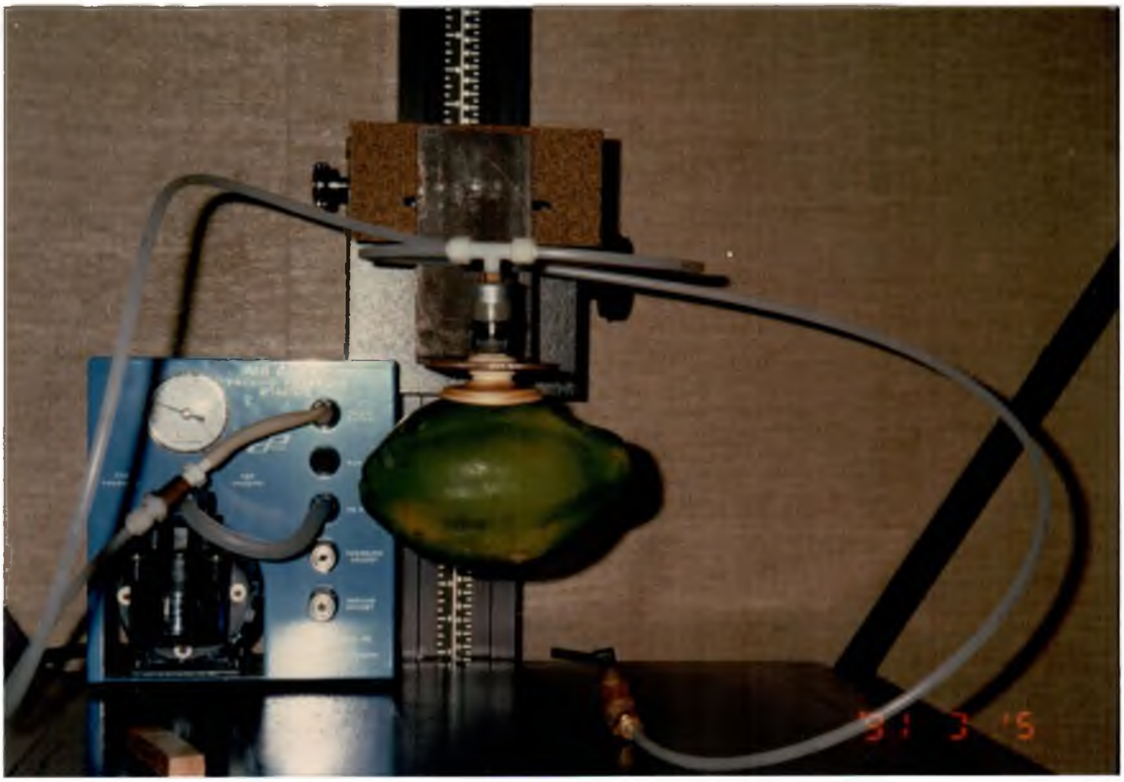


Figure 1. Apparatus used to drop papaya fruit at a certain orientation and height.

Harvested ---degree of yellowing < 25%
---min. 11.5% TSS
---absence of defects

Placed in field bin (4'x 4'x 2')

Transported to packing shed

Unload by floating in water ---washed

Sorted for defects and damage

Placed into bin (4'x 4'x 2')

Hot water treated for disinfestation ---(30', 42°C) + (20', 49°C)

Cold shower for 30' with 20°C water

Floated out of bin

Elevated to waxing station

Dryer

Visual inspection + culled

Onto weighing belt
Sometime sorted electronically for color (other packing plants)

Drop onto packing tables

Hand packed into cartons

Onto conveyor

Visual inspection

Treated with fungicide (TBZ)

Carton sealed

Placed onto pallet

Moved to cool room (10°C)

Shipping container

Figure 2. Flowchart of a commercial papaya postharvest handling system.

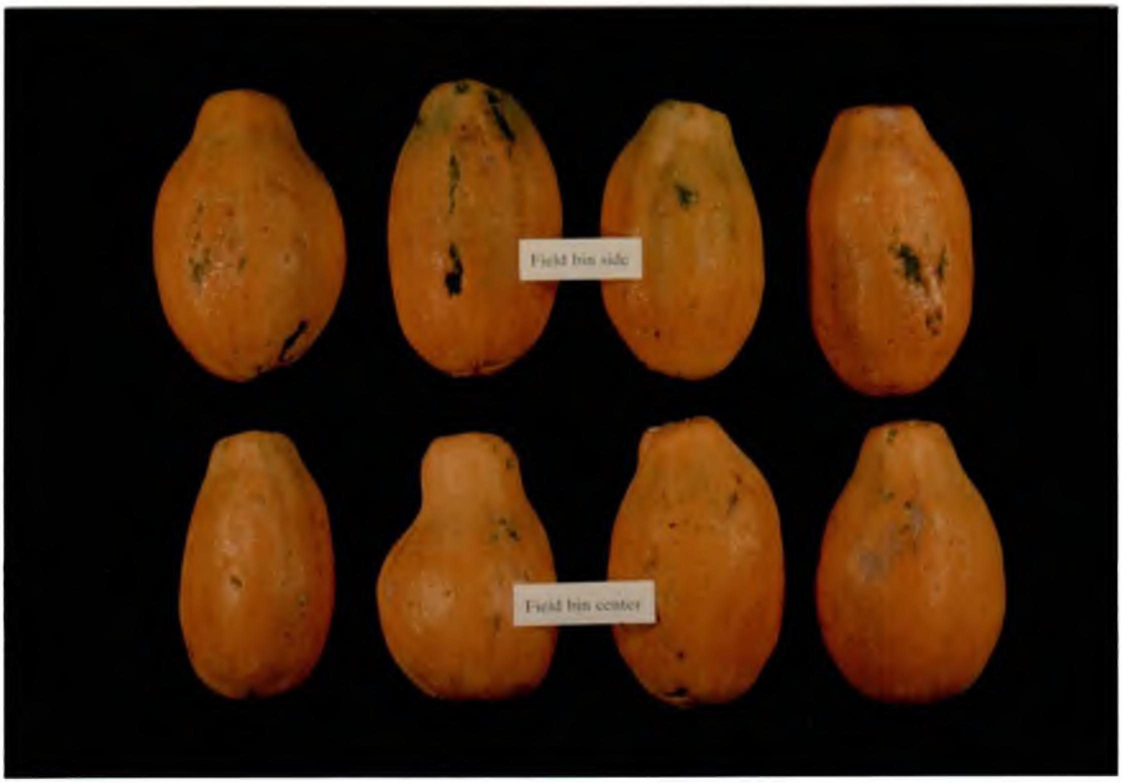


Figure 3. Papaya fruit taken from the side and center of the field bin after culling.

Figure 4. Internal abnormality seen in 40 to 50% yellow fruit dropped onto a smooth steel plate from 100 cm. Fruit were ripened at 25°C. Injury was manifested as water-soaked tissue adjacent to the point of impact.

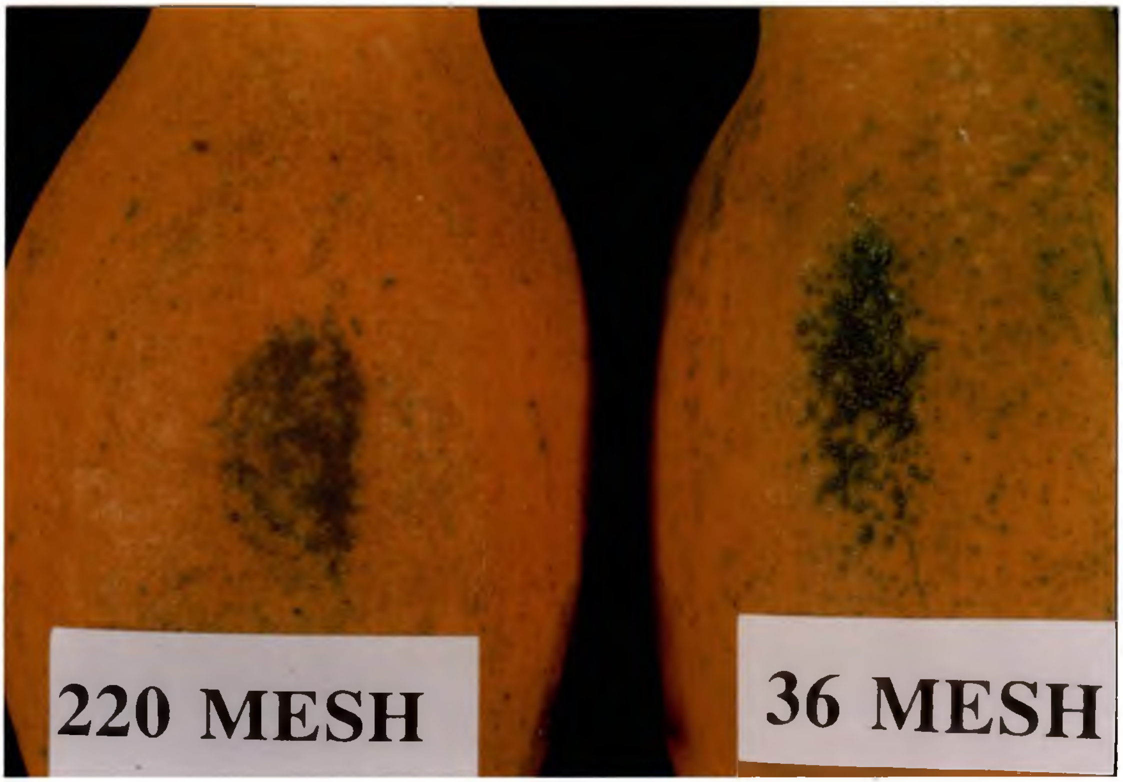
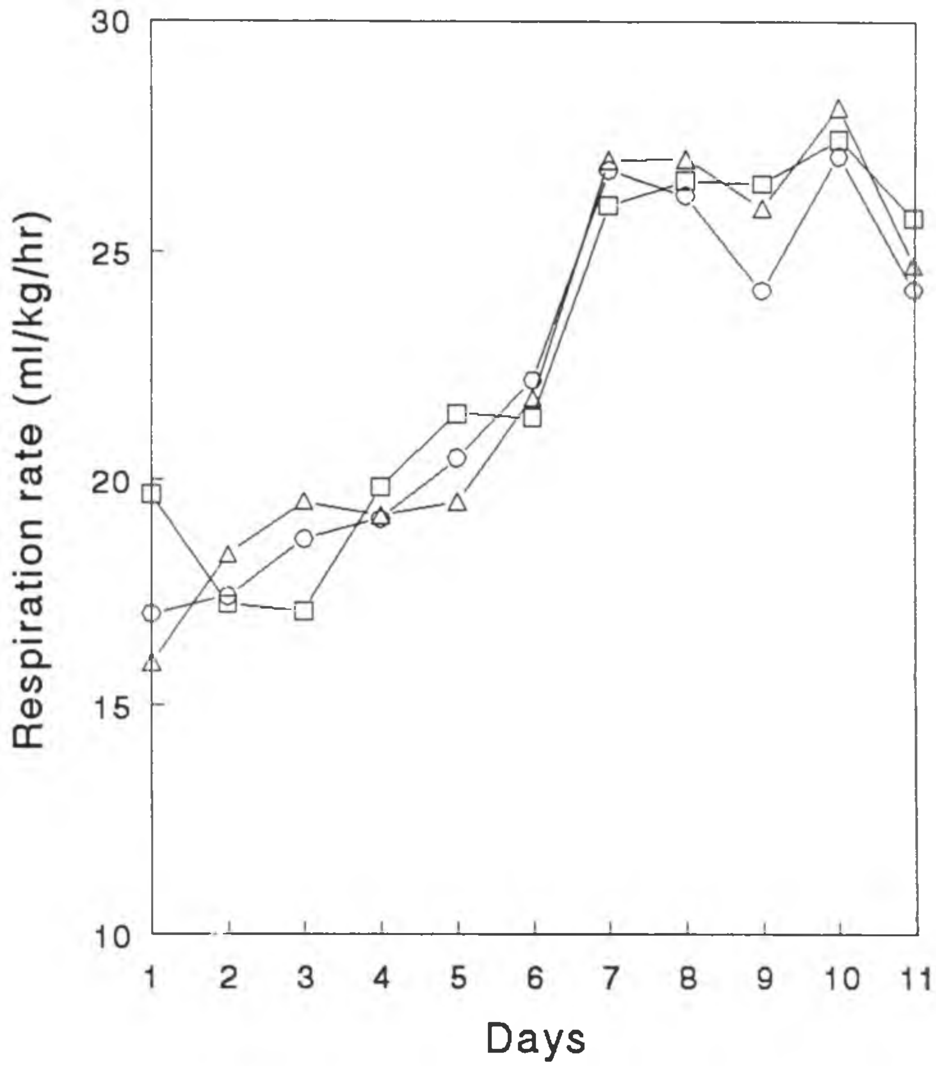


Figure 5. Injury seen in papaya fruit dropped onto a smooth steel plate covered with fine (220 mesh) and coarse (36 mesh) sandpaper from a height of 10 cm. Fruit were ripened at 25°C. Severity of green islands was greater in fruit dropped on fine sandpaper than on coarse sandpaper because of more skin penetration per unit area in fruit dropped on fine sandpaper.

Figure 6. Green islands in heated (left) and unheated (right) papaya fruit. Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C. Heating aggravated the severity of green islands.

Figure 7. Green islands in waxed (left) and unwaxed (right) papaya fruit. Fruit were waxed then heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C. Waxing alleviated the severity of green islands.

Figure 8. Effect of dropping on different surfaces (□ Control, △ Steel plate, ○ Sandpaper) on respiration rate of papaya fruit. Fruit were dropped from a height of 10 cm and ripened at 25°C. Each point is a mean of 5 fruit.



30
25
20
15
10
Respiration rate (ml/kg/hr)
1
2
3
4
5
6
7
8
9
10
11
Days

Figure 9. Effect of dropping on different surfaces (□ Control, △ Steel plate, ○ Sandpaper) on ethylene production of papaya fruit. Fruit were dropped from a height of 10 cm and ripened at 25°C. Each point is a mean of 5 fruit.

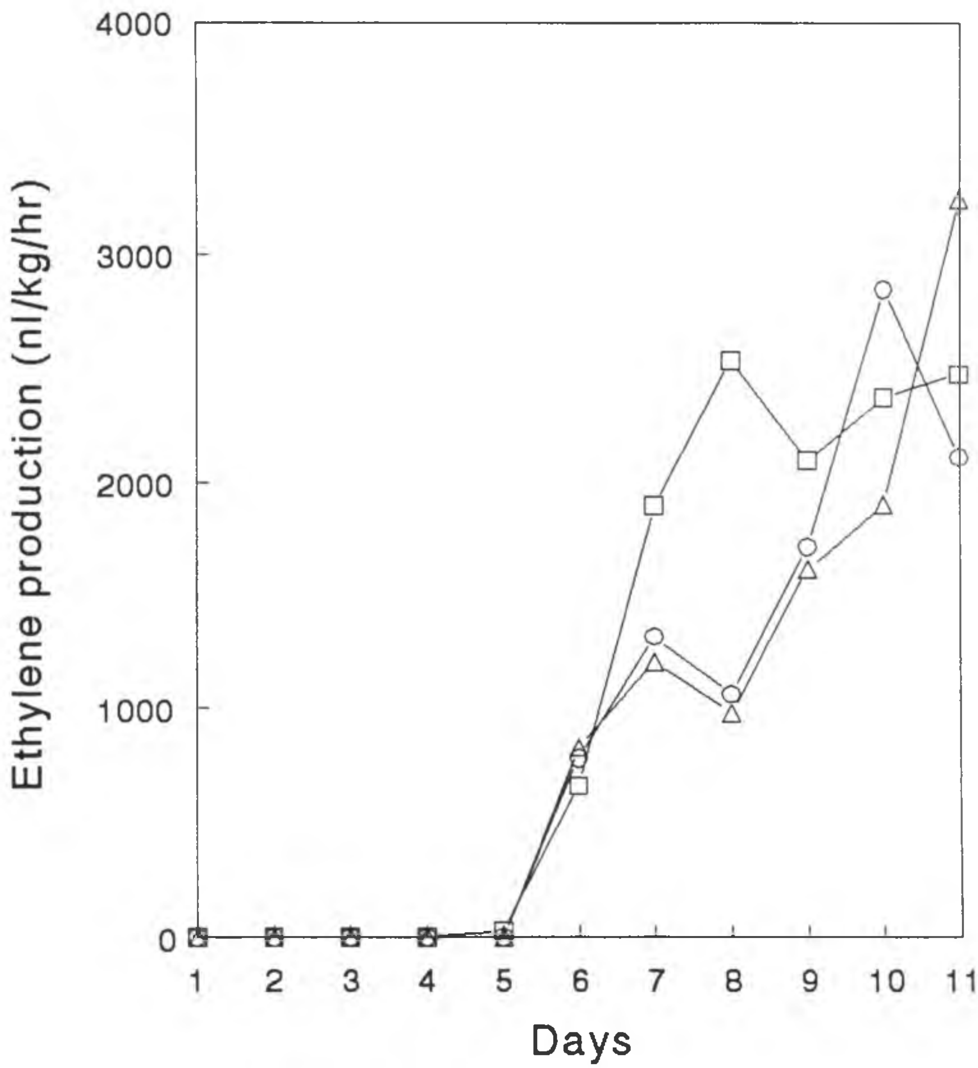
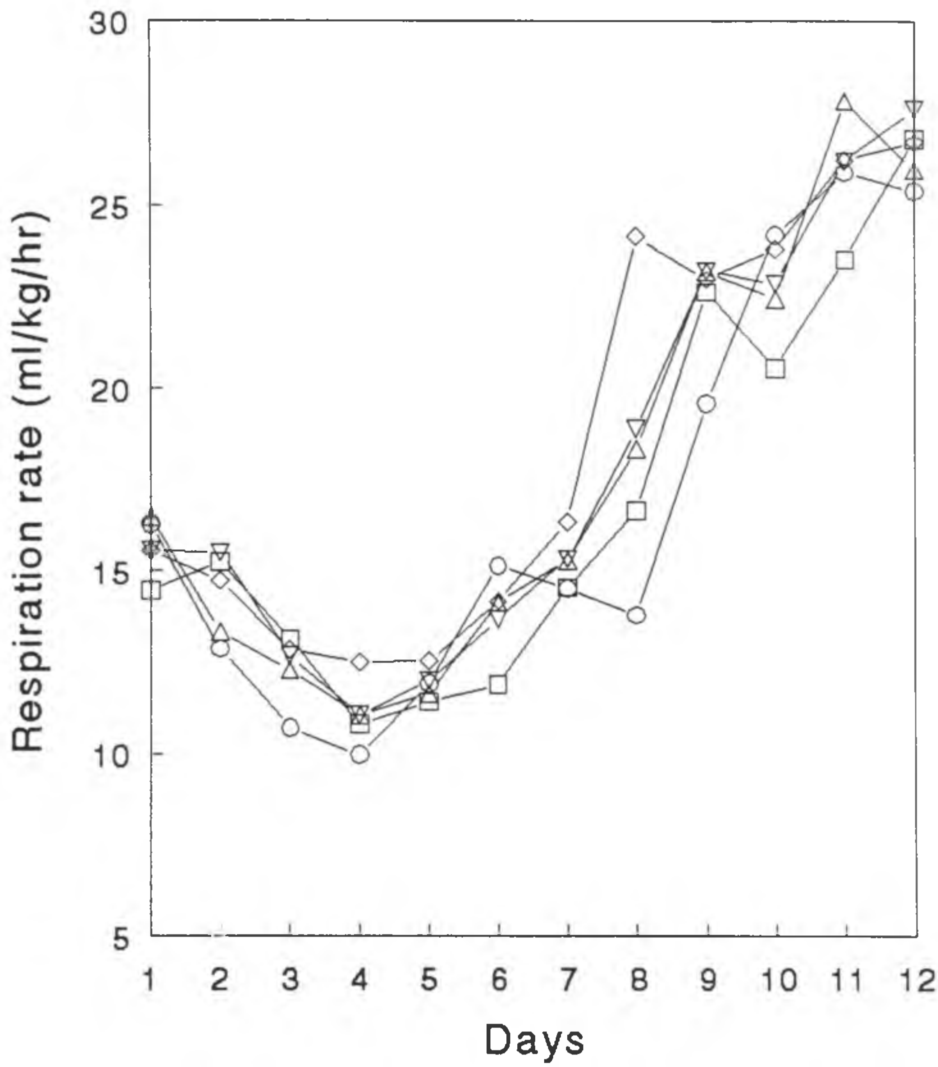
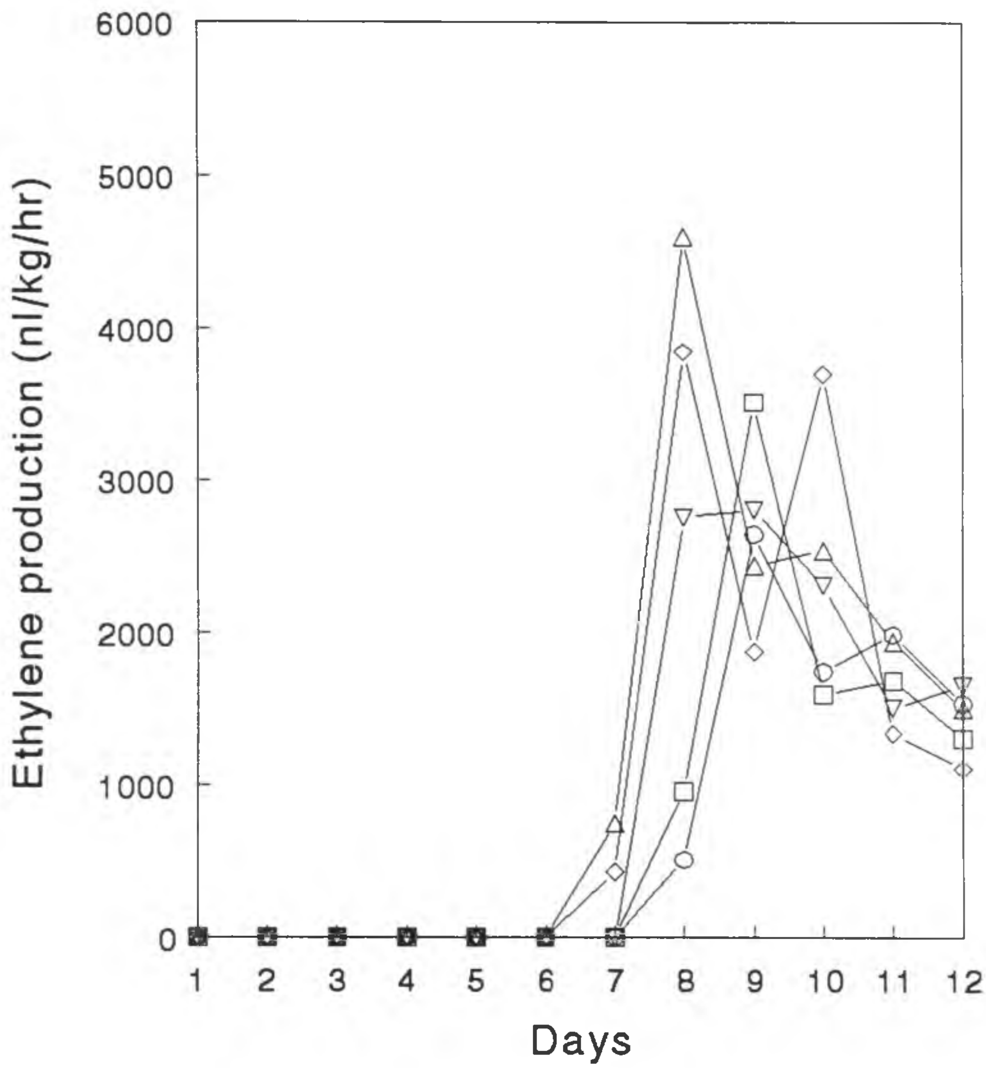

4000
3000
2000
1000
0
Ethylene production (nl/kg/hr)
1
2
3
4
5
6
7
8
9
10
11
Days

Figure 10. Effect of □ 0 drop, △ 1 drop, ○ 2 drops, ▽ 4 drops, ◇ 8 drops on respiration rate of papaya fruit. Fruit were dropped from a height of 10 cm and ripened at 25°C. Each point is a mean of 4 fruit.



30
25
20
15
10
5
Respiration rate (ml/kg/hr)
1
2
3
4
5
6
7
8
9
10
11
12
Days

Figure 11. Effect of □ 0 drop, △ 1 drop, ○ 2 drops, ▽ 4 drops, ◇ 8 drops on ethylene production of papaya fruit. Fruit were dropped from a height of 10 cm and ripened at 25°C. Each point is a mean of 4 fruit.


6000
5000
4000
3000
2000
1000
0
Ethylene production (nl/kg/hr)
1
2
3
4
5
6
7
8
9
10
11
12
Days

Discussion

Capellini and his co-workers (1988) reported that papaya shipments arriving at the New York market had several disorders that included bruise damage and sunken discoloration. For the period of 1972 to 1985, bruise damage and sunken discoloration is reported in 14.8% and 6.7%, respectively, of the shipments inspected. In the present study, mechanical injury was evaluated as green islands (GI) that we believed to be what Capellini et al. (1988) refer to as bruise damage and sunken discoloration. GI in fruits increased as fruits moved along the postharvest handling system (Table 1) when the fruit were allowed to ripen at 25°C. Fruit damage increased as fruit moved along the handling chain. This increase could indicate cumulative injury with each impact or more damage occurs at certain points in the handling chain. 'Golden Delicious' apples taken off packing lines show impact bruise, cut and puncture damage that is cumulative (Brown, et al., 1989). Damage increases in each of the handling operations between harvesting and retailing. Similarly, in a citrus packing line, injury detected by using a dilute solution of 2,3,5-triphenyl-tetrazolium chloride to outline each lesion in red, increases as fruits moved from one handling operation to another (Eaks, 1961).

A higher GI was seen between point 3 (After culling) and point 6 (After packing) (Table 1). Timm and Brown (1989, 1991) using an instrumented sphere (IS) on the same packing line at the same time showed that samples taken for this experiment recorded the highest impacts at the following transfer points:

Culling line: 1) roll conveyor after the culling station;

2) lowerator into bin;

Packing line: 3) transfer belt;

4) belt to brusher and

5) onto packing table.

Transfer point 2 (lowerator into bin) corresponds to point 3 (After culling) in the present study, where there was high GI. At this point, fruit were lowered into the bin by holding the fruit between a pair of looped belts. A contact sensor was used to control the filler head so as to keep it just above the surface of the fruit already present in the bin. To avoid pyramid piling, the lowerator automatically travelled back and forth in the bin to spread the fruit. Fruit to fruit impact was reduced by using a padded horizontal plate under the lowerator outlet. This padded plate deflected the fruit dropping from the lowerator belts so that they did not drop directly on top of fruit already present in the bin. Fruit hitting the bin sides or bottom probably were the cause of the hard impacts measuring from 60 to 70 g's. Hard impacts in the range of 50 to 100 g's were thought to cause the GI. Low level impacts were recorded against fruit. The only other transfer point that corresponds to a sampling point in the present study is the transfer to the packing table. At this point, fruit dropped 10 cm onto the flat side of a steel angle iron, then about 2.5 cm onto the padded surface of a rotary packing table. Hard impacts occurred when the table was nearly empty and padding over the angle iron was missing (Timm and Brown, 1989). Low level impacts were against fruit accumulated at the outlet. Timm and Brown (1989) results suggest that the GI could have been caused by the hard impacts the fruits were experiencing in certain points in the handling system. In the present study, it was observed that fruits from the side of the field bin had more GI than fruits taken from the center of the field bin; difference in GI was significant only at the 10% level. The nonsignificance at a lower significance level might have been due to the fact that fruits were taken only after two drops into the bin---at harvest and after culling. There would have been mixing of the fruits between the two drops into the bin, thus fruits that came in contact with the sides of the field bin while still in the field can be the same fruits in the center of the bin after the second drop. This suggests that the GI was caused by abrasion damage by contact against the bin wall and not impact injury. Fruits roll when put into the field bins. This rotation of fruit causes linear displacement of one surface (fruit skin) in relation to another surface (field bin side), thus causing removal of skin material onto wood. The side of the field bins were made of plywood that was not always smooth and became rougher with use and age due to fiber splitting and damage. Lemons taken off a packing line have surface lesions due to abrasion damage when fruits came in contact with rough surfaces of boxes and equipment (Eaks, 1961). This contrasts with impact, vibration and excessive conveyor speeds contributing to fruit damage in oranges (Eaks, 1961) and 'Golden Delicious' apples (Brown et al., 1989).

Disease incidence and severity of fruits decreased in fruits taken further along the handling system regardless if stored or not (Tables 1 and 3). This decrease indicates that the hot water dip used to disinfest the fruits of fruit fly was effective in controlling/minimizing disease and that the TBZ incorporated in the wax was effective to control disease (Couey and Farias, 1979). Disease was more severe in fruits that were stored at 10°C for two weeks compared to unstored fruits. This is to be expected since conditions during storage are favorable for disease development.

Rhizopus stolonifer is unable to penetrate papaya fruit cuticle (Alvarez and Nishijima, 1987) due to the absence of cutinase. Hence, a break in the cuticle caused by injury is required for entry and disease initiation. Inoculating the fruits with *Rhizopus stolonifer* was therefore considered as a measure of fruit damage seen in the handling system. Neither significant differences nor definite trends were seen in inoculated fruits in terms of GI, disease incidence and severity. These results indicate that the use of a pathogen to measure mechanical damage on a postharvest handling system was not effective. This may be due to either the use of an ineffective inoculum or the storage condition immediately after injury and inoculation were not optimum. Rinsing fruits with water after coming out of the chlorinated wash tanks to remove chlorine also did not alter disease incidence or severity.

Damage seen in fruits taken from the postharvest handling system was duplicated by dropping fruits onto a smooth steel plate. Injury was seen in fruit dropped from different heights (Table 4), however, the injury was not similar to the fruit injury, manifested as GI, seen in fruits taken off the handling system. External injury due to impact on the smooth steel plate was minor with the fruit skin not apparently being broken. Internal abnormality was seen only in 40 to 50% yellow fruits dropped from a height of 100 cm (Table 5). This injury was manifested as water-soaked tissue adjacent to the point of impact. This suggests that mature green papaya fruits were very elastic and can withstand impact damage up to a certain stage of ripeness. There is greater than three-fold reduction in the modulus of elasticity in Malaysian papaya from the mature to the overripe stage (Zohadie, 1982). Since elasticity is the capacity of the material for taking elastic or recoverable deformation, the results suggest that the resistance to bruising and damage is lowered considerably as the fruit matures. Similar results were reported for 'Babygold Five' peaches where the modulus of elasticity decreased with increasing fruit maturity (measured as degree-day-sunshine-hours) (Genge et al., 1977). Furthermore, more mature 'Red Globe' peaches were more susceptible to bruising and had larger bruise volumes than the less mature ones (Hung and Prussia, 1989). Fruit ripening, measured as change in fruit firmness, was not significantly affected in dropped fruit (Table 6), except for fruits that were dropped when more than 40 to 50% yellow.

Dropping onto sandpaper was done to simulate abrasion injury. Sandpaper was used because the paper is available in uniform sheets with narrowly defined particle sizes. This uniformity allowed injury to be readily duplicated. Injury was seen in all fruits dropped onto all grades of sandpaper (220 to 36 mesh). This injury was similar to the symptoms seen in fruits taken off the handling system. The GI expressed as percentage of fruit area affected was not significantly different with all grades of sandpaper tested (data not shown), since the drop height was controlled . Difference noted in injury area may possibly be due to the impacted area of the fruit being flatter or rounder. The severity of GI significantly increased (Table 7) as the sandpaper mesh size increased, finer sandpaper giving the greatest severity of GI.

The abrasion damage on fruit dropped onto fine sandpaper would have more skin penetration per unit area compared to a fruit dropped on coarse sandpaper (Figure 5), hence the higher severity of GI.

The severity of GI was significantly lower when dropped at 40 to 50% yellow (Table 9) as measured subjectively by peel color at the time of dropping (Table 8) and the C.I.E. *L*, *a* and *b* values of the impact area. Fruits that were less green (higher C.I.E. *a* values) and more yellow (higher C.I.E. *b* values) at time of dropping had a lower severity of GI after ripening at 25°C (Tables 8 and 9). Total carotenoids in the outer cell layers of papaya fruit increases from the immature green stage (3.4 ug/cm^2) to the dead green stage (14.2 ug/cm^2) and upon further ripening, concentrations vary, declining when the fruit reaches the 3/4 ripe stage (8.1 ug/cm^2) (Sanxter, 1989). A maximal level of total chlorophylls (62.4 ug/cm^2) is found in the dead green stage and as ripening progresses, chlorophylls in the adaxial-equatorial skin layers decline. Mature green and 1/4 ripe fruit contains approximately equal amounts of chlorophylls (41.0 and 41.8 ug/cm^2, respectively). Three-quarter ripe fruit on the average contains less chlorophylls (10.2 ug/cm^2) than fruit at the immature stage (15.8 ug/cm^2). These findings explain the lower severity of GI in fruits that were at an advanced stage of ripeness at the time of dropping. Fruit with less chlorophyll in the peel or with active chlorophyll degradation at the time of dropping were not as suceptible compared to green fruits.

Generally, less latex was exuded from the peel when the skin laticifers are broken in riper fruit compared to greener fruits (Becker, 1958). No latex was obtained from fully ripe fruits (Skelton, 1969). Latex exudation does not seem to be one of the factors affecting the severity of GI (Table 10). However, latex released from ruptured laticifers under the epidermis could play a role in the development of GI.

Heating at a certain temperature adversely affects fruit ripening (Maxie et al., 1974; Akamine, 1977; Chan et al., 1981; Yoshida et al., 1984; Paull and Chen, 1990). The same is true in the present study where fruit firmness was significantly affected by heating fruits at 48°C for ~6 hours or until FCT reached 47.5°C (Table 13). Heating resulted in significantly firmer fruits except for those fruits heated 24 hours after dropping. When heated fruits were cut open, no hard lumps were seen in the mesocarp, however, the pulp had a rubbery texture. This was one of the observations made by Akamine (1977) when papaya fruits were exposed to temperatures above 32.2°C. Paull and Chen (1990) reported that mesocarp softening during papaya ripening was impaired by heating at 42°C for 30 minutes followed by 49°C for 70 minutes. Firmer fruits might have resulted from several factors: 1) failure to produce adequate ethylene for papaya ripening (Maxie et al., 1974); 2) a decrease in sensitivity in response to ethylene (Maxie et al., 1974); or 3) the damage of the polygalacturonase (PGase) synthesis system (Chan et al., 1981; Yoshida et al., 1984). Normal peel color and flesh color development in waxed and heated fruits were retarded by heating (Table 18). The heat treatment must have suppressed ethylene production by the fruit (Chan, 1986) and therefore did not normally trigger chlorophyll breakdown and carotenoid synthesis. 'Sunset' papayas, which is a red-fleshed cultivar ripened at 32.5°C had poor red color development (An, 1988).

Heating aggravated the severity of GI regardless of whether the fruits were heated immediately after dropping or several hours later (Figure 5, Table 14). It is possible that heating the fruits further suppressed the production of ethylene (Maxie et al., 1974), in the injured cells of the GI area. This might inhibit chlorophyll breakdown in the injured area. However, the severity of GI was alleviated in fruits heated 24 hours after dropping (Table 14) and this was also observed in previous trials (data not shown). The reason for this is unknown. The unusual behavior of fruits (in terms of firmness and severity of GI) heated 24 hours after dropping might be explained by the fact that there was a significant difference in the change of peel color between dropping and heating the fruits (Table 12). It was in fruits heated 24 hours after dropping that the significant change in peel color started.

Waxing papaya fruits reduces weight loss by 14 to 40% (Paull and Chen, 1989). The alleviation of the severity of GI by fruit waxing was possibly due to reduced weight loss. Papaya fruit peel from a GI area had a lower fresh weight percentage than peel from a non-injured area with the same surface area. Waxing the fruits either before or after the heat treatment did not significantly affect the severity of GI.

Unlike most fruits (Marks and Varner, 1957; Eaks, 1961; McGlasson and Pratt, 1964; Robitaille and Janick, 1973; MacLeod et al., 1976; Hyodo, 1978; Hoffman and Yang, 1982; Massey et al., 1982; Parker et al., 1984; Burton and Schulte-Pason, 1987), impact and abrasion damage in papaya fruits did not significantly increase respiration rate (Figure 7) or ethylene production (Figure 8) during ripening. Increasing the number of impact drops also did not significantly increase the respiration rate (Figure 9) or ethylene production (Figure 10) of fruits during ripening. One possible explanation was that the increase in respiration rate and ethylene production by the damaged area was too small to be measured against the overall fruit respiration rate and ethylene production. Another possible explanation was that impact force was spread throughout the whole fruit and thus not exceeding cell burst strength (cells were not damaged) as occurs in apples (Brusewitz and Bartsch, 1989; Roudot et al., 1991). These results on ethylene evolution are similar to those reported by Wade and Bain (1980) that impact bruising did not significantly affect ethylene evolution in sweet cherry fruits.

Wounding induces the synthesis of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase, the rate controlling enzyme in ethylene biosynthesis (Yu and Yang, 1980; Wang and Yang, 1987; Hyodo et al., 1989). This leads to an accumulation of ACC, ethylene precursor, and then an increase in ethylene production. In osmoticum sensitive cells, ethylene-forming activity is mainly located at the plasmalemma with small activity inside the cell (Pech et al., 1989). On the other hand, in osmoticum insensitive cells, the bulk of ethylene production is intracellular. Therefore the presence of living cells is necessary for ethylene production. It is possible that the absence of a significant increase in ethylene production in injured papaya fruits was due to killing the peel cells by abrasion. Preliminary histological examination of papaya fruit peel with and without the GI, indicated the cells in the GI area were still intact though somewhat compressed compared to a normal peel area. The presence of live cells still needs to be confirmed with a vital stain. Another possible reason might be the presence of a high degree of injury which would favor more the accumulation of MACC rather than ACC. This condition has been reported in soybean, where ACC accumulation and ethylene production was observed in leaves showing electrolyte leakage less than 40% of total (Kacperska and Kubacka-Zebalska, 1989). However, in tissues showing a relatively higher level of injury, greater than 50% electrolyte leakage, MACC formation predominated over ACC accumulation and no further synthesis of ethylene was observed.

In the commercial postharvest handling system for Solo papaya, fruit damage occurs at certain points in the handling system associated with contact with the field bins. Mechanical injury due to abrasion, was manifested on ripe yellow fruits as sunken areas that remained green. This damage was referred to as GI. The fruit fly disinfestation heat treatments aggravate the severity of GI. On the other hand, waxing the fruits alleviate the severity of GI. Research should be first directed at determining whether the cells in the abraded area are alive and capable of respiration and ethylene production. The viability of the abraded cell area could be supported by a physiological measure such as the photosynthetical related flourescence activity of the bruised area. Polyamine in the peel with and without GI may also play a role, as polyamines increase in barley leaves infected with rust

(Greenland and Lewis, 1984) and have symptoms similar to GI. Clearly, the physiological reason for the abraded area remaining green is not clear cut.

Appendix

Table 23. Evaluation of papaya fruit taken off different points in the postharvest handling system.[a] Fruit were ripened at 25°C.

Points in the handling system	final Peel Color[b]	Firmness (kg)	Flesh color[c]	Shrivelling[d]	Scald[e]
At harvest	94.5 a	3.5 a	100.0 a	0.3 c	0 a
Before culling	92.2 a	2.7 a	100.0 a	0.5 bc	0 a
After culling	90.4 a	2.8 a	97.0 a	0.6 abc	0 a
Before waxing	97.6 a	2.6 a	100.0 a	0.9 ab	0 a
After waxing	97.4 a	3.6 a	100.0 a	1.0 a	0 a
After packing	88.6 a	4.6 a	93.0 a	0.7 abc	0 a

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of the whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[e] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 24. Evaluation of papaya fruit taken off different points in the postharvest handling system.[a] Fruits were stored at 10°C for two weeks then ripened at 25°C.

Points in the handling system	final Peel Color[b]	Firmness (kg)	Flesh color[c]	Shrivelling[d]	Scald[e]	Internal abnormality[e]
At harvest	96.7 a	4.4 a	100.0 a	0 a	0 a	2.0 a
Before culling	93.3 a	4.9 a	100.0 a	0 a	0 a	2.4 a
After culling	94.0 a	6.1 a	100.0 a	0 a	0 a	2.4 a
Before waxing	90.0 a	7.8 a	98.0 a	0 a	0 a	0.6 b
After waxing	86.5 a	6.5 a	100.0 a	0 a	0 a	0 b
After packing	87.0 a	6.1 a	100.0 a	0 a	0 a	0 b

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of the whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[e] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 25. Evaluation of 5 to 10% yellow papaya fruit dropped onto a smooth steel plate from different heights.[a] Fruit were ripened at 25°C.

Drop height (cm)	initial Peel Color[b]	final Peel Color[b]	Flesh color[c]	Disease incidence[d]	Disease severity[e]
0	7.5 a	89.6 a	104.0 ab	0 a	0 a
10	6.0 a	79.5 ab	90.0 bc	0.2 a	0.2 a
25	8.5 a	95.4 a	112.0 ab	0 a	0 a
50	7.0 a	69.6 b	98.0 abc	0 a	0 a
75	6.5 a	65.0 b	80.0 c	0 a	0 a
100	7.0 a	82.4 ab	115.0 a	0.1 a	0.1 a

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of the whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = disease absent, 1 = disease present.

[e] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 26. Evaluation of 25 to 30% yellow papaya fruit dropped onto a smooth steel plate from different heights.[a] Fruit were ripened at 25°C.

Drop height (cm)	initial Peel Color[b]	final Peel Color[b]	Flesh color[c]	Disease incidence[d]	Disease severity[e]
0	27.5 a	77.0 ab	97.0 a	0 a	0 a
10	25.5 a	66.0 b	93.0 a	0 a	0 a
25	26.5 a	77.0 ab	98.0 a	0 a	0 a
50	26.0 a	82.0 a	97.0 a	0 a	0 a
75	26.5 a	76.0 ab	97.0 a	0 a	0 a
100	27.0 a	79.0 a	100.0 a	0 a	0 a

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of the whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = disease absent, 1 = disease present.

[e] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 27. Evaluation of 40 to 50% yellow papaya fruit dropped onto a smooth steel plate from different heights.[a] Fruit were ripened at 25°C.

Drop height (cm)	initial Peel Color[b]	final Peel Color[b]	Flesh color[c]	Disease incidence[d]	Disease severity[e]
0	46.0 a	71.0 b	92.5 a	0 a	0 a
10	47.0 a	77.5 ab	82.5 b	0 a	0 a
25	47.0 a	84.0 a	82.5 b	0 a	0 a
50	47.0 a	78.0 ab	86.5 ab	0.1 a	0.1 a
75	47.0 a	73.0 b	85.0 ab	0 a	0 a
100	47.0 a	78.5 ab	82.0 b	0 a	0 a

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of the whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = disease absent, 1 = disease present.

[e] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 28. Ripening of 10 to 15% yellow papaya fruit dropped onto a smooth steel plate covered with different grades of sandpaper from a height of 10 cm.[a] Fruit were ripened at 25°C.

Grade of sandpaper	initial Peel Color[b]	final Peel Color[b]	Firmness (kg)
Control (TBZ dip only)	11.0 a	75.0 a	3.5 a
mesh 220 (very fine)	11.0 a	80.0 a	2.8 a
mesh 150	11.0 a	79.5 a	3.1 a
mesh 100	11.0 a	81.0 a	3.5 a
mesh 50	11.0 a	79.0 a	3.6 a
mesh 36 (very coarse)	11.0 a	73.0 a	3.9 a

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).

[b] Expressed as % yellow peel of the whole surface area.

Table 29. Ripening of papaya fruits subjected to different latex treatments.[a] Fruit were dropped onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm. Fruit were ripened at 25°C.

Treatments	initial Peel Color[b]	final Peel Color[b]	Firmness (kg)
Control - no drop	11.5 a	91.0 a	5.0 a
No drop - wipe with latex	11.5 a	88.0 a	3.4 a
Drop - leave latex on	11.5 a	87.0 a	5.0 a
Drop - wash off latex immediately	11.5 a	92.0 a	3.3 a
Drop - wash off latex 1 hour later	11.5 a	88.0 a	4.0 a

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=10).
[b] Expressed as % yellow peel of the whole surface area.

Table 30. Wax effect on final peel color, flesh color, and scald of papaya fruit waxed and heated after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Wax	final Peel Color[b]	Flesh color[c]	Scald[d]
none	78.1 a	95.7 a	1.6 a
FMC-819	79.7 a	91.9 a	1.6 a
FMC-820	82.5 a	93.1 a	1.4 a

[a] Data were analyzed using the Waller-Duncan K-ratio T test. Means within a column followed by the same letter are not significantly different at the 5% level (n=36).

[b] Expressed as % yellow peel of the whole surface area.

[c] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 31. Temperature effect on shrivelling, severity of green islands and % weight loss of papaya fruit waxed and heated after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Temperature (°C)	Shrivelling[b]	Severity of green islands[c]	%Weight loss
25	0.6 a	0.8 a	4.7 a
47.5	0.8 a	1.0 a	5.6 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=54).

[b] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[c] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

Table 32. Handling effect on final peel color, shrivelling, flesh color, firmness, scald and % weight loss of papaya fruit waxed and heated after dropping onto a smooth steel plate covered with 150 mesh sandpaper from a height of 10 cm.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Handling	final Peel Color[b]	Shrivelling[c]	Flesh color[d]	Firmness (kg)	Scald[e]	%Weight loss
No drop	79.4 a	0.7 a	93.4 a	8.8 a	1.3 a	5.0 a
Drop	80.7 a	0.8 a	93.7 a	7.6 a	1.7 a	5.4 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=54).

[b] Expressed as % yellow peel of the whole surface area.

[c] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[d] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[e] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 33. Handling effect on shrivelling, flesh color, firmness, scald and % weight loss in papaya fruit waxed before and after heating.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Handling	Shrivelling[b]	Flesh color[c]	Firmness (kg)	Scald[d]	%Weight loss
No drop	0 a	84.0 a	13.1 a	0 a	2.9 a
Drop	0.2 a	88.6 a	9.9 a	0 a	3.1 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=50).

[b] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[c] Expressed as % full-ripened color with normal color development (0 to 100%) and overripe scale (101 to 140%) with water-soaked flesh.

[d] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 34. Time of waxing effect on shrivelling, severity of green islands and scald in papaya fruit waxed before and after heating.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Time of waxing	Shrivelling[b]	Severity of green islands[c]	Scald[d]
waxed before heating	0 a	0.5 a	0 a
waxed after heating	0 a	0.5 a	0 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=50).

[b] Evaluated using the following scale: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

[c] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

[d] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 35. Effect of temperature on final peel color, severity of green islands and scald in papaya fruit waxed before or after heating.[a] Fruit were heated at 48°C for ~6 hrs or until FCT reached 47.5°C, after which fruit were quickly cooled down with a cold water shower until FCT reached ~30°C. Fruit were ripened at 25°C.

Temperature (°C)	final Peel Color[b]	Severity of green islands[c]	Scald[d]
25	73.4 a	0.6 a	0 a
47.5	74.8 a	0.7 a	0 a

[a] Data were analyzed using the T test procedure. Means within a column followed by the same letter are not significantly different at the 5% level (n=50).

[b] Expressed as % yellow peel of the whole surface area.

[c] Evaluated using the following scale: 0 = no green islands, 1 = light green, 2 = medium green, and 3 = dark green.

[d] Evaluated using the following scale: 0 = 0%, 1 = 1 to 10%, 2 = 11 to 30%, 3 = 31 to 60%, 4 = 61 to 90%, 5 = 91 to 99%, and 6 = 100%.

Table 36. Respiration rate of papaya fruit dropped onto different surfaces.[a] Fruit were dropped by vacuum from a height of 10 cm. Fruit were ripened at 25°C.

Days	Respiration rate (ml/kg/hr)		
	Treatment		
	Control (no drop)	Steel plate	Sandpaper
1	19.67(1)	15.94(3) ± 1.18	17.02(2) ± 0.43
2	17.23 ± 3.22	18.33(4) ± 3.24	17.40 ± 3.27
3	17.08 ± 1.41	19.51 ± 3.61	18.67 ± 3.76
4	19.82 ± 1.51	19.19 ± 1.28	19.12 ± 0.87
5	21.43 ± 3.17	19.49 ± 1.88	20.46 ± 2.00
6	21.34 ± 5.05	21.77 ± 2.72	22.16 ± 3.11
7	26.02 ± 3.26	27.02 ± 7.44	26.80 ± 2.17
8	26.57 ± 2.48	27.05 ± 3.46	26.25 ± 0.82
9	26.51 ± 3.07	25.97 ± 3.20	24.16 ± 0.72
10	27.46(4) ± 2.53	28.14 ± 3.60	27.10 ± 2.65
11	25.75(4) ± 3.05	24.72(2) ± 1.17	24.18(3) ± 0.75

[a] Most values are means of 5 fruit except where indicated in parenthesis. Standard deviation values are also given.

Table 37. Ethylene production of papaya fruit dropped onto different surfaces.[a] Fruit were dropped by vacuum from a height of 10 cm. Fruit were ripened at 25°C.

Days	Ethylene production (nl/kg/hr)		
	Treatment		
	Control (no drop)	Steel plate	Sandpaper
1	0 ± 0	0 ± 0	0 ± 0
2	0 ± 0	0 ± 0	0 ±
3	0 ± 0	0 ± 0	0 ±
4	0 ± 0	0 ± 0	0 ± 0
5	29.21 ± 18.30	0 ± 0	0 ± 0
6	663.92 ± 995.83	828.26 ± 864.04	781.86 ± 762.11
7	1900.53 ± 2269.31	1206.04 ± 1072.29	1318.02 ± 696.53
8	2531.90 ± 3918.66	978.30 ± 148.97	1064.60 ± 350.79
9	2097.43 ± 1651.53	1617.02 ± 523.89	1718.49 ± 427.67
10	2373.41(4) ± 1890.25	1904.10 ± 1082.72	2848.46 ± 1882.99
11	2475.22(4) ± 1159.77	3241.92(2) ± 597.87	2112.84(3) ± 235.63

[a] Most values are means of 5 fruit except where indicated in parenthesis. Standard deviation values are also given.

Table 38. Respiration rate of papaya fruit receiving from 0 to 8 drops onto a smooth steel plate.[a] Fruit were dropped by vacuum from a height of 10 cm. Fruit were ripened at 25°C.

Days	Respiration rate (ml/kg/hr)				
	Number of drops				
	0	1	2	4	8
1	14.46(1)	16.50(3) ± 2.17	16.30 ± 1.59	15.58(2) ± 0.17	15.56(3) ± 2.73
2	15.26 ± 2.81	13.32(3) ± 2.12	12.86 ± 2.43	15.52 ± 3.54	14.74 ± 4.22
3	13.14 ± 2.19	12.28 ± 3.03	10.71 ± 0.69	12.68 ± 2.47	12.84 ± 2.63
4	10.81 ± 0.58	11.06 ± 2.23	9.98 ± 0.47	11.05 ± 1.41	12.51 ± 3.28
5	11.42 ± 2.57	11.63 ± 1.64	11.91 ± 2.13	12.00 ± 3.18	12.53 ± 2.70
6	11.88 ± 2.38	14.14 ± 2.88	15.15 ± 0.64	13.67 ± 2.65	14.17 ± 1.13
7	14.55 ± 1.29	15.30 ± 0.92	14.53 ± 1.49	15.34 ± 0.95	16.36 ± 1.92
8	16.66 ± 2.57	18.36 ± 6.41	13.79 ± 0.57	18.91 ± 4.59	24.17 ± 4.06
9	22.64 ± 1.85	23.22 ± 5.44	19.60 ± 2.24	23.23 ± 2.90	22.99 ± 5.56
10	20.56 ± 4.47	22.45 ± 8.40	24.21 ± 1.80	22.89 ± 4.46	23.83 ± 2.67
11	23.55 ± 1.62	27.84 ± 2.69	25.91 ± 2.59	26.22 ± 1.35	26.25(3) ± 1.23
12	26.82 (3)± 1.56	25.98(3) ± 2.16	25.41(3) ± 2.03	27.63(3) ± 1.99	26.74(3) ± 3.07

[a] Most values are means of 4 fruit except where indicated in parenthesis. Standard deviation values are also given.

Table 39. Ethylene production of papaya fruit receiving from 0 to 8 drops onto a smooth steel plate.[a] Fruit were dropped by vacuum from a height of 10 cm. Fruit were ripened at 25°C.

Day	Ethylene production (nl/kg/hr)				
	Number of drops				
	0	1	2	4	8
1	0(1)	0(3) ± 0	0 ± 0	0(2) ± 0	0(3) ± 0
2	0 ± 0	0(3) ± 0	0 ± 0	0 ± 0	0 ± 0
3	0 ±	0 ± 0	0 ± 0	0 ± 0	0 ± 0
4	0 ±	0 ± 0	0 ± 0	0 ± 0	0 ± 0
5	0 ±	0 ± 0	0 ± 0	0 ± 0	0 ± 0
6	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
7	0 ± 0	746.69 ± 712.75	0 ± 0	0 ± 0	427.08 ± 359.07
8	959.30 ± 1112.90	4604.76 ± 2676.67	506.83 ± 313.52	2754.47 ± 2526.49	3847.20 ± 1487.38
9	3515.79 ± 2063.16	2437.56 ± 838.24	2642.56 ± 1239.55	2803.32 ± 1952.90	1876.28 ± 709.26
10	1596.43 ± 286.57	2536.79 ± 353.26	1744.68 ± 649.31	2307.83 ± 251.34	3699.75 ± 951.29
11	1687.65 ± 378.60	1939.90 ± 799.96	1985.73 ± 202.69	1504.38 ± 706.87	1340.39(3) ± 260.34
12	1304.29(3) ± 230.58	1503.73(3) ± 798.39	1535.08(3) ± 325.18	1653.11(3) ± 402.58	1106.96(3) ± 219.52

[a] Most values are means of 4 fruit except where indicated in parenthesis. Standard deviation values are also given.

Literature Cited

Abeles, F.B. 1973. Ethylene in Plant Biology. Academic Press, New York.

Akamine, E.K. 1966. Respiration of fruits of papaya with reference to the effect of quarantine disinfestation treatments. Amer. Soc. Hort. Sci. 89:231-236.

Akamine, E.K. 1977. Hastening the ripening of papayas for processing. Proc. 13th Ann. Hawaii Papaya Industry Assn. Conference.

Alvarez, A.M., J.W. Hylin and J.N. Ogata. 1977. Postharvest diseases of papaya reduced by biweekly orchard sprays. Plant Dis. Rep. 61:731-735.

Alvarez, A.M. and W.T. Nishijima. 1987. Postharvest diseases of papaya. Plant Disease 71:681-686.

An, J.F. 1988. Effects of temperature and ethylene on papaya (*Carica papaya* L., Sunset) ripening. M.S. Thesis, Dept. of Horticulture, Univ. of Hawaii.

Anonymous. 1984. Ethylene dibromide: Amendment of notice to cancel registration of pesticide products containing ethylene dibromide. Federal Register 49:14182-14185.

Armstrong, J.W., J.D. Hansen, B.K.S. Hu and S.A. Brown. 1989. High-temperature forced-air quarantine treatment for papayas infested with Tephritid fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 82:1667-1674.

Aworh, O.C., A.O. Olorunda and I.A. Akhuemonkhan. 1983. The effects of postharvest handling on quality attributes of tomatoes in the Nigerian marketing system. Food. Chem. 10:225-230.

Balock, J.W. and T. Kozuma. 1954. Sterilization of papaya by means of vapor-heat quick run-up. Special report 7, fruit fly investigations in Hawaii. USDA Entomology Research Branch, Honolulu, Hawaii.

Bassi, P.K. and M.S. Spencer. 1985. Comparative evaluation of photoionization and flame ionization detectors for ethylene analysis. Plant, Cell and Environ. 8:161-165.

Becker, S. 1958. The production of papain---an agricultural industry for tropical America. Econ. Bot. 12:62-79.

Brown, G.K., C.L. Burton, S.A. Sargent, N.L. Schulte-Pason, E.J. Timm and D.E. Marshall. 1989. Assessment of apple damage on packing lines. Applied Engg. Agric. 5:475-484.

Brusewitz, G.H. and J.A. Bartsch. 1989. Impact parameters related to postharvest bruising of apples. Trans. ASAE 32:953-957.

Burton, C.L. and N.L. Schulte-Pason. 1987. Carbon dioxide as an indicator of fruit impact damage. HortScience 22:281-282.

Cappellini, R.A., M.J. Ceponis and G.W. Lightner. 1988. Disorders in apricot and papaya shipments to the New York market 1972-1985. Plant Disease 72:366-368.

Chan, H.T., Jr. 1986. Effects of heat treatments on the ethylene forming enzyme system in papayas. J. Food. Sci. 51:581-583.

Chan, H.T., Jr., S.Y.T. Tam and S.Y. Seo. 1981. Papaya polygalacturonase and its role in thermally injured ripening fruit. J. Food. Sci. 46:190-191,197.

Chen, P., M. Ruiz, F. Lu and A.A. Kader. 1987. Study of impact and compression damage in Asian pears. Trans. ASAE 30:1193-1197.

Clegg, M.D., C.Y. Sullivan and J.D. Eastin. 1978. A sensitive technique for the rapid measurement of carbon dioxide concentrations. Plant Physiol. 62:924-926.

Couey, H.M. and G. Farias. 1979. Control of postharvest decay of papaya. HortScience 14:719-721.

Couey, H.M. and C. Hayes. 1986. Quarantine procedures for Hawaiian papaya using selection and a two-stage hot water immersion. J. Econ. Entomol. 79:1307-1314.

Couey, H.M. and T.R. Wright. 1974. Impact bruising of sweet cherries related to temperature and fruit ripeness. HortScience 9:586.

Dedolph, R.R. and M.E. Austin. 1962. The evaluation of impact bruises on apple fruit. Proc. Amer. Soc. Hort. Sci. 80:125-129.

Delwiche, M.J., T. McDonald and S.V. Bowers. 1987. Determination of peach firmness by analysis of impact forces. Trans. ASAE 30:249-254.

Denny, E.G., D.C. Coston and R.E. Ballard. 1986. Peach Skin discoloration. J. Amer. Soc. Hort. Sci. 111:549-553.

Dickman, M.B. and Alvarez, A.M. 1983. Latent infection of papaya caused by *Colletotrichum gloeosporioides*. Plant Disease 67:748-750.

Dickman, M.B. and S.S. Patil. 1984. Induction and selection of *Colletotrichum gloeosporioides* mutants deficient in production of cutinase. Phytopathology 74:835 (Abstr.).

Dickman, M.B., S.S. Patil and P.E. Kolattukudy. 1982. Purification, characterization and role in infection of an extracellular cutinolytic enzyme from *Colletotrichum gloeosporioides* Penz. on *Carica papaya* L. Physiol. Plant Pathol. 20:333-337.

Diehl, K.C. and D.D. Hamann. 1980. Relationships between sensory profile parameters and fundamental mechanical parameters for raw potatoes, melons and apples. J. Text. Studies 10:401-420.

Diehl, K.C., D.D. Hamann and J.K. Whitfield. 1980. Structural failure in selected raw fruit and vegetables. J. Text. Studies 10:371-400.

Eaks, I.L. 1961. Techniques to evaluate injury to citrus fruit from handling practices. Proc. Amer. Soc. Hort. Sci. 78:190-196.

Esguerra, E.B., P.A. Nuevo, M.E.G. Quintana, M.C.C. Lizada and L.C. Tapia. 1987. Evaluation of the vapor heat treatment for use on papaya fruit injury tests. Report submitted by the Bureau of Plant Industry and the Postharvest Horticulture Training and Research Center, University of the Philippines at Los Banos.

Garcia, C., M. Ruiz and P. Chen. 1988. Impact parameters related to bruising in selected fruits. ASAE Paper No. 88-6027. St. Joseph, MI:ASAE.

Genge, R.A., W.K. Bilanski and D.R. Menzies. 1977. The physical-biological properties of Babygold Five peaches as related to mechanical harvesting. Trans. ASAE 20:772-775.

Graham, S.O., M.E. Patterson and B. Allen. 1967. Bruising as a predisposing factor in the decay of stored cranberries. Phytopathology 57:497-501.

Green, H.C. 1956. Potato damage. J. Agr. Eng. Res. 1:56-62.

Green, H.C. 1962. The resistance of apples to damage. J. Agr. Eng. Res. 7:155-157.

Greenland, A.J. and D.H. Lewis. 1984. Amines in barley leaves infected by brown rust and their possible relevance to formation of 'green islands'. New Phytol. 96:283-291.

Hanson, A.D. and H. Kende. 1976. Biosynthesis of wound ethylene in morning-glory flower tissue. Plant Physiol. 57:538-541.

Herner , R.C. and K.C. Sink. 1973. Ethylene production and respiratory behavior of the *rin* tomato mutant. Plant Physiol. 52:38-42.

Hills, F. J., L. Chiarappa and S. Geng. 1980. Powdery mildew of sugar beet: disease and crop loss assessment. Phytopathology 70:680-682.

Hoffman, N.E. and S.F. Yang. 1982. Enhancement of wound-induced ethylene synthesis by ethylene in preclimacteric cantaloupe. Plant Physiol. 69:317-322.

Holt, J.E. and D. Schoorl. 1982. Mechanics of failure in fruits and vegetables. J. Text. Studies 13:83-96.

Hsia, C.L., B.S. Luh and C.O. Chichester. 1965. Anthocyanin in freestone peaches. J. Food Sci. 30:5-12.

Hung, Y.-C. and S.E. Prussia. 1989. Effect of maturity and storage time on the bruise susceptibility of peaches (cv. Red Globe). Trans ASAE 32:1377-1382.

Hyde, J.E. and M. Ingle. 1968. Size of apple bruises as affected by cultivar, maturity and time in storage. Proc. Amer. Soc. Hort. Sci. 92:735-738.

Hyodo, H. 1978. Ethylene production by wounded tissue of citrus fruit. Plant Cell Physiol. 19:545-551.

Hyodo, H., H. Fujinami, E. Okada and T. Mochizuki. 1989. Wound-induced ethylene production and 1-aminocyclopropane-1-carboxylic acid synthase in mesocarp tissue of *Cucurbita maxima*. pp. 229-236. *In* H. Clijsters et al., (eds.) Biochemical and Physiological Aspects of Ethylene Production in Lower and Higher Plants. Kluwer Academic Publishers. Dordrecht.

Imaseki, H., I. Uritani and M.A. Stahmann. 1968. Production of ethylene by injured sweet potato root tissue. Plant & Cell Physiol. 9:757-768.

Ingle, M. and J.F. Hyde. 1968. The effect of bruising on discoloration and concentration of phenolic compounds in apple tissue. Proc. Amer. Soc. Hort. Sci. 93:739-745.

Isenberg, F.M. 1955. The effect of height of fall on onion bruising. Proc. Amer. Soc. Hort. Sci. 65:331-333.

Jackson, M.B. and J. Osborne. 1970. Ethylene, the natural regulator of leaf abscission. Nature 225:1019-1022.

Jurd, L. and S. Asen. 1966. The formation of metal and "co-pigment" complexes of cyanidin-3-glucoside. Phytochemistry 5:1263-1271.

Kacperska, A. and M. Kubacka-Zebalska. 1989. Stress ethylene metabolism as related to degree of tissue injury. pp. 211-218. *In* H. Clijsters et al., (eds.) Biochemical and Physiological Aspects of Ethylene Production in Lower and Higher Plants. Kluwer Academic Publishers. Dordrecht.

Kader, A.A. and A. Chordas. 1984. Evaluating the browning potential of peaches. Calif. Agric. 14-15.

Kahl, G. 1974. Metabolism in plant storage tissue slices. Bot. Rev. 40:263-314.

Kende, H. and A.D. Hanson. 1976. The relationship between ethylene evolution and senescence in morning-glory flower tissue. Plant Physiol. 57:523-527.

Klein, J.D. 1987. Relationship of harvest date, storage conditions and fruit characteristics to bruise susceptibility of apple. J. Amer. Soc. Hort. Sci. 112:113-118.

Kumar, L. and J.-K. Wang. 1971. Response of papaya fruit to dynamic loading. Trans. ASAE 14:263-267, 272.

Lidster, P.D. and M.A. Tung. 1980. Effect of fruit temperatures at time of impact damage and subsequent temperature and duration on the development of surface disorders in sweet cherries. Can. J. Plt. Sci. 60:555-559.

Lidster, P.D., K. Muller and M.A. Tung. 1980. Effects of maturity on fruit composition and susceptibility to surface damage in sweet cherries. Can. J. Plt. Sci. 60:865-871.

Lougheed, E.C. and E.W. Franklin. 1974. Ethylene production increased by bruising of apples. HortScience 9:192-193.

MacLeod, R.F., A.A. Kader and L.L. Morris. 1976. Stimulation of ethylene and carbon dioxide production of mature-green tomatoes by impact bruising. HortScience 11:604-606.

Marks, J.D. and J.E. Varner. 1957. The effects of bruising injury on the metabolism of the fruit. Plant Physiol. 32(Suppl.):xlv.

Martin, J.T. 1964. Role of cuticle in the defense against plant disease. Annu. Rev. Phytopath. 2:81-100.

Massey, L.M., Jr., B.R. Chase and M.S. Starr. 1981. Impact-induced breakdown in commercially screened 'Howes' cranberries. J. Amer. Soc. Hort. Sci. 106:200-203.

Massey, L.M., Jr., B.R. Chase and M.S. Starr. 1982. Effect of rough handling on carbon dioxide evolution from 'Howes' cranberries. HortScience 17:57-58.

Maxie, E.C., F.G. Mitchell, N.F. Sommer, R.G. Snyder and H.L. Rae. 1974. Effect of elevated temperature on ripening of 'Barlett' pear, *Pyrus communis* L.. J. Amer. Soc. Hort. Sci. 99:344-349.

McGlasson, W.B. and H.K. Pratt. 1964. Effects of wounding on respiration and ethylene production by cantaloupe fruit tissue. Plant Physiol. 39:128-132.

McKeen, W.E. 1974. Mode of penetration of epidermal cell walls of *Vicia faba* by *Botrytis cinerea*. Phytopathology 65:461-467.

McMichael, B.L., W.R. Jordan and R.D. Powell. 1972. An effect of water stress on ethylene production by intact cotton petioles. Plant Physiol. 49:658-660.

Mellenthin, W.M., P.M. Chen and O.M. Borgic. 1982. In-line application of porous wax coating materials to reduce friction discoloration of 'Bartlett' and 'd'Anjou' pears. HortScience 17:215-217.

Miles, J.A. and G.E. Rehkugler. 1973. A failure criterion for apple flesh. Trans. ASAE 16:1148-1153.

Miller, A.R., J.P. Dalmasso and D.W. Kretchman. 1987. Mechanical stress, storage time and temperature influence cell wall-degrading enzymes, firmness, and ethylene production by cucumbers. J. Amer. Soc. Hort. Sci. 112:666-671.

Mitsuhashi-Kato, M., H. Shibaoka and M. Shimokoriyama. 1978. Anatomical and physiological aspects of developmental processes of adventitious root formation in *Azukia* cuttings. Plant Cell Physiol. 19:393-400.

Mohsenin, N.N. 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York.

O'Brien, M., L.L. Claypool, S.J. Leonard, G.K. York and J.H. MacGillivray. 1963. Causes of bruising on transport trucks. Hilgardia 35:113-124.

Olorunda, A.O. and M.A. Tung. 1985. Simulated transit studies on tomatoes; effects of compressive load, container, vibration and maturity on mechanical damage. J. Food. Tech. 20:669-678.

Parker, M.L., W.F. Wardowski and D.H. Dewey. 1984. A damage test for oranges in a commercial packinghouse line. Proc. Fla. State Hort. Soc. 97:136-137.

Patterson, M.E., C.C. Doughty, S.O. Graham and B. Allan. 1967. Effect of bruising on postharvest softening, color changes and detection of polygalacturonase enzyme in cranberries. Proc. Amer. Soc. Hort. Sci. 90:498-505.

Paull, R.E. and N.J. Chen. 1989. Waxing and plastic wraps influence water loss from papaya fruit during storage and ripening. J. Amer. Soc. Hort. Sci. 114:937-942.

Paull, R.E. and N.J. Chen. 1990. Heat shock response in field-grown, ripening papaya fruit. J. Amer. Soc. Hort. Sci. 115:623-631.

Peacock, B.C. 1973. Effect of mechanical injury on the preclimacteric life of banana fruits. Queensland J. Agric. Anim. Sci. 30:39-40.

Peacock, B.C. and J.R. Blake. 1970. Some effects of non-damaging temperatures on the life and respiratory behavior of bananas. Queensland J. Agric. Anim. Sci. 27:147-168.

Pech, J.C., M. Bouzayen, G. Alibert and A. Latche. 1989. Subcellular localization of 1-aminocyclopropane-1-carboxylic acid metabolism in plant cells. pp. 33-40. *In* H. Clijsters et al., (eds.) Biochemical and Physiological Aspects of Ethylene Production in Lower and Higher Plants. Kluwer Academic Publishers. Dordrecht.

Peleg, M. and L.G. Brito. 1977. Textural changes in ripening plantains. J. Text. Studies. 7:457-463.

Peleg, M., G.L. Brito and Y. Malewski. 1976. Compressive failure patterns of some juicy fruits. J. Food. Sci. 41:1320-1324.

Pollack, R.L. and C.H. Hills. 1956. Respiratory activity of normal and bruised red tart cherries (*Prunus cerasus*). Fed. Proc. Fed. Amer. Soc. Expt. Biol. 15:328.

Randle, W.M. and W.R. Woodson. 1986. The effect of storage and wounding on ethylene production by sweet potato. HortScience 21:1018-1019.

Robitaille, H.A. and J. Janick. 1973. Ethylene production and bruise injury in apples. J. Amer. Soc. Hort. Sci. 98:411-413.

Roudot, A.-C., F. Duprat and C. Wenian. 1991. Modelling the response of apples to loads. J. Agric. Engng. Res. 48:249-259.

Saltveit, M.E., Jr. 1984. Effects of temperature on firmness and bruising of 'Starkrimson Delicious' and 'Golden Delicious' apples. HortScience 19:550-551.

Sanxter, S.S. 1989. Ontogeny and senescence of photosynthetic activity in the exocarp of *Carica papaya* L. M.S. Thesis in Botanical Sciences, Plant Physiology, Univ. of Hawaii.

Saltveit, M.E., Jr. and D.R. Dilley. 1978. Rapidly induced wound ethylene from excised segments of etiolated *Pisum sativum* L., cv. Alaska. Plant Physiol. 61:447-450.

Schoorl, D. and J.E, Holt. 1977. The effects of storage time and temperature on the bruising of 'Jonathan', 'Delicious' and 'Granny Smith' apples. J. Text. Studies 8:409-416.

Skelton, G.S. 1969. Development of proteolytic enzymes in growing papaya fruit. Phytochemistry 8:57-60.

Sommer, N.F. 1957a. Surface discoloration of pears. Calif. Agric. 11:3-4.

Sommer, N.F. 1957b. Pear transit simulated in test. Calif. Agric. 11:3-5, 16.

Sommer, N.F., F.G. Mitchell, R. Guillon and D.A. Luvisi. 1960. Fresh fruit temperature and transit injury. Proc. Amer. Soc. Hort. Sci. 76:156-162.

Souza, R.A. 1991. Papaya: Production, marketing, income and industry review. Paper presented by the Papaya Administrative Committee Manager during the Hawaii Papaya Industry Association 27th Annual Convention, June 28, 1991, Hilo, Hawaii.

Spayd, S.E., E.L. Proebstring and L.d. Hayrynen. 1986. Influence of crop load and maturity on quality and susceptibility to bruising of 'Bing' Sweet cherries. J. Amer. Soc. Hort. Sci. 111:678-682.

Timm, E.J. and G.K. Brown. 1989. Handling impact assessment for papaya. Internal report. Conducted at Amfac, Inc., Keaau, HI by USDA's Agric. Res. Service and the Agric. Engg. Dept. at Michigan State Univ., East Lansing, MI in cooperation with the Univ. of Hawaii on September 17 and 18, 1989.

Timm, E.J. and G.K. Brown. 1991. Impacts recorded on avocado, papaya and pineapple packing lines. ASAE Paper No. 90-6007. St. Joseph, MI: ASAE.

Topping, A.J. and M.T. Luton. 1986. Cultivar differences in the bruising of English apples. J. Hort. Sci. 61:9-13.

Uritani, I. and T. Asahi. 1980. Respiration and related metabolic activity in wounded and infected tissues. pp. 463-485. *In* D.D. Davies (ed.). The Biochemistry of Plants---A Comprehensive Treatise. Vol. 2. Academic Press, New York.

Van Blaricom, L.O. and T.L. Senn. 1967. Anthocyanin pigments in freestone peaches grown in the southeast. J. Amer. Soc. Hort. Sci. 90:541-545.

Van Buren, J.P., G. Hrazdina and W. B. Robinson. 1974. Color of anthocyanin solutions expressed in lightness and chromaticity terms: effect of pH and type of anthocyanin. J. Food. Sci. 39:325-328.

Van den Ende, G. and H.F. Linskens. 1974. Cutinolytic enzymes in relation to pathogenesis. Annu. Rev. Phytopath. 12:247-258.

Wade, N.L. and J.M. Bain. 1980. Physiological and anatomical studies of surface pitting of sweet cherry fruit in relation to bruising, chemical treatments and storage conditions. J. Hort. Sci. 55:375-384.

Wang, J.-K. and H.-S. Chang. 1970. Mechanical properties of papaya and their dependence on maturity. Trans. ASAE 13:369-371.

Wang, T.T. and S.F. Yang. 1987. The physiological role of lipoxygenase in ethylene formation from 1-aminocyclopropane-1-carboxylic acid in oat leaves. Planta 170:190-196.

Yang, S.F. and H.K. Pratt. 1978. The physiology of ethylene in wounded plant tissue. pp. 596-622. *In* G. Kahl, ed. Biochemistry of Wounded Plant Tissues. Walter de Gruyter, Berlin.

Yoshida, O., O. Nakagawa, N. Ogura and T. Sato. 1984. Effect of heat treatment on the development of polygalacturonase activity in tomato fruit during ripening. Plant & Cell Physiol. 25:505-509.

Yu, Y.B. and S.F. Yang. 1980. Biosynthesis of wound ethylene. Plant Physiol. 66:281-285.

Zauberman, G. and Y. Fuchs. 1981. Effect of wounding on 'Fuerte' avocado ripening. HortScience 16:496-497.

Zohadie, M. 1982. Elasticity of Malaysian papaya as a design criterion for prevention of damage during transportation. Pertanika 5:178-183.