STUDIES ON THE MATURITY, POSTHARVEST PHYSIOLOGY AND CANNING OF 'STANLEY' PLUMS

by

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ABSTRACT

STUDIES ON THE MATURITY, POSTHARVEST PHYSIOLOGY
AND CANNING OF 'STANLEY' PLUMS

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Assessment of 'Stanley' plum (Prunus domestica, L.) fruit maturity indices showed flesh firmness, and soluble solids were reliable while titratable acidity, extractable pigments and ethylene evolution were not consistent. Maturity at harvest was a greater determinant of ripening than cold storage (0°C), or conditioning period (20°C). Fruit weight often did not increase with progressive harvest. Ethylene gassing (100 ppm) for 2 - 4 days enhanced flesh softening, pit removal and increased skin cracking, but had no significant effects on color, acidity, soluble solids or pitting losses and quality of the canned product. CO_2 production increased after 4 - 6 weeks at 0°C. Ethylene production increased after 2 weeks at 0°C but diminished with longer storages. Quality and pitting losses of processed plums were significantly affected by conditioning period and harvest date. A predictive equation was developed based on gains in soluble solids and decreases in flesh firmness of the harvested fruit.

DEDICATION

to
Juniper Li,
who was plucked
right on time and
helped make this
thesis a little
plumper and
sweeter!

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

Page

LIST OF TABLES

LIST OF FIGURES

FIGURE | Page

Section 1

LIST OF FIGURES--Continued

LIST OF FIGURES--Continued

THESIS INTRODUCTION

The importance of 'Stanley' plums as a fruit crop in Michigan has increased in recent years. Total plum production has doubled in the last twenty years from 8 to 16 thousand tons. 'Stanley' is the major variety and comprises over 86% of the total volume. In recent years the plum crop has ranged between 2 and 3 million dollars in total value. Besides its production figures, 'Stanley' plum is vital to Michigan for two major reasons: 1) timing of harvest falls between that of two main fruit crops, cherry and apple, thus optimizing available labor and equipment; 2) culture of 'Stanley' plums is especially suited to Michigan's climate. The development of strong markets for Michigan plums is essential for the state's fruit growers as it is one of their most important minor crops.

Michigan plums have two major outlets, fresh market and processed, which are primarily canned. In the last ten years the fresh market has increased from 39% to 47% of the total plum tonnage. Since both markets currently hold about 50% of the volume, marketing high quality fruits through both channels is vital to the industry.

The lack of definitive research on 'Stanley' plum maturity coupled with pressures in the marketing channels often force fruit of low quality into both markets. To promote the availability of high quality fruit, research was conducted with three distinct objectives: 1) determine the optimum maturity for harvest of plums for both fresh and processing markets; 2) evaluate parameters which can be used to assess optimum maturity; 3) develop postharvest treatments to maximize quality of both fresh and processed fruit.

Recent advances at Michigan State University on mechanical pitting of 'Stanley' plums has encouraged development of a canned pitted product. Currently Michigan processors do not pit and halve plums, while Oregon processors, who are strong competitors, handle about 50% of their total canned volume in this manner using 'Italian' purple plums. Therefore, regarding processed plums, the target of this thesis research has been to develop a high quality pitted product with the hopes of implementation and market expansion in Michigan.

At present the maturity of 'Stanley' plums is commonly determined by color change for the fresh pack and sugar content for the canned market, although in some cases determination is totally qualitative. Knowledge of when fruits in the orchard are approaching optimal maturity could be a cornerstone of sound marketing, ultimate demand and profit to the grower. To insure a consistant supply of high quality plums and eliminate human errors in harvest determination, growers have voiced a priority for improvements in maturity indicators. As a result this thesis research was funded through an organization supported and organized by growers, the Michigan Plum Advisory Board.

In common usage "plum" indicates a fresh market product, while "prune" indicates a dried product. However, the word prune is commonly used for many cultivars (e.g. Italian prune, French prune, Stanley prune) regardless of the treatment of the crop. Throughout this thesis, the word prune is used synomously with plum and is not an indicator of a dried product unless specifically stated.

REVIEW OF LITERATURE

A. Introduction

The following literature review focuses on varieties of European plum (*Prunus domestica*); however, references to oriental plums (*Prunus salicina*) have been included because of their similar physiology. Research on plums utilized for a dried product are also included in this review since they involve the use of similar harvest indicators. While many varieties are discussed, the cultivar 'Stanley' is the only one evaluated in the thesis and is of European origin.

B. Harvest Indices

Harvest indices have been evaluated for over sixty years; however, only one major study is known which deals with 'Stanley' plum in Michigan (18). This review presents research on other varieties of *Prunus domestica*, but different growing conditions and marketing situations limit the direct application to Michigan's 'Stanley' crop. A wide variety of indices has been employed in plum maturity including; soluble solids, firmness, acidity, soluble solids to acid ratio, flesh color, specific gravity, separation of the pit and taste.

Hartman (13), working with 'Italian' prunes in Oregon, observed marked increases in sugar content and size together with decreases in firmness and acidity as plums matured. Using a now obselete firmness tester he concluded that firmness was the most reliable maturity guide. Similar findings on 'Italian' prunes in Idaho were reported by Vincent et al. (52) and Verner (51) using the modified Murneek pressure tester. Vincent et al. (52) and Tucker et al. (48) determined that sugar readings via a hydrometer were cumbersome and too susceptible to error to be practical as a harvest indicator. Likewise, acid changes were too small to be reliable. Their recommendations, based on a 5/16" diameter firmness tester, were 12 - 8.5 pounds for immediate shipment and 11.5 - 9 pounds for storage. La Rosa (18) concluded that flesh firmness was the most satisfactory single index of maturity for Michigan 'Stanley' plums. It was superior to soluble solids because of decreased seasonal variation; however, he recommended no workable tolerances for harvest. In a concurrent study Kenworthy (16) recommended 15-20 pounds firmness for fresh market Michigan 'Stanley' plums.

Fisher (9) concluded that the firmness test for 'Italian' prunes in British Columbia was inadequate because of seasonal variability in firmness from prunes harvested at a constant soluble solids level of 17%. He therefore recommended that fresh market plums be harvested only after attaining a soluble solids level of 17%. Gerhardt, English and Smith (10) echoed similar conslusions working with 'Italian' prunes in Washington.

They suggested that soluble solids levels of 14 - 16% and a soluble solids to acid ratio between 12 and 15 were optimal for fresh market plums for distant markets. They also integrated qualitative visual skin color changes in their harvest strategy. Gerhardt et al. (11), after a follow-up study a few years later, decided that soluble solids alone was an unworkable parameter. They restated a soluble solids-acid ratio of 13 - 15, and further recommended that flesh color changes to dark amber also be incorporated into harvest decisions for long distance shipping.

Robinson and Holgate (33) have studied the two primary parameters, soluble solids and flesh firmness, for four varieties of European plums in New York State, where climatic and cultural conditions are similar to those in Michigan. Their findings were that soluble solids ranged from 10 - 14% in the least sweet to 15 - 25% in the sweetest variety, suggesting that optimal soluble solids was dependent on the variety. They suggested that firmness changes were more indicative of ripening changes than were soluble solids. Using the Ballauf firmness tester with a 7/16" plunger, they recommended that 10 pounds firmness was the maximum for harvest firmness. They found that freshly harvested fruit firmer than 10 pounds may be better suited for long distance shipment in some cases, but such fruit may not fully ripen.

Tucker (47) studied the relationship between soluble solids, firmness and taste in 'Italian' prunes. He found that both flavor and firmness, and flavor and sugar content had strong correlations. However, a correlation between sugar content and firmness was insignificant. When either factor was held constant, the other factor affected the flavor. Nevertheless, because of large variabilities in both orchard and season, when firmness was constant, quality and soluble solids varied considerably. Sibbett et al. (38), working with California 'French' prunes for drying, found that accumulation of solids proceeded until fruit reached three to four pounds flesh firmness. Beyond this, apparent increases in soluble solids were due simply to water loss. The research team stressed that refractometer readings alone didn't measure maturity but had to be combined with a flesh firmness reading in order to determine potential fruit quality. Ryall (34) reported that sugar content of 'Italian' prunes did not increase after harvest as they are a non-starchy fruit.

McBean et al. (23) also worked with soluble solids as an indicator in the maturity of 'D'Agen' plums in Australia. By developing a specific gravity hydrometer that was practical for field use, he used specific gravity in concert with soluble solids readings to pinpoint harvest date. The mean regression of soluble solids with specific gravity was utiled to predict the time it would take a crop to reach optimal soluble solids levels. Saleem et al. (35) reported that brix, reducing sugars, total carbohydrates, and nitrogen content increased as fruit maturity advanced; however, vitamin C content of the plums did not exhibit any specific trend.

Westwood (55) reports that for many years 'Italian' prune maturity in the Willamette Valley in Oregon has been estimated by the change of flesh color from yellow-green to golden-yellow (amber), and is the present maturity index in the voluntary grades and standards adopted by the Northwest Canners and Freezers.

C. Plum Variability

Plum ripening variability is a major problem in the resolution of fixed indicators. Vincent et al. (52) state that the irregularity of ripening of the fruit o individual trees constitutes by far the greatest obstacle to successful storage of the prunes. La Rosa (18) made an identical observation with Michigan 'Stanley' prunes, finding variability between fruits on the same tree greater than between orchards. Wiley (56) found that there was significant variation between trees in firmness but not in soluble solids, acidity or flesh color. Tucker and Verner (48) noted that season and orchard variations were also striking with season having the stronger effect. Hartman (13), Gerhardt and English (10) and Sibbett et al. (38) had similar findings.

D. Temperature During Storage

Early research by Ramsey (31) indicated that cold storage lengthened the time prunes would keep and that removal from storage led to rapid deterioration. Furthermore, he showed that precooling of plums before iced shipment could greatly reduce decay during and after transport. Hartman (13) determined that when 12 days storage at 45°F (7.2°C) with 3-4 days after-ripening was used as a postharvest temperature regime, later harvested fruit were of a better dessert quality than earlier halved fruit.

Vincent et al. (52) found that storage periods of about one week did not appreciably affect the physical condition and edibility of plum fruits. At higher temperatures there was more rapid ripening. Shriveling was by far the largest postharvest problem, followed by soft rots. Cracking and internal browning were relatively minor problems. Longer storage at 32°F (0°C) promoted increased deterioration due to soft rots.

Tucker and Verner (48) reported rapid decreases in flesh firmness of prunes stored at room temperature compared to those stored at 32°F (0°C). While they found prune storage to be limited by shriveling, decay and internal browning, shriveling was usually the limiting factor. Nevertheless, the increase in shrivelling was not paralleled by a decline in flavor. The authors found that firm fruit held up better than soft so that firm fruit with a high sugar content was recommended for storages. They recommended "limited" periods of storage at 32-35°F (0-1.7°C) for 'Italian' prunes.

Fisher (9) reported that Italian prunes held in 32°F (0°C) storage for four weeks attained satisfactory quality. The fruit, which had reached soluble solids levels of 18%, developed into good quality dessert plums and maintained market quality with 5-7 days at room temperatures of 65°F (18.3°C). Ryall (34) showed that three weeks in cold storage caused plums to have a characteristic browning of the pit upon ripening at 65°F (18.3°C). He attributed this to normal deterioration in storage. Pentzer and Allen (27) studied transit temperature regimes extensively in both European and Japanese varieties of plum and concluded that 32°F (0°C) for 12 days was the best temperature to retard ripening. Temperatures of 40°F (4.4°C) permitted small amounts of ripening while 45-55°F (7.2-12.8°C) resulted in considerable softening and coloring of the fruit. They also recommended a ripening temperature of 55°F (12.8°C) rather than 65°F (18.3°C) for both improved color and texture. 80°F (26.7°C) was found to have a retarding affect on ripening. 'President,' a European plum variety, was held in good condition at temperatures of 32, 35, 40 and 45°F (0, 1.7, 4.4 and 7.2°C) for 30 days.

Gerhardt, English and Smith (11) found that 'Italian' prunes held at 31-36°F (-0.6 - 2.2°C) for 10 days would not ripen normally when moved to room temperatures of 65°F (18.3°C).

However, fruit held at 45°F (7.2°C) for 10 or 20 days produced a prune that ripened normally. Gerhardt and English (10) reported a low temperature injury which resulted from immediate storage at 31°F (-0.6°C). They indicated that the disorder could be remedied by partial ripening of the fruit prior to storage at 31°F (-0.6°C) or by holding it at temperatures of 40-45°F (4.4-7.2°C). Verner et al. (51) studied the effects of delaying cold storage placement after harvest. However, they found that this didn't prevent development of internal browning, one of the major postharvest problems in European plums.

Proebsting and Mills (30) discovered a cold requirement for the ripening of 'Early Italian' prunes. Based mainly on sheer press values, they showed that when prunes were subjected to a two week 35°F (1.7°C) cold treatment prior to 70°F (21.1°C) ripening, softening was significantly advanced. Proebsting et al. (28) did further work and showed an improved ripening response in firmness, color and acidity using the previous cold treatment. No soluble solids changes occured. Taste panels indicated that the canned juice of cold treated plums was sweeter, more flavorful and less astringent than that of non-treated controls. La Rosa (18) also concluded that a 32°F (0°C) cold storage for one or two weeks appeared to be essential for the development of maximum quality of 'Stanley' and 'Bluefree' varities of an early harvest. This treatment, however, benefited fruit harvested at any stage of maturity.

W. H. Smith (44) determined 34°F (1.1°C) to be an ideal storage temperature for 'Victoria' and 'Monarch' plums in England. Both jellying and internal browning were lower at this temperature. He found that internal browning could be further checked by interrupting a 35 day cold storage period midway with four days of 65°F (18.3°C) temperatures. Smith also showed that a combination of low O_2 atmospheres with 34°F (1.1°C) temperatures could lengthen the storage and maintain the quality of 'Victoria' plums. Considerable research has been done on Japanese plum varieties involving controlled atmospheres and yielding similar results (8, 40, 41).

Sibbett et al. (38) studied the effects of storage temperature on the keeping quality of California's 'French' prunes. These fruit were harvested when quite ripe due to their use as a dried fruit. Nevertheless both at 32°F (0°C) and 41°F (5°C), internal breakdown symptoms were delayed for considerable time by storage for six weeks at 41°F (5°C) and for five weeks at 32°F (0°C). Since softening was more rapid at 41°F (5°C), 32°C (0°C) was the preferred temperature. Mitchell, Mayer and Beede (24) studied the effects of temperature on flesh softening in 17 varieties of plums including European and Japanese varieties. After 3 weeks of storage, flesh firmness had dropped 8% at 32°F (0°C) vs. 32% at 41°F (5°C). When held at 32° (0°C), firmness in all varieties remained relatively stable for 5 - 6 weeks.

E. Weight Changes During Harvest

Enlargement during the final swell accompanying maturity is significant in European plum varieties. Vincent et al. (52) reported an average daily volume increase of 0.5% from August 31st until Sept. 16th. Gerhardt, English and Smith (11) witnessed a daily average of 1.1% per day during a similar 3 week harvest period, and therefore discouraged premature harvests because of losses in tonnage. Fisher (9) noted a 1-2% daily increase in one week. Westwood (56) summarized that prunes grow at a rate of 0.5 to 1% during the pre-harvest period and can gain 20-25% in weight from the first picking until they are tree ripe. La Rosa (18) found considerable variation in weight gains with 'Stanley' plums. Depending on location, his data indicates weight increases ranging from 0-25% within one week's time. Claypool and Kilbuck (6) found that 'French' prune weight increased greatly after the disappearance of chlorophyll from the flesh. Color change was thus rejected as being a good maturity index because of large sacrifices that might be made in yields. None of these researchers recommended weight change as a harvest index, yet, all stress it as a major harvest consideration.

F. Weight Losses in Storage

There is less research about weight loss during storage. Couey (8) working with an oriental variety 'El Dorado', observed considerable weight loss during a six week storage period. Plums in sealed and vented liners averaged less than

0.5% weight loss while those in open containers averaged 4.6% loss. Mitchell, Mayer and Beede (24) studied the effect of waxing on both oriental and European plums. Overall, waxing resulted in a 16% reduction in water loss from the combined 17 varieties. Waxing treatments were particularly effective in preventing water losses in 'President' plums, a European variety.

G. Plum Storage Disorders

There are several postharvest disorders in plums. Verner et al. (51) cites shriveling and internal browning to be the main problems in 'Italian' prunes. Lutz and Hardenburg (20) state that the three major plum problems; decay, shriveling and internal browning, all become apparent after three days removal from storage, but are often not visable during the storage period. This makes the identification of these disorders very deceiving.

1. Shriveling

Tucker and Verner (48) reported that shriveling is usually the limiting storage factor for western 'Italian' prunes and that riper and softer fruit shrivel sooner than immature ones. Rate of flavor loss, however, does not run parallel with shriveling for prunes picked at different stages of maturity. Hulme (14) reports that control of relative humidity can reduce shrivel problems. Atmospheres of near saturation result in abnormal skin splitting, while dry atmospheres lead to shrivel. Lutz and Hardenburg (20) recommended relative humidities of 90-95% for plums.

2. Internal Browning and Soft Rots

Verner et al. (51) noted that while internal breakdown is associated with ripening, its predisposing cause resides in the orchard. There was a high positive correlation between fruit firmness and resistance to browning. Smith (44) and Gerhardt et al. (11) both indicated low temperature storage under 34°F (1.1°C) to be a factor in the development of internal breakdown. As cited before, both reports recommended some warmer temperature treatment to circumvent this disorder. Conversely, Mitchell et al. (24) studied four varieties of Japanese plum along with several varieties of peach and nectarine. They noted that browning and mealiness was most severe following storage between 36°F (2.2°C) and 41°F (5°C), and least severe at or near 32°F (0°C). However, these researchers also indicated that exposure of fruit to temperatures over 68°F (20°C) delays the onset of breakdown.

Cargill et al. (4) have noted that brown rot and penicillium rots are prominent problems with 'Stanley' plums. Jones et al. (15) have found that fungicide sprays and dips did not significantly reduce postharvest decay in plums. However, a hot water dip of 51.5°C for three minutes did an excellent job in controlling postharvest diseases. Cargill et al. (4) reported that a three day treatment of 100 ppm of ethylene gas eliminated any noticible fruit rot on 'Stanley.'

3. Bruising

Bruising, while not a postharvest disorder, is also a major problem in plum handling and storage as its occurrance increases the incidence of other disorders. Ramsey (31), though working during a time of primitive refrigeration, clearly showed that the careful handling of plums reduces the incidence of decay at distant markets. Ceponis and Friedman (5) discovered a positive correlation between the amount of bruising and the percentage decay of fresh market Idaho grown 'Italian' prunes. Furthermore, temperatures of 70°F (21.1°C) for 3 to 5 days greatly accelerated the bruise induced decay, whereas holding fruit at 35°F (1.7°C) for two weeks markedly curbed the decay development. Mitchell, Mayer and Beede (24) determined that waxing could reduce the bruise scores of plums, peaches and nectarines.

H. Ethylene in Plum Ripening

There is a limited amount of research dealing with ethylene production and action in the ripening of plums. According to Abeles (1), the plum, like all members of the stone fruit family, is climacteric. However, all plum varieties do not produce or respond to ethylene in a similar fashion.

Uota (49) has reported a correlation between the ability of a fruit to evolve ethylene and the speed at which it ripens. Working only with Japanese varieties of plums, Uota showed that cultivars which ripened normally at 90°F (32.2°C) produced measurable amounts of ethylene gas at that temperature but production was supressed in varieties that did not ripen properly at 90°F (32.2°C) without added ethylene gas. Mitchell et al. (24) also studied varietal responses of plums to ethylene. 'Santa Rosa,' a late variety, ripened normally only after two days of ethylene exposure and was also unaffected by a two week 32°F (0°C) treatment. On the other hand, 'Wickson,' an earlier variety, ripened well without added ethylene and developed accelerated ripening after the two week's cold treatment.

Uota (49) also studied the effects of ethylene gassing on Japanese plums. In general, fruits gassed with 2000-5000 ppm of ethylene at temperatures of 70°F (21.1°C) and 90°F (32.2°C) increased their rates of respiration and ethylene evolution. There was a similar but greatly reduced respiratory response with ethylene gassing at 55°F (12.8°C) and no response at 35°F (1.7°C). Volatiles, including ethylene, seemed to be involved in ripening; however, volatiles other than ethylene did not significantly change with applied ethylene. This was determined by absorbing volitles on a sulfuric acid tower and oxidizing them with a sulfato-cerate solution at high temperature and pressure. Smith (44) found that CO_2 evolution from 'Victoria' plums exhibited a climacteric about 10 days after harvest without added ethylene. In Uota's report untreated plums reached a respiratory peak in 4 - 6 days at 70°F (21.1°C).

Plums treated with ethylene gas reached their peaks about one day in advance of these controls.

In a preliminary study Cargill et al. (4) found that ethylene gassing for 3 days at 100 ppm had a positive effect on the ease of pitting of 'Stanley' plums. After treatment, plum pits did not cling to the flesh during pitting and the percentage of halves with pit fragments had decreased.

Smith (43) reported a maturity advancement in the European variety, 'Monarch,' following a 10,000 ppm acetylene gassing for one day. Treated fruits (probably of an early harvest) showed improvements in color, odor, and maturity as judged by subjective analysis. After storage at 31°F (-0.6°C) for 1, 2 or 3 weeks, plums were gassed with various high concentrations (2000 ppm and over) of acetylene or ethylene for one to two days. The general trend was a narrowing of the ripening differences between gassed and control fruits as the storage period progressed. Treated fruit was most notably different from non-treated in having: 1) stronger plum odors; 2) more uniform ripening; 3) a smaller percentage of clingstones; and 4) a higher percentage of rot. Similar but weaker ripening effects were noted with two other treatments: 1) fruit which had been treated with the air that had been passed over already ripened plums; 2) fruit which had been confined to an atmosphere with limited ventilation. However, a one day ethylene or acetylene gassing of fruits while in storage at the 8th, 13th or 18th day after harvest had only a slight effect. While the author suggested that longer gassing during storage might be effective, it appeared that gassing effects were greatest under room temperature conditions.

I. Exogenous Growth Regulators' Effects on Maturity

There are a few reports on the effects of ethephon sprays to plums which further implicate a role for ethylene in plum ripening. Paunovic et al. (26) observed a 8 - 10 day advancement in maturity with the 'Pozegada' cultivar, while Savic et al. (36) noted a ten day advancement in both 'Pozegada' and 'Stanley' plums. Proebsting and Mills (29) obtained a two week advancement in color and soluble solids combined with a one week advancement in softening following ethephon treatment of 'Early Italian' prunes. Responses were greatest at 80 ppm but lower rates down to 10 ppm produced lesser effects. All of these above reports were on European varieties. Similarly the maturation enhancement with ethephon has been reported on Japanese plums by some researchers. Guelfat-Reich and Ben Aire (12) noticed the promotion of coloring, fruit softening, ethylene and CO_2 evolution with a one minute dip in 250-500 ppm of ethephon. Soluble solids and acidity were not affected. Bloomaert et al. (2) also witnessed an earlier and more uniform ripening of the 'Santa Rosa' variety as judged by the advancement of color.

Succinic acid 2,2, dimethylhydrazide (Alar) has also been used in an attempt to enhance plum ripening (19). Yeager et al.

(57) found that Alar advanced the maturity of California's 'French' prunes by eight days, while La Rosa (18) found that the ripening of 'Stanley' and 'Bluefree' was not affected using several concentrations of Alar.

J. Research on Canned Plums

Hartman (13) reported that cold-treated 'Italian' prunes of earlier harvests developed a high quality canned product, provided they were picked within a desirable picking range and allowed to become ripe before canning. After cold treatments, plum color development was so enhanced that treated fruit had an appearance similar to tree ripe fruit.

Proebsting et al. (30) found that a cold treatment enhanced ripening. Cold-treated 'Italian' prunes yielded juice that was preferred to non-treated, being judged as less acid and astringent and having more plum flavor. The appearance of the canned plums was also influenced by cold treatment. Less mature fruit that received a cold treatment tended to split in cooking and the flesh darkened. Some cold treated, canned fruit was downgraded by industry inspectors because of soft flesh. La Rosa (18) found that cold treatment did not improve color in canned 'Stanley' and 'Bluefree' plums. Conditioning the fruit, however, whether it recieved a cold treatment or not, improved the color rating of the canned product. He also witnessed lower texture ratings as the fruit matured and the conditioning period lengthened, but again, no effects due to cold treatment were observed. There were no significant differences in the flavor ratings for 'Stanley' and 'Bluefree' plums. In paired tests for preference cold storage had no effect on improving the quality of the canned plums.

Working specifically with maturity parameters for a canned plum, Wiley (56) discovered good correlations between quality of the canned product and the following indices: flesh firmness, percent soluble solids, percent acidity, soluble solids to acid ratio and flesh color as measured by the Hunter A scale. Westwood (55) states that the Oregon State University Food Science Department has determined that the ss/acid ratio is the best criterion for canning maturity. Kenworthy et al. (17) considered the separation of the pit from the flesh to be the most workable guide for determining the readiness of a 'Stanley' crop destined for canning.

MATERIAL AND METHODS

A. Sampling and Design

Data were gathered in three harvest seasons, 1980, 1981 and 1982. The techniques varied slightly for the three years but the experimental designs were similar. A major sampling difference existed in monitoring of maturity for the two harvest seasons. In 1980 one sample of ten individual plums was chosen per treatment; data were recorded for each fruit. After an evaluation of the variation within the treatments, a new sampling scheme was designed for 1981. Three samples of ten plums each were used, and the mean of each sample was used for statistical analysis. During 1982, these three samples were reduced to 8 plums each to facilitate the broad testing of a harvest model developed during the first two years research.

In 1980 and 1981 a four way factorial was utilized with variables of: 1) orchard location; 2) harvest date; 3) duration of 0°C storage and 4) duration of 20°C conditioning. In 1980 only, a fifth factor of ethylene treatment was added. In 1982 only, the factors of location, harvest date and conditioning time were studied.

B. Harvest Sites

In 1980 two orchards were employed, the Michigan State University Horticulture Research Center in East Lansing and the Graham Experiment Station near Grand Rapids. In 1981 the research was expanded to four orchards: three commercial orchards from the Grand Rapids area of Michigan (Rasch, Thome and Reister) and the Graham Experiment Station. Different blocks were used at the Graham Station in 1980 and 1981 which had different sites and tree age. In 1982 8 orchards were researched. The 4 identical blocks (and trees) from the 1981 study were used in 1982 in the Grand Rapids area. Four other orchards were harvested in Southwest Michigan (Biaers, Berrybrook, Buskirk A and Buskirk B). A code used throughout the thesis is listed below:

Orchard Code	Orchard Code
1980	1982
#1 - Horticulture Research Center	A, B, C, D - same as 1981
#2 - Graham Experiment Station	E - Buskirk's A Orchard
1981	F - Buskirk's B Orchard
A - Rasch's Orchard	G - Berrybrook Farms
B - Thome's Orchard	H - Biaers' Orchard
C - Reister's Orchard	
D - Graham Experiment Station	

C. Harvesting

Random samples of about 50 lbs. of fruit were picked at weekly intervals from each of four trees sectioned into quadrants. A new quadrant was used for each harvest. The first sample was taken before normal commercial harvest (final stages of skin chlorophyll degradation) and the last at least one week after commercial harvest when the fruits were approaching an overripe condition for fresh market. The number of fruits in each sample was recorded and fruits from each tree were weighed in order to determine the change in average fruit size.

The harvest dates were as follows: 1980 - Sept. 2, 9, 16 and 23; 1981 - Aug. 27, Sept. 3, 10 and 17; 1982 (southwest area) - Aug. 19, 26 and Sept. 3; 1982 (Grand Rapids area) - Aug. 30, Sept. 6 and 13. Fruit of the last harvest in 1980 was not used for maturity experiments as it was overripe; however, weight measurements were taken.

D. Main Treatments

Readings for harvest maturity were obtained as soon as the fruit was transferred to the laboratory. Fruit for storage treatment was immediately placed in refrigerated storage at 0°C and 90% relative humidity. Times of storage were 0, 2, 4 and 6 weeks in 1980. This was reduced to 0, 2 and 4 weeks in 1981 as the majority of the ripening transformations had occurred within four weeks. In 1982 storage treatments were not performed.

At harvest and after storage, samples of fruits were conditioned for various lengths of time at 20°C (room temperature) to assess shelf-life of the fruit during retailing. Times were 0, 2 and 4 days in 1980; 0, 2, 4 and 6 days in 1981 and 1, 3, 5 and 7 days in 1982. Throughout the thesis this treatment will be referred to as conditioning. In 1980, samples of fruits were gassed with 100 ppm ethylene during the postharvest and poststorage conditioning treatments. Utilizing flow boards and capillary tubes, 120 fruit from each orchard-harvest-storage combination were placed in 10 liter desiccators and 100 ppm of ethylene in air was administrated at a flow rate of about 100 ml/min. Non-treated controls were maintained in desiccators in flowing air, scrubbed free of ethylene. Fruits were examined every other day according to conditioning times to assess the effect of ethylene treatment at harvest and after storage.

E. Evaluation of Maturity

In 1980 the following parameters were used to measure maturity: 1) skin color, 2) soluble solids, 3) percent titratable acidity, 4) flesh firmness, 5) soluble solids:acid ratio, 6) pit removal force and 7) weight. In 1981 all but the last two parameters were used, while in 1982 only soluble solids and firmness were used. In all 3 years ethylene measurements were made and will be discussed in the next section.

Skin color was measured objectively by extraction of skin pigments. Small discs of skin tissue were obtained from the larger cheek of plums by cutting the skin with a 1.27 cm diameter cork borer and removing the disc and a thin layer of flesh with a razor. Then discs were placed in a test tube and anthocyanin extracted with 10% oxalic acid over a period of three days at 5°C. Absorbance at 515 nm was read with a spectophotometer and expressed as units O.D. In 1980 one disc per fruit was extracted with 10 ml of oxalic acid solution. In 1981, ten discs (one from each of 10 fruits) were extracted with 10 ml of acid. The pigmented solution was then diluted with nine volumes of 10% oxalic acid to be similar in absorbance to the 1980 readings. Three reps of ten discs were read in 1981.

In order to determine the adherence of the pit to the flesh as affected by maturity, a system was devised for measuring the pit removal force. Plums were cut transversely, approximately 1 cm from the stem end near the point where the pit tapers. The skin was then cut at the distal end to facilitate pit excision and the fruit positioned longitudinally in a rubber cup. A 7/16 inch plunger with a concave surface was installed on an Effegi firmness tester and used to measure the force required to expel the pit from the opening at the base of the fruit. The force required to remove the pit was recorded in pounds and is termed the pit removal force. This measurement was done in 1980 but not repeated in 1981 or 1982. This index is similar to flesh firmness in that it is measured with the same instrument and is a rough indicator of the cell wall changes a plum is undergoing. It does perhaps give a closer picture of the internal plum ripening as the flesh firmness measures only the outer 1 cm of the flesh.

Soluble solids were measured with a Bausch and Lomb ABBE-3L refractometer. After the firmness test was completed, 1-3 drops of juice from each fruit were transferred to the prism of the refractometer. Individual plums were used in 1980, while in 1981 and 1982, 2 drops of juice were collected from each plum in the 10 or 8 plum sample and pooled as one replication.

Titratable acidity was determined by titrating to pH 8.1 with 0.1 N sodium hydroxide and is expressed as malic acid equivalents. Because of time limitations, fruits were frozen at -20°C and acidity measurements were made several weeks after harvest. Pitted plums were removed from the freezer, weighed, boiled in 100 ml of distilled water and blended for two minutes in a Waring blendor at high speed. Titration was done after cooling and acidity computed as grams of acid per 100 grams of flesh weight. In 1980 data were recorded for individual plums while in 1981 a 1/10th slice was taken from each of ten plums and the pooled sample was used as one replication.

In 1980, in order to determine the weight losses due to storage, conditioning or ethylene treatments, 10 plums were weighed after their respective treatments and the mean used for statistical analysis.

F. Measuring Ethylene and Carbon Dioxide

Ethylene and carbon dioxide evolution was measured in 1980 by holding individual plums in one pint jars equipped with inlet and outlet ports. Ten plums were used per treatment. Half of the fruits in each treatment were exposed to air streams containing 100 ppm ethylene (plus or minus 5 ppm) at 10 ml per minute, and half of them exposed to ethylene-free air at the same rate. Flow boards and capillary tubes were utilized to obtain the proper gas mixture. Ethylene and CO_2 production were monitored by gas chromatography in 1 ml gas samples at one to two day intervals and the rates were expressed as ul/kg/hr and ml/kg/hr for ethylene and CO_2, respectively.

In 1981 and 1982, samples of ten plums were placed at 20°C in nearly air tight 2.6 liter plastic containers equipped with a serum stopper for gas sampling with a syringe. A 50 gram paper envelope of dry hydrated lime was placed in each container to absorb CO_2. This closed system allowed ethylene to accumulate and in the absence of CO_2 (an inhibitor of ethylene action) so that autocatalytic ethylene production could be induced. Oxygen was partially depleted in the containers but did not fall below 14% due to O_2 moving through the seal. CO_2 levels were checked periodically but did not rise above 2% due to $Ca(OH)_2$ scrubbing. There was an undeterminable leakage of ethylene out so that readings could not reflect real production rates but only relative changes in this semi-closed system. Gas samples of one ml were taken daily and analyzed for ethylene and CO_2 by gas chromatography. In 1981 a four container sample for each harvest x location treatment was used. This was increased to six containers in 1982.

Upon observation that short chilling treatments advanced ethylene production in closed containers, several auxillary experiments were performed in 1982. Plums were given treatments at 0 or 5°C for various lengths of time, from 3 to 70 hours, before being placed in containers. Ethylene production was measured as above.

G. Evaluation of Quality of Canned Product

In the first two years of the study (1980 and 1981) fruits of the same lots used for ripening measurements were hot pack processed in No. 303 cans for future taste panel evaluation. In 1980, fruit from each harvest and orchard combination received storage treatments in addition to a gassing treatment with ethylene. Because of time and logistical limitations, all 1980 fruits were held for six days at room temperature prior to processing.

In 1981, a similar scheme was utilized, but room temperature conditioning periods of 0, 2, 4 and 6 days were used as treatments prior to canning. Due to time limitations, only fruit of two weeks storage was evaluated in 1981. After conditioning, plums were halved and pitted using a manual pitter with cups and blades from a German Herbort plum pitter. Plums were pitted singly and the pit and waste flesh and juice collected and weighed. Pitting loss as a percentage of original weight was calculated for each treatment.

Three hundred grams of plums were placed in each #303 can and filled with a boiling sugar syrup. In 1980 a 30% brix was used but this was dropped to 20% brix in 1981 to eliminate potential masking effects of heavy syrups on flavor. Cans were heated in a water bath to 90°C to exhaust gas. After sealing, the cans were processed in a boiling water bath for ten minutes and immediately cooled in cold tap water for about 15 minutes. Three cans per treatment were processed.

In 1980 only, prior to canning, plum halves were analyzed on the Hunter color meter. The color values of plums were compared to a standard red plate on all 3 scales of the meter: L, dark to light value; A, green to red value; B, yellow to blue value. Approximately 6 to 10 plum halves were placed in the reading cup with the skin side exposed to the light source. Plums were rotated and 3 replications were made per treatment.

In both years drained weights were recorded for the canned fruits about 6 months after processing. Each can of plums was drained for two minutes on a U. S. Standard Seive Series screen, 0.0937 inch opening. The drained weights were not replicated and were recorded in grams.

Canned fruit of both harvest years and on fresh fruit of the 1981 season was evaluated at the taste panel labs of Michigan State University's Food Science Department. Ten panelists per treatment were selected from students, faculty and staff of MSU's Horticulture and Food Science Departments. Panelists were given a random selection of six treatments to evaluate. Different panelists scored each group of six so that no panelist was used for tasting and comparing all treatments. In 1981 the following parameters were rated: 1) texture, 2) flavor, 3) acidity, 4) color, 5) sweetness, and 6) overall quality. All scales except the last had a plus and minus range, e. g., texture ranged from too soft to too firm. The judgements of each panelist were translated into quantitative scores and the mean of the ten panelists was used as the treatment score. There was no replication.

H. Evaluation of Quality of Fresh Plums

In 1981 a second taste panel similar to 1980's evaluated the fresh product. In order to compare different harvest dates at the same sitting, fruits were kept in cold storage until the last harvest. Then fruits of all four harvests were compared with each other. Fruits from earlier harvests were therefore stored longer than those from later harvests. This design handicap will be considered when weighing the results.

Taste panels evaluated fresh plums from 12 treatments; four harvest dates and three conditioning times (0, 3 and 6 days). Storage treatments were excluded due to the design problems as indicated above. Data for each orchard were analyzed separately.

I. Mean Separation

Most of the 1980 data and some of the 1981 data were not replicated; therefore the mean square error consisted of four and five way interactions of major treatments. Least significant difference (LSD) and honestly significant difference (HSD) are expressed with bars in each figure at the 5% level. Discussion of significant differences refer to the LSD's. In all cases the LSD and the HSD apply to all means (points visible in the graph), and are not limited to separation of one main effect.

RESULTS AND DISCUSSION

A. Section I: Maturity Indices - Evaluating Parameters that Assess Optimum Harvest Date

1. Introduction

In order to harvest plums for optimum quality and storagability, maturity indices must be selected with the following criteria: 1) effectiveness and reliability; 2) broad applicability over varying locations and seasons; 3) economical; 4) accessible to growers; 5) quick and 6) in line with physiological changes in the plums.

Five primary maturity indices were observed throughout harvests in 1980 and 1981. These include; color, firmness, soluble solids, acidity and ease of pit removal. The data of this section is organized in paired graphs to illustrate two aspects of harvest date effects. The first graph of each pair shows the direct effects of harvest date only. The second graph of each pair shows the main effects of harvest date (as pooled over postharvest treatments of conditioning and storage). Data for each season is presented in an individual graph.

2. Rationale for Seasonal Analysis

Before examining the data for each index, an important generality can be drawn about data from Orchard #1 in 1980:

with regard to all parameters, fruits of Orchard #1 were considerably advanced in comparison with those from Orchard #2 and all four orchards of 1981. This is particularly true with respect to color and soluble solids. This orchard was the only one atypical of a commercial operation: poor weed, insect and disease control were evident along with declining vigor. The advanced age of the orchard coupled with these stresses induced early ripening of the fruit and limits the applicability of the data in comparison with other orchards. Thus, the data for the two years was not pooled, but is presented separately to avoid a bias in evaluating seasonal variation. It should be further pointed out that maturation occured about one week later in 1980 than in 1981; for example, the 3rd harvest of 1980 would most closely approximate the 4th harvest of 1981 in physiological maturity.

3. Skin Color

Color changes were generally gradual and OD values climbed nearly consistently with progressive harvests throughout both harvest seasons (Figures 1 and 2). An exception to this was a drop in color in the 4th harvest of 1980 (Figure 1). A possible explanantion for such a dip could be the dropping of more advanced fruit leaving the least mature ones attached. As mentioned earlier, color advancement was much more rapid in Orchard #1 than in the other orchards. Color increased with progressive harvest in most orchards. This was not the case, however, with the Graham Station fruit (orchards #2 and D) for either 1980 or 1981 (Figure 1).

By casual observation there was no correlation between the timing of a visible purple overcoloring and a notable increase in anthocyanin pigmentation. This visual skin color change preceeded commercial harvest by at least one week and occurred between the first and second harvest for most orchards. Looking at only three commercial orchards (A, B and C) in 1981, absorbance values approaching 1.00 roughly corresponded with commercial harvests (Figure 1). Color (both visable and extractable pigments) changes with conditioning and storage (to be discussed later), so that color levels of fruit immediately after picking are not critical in deciding the optimal timing of harvest. In addition, complicated instrumentaion, location and seasonal variation, along with very gradual changes over time, limits the use of a color index as a worthwhile harvest indicator.

Figure 1. Effects of the time of harvest and source of fruit on pigment content of skin of 'Stanley' plum at time of harvest in 1980 and 1981.

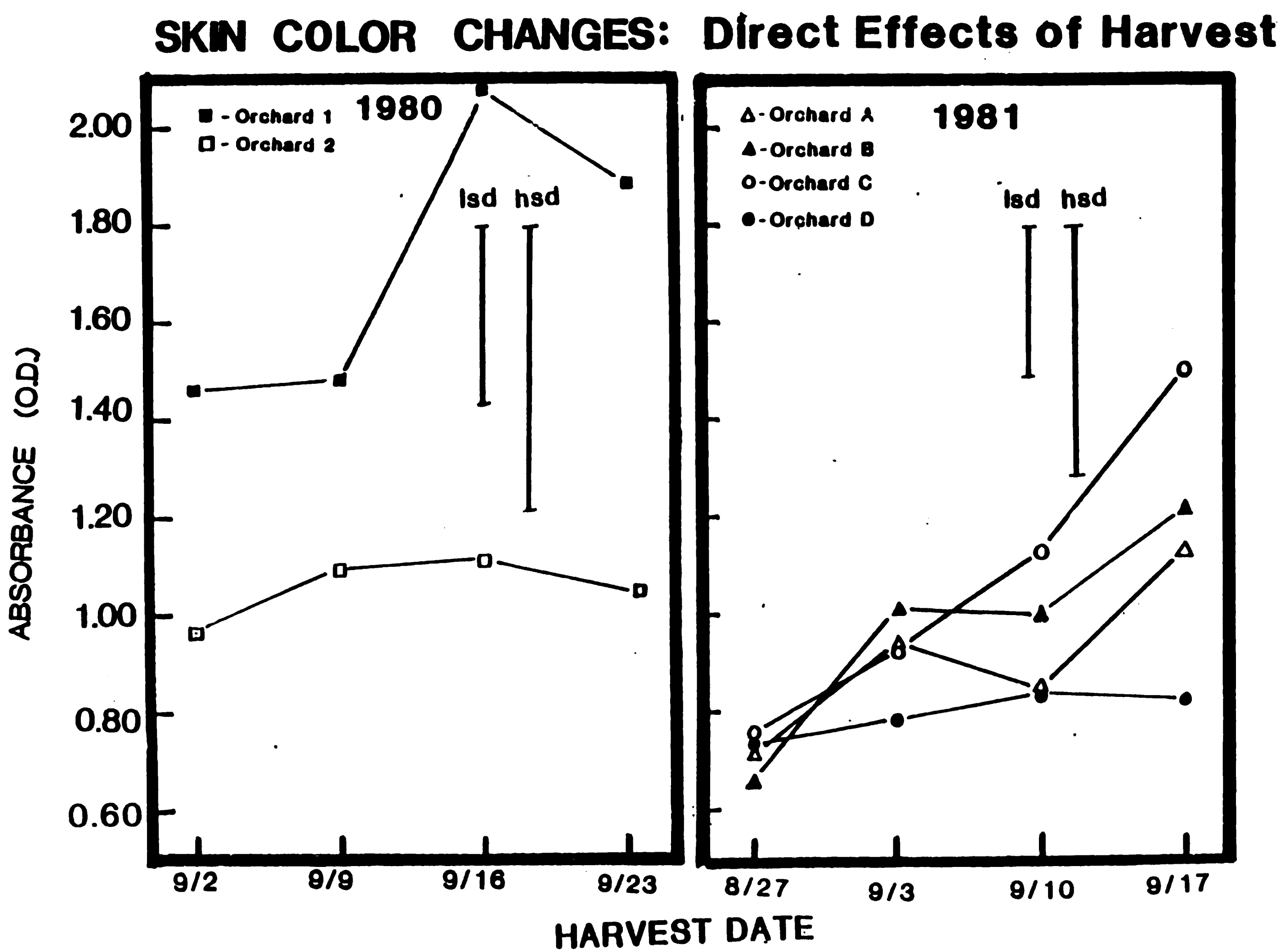

SKIN COLOR CHANGES: Direct Effects of Harvest
■ - Orchard 1
□ - Orchard 2
1980
lsd hsd
Δ - Orchard A
▲ - Orchard B
O - Orchard C
● - Orchard D
1981
lsd hsd
ABSORBANCE (O.D.)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
9/2
9/9
9/16
9/23
8/27
9/3
9/10
9/17
HARVEST DATE

Figure 1

Figure 2. Effects of time of harvest and source of fruit on pigment content of skin of 'Stanley plum in 1980 and 1981. Means pooled over conditioning and storage time.

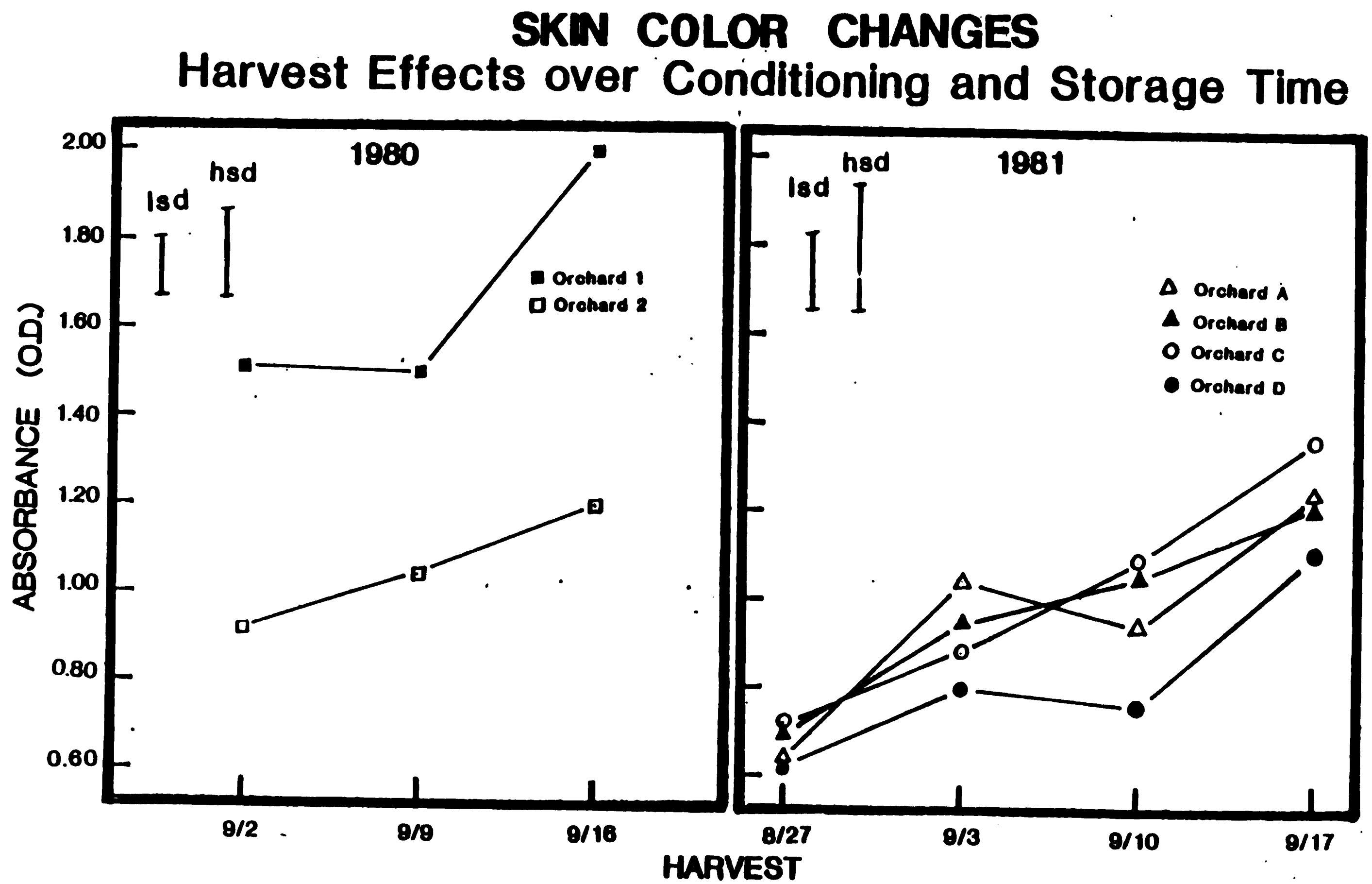

SKIN COLOR CHANGES
Harvest Effects over Conditioning and Storage Time
ABSORBANCE (O.D.)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
lsd
hsd
1980
Orchard 1
Orchard 2
9/2
9/9
9/16
1981
Orchard A
Orchard B
Orchard C
Orchard D
8/27
9/3
9/10
9/17
HARVEST

Figure 2

4. Flesh Firmness

Flesh firmness levels consistantly fell as the harvest season progressed in both years, except for one orchard at the last harvest of 1981 (Figure 3). In both years and with both immediate and pooled harvest data, the effects of harvest date were nearly linear except for a slight plateauing of downward slopes at the last harvest.

Each succeeding harvest is significantly lower than the preceeding one through the first three harvests (Figures 3 and 4). There were also significant differences between orchards at the same harvest date in many cases (Figures 3 and 4). Commercial harvests commenced when flesh firmness ranged from 9 to 13 lbs. and proceeded until the firmness leveled at about 7 lbs. The relatively rapid decrease in flesh firmness as fruit mature, and the generally significant differences between successive harvests, indicate that flesh firmness has a strong potential as a workable index. Its relative ease and low cost add to this potential; however, sizeable plum to plum and orchard to orchard to orchard variability, along with mechanical errors in operation demand large sampling sizes.

Figure 3. Effects of the time of harvest and source of the fruit on flesh firmness of 'Stanley' plum at time of harvest in 1980 and 1981.

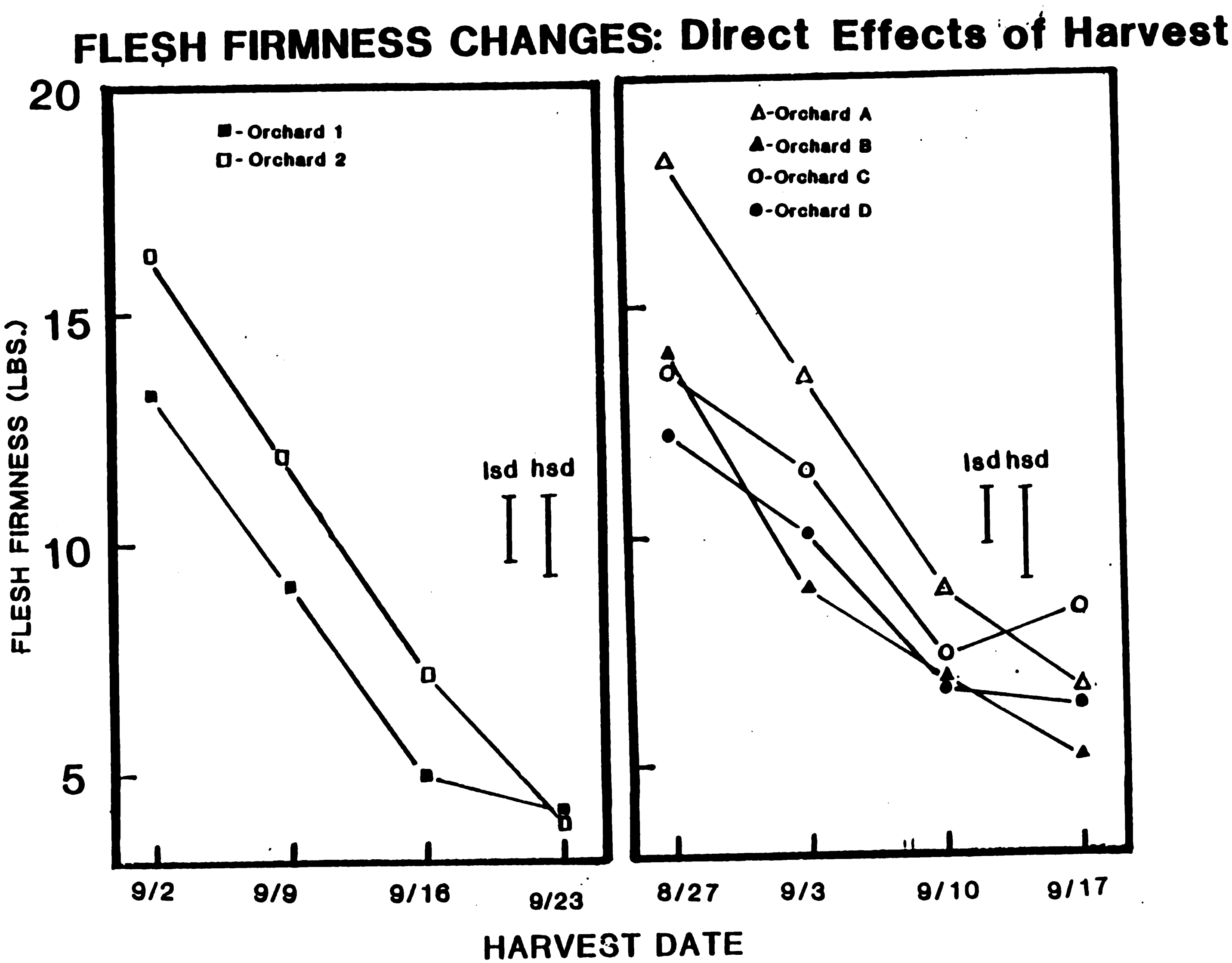

FLESH FIRMNESS CHANGES: Direct Effects of Harvest
FLESH FIRMNESS (LBS.)
20
15
10
5
■ - Orchard 1
□ - Orchard 2
lsd hsd
9/2
9/9
9/16
9/23
Δ-Orchard A
▲-Orchard B
O-Orchard C
●-Orchard D
lsd hsd
8/27
9/3
9/10
9/17
HARVEST DATE

Figure 3

Figure 4. Effects of time of harvest and source of fruit on flesh firmness of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning and storage time.

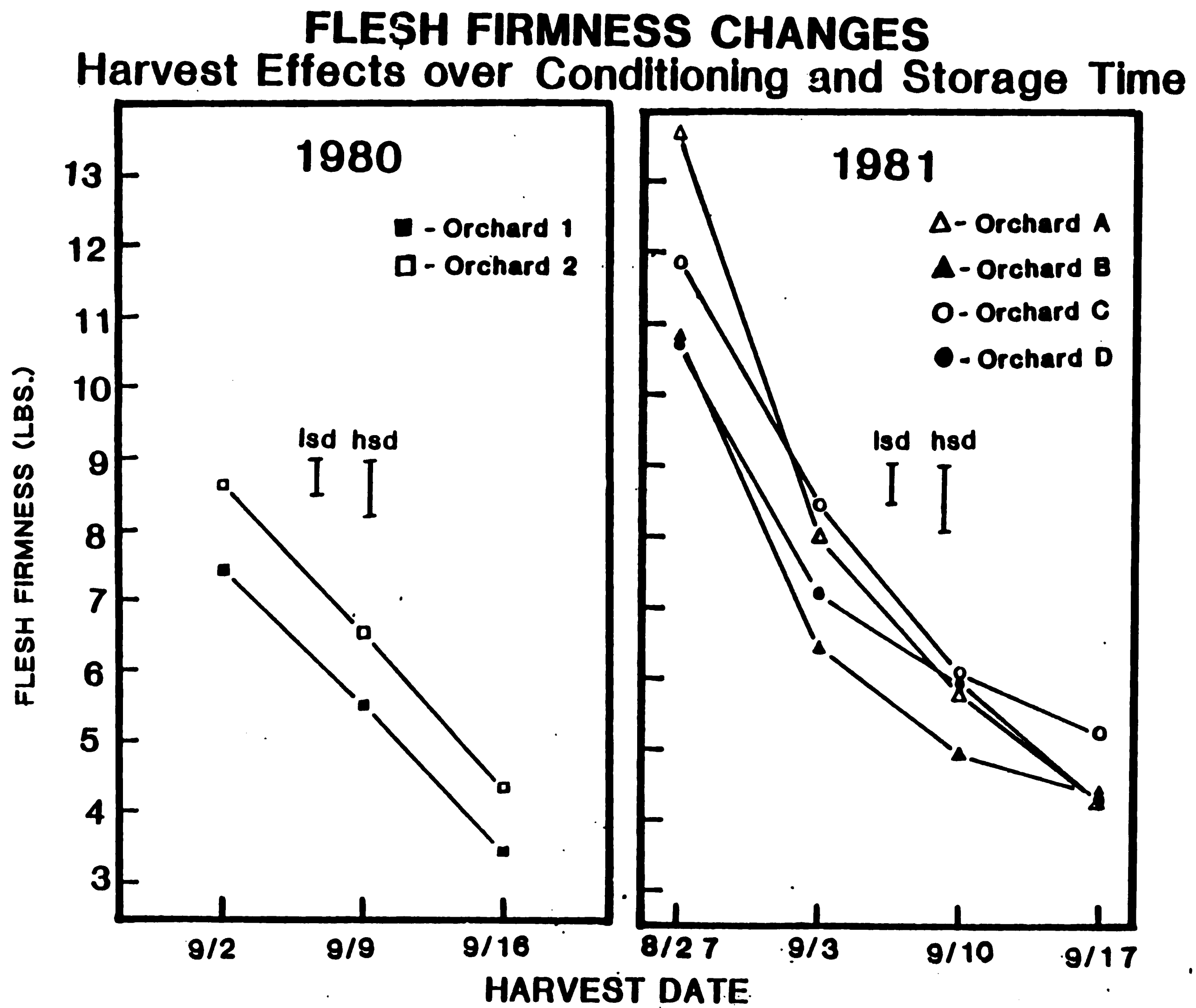

FLESH FIRMNESS CHANGES
Harvest Effects over Conditioning and Storage Time
1980
■ - Orchard 1
□ - Orchard 2
lsd hsd
1981
△ - Orchard A
▲ - Orchard B
○ - Orchard C
● - Orchard D
lsd hsd
FLESH FIRMNESS (LBS.)
13
12
11
10
9
8
7
6
5
4
3
9/2
9/9
9/16
8/27
9/3
9/10
9/17
HARVEST DATE

Figure 4

5. Pit Removal Force

Pit removal force generally paralleled the flesh firmness readings (compare Figures 3 with 5, and 4 with 6). Responses were basically linear with values 4-8 lbs. greater than the corresponding flesh firmness readings. An interesting exception to this decreasing slope was witnessed in the 2nd orchard between the 1st and 2nd harvests (Figure 5). Here the reading increased slightly followed by a rapid decrease by the next harvest period. From all physical parameters and additional subjective taste evaluations, the pit removal force decrease corresponded with the completion of maturation of the plums from this 2nd orchard, whereas these changes had occurred in the 1st orchard somewhat earlier. There was basically no separation of orchards with the LSD. There were significant differences with respect to harvest date (Figure 5). The rapid decreases in pit removal force (Figure 5: Orchard 1 - 1st and 2nd harvest; Orchard 2 - 2nd harvest) appears to correspond with accelerated maturation of the internal flesh of the fruit and provides a good indicator of ripening.

The pooled data show that the main effects of harvest date also significantly decreased with each progressive harvest (Figure 6). Here, however, the orchard differences were larger than those of the direct harvest data, reflecting the general advanced condition of Orchard #1.

Figure 5. Effects of the time of harvest and source of the fruit on pit removal force of 'Stanley' plum at time of harvest in 1980 and 1981.

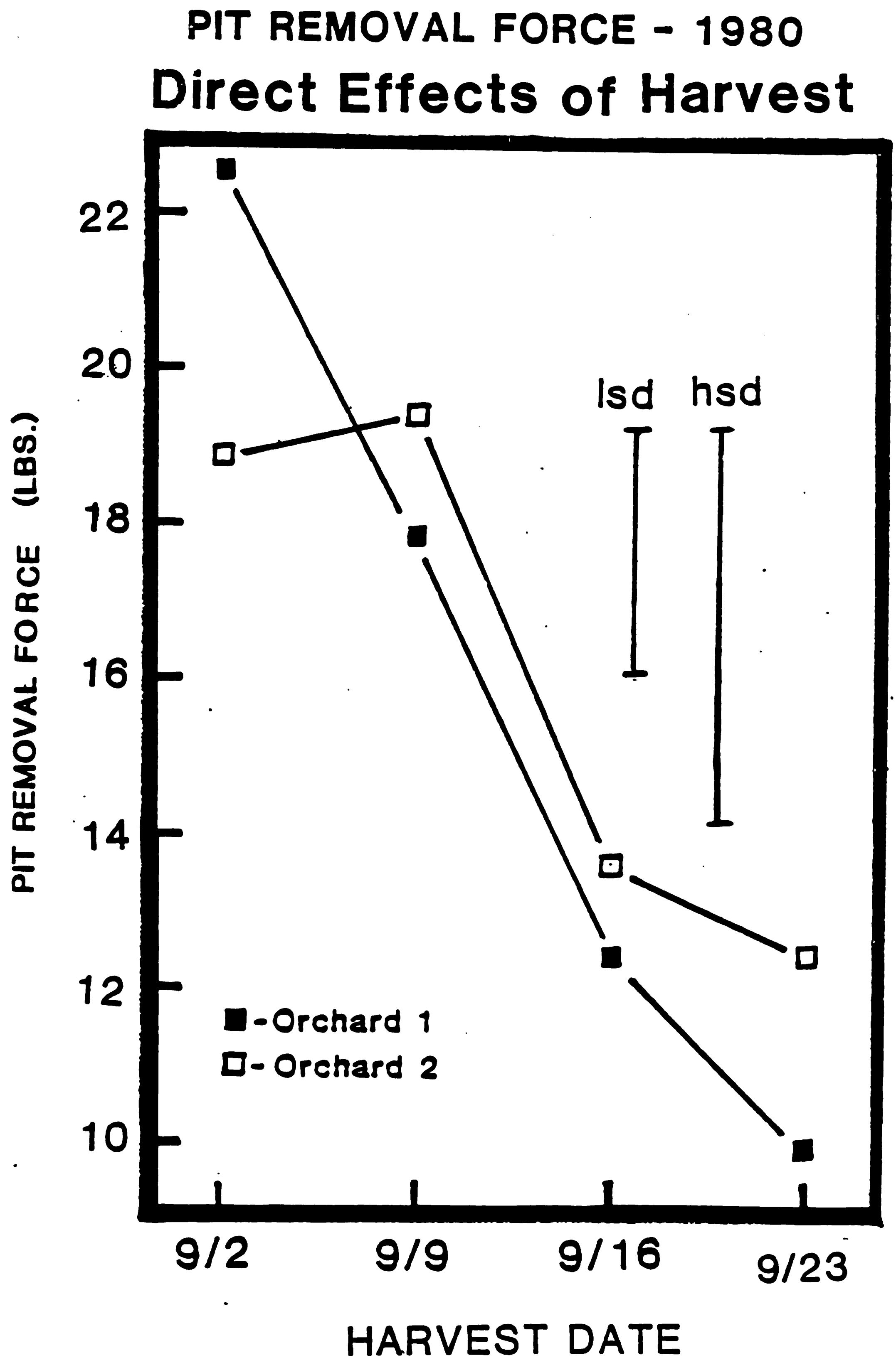

PIT REMOVAL FORCE - 1980
Direct Effects of Harvest
22
20
18
16
14
12
10
PIT REMOVAL FORCE (LBS.)
lsd
hsd
■-Orchard 1
□-Orchard 2
9/2
9/9
9/16
9/23
HARVEST DATE

Figure 5

Figure 6. Effects of time of harvest and source of fruit on pit removal force of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning and storage time.

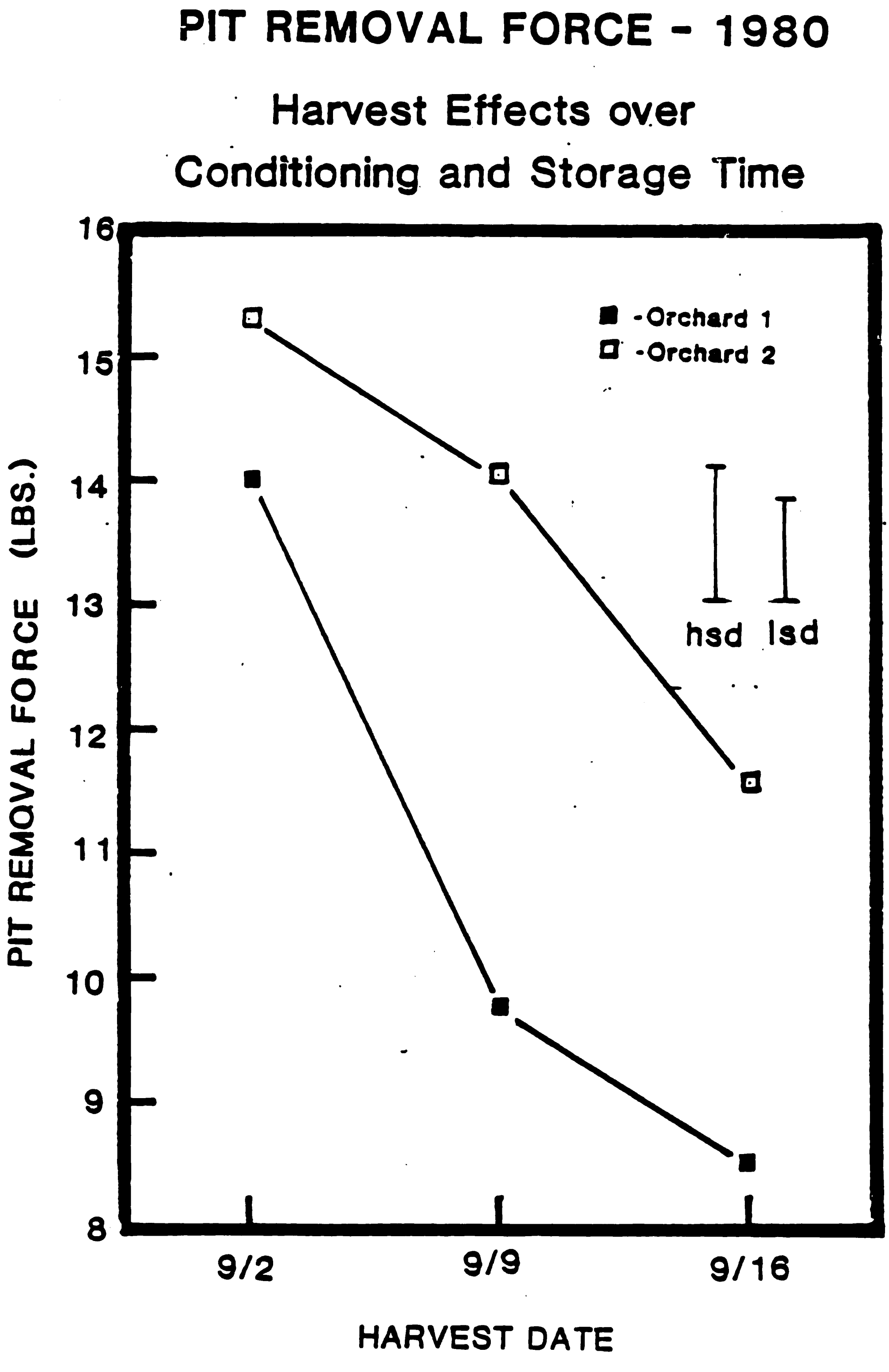

PIT REMOVAL FORCE - 1980
Harvest Effects over
Conditioning and Storage Time
-Orchard 1
-Orchard 2
hsd
lsd
PIT REMOVAL FORCE (LBS.)
16
15
14
13
12
11
10
9
8
9/2
9/9
9/16
HARVEST DATE

Figure 6

Despite the potential of this indicator, it was discontinued in 1981 since it gave similar results to flesh firmness and was more involved and time consuming. However, it is clearly as workable as flesh firmness and is a good indicator of cell wall changes within the flesh.

6. Soluble Solids

Soluble solids levels also displayed rapid changes as the season progressed. In both data sets, with successive harvests, soluble solids increased during the two seasons except in one orchard at the 4th harvest of 1980. This may have been due to ripe fruit dropping in the more advanced Orchard #1.

Utilizing the LSD's in the direct harvest data of 1981 (Figure 7), all locations showed a significant increase in soluble solids with later harvests while in most cases this was not evident with each progressive harvest. Using mean separation in 1980, there was little significance with respect to harvest due to the large variation between individual plums. Also, there was little separation in the orchard means. In contrast there was strong harvest separation in the pooled data in 1980 and 1981 (Figure 8), with strong orchard separation in 1980 but not 1981.

As indicated earlier, Orchard #1 (1980) was greatly advanced over the others in soluble solids development. Excluding Orchard #1's data, the commercial harvests of the other 5 orchards (1980-81) commenced when soluble solids readings approached the

Figure 7. Effects of time of harvest and source of fruit on soluble solids of 'Stanley' plum at time of harvest in 1980 and 1981.

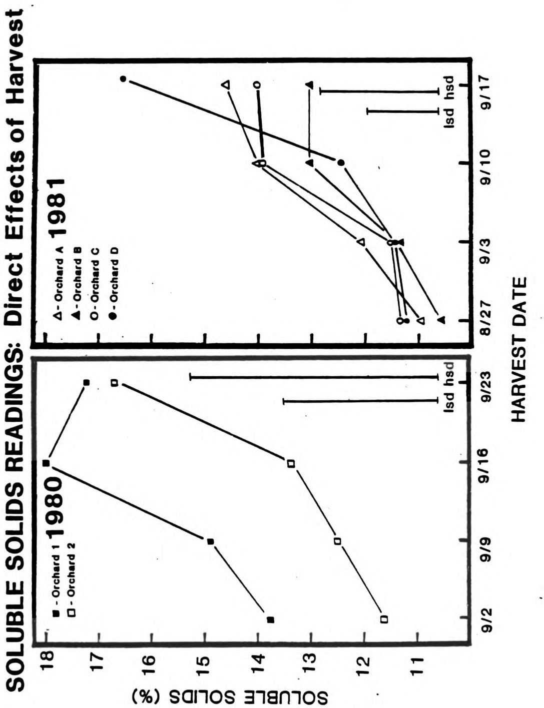

SOLUBLE SOLIDS READINGS: Direct Effects of Harvest
SOLUBLE SOLIDS (%)
18
17
16
15
14
13
12
11
1980
■ - Orchard 1
□ - Orchard 2
9/2
9/9
9/16
9/23
lsd hsd
1981
Δ - Orchard A
▲ - Orchard B
O - Orchard C
● - Orchard D
8/27
9/3
9/10
9/17
lsd hsd
HARVEST DATE

Figure 7

Figure 8. Effects of time of harvest and source of fruit on soluble solids of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning and storage time.

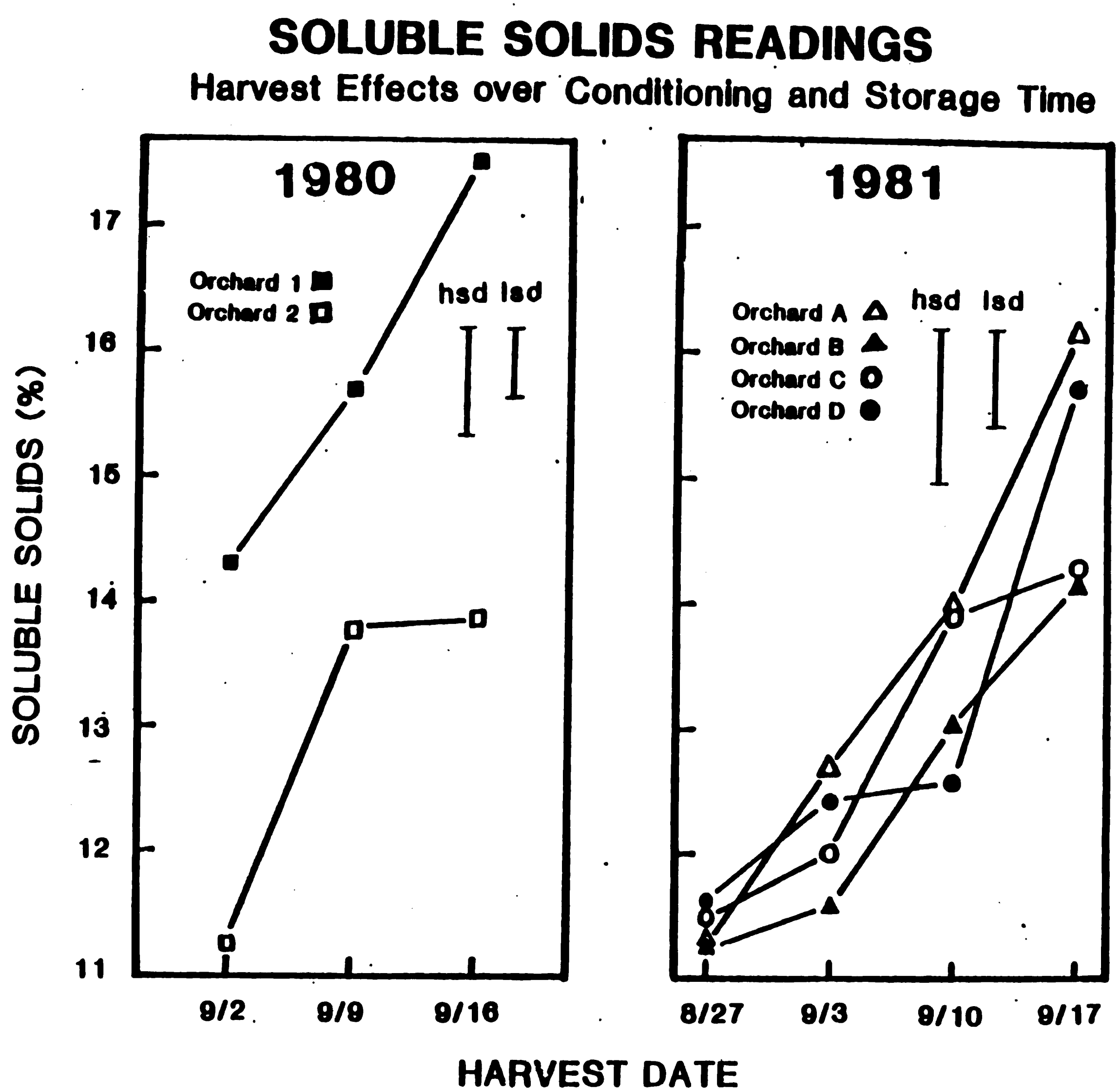

SOLUBLE SOLIDS READINGS
Harvest Effects over Conditioning and Storage Time
1980
1981
Orchard 1
Orchard 2
Orchard A
Orchard B
Orchard C
Orchard D
hsd lsd
hsd lsd
SOLUBLE SOLIDS (%)
17
16
15
14
13
12
11
9/2
9/9
9/16
8/27
9/3
9/10
9/17
HARVEST DATE

Figure 8

12-13% range. This parameter is applicable for harvest date determination for the following reasons: 1) it rises steadily throughout the harvest period; 2) it reflects significant differences in harvest date; 3) it utilizes a rapid and simple technique; 4) it is economical.

7. Acidity

In both 1980 and 1981 titratable acidity dropped as harvest progressed, with linear tendencies similar to the other parameters (Figures 9 and 10). The exception to this trend occurred in the immediate harvest effects (Figure 9) at the 4th harvest - 1980, where there was a considerable increase in acidity. Again, the probable cause for this unexpected rise could have been the drop of ripe fruit leaving a less ripe, more acid sample on the tree for harvest. For both sets of data (Figures 9 and 10) 1980's fruit was much lower in acidity than 1981's, demonstrating substantial seasonal variation. In the pooled data (Figure 10) there was a large variation between the two orchards of 1980 with Orchard #1 being again far advanced.

In 1981 acidity decreased significantly at each succeeding harvest. However, in 1980 the only significance occurs between the 2nd and 3rd harvest in Orchard #1. In the main effects of harvest date (Figure 10), there was nearly complete separation of means with respect to harvest in both years. The acidity levels which corresponded to the commencement of commercial harvesting ranged from 0.80 - 0.95%.

Figure 9. Effects of the time of harvest and source of fruit on titratable acidity of 'Stanley' plum at time of harvest in 1980 and 1981.

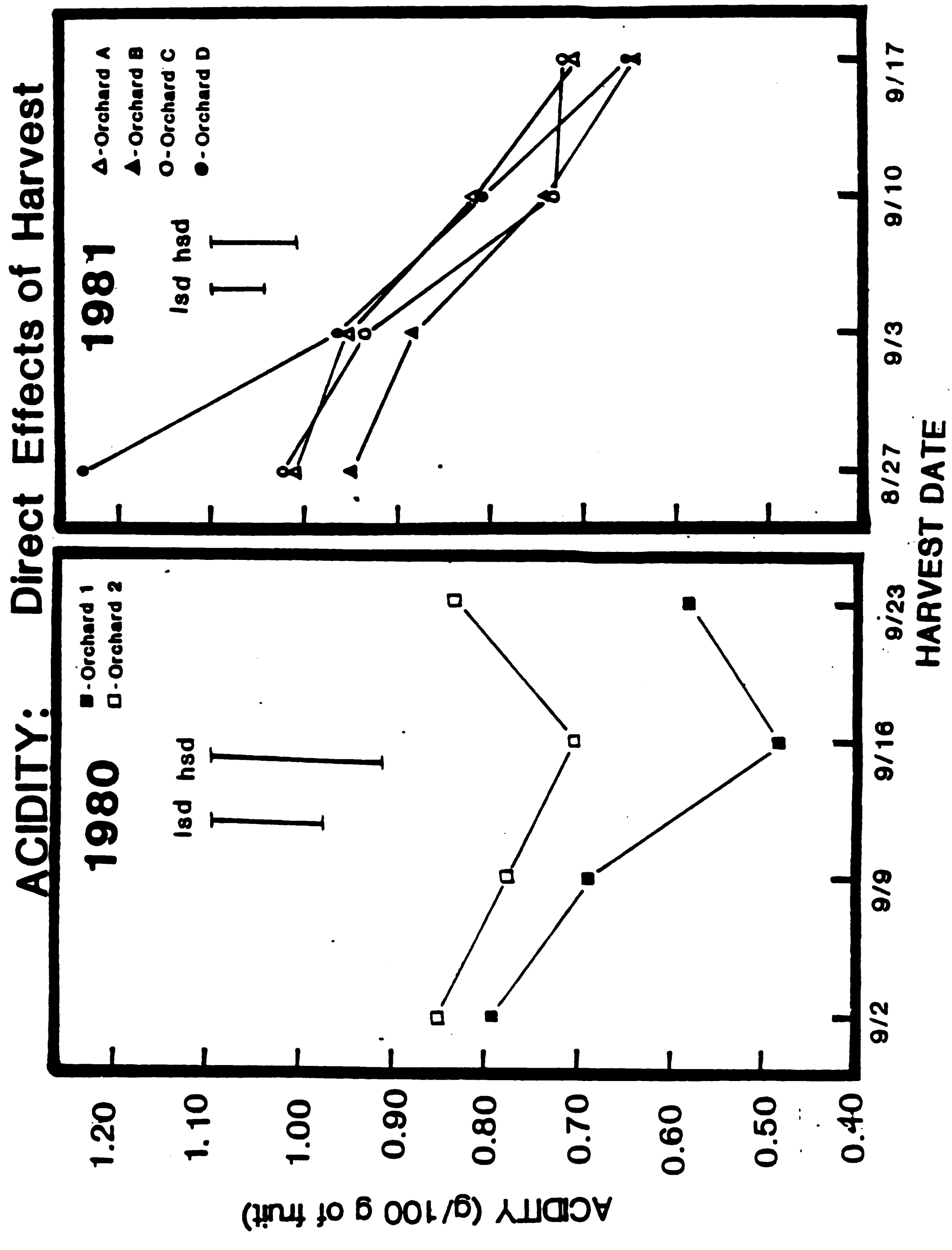

ACIDITY: Direct Effects of Harvest
1980
lsd hsd
■-Orchard 1
□-Orchard 2
1981
lsd hsd
Δ-Orchard A
▲-Orchard B
O-Orchard C
●-Orchard D
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
ACIDITY (g/100 g of fruit)
9/2
9/9
9/16
9/23
8/27
9/3
9/10
9/17
HARVEST DATE

Figure 9

Figure 10. Effects of time of harvest and source of fruit on titratable acidity of 'Stanley' plum in 1980 and 1981. Means pooled over storage and conditioning time.

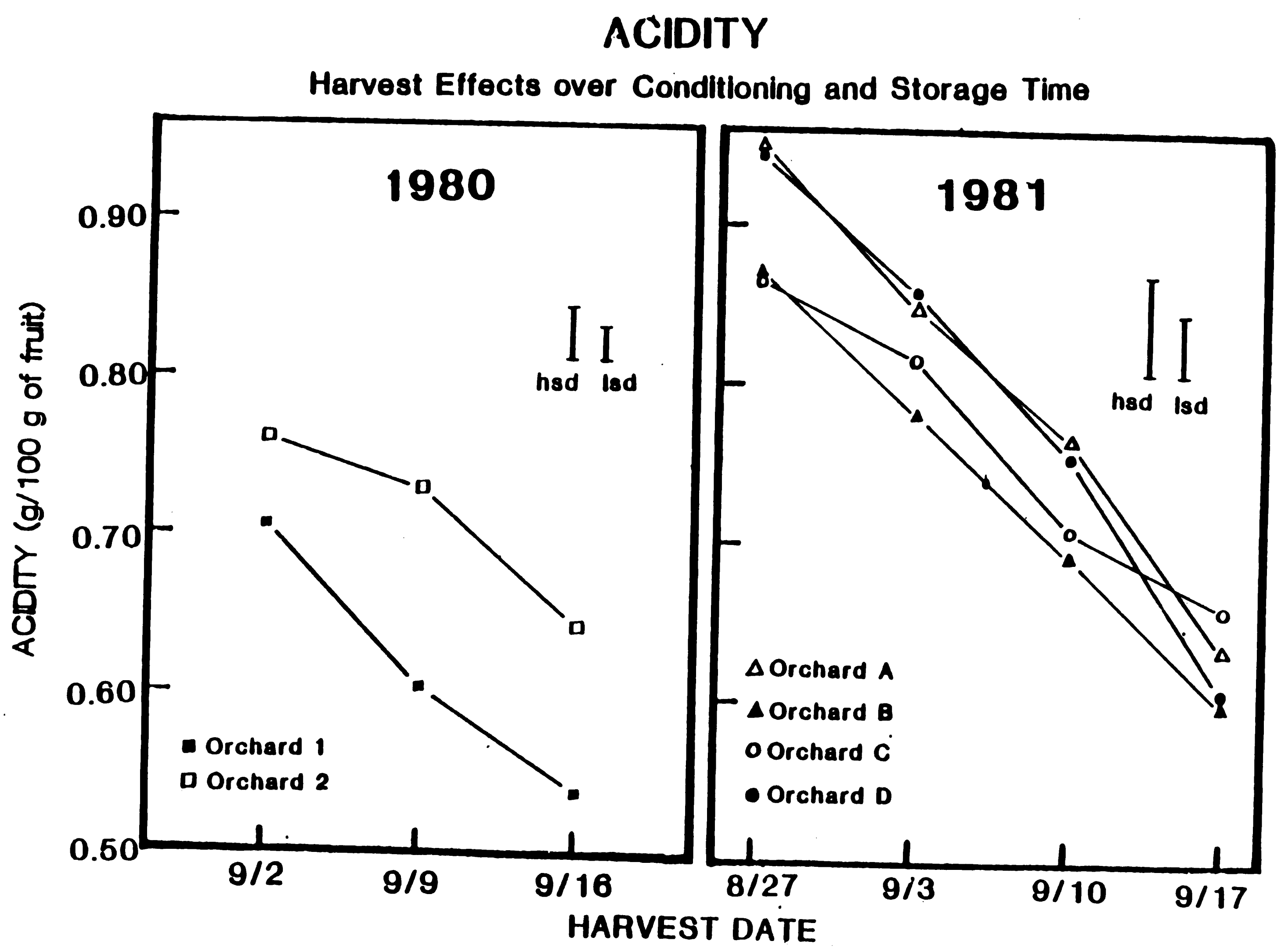

ACIDITY
Harvest Effects over Conditioning and Storage Time
1980
1981
ACIDITY (g/100 g of fruit)
0.90
0.80
0.70
0.60
0.50
hsd
lsd
hsd
lsd
Orchard 1
Orchard 2
Orchard A
Orchard B
Orchard C
Orchard D
9/2
9/9
9/16
8/27
9/3
9/10
9/17
HARVEST DATE

Figure 10

Acidity does show striking seasonal variation and substantial orchard variation. As with the other parameters, changes are gradual and there is no clear demarcation to separate mature from ripening fruit. The relative difficulties involved in making this index field accessible makes it of limited value for formulating grower recommendations. At best, acidity along with color might be used as backup information for the other parameters. When soluble solids to acid ratios were reviewed, they showed abnormal variations which did not correspond with plum quality changes. Therefore this index was omitted.

B. Section 2: Maturity Indices - The Effects of Postharvest Treatments

1. Introduction

The effects of the two major postharvest treatments, storage and room temperature conditioning are presented together and are arranged according to the five ripening parameters. In all cases the data represents main effects involving means pooled over 2 or 3 of the remaining treatments. Each harvest season's data is plotted separately in the graphs.

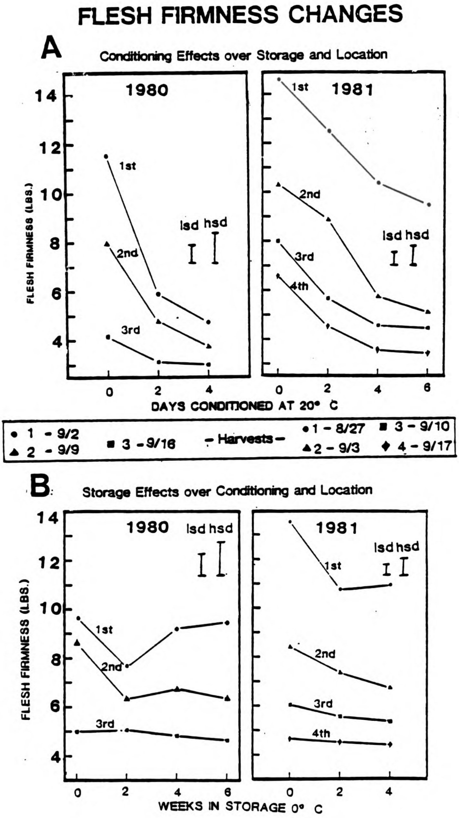
2. Flesh Firmness

In both years flesh firmness was significantly reduced by room temperature conditioning (Figure 11A). However, at longer conditioning periods (4 days 1980, 6 days 1981) there was a leveling in the firmness decreases and here some means were not significantly lower than the preceding conditioning treatment. The effect of conditioning on fruit texture (flesh firmness and pit removal) is one of the most pronounced of all postharvest treatments.

The effect of increasing cold storage periods on flesh firmness is less dramatic and exhibits a less parallel response (Figure 11B). Particularly in regard to seasonal changes, the two years' results are dissimilar. In 1981 there was a ripening trend for the fruit of the earlier harvests with additional

Figure 11A. Effects of conditioning and harvest date on flesh firmness of 'Stanley' plum in 1980 and 1981. Means pooled over storage and location.

Figure 11B. Effects of storage and harvest date on flesh firmness of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning and location.



Figures 11A and 11B

storage. In 1980, however, this trend was only apparent from zero to two weeks storage. Thereafter, the firmness either leveled or actually increased (in the case of the first harvest). In general there was a clear decrease in the flesh firmness of fruits from the two earlier harvests (both years) at two weeks duration.

3. Pit Removal Force

Pit removal force data were collected in the 1980 season only. Pit removal force data parallel flesh firmness with respect to both storage and conditioning effects. Conditioning, in particular, brought on steady decreases in the pit removal force. These reductions are most evident after two days, followed by a leveling at four days conditioning (Figure 12B).

The effects of storage on pit removal force resulted in both significant decreases and increases (Figure 12A). The major trend is for a drop or plateauing at two weeks storage, followed by a steady increase at four and six weeks. This was similar to some of the flesh firmness data discussed above, reinforcing the observation that there is a firming effect when fruits are stored for extended periods (4 - 6 weeks). While not visible from the graphs, there was an interaction of storage with conditioning. The high values at four and six weeks conditioning were not the result of the pit becomming more tightly bound to the flesh during storage, but rather due to the failure of the fruit to undergo normal flesh softening when long storage periods (4 - 6 weeks) were followed by

Figure 12A. Effects of conditioning and harvest date on pit removal force of 'Stanley' plum in 1980 and 1981. Means pooled over storage and location.

Figure 12B. Effects of storage and harvest date on pit removal force of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning and location.

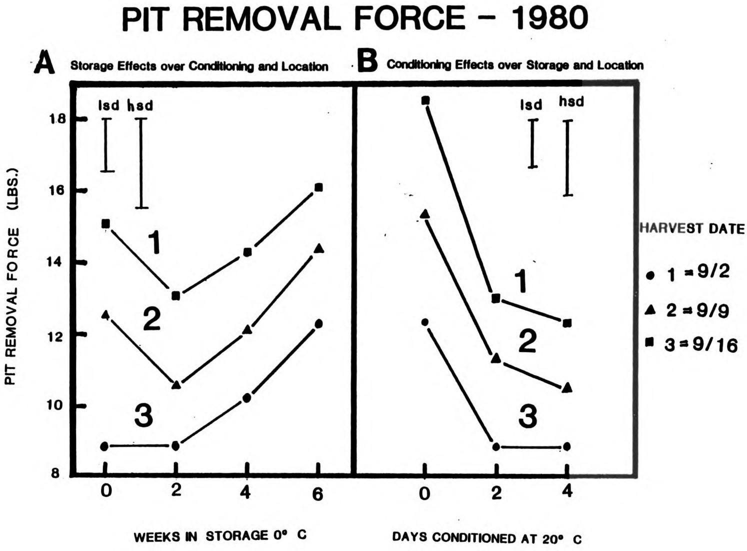


Figure 12A and 12B

conditioning for two to four days. When short storage was followed by conditioning, softening and smooth pit removal was enhanced. However, following long storage, conditioning treatments didn't change softening and pit removal.

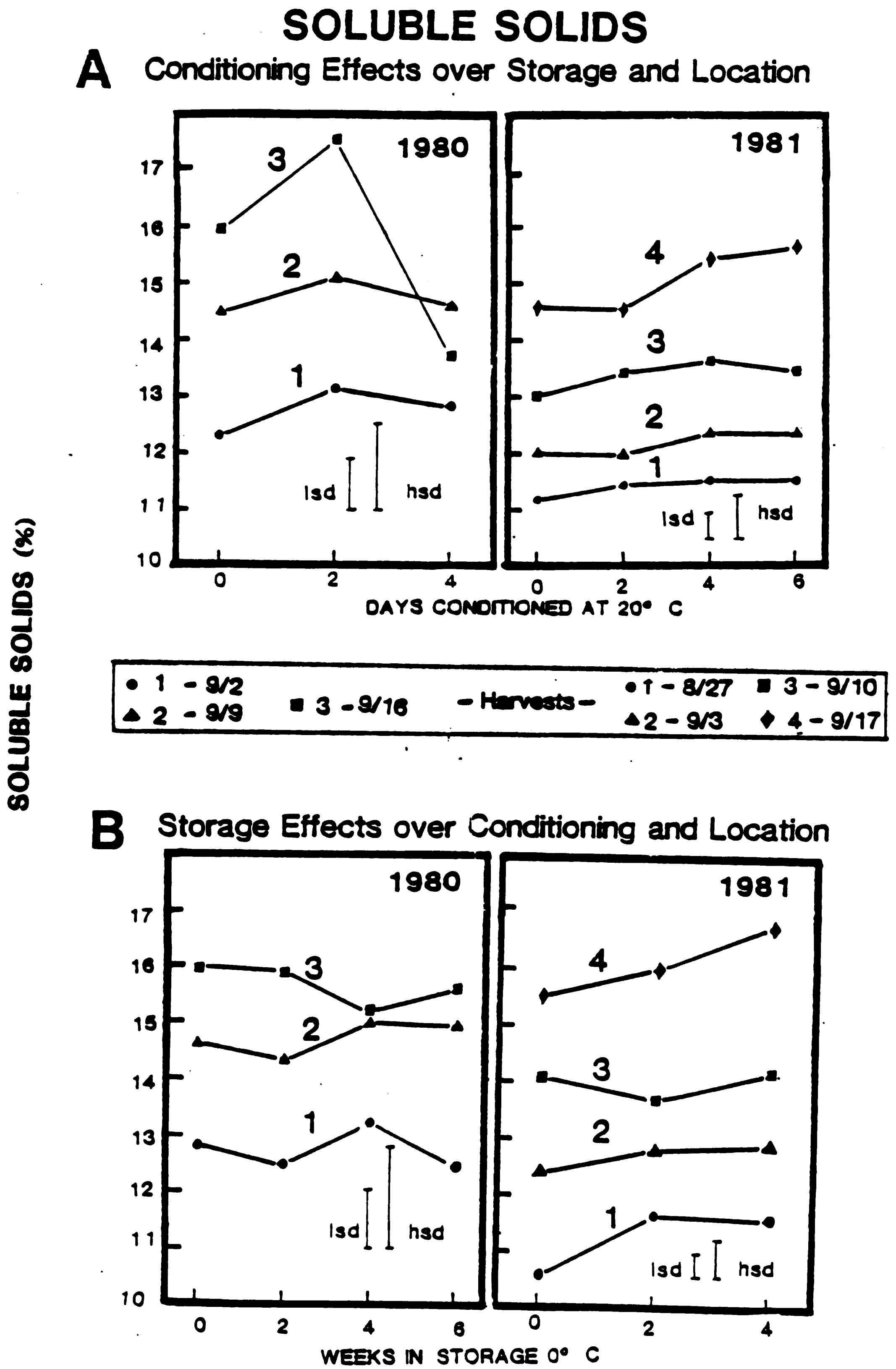
A possible hypothesis for such a phenomenon could be the loss of some of the enzyme systems involved in pectic changes during the prolonged storage periods. Since membranes can incur degenerative damages with prolonged cold storage (21), the activity of membrane bound enzymes could be reduced at long storages (4 and 6 weeks). Thus flesh softening would be retarded and prevent the smooth removal of the pit. The reduction of softening following prolonged storage reinforces the practice of holding plums for about a maximum of four weeks in standard cold storage and utilizing CA if longer storage life is desired. This firming trend (or reduction in softening) was also witnessed during the pitting process for canned plums, and will be discussed later.

4. Soluble Solids

The storage and conditioning effects were the least dominating on the variable of soluble solids when compared to the other 4 indices. This was particularly true of conditioning. In all harvests except the last (both 1980 and 1981 data) there was no significant difference between the soluble solids treatment means after various conditioning periods (Figure 13A). Storage,

Figure 13A. Effects of conditioning and harvest date on soluble solids of 'Stanley' plum in 1980 and 1981. Means pooled over storage and location.

Figure 13B. Effects of storage and harvest date on soluble solids of 'Stanley plum in 1980 and 1981. Means pooled over conditioning and location.



Figures 13A and 13B

also, had minor effects (Figure 13B). There was no change in soluble solids in 1980, but in 1981 soluble solids increased slightly during four weeks storage.

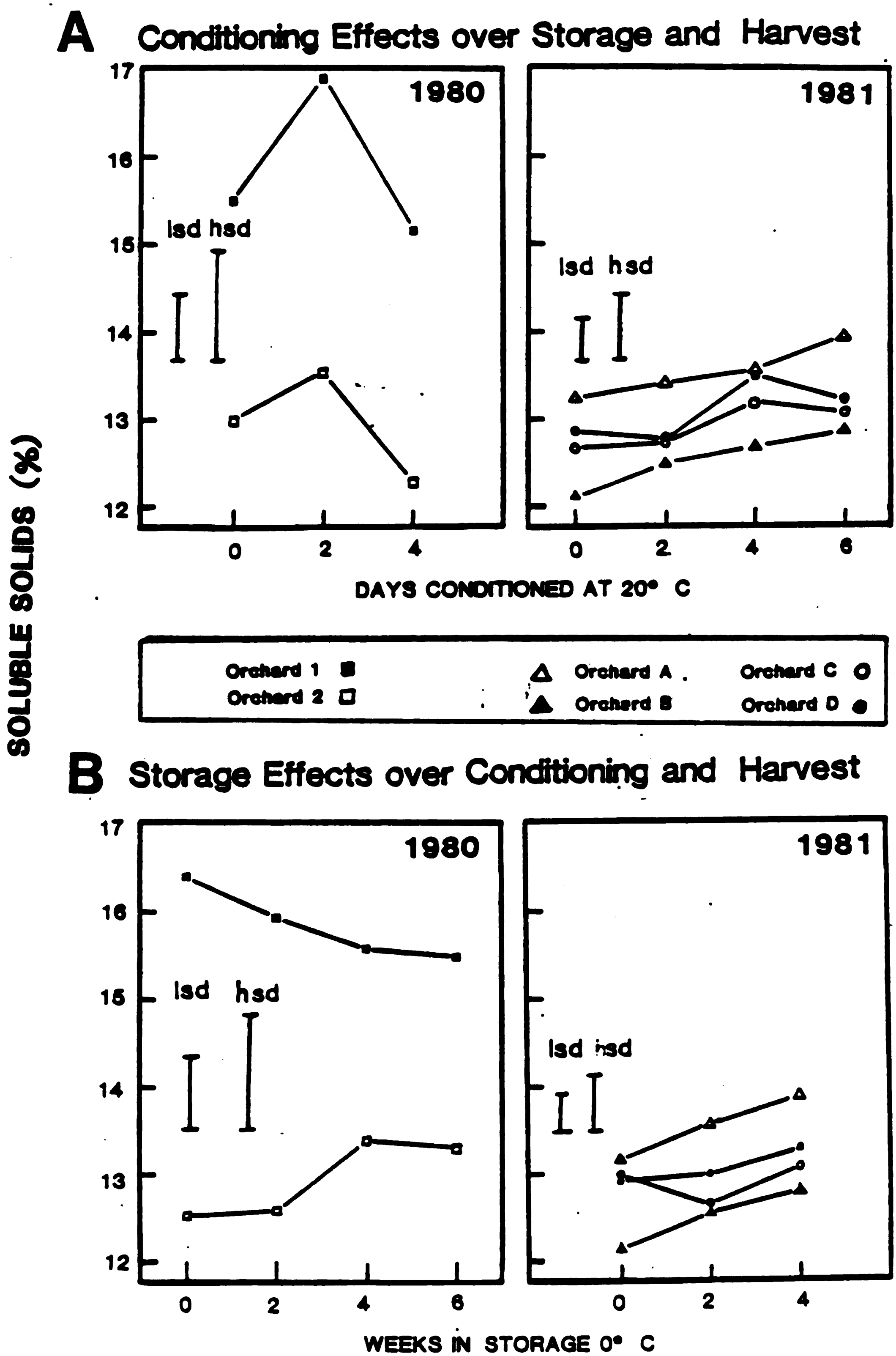
Since the effects of location had greater influence than either storage or conditioning, a second set of graphs has been added, breaking down conditioning and harvest treatments by location in order to illustrate postharvest treatment effects. In Figure 14, each line represents a different orchard. The data for 1981 again produced clearer trends than 1980, showing soluble solids increasing with days at room temperature (Figure 14A). Equally evident were some significant differences between orchards. The data of 1980 possibly suffers from sampling problems caused by pulpy fruit.

The storage data reflect similar trends with 1981's data showing a slight soluble solids increase with extended storage (Figure 14B). In 1980, fruits from the second orchard significantly increased in soluble solids while those from the first orchard continuously dropped, perhaps due to its highly advanced maturity compared to the other locations. These data suggest that desirable soluble solids levels are best achieved by selection of proper harvest date at a given location.

Figure 14A. Effects of conditioning and source of fruit on soluble solids of 'Stanley' plum in 1980 and 1981. Means are pooled over storage and location.

Figure 14B. Effects of storage and source of fruit on soluble solids of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning and harvest.

SOLUBLE SOLIDS READINGS



Figures 14A and 14B

5. Acidity

Acidity was decreased by storage and conditioning treatments (Figures 15A and 15B). The effect of conditioning on acidity was significant and acidity consistantly decreased in 1981 while it leveled at long conditioning periods in 1980 (Figure 15A). The effect of storage on acidity was also significant (Figure 15B). In 1981 there were consistent significant decreases with progressive harvests. In 1980 there were significant decreases only at 6 weeks storage as fruit acidity stayed relatively level up to 4 weeks storage.

Harvest date had equal or greater effects than either postharvest treatment in regulating acid levels. There were consistent significant decreases in acidity with progressive harvest in 1981 with similar trends in 1980.

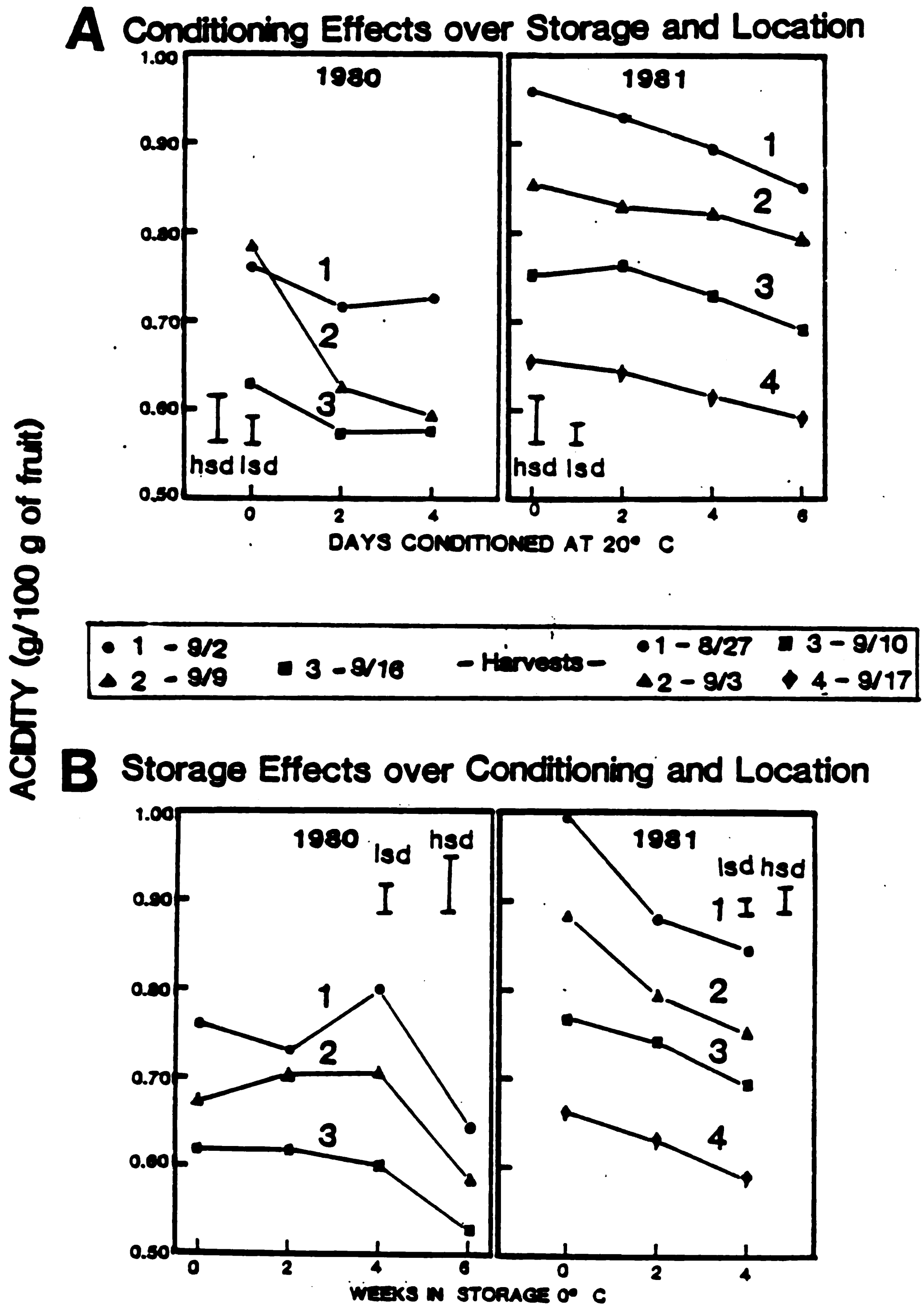
6. Skin Color

Skin color (extractable pigments), like flesh firmness. is a variable affected by the conditioning period. The data in Figure 16A are simply presented with conditioning main effects without the harvest lines plotted. In 1980 the increases are immediate; however, in 1981 the fruit did not advance until after the second day of conditioning. The general riper condition of the 1980 fruit might have been responsible in part for this. Outside of the changes in texture, skin color was the only parameter where conditioning

Figure 15A. Effects of conditioning and harvest date on titratable acidity of 'Stanley' plum in 1980 and 1981. Means pooled over storage and location.

Figure 15B. Effects of storage and harvest date on titrat-acidity of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning and location.

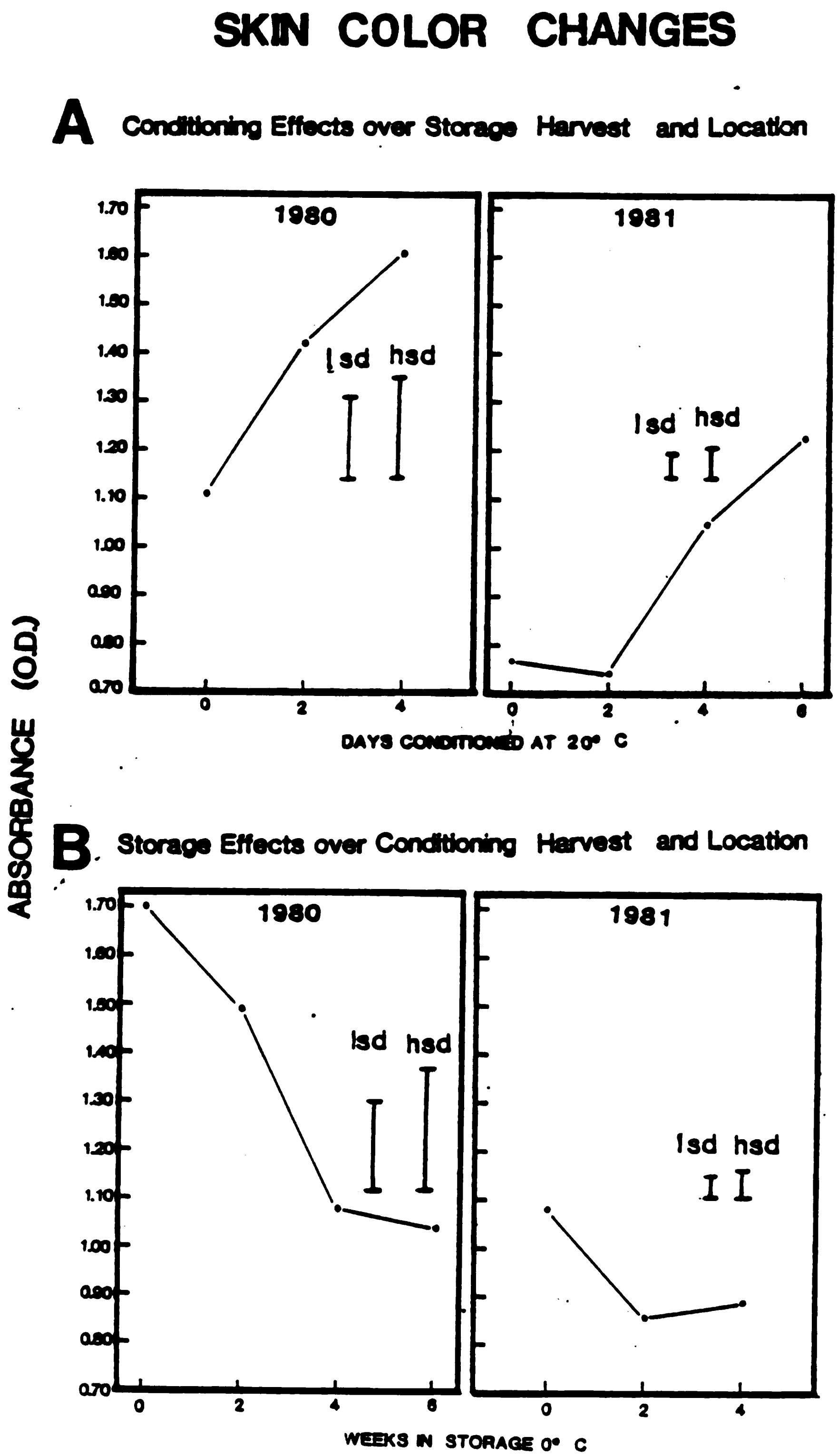
ACIDITY



Figures 15A and 15B

Figure 16A. Main effects of conditioning on skin color of 'Stanley' plum in 1980 and 1981. Means pooled over storage, harvest and location.

Figure 16B. Main effects of storage on skin color of 'Stanley' plum in 1980 and 1981. Means pooled over conditioning, harvest and location.



Figures 16A and 16B

had an equal or greater effect than the harvest date. Consequently, fruit of a given harvest could be advanced considerably by conditioning. The change in extractable pigments was not reflected in visible color.

The effect of storage was to decrease the extractable pigments. Pigments may have migrated from the skin tissue to the flesh as storage duration increased. Since these two postharvest treatments act in different directions, this precludes a more detailed breakdown of the data.

7. Conditioning and Storage - Overall

In summarizing the postharvest treatments, the following generalizations can be made. All postharvest treatments tend to advance ripening. Conditioning markedly reduces flesh firmness and pit removal and increases skin pigmentation. Storage decreases pit removal force and may promote pigment migration from the skin to the flesh. Storage also decreases the acidity levels while having relatively minor effects on the soluble solids levels.

In the majority of the graphs of this section the harvest date effects predominate over the postharvest effects, as evidenced by comparing the separation between lines (harvest date effects) with the slope of the lines (postharvest effects). This trend of the overriding influence of harvest date can be further illustrated by observing the graphs of Section 1. When comparing the direct effects of harvest date with the pooled effects of harvest date (Figures 1 to 2, 3 to 4, 5 to 6, 7 to 8, and 9 to 10), values were slightly altered by the pooled postharvest effects, but the direction of the slopes and the rates of change remained similar to the data of directly harvested fruit. While Section 2 indicates that both conditioning and storage significantly affect the ripening indices, these variations were on the whole dwarfed by harvest date effects.

C. Section 3: Weight Changes

1. Effect of Date of Harvest

There was a striking difference between the 3 seasons with respect to harvest effects on weight changes. In 1980 there were clear increases with advancing harvest during the beginning of the season (Figure 17). In 1981 (Figure 17) and in 1982 (Figure 18) in the four orchards from the Grand Rapids area, there were small weight differences between harvest dates. Finally in the four orchards from Southwest Michigan in 1982 (Figure 18) there were steady weight increases in all orchards as the harvest season progressed. Large differences between orchards were apparent in both years (Figures 17 and 18).

In 1980 fruits from both locations decreased in weight at the latter harvests (Figure 17), possibly because of sampling error from fruit drop. In Orchard #1, which was the most advanced, fruit drop was observed earlier than in Orchard #2, where a substantial drop did not occur until the last harvest. Since the most advanced fruit tend to drop first, and also tend to be heavier, this would bias the remaining sample to be underweight; however, it would not reflect any actual weight loss of the individual fruits.

In 1980 fruit from Orchard #2 increased 13.9% in two weeks, while fruit from Orchard #1 increased 9.6% in one week,

Figure 17. The effects of harvest date and location on the average weight of 'Stanley' plums in 1980 and 1981.

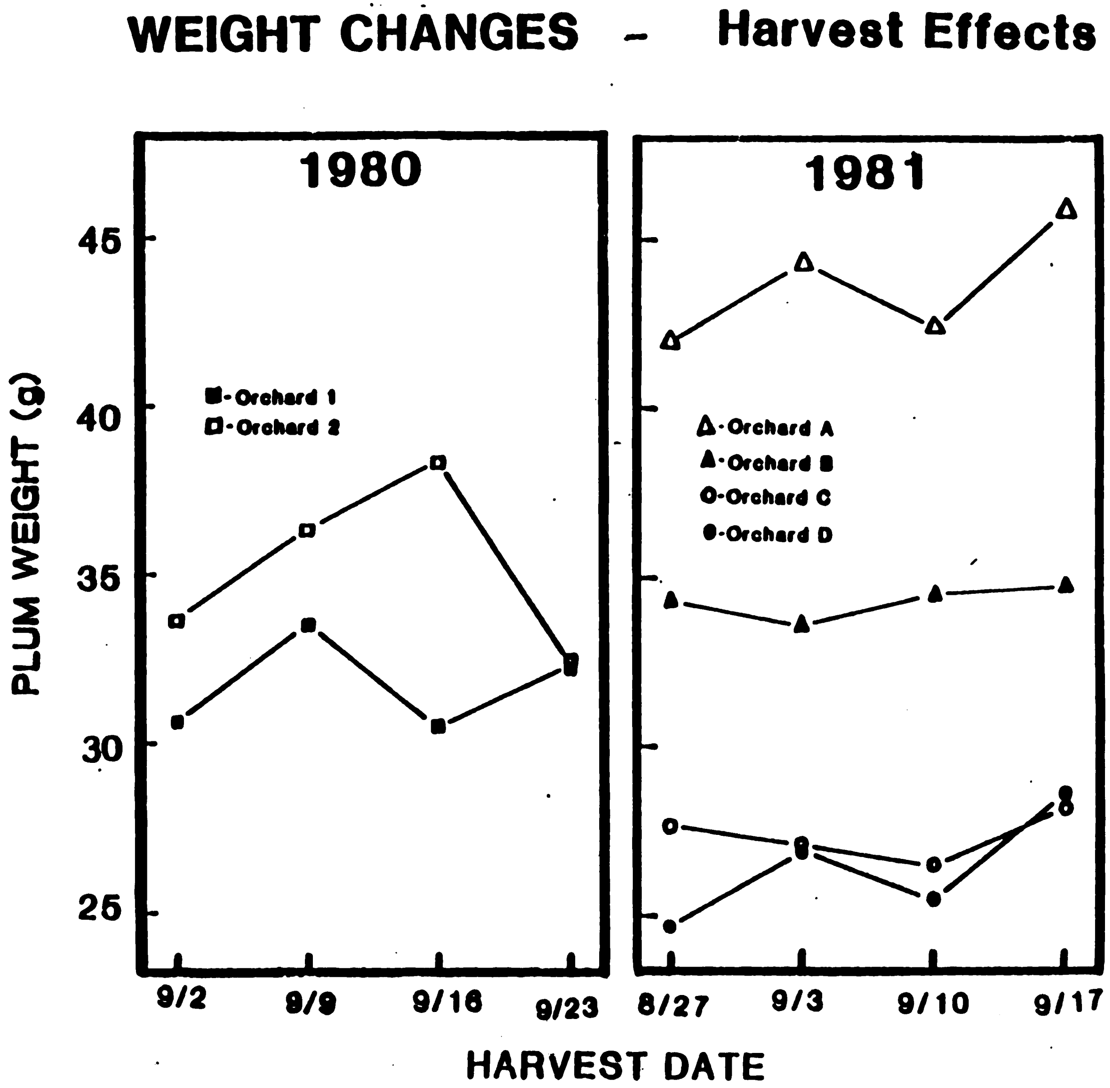

WEIGHT CHANGES - Harvest Effects
1980
1981
PLUM WEIGHT (g)
45
40
35
30
25
■-Orchard 1
□-Orchard 2
Δ-Orchard A
▲-Orchard B
O-Orchard C
●-Orchard D
9/2
9/9
9/16
9/23
8/27
9/3
9/10
9/17
HARVEST DATE

Figure 17

Figure 18. The effects of harvest date and location on the average weight of 'Stanley' plums in 1982.

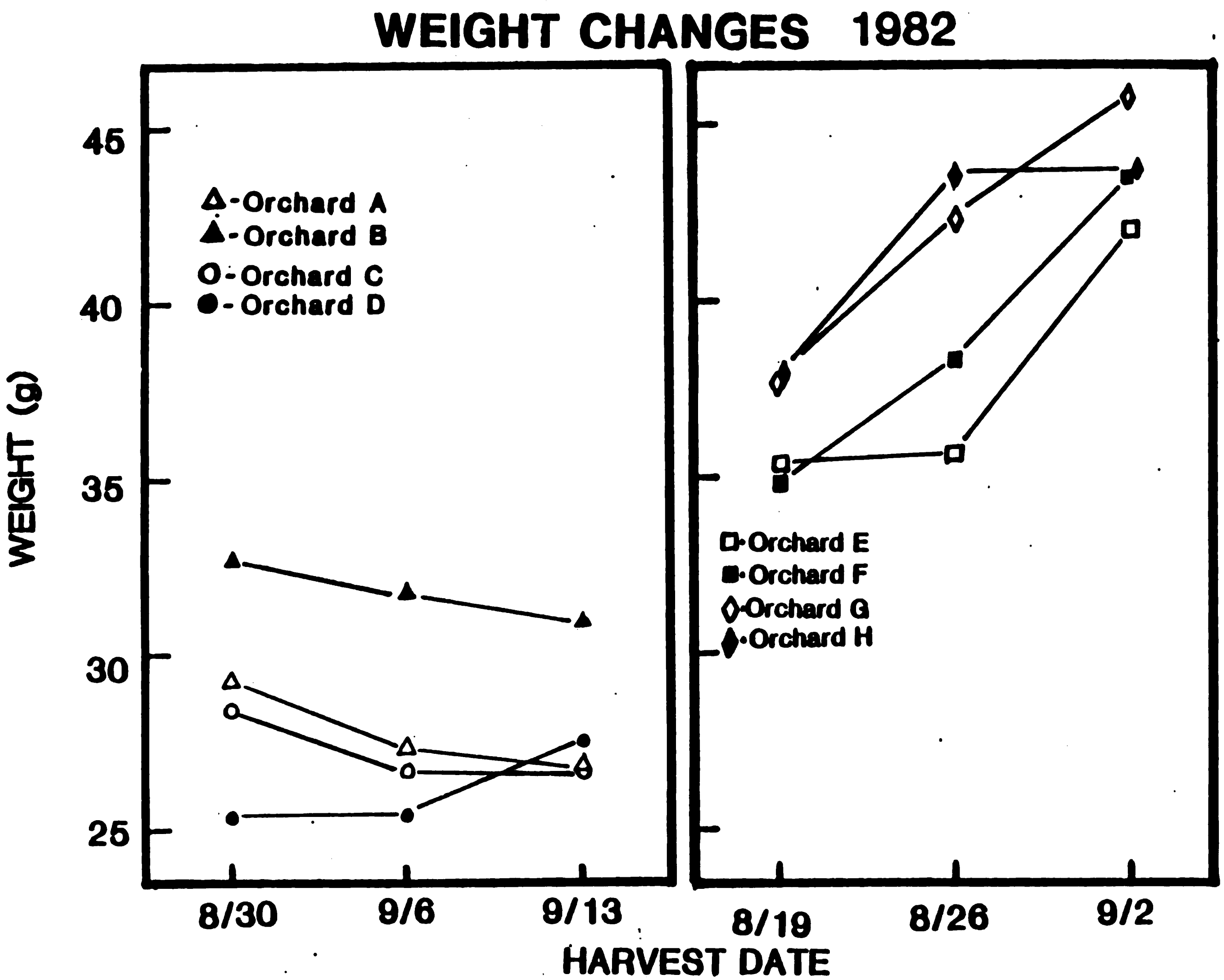

WEIGHT CHANGES 1982
WEIGHT (g)
45
40
35
30
25
Δ-Orchard A
▲-Orchard B
O-Orchard C
●-Orchard D
□-Orchard E
■-Orchard F
◊-Orchard G
♦-Orchard H
8/30
9/6
9/13
8/19
8/26
9/2
HARVEST DATE

Figure 18

indicating that weight gains can average 1% per day given satisfactory conditions.

In 1981, fruit weight increased with harvest date in only a few instances. During the second harvest, two of the locations showed weight decreases. Since fruit were too immature for drop at this point, environmental conditions were likely responsible for such a decline. As the weather preceding the third harvest was a mix of heavy rains, cloudy skies and low temperatures, conditions for transpiration were at a minimum, thus likely delaying weight gains till the following week. In the final week, all locations showed some increases, 3 of the 4 being relatively high.

In 1982, weight changes of fruits of four of the same locations were observed (Figure 18, Orchards A-D). The predominant trend was for a loss in weight with advancing harvest. Except for a light rain on the date of the second harvest there was no precipitation during the whole harvest period, this water stress may have also minimized transpiration and contributed to the lack of weight gain. The fruit weights from Orchards B, C and D were roughly the same in both years while the weights from Orchard A decreased over 30% in 1982.

In 1982 the four orchards in Southwest Michigan displayed weight increases typical of stone fruits during final swell. Except for two instances, there were large increases with later harvest. The weight increases over the harvest season for all four orchards ranged from 16 to 25%.

2. Effect of Storage

There was a significant decrease in weight during the first 2 weeks of storage of about 4-5% (Figure 19). However, there were no further significant decreases in weight after 2 weeks storage. This initial weight loss was probably due largely to transpiration.

3. Weight Changes - Summary

Considering the variation in the performance of the three seasons, predicting weight increases during final swell is complex. Environmental factors such as weather, and physiological events like fruit drop can even create apparent decreases in weight when a continuous final swell might be assumed. There is a high potential for weight increases as demonstrated in Southwest Michigan in 1982 with 16-25% weight gains during the harvest period. Considering the economic effects of optimum tonnage on marginal profits, the careful monitoring of weight within both a harvest and the bearing life of an orchard appears to be a worthwhile time investment for growers.

Figure 19. The effects of storage on fruit weight of 'Stanley' plums in 1980. Means are pooled over harvest, conditioning and location.

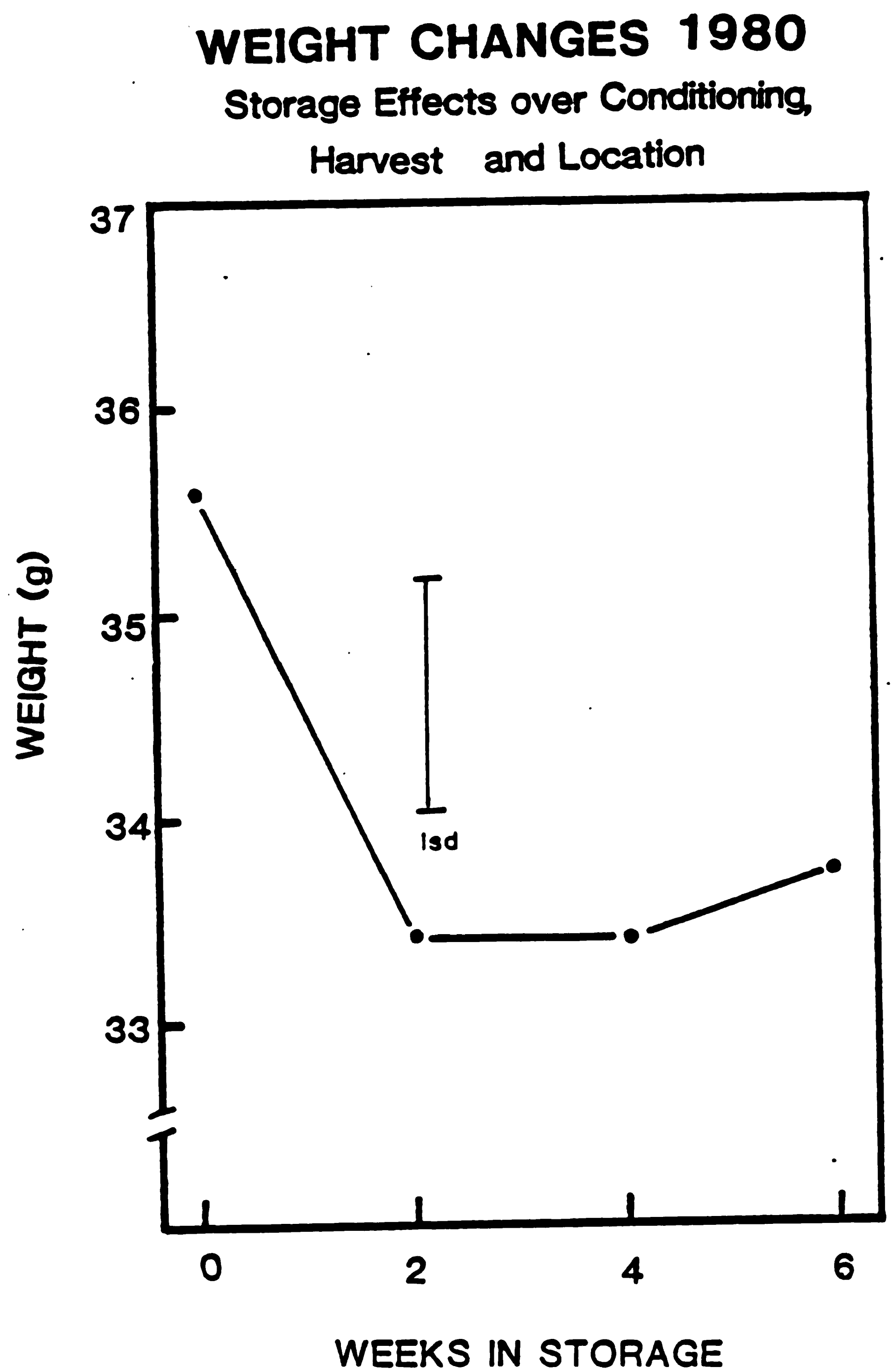

WEIGHT CHANGES 1980
Storage Effects over Conditioning, Harvest and Location
37
36
35
34
33
WEIGHT (g)
lsd
0
2
4
6
WEEKS IN STORAGE

Figure 19

D. Section 4: Effects of Ethylene Gassing

1. Ethylene Gassing Effects on Flesh Firmness

The effects of continuous ethylene gassing at 100 ppm were observed on the flesh softening of plums at 0, 2 and 4 days directly after harvest (Figure 20). LSD's were computed for 2 and 4 days only as there was no time for ethylene to act at the zero day reading. Flesh firmness had reached such low levels by the last harvest that firmness differences between fruits from gassed and non-gassed treatments were undetectable. While additional flesh softening may have occured at the last harvest with gassing, these were not reflected in the data since the penetrometer had minimum readings of three pounds.

At both harvests, means separated with respect to gassing at 2 days. The gassing effects were greater in the second orchard where the fruit was less mature. Except for the least mature fruits (2nd orchard - 1st harvest), the softening in the non-gassed controls equaled that of the gassed treatments after 4 days. This indicates that once the fruits have attained a certain level of maturity, normal ripening processes can regulate softening without much improvement from gassing treatments.

Figure 20. The effects of ethylene gassing at 100 ppm on the flesh firmness of 'Stanley' plums in 1980. Fruits of two harvests and two locations gassed continuously for 2 and 4 days.

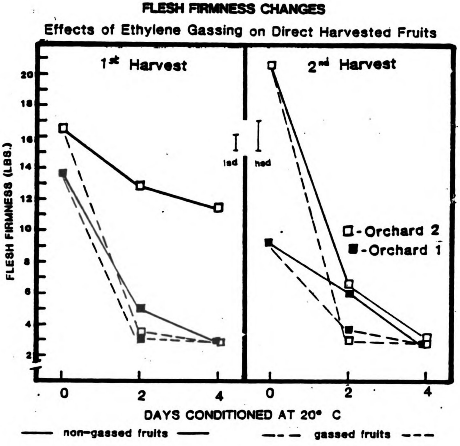

FLESH FIRMNESS CHANGES
Effects of Ethylene Gassing on Direct Harvested Fruits
1st Harvest
2nd Harvest
lsd
hsd
□-Orchard 2
■-Orchard 1
FLESH FIRMNESS (LBS.)
20
18
16
14
12
10
8
6
4
2
0
2
4
0
2
4
DAYS CONDITIONED AT 20° C
non-gassed fruits
gassed fruits

Figure 20

2. Ethylene Gassing Effects on Pit Removal Force

As with the ripening data, the effect of gassing treatments on pit removal force approximately paralleled the effect on flesh firmness (Figure 21). The trend was similar in that greater separation between treated and non-treated lots occurs at 2 days compared to 4 days of gassing. The non-treated lots of the more advanced first orchard, converged on the treated lots by the second harvest with no significant differences.

3. Ethylene Gassing Effects on Other Parameters

While data was not generated, ethylene gassing affected the plums in two other areas: 1) gassing promoted the incidence of skin cracking; 2) gassing promoted the development of pungent plum aroma. After several days exposure to gassing, skin cracking occured. This was apparent at all harvest dates but was particularly common in earlier harvests for fruit which had not yet received a cold storage. Rapid pectic changes as evidenced in the softening of gassed fruits and possible ethylene induced changes in cell membranes could have been responsible for the cracking response. Plum aroma was also studied by subjective evaluations. Plum-like odor was much more intense in gassed fruits relative to control fruits. Upon tasting, the treated plums reflected flavor and softness development but not increased sweetness.

Figure 21. The effects of ethylene gassing at 100 ppm on the pit removal force of 'Stanley' plums in 1980. Fruits of two harvests and two locations were gassed continuously for 2 and 4 days.

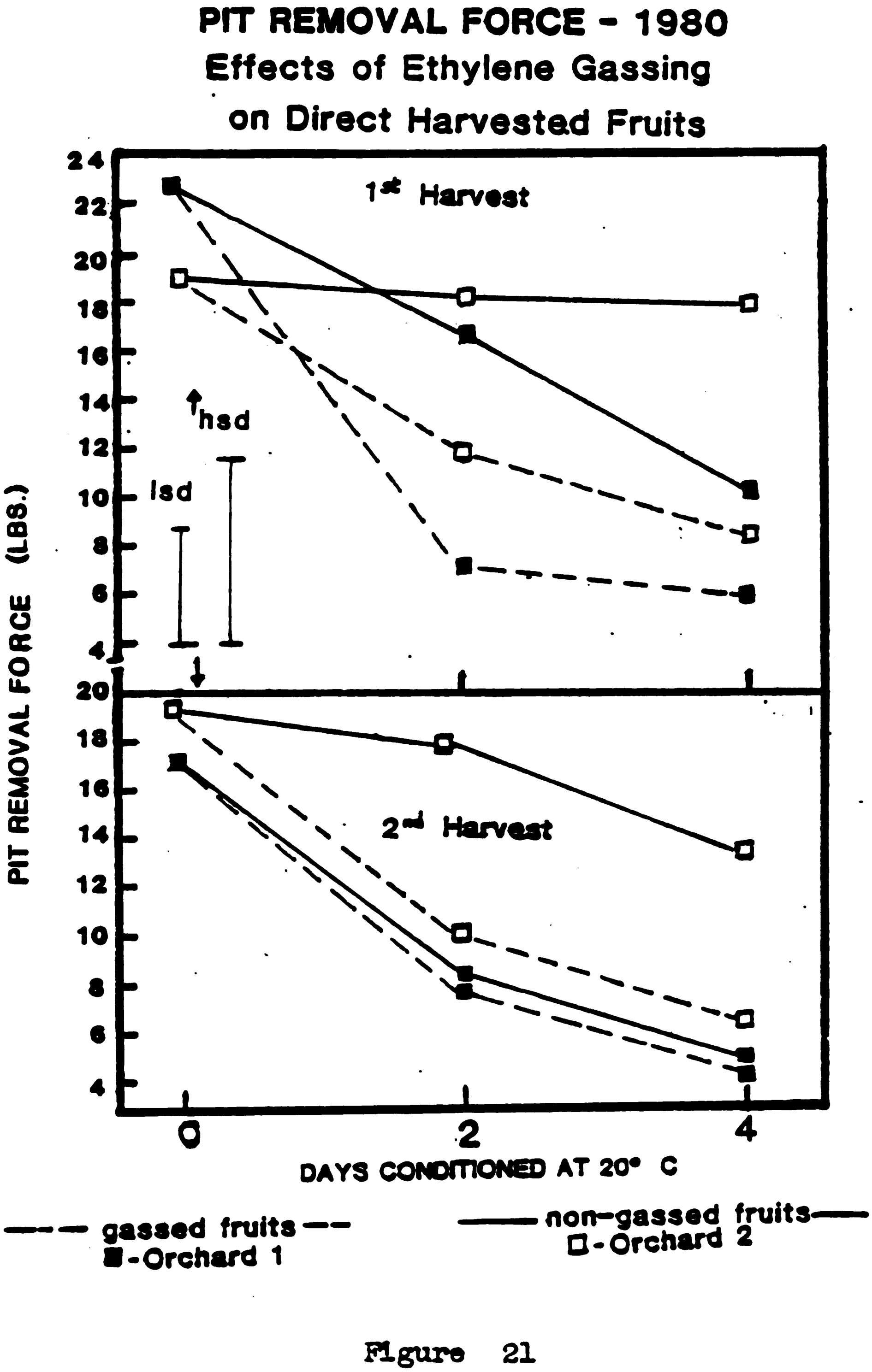

PIT REMOVAL FORCE - 1980
Effects of Ethylene Gassing
on Direct Harvested Fruits
1st Harvest
2nd Harvest
hsd
lsd
PIT REMOVAL FORCE (LBS.)
DAYS CONDITIONED AT 20° C
gassed fruits
■-Orchard 1
non-gassed fruits
□-Orchard 2

Figure 21

In addition to flesh firmness and pit removal force, observations were made on three other ripening indices. Ethylene gassing had no effect on soluble solids or acidity. A non-significant trend towards increased absorbance readings (extractable pigments) occurred in unstored fruits of early harvests. Ethylene gassing effects were also studied in processed plums. Gassing treatments had no effect on the amount of pitting waste of fruits destined for processing, and no effect on the quality of the canned product.

These results suggest that ethylene would not benefit fruits used for processing. On the other hand, there may be some potential for using ethylene as a ripening agent to market fresh fruit early. Such a practice is common in California on other plum varieties (24). However, since softening and color changes in the present study were accompanied by skin cracking, practicioners should be cautious.

E. Section 5: Ethylene and Carbon Dioxide Production

1. Introduction

Data for the evolution of ethylene and carbon dioxide was collected for 1980 only. No statistical analysis was run on this data because of complexities resulting from different sampling times. However, the differences in the data due to treatment are wide enough to conjecture real effects.

2. Ethylene Production - Location Effects

Ethylene evolution was plotted with respect to storage duration, harvest date, conditioning period and location (Figure 22). Data from the two locations were nearly parallel although values for Orchard #1 were higher. This was particularly noticable in non-stored plums during the 2nd harvest, where ethylene production by fruits from Orchard #1 was above Orchard #2. At this harvest some major differences occur between fruits from the two orchards as reflected by other indices. Notable in reference to this are Figures 1, 7 and 9, where skin color, soluble solids and acidity advance more rapidly in the first orchard, the site of the higher ethylene production. Ethylene evolution may be linked to these changes. Also, the higher level of ethylene production by fruits from

Figure 22. The effects of length of storage at $0^{o}C$, time of harvest, length of conditioning and source of fruit on ethylene production of 'Stanley' plums in open systems in 1980.

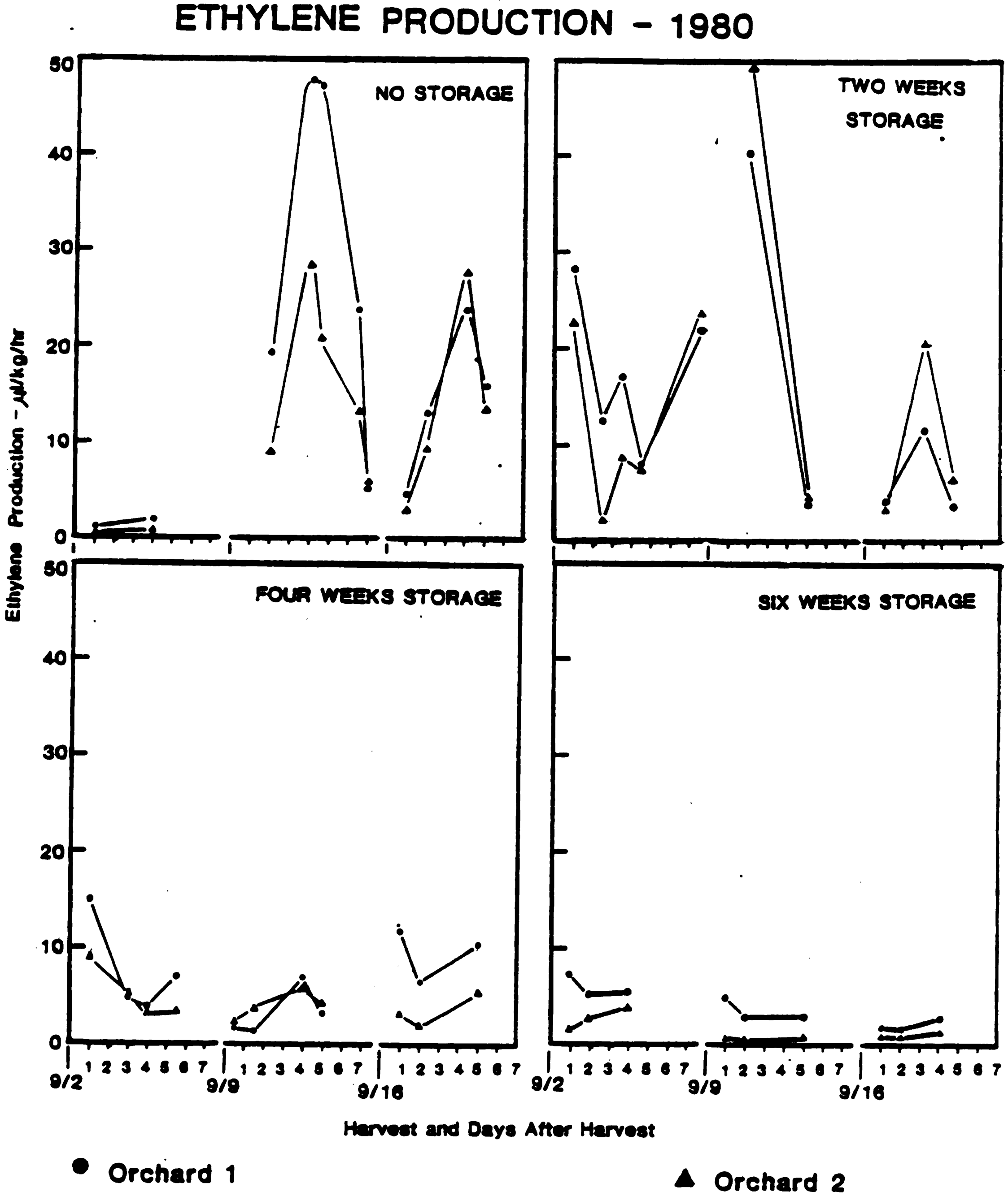

ETHYLENE PRODUCTION - 1980
NO STORAGE
TWO WEEKS STORAGE
FOUR WEEKS STORAGE
SIX WEEKS STORAGE
Ethylene Production - µl/kg/hr
0
10
20
30
40
50
1 2 3 4 5 6 7
9/2
9/9
9/16
Harvest and Days After Harvest
Orchard 1
Orchard 2

Figure 22

Orchard #1 coincided with completion of fruit maturation, suggesting that a large burst of endogenous ethylene accompanies and possibly triggers ripening. The action of ethylene could influence more ripening parameters than the color and textural advances that were accelerated by artificial ethylene treatments.

Fruits of the second orchard produced equal amounts of ethylene at the 2nd and 3rd harvests. After the fruit remained in storage for some time, the fruits from the 2nd orchard produced ethylene in quantities similar to the 1st orchard.

3. Ethylene Production - Harvest Date Effects

The effects of harvest date were notable only for fruits of the control (no storage) or the first storage treatment (2 weeks). In both cases, there was a predominant increase in ethylene evolution from fruits of the second harvest, which was always higher than the first and generally higher than the 3rd harvest.

4. Ethylene Production - Storage Effects

Storage had the most dramatic effect of any treatment (Figure 22). In general, fruits not stored and those after 2 weeks storage produced ample ethylene. Ethylene production declined at longer storage periods (4 and 6 weeks) and harvest differences became indistinguishable.

There was an acceleration of ethylene evolution by fruit of the first harvest after any cold storage treatment, but most significantly after two weeks. Fruits from the second harvest (Orchard #2) also had higher ethylene levels at two weeks storage. The study of ethylene synthesis in chilled cucumbers by Wang et al. (54) could offer some hypotheses in interperting these trends. They concluded that increased C_2H_4 production from chilled cucumbers appeared to be a result of increased capacity of the chilled tissues to make ACC, and that the system that converts ACC to C_2H_4 was damaged with prolonged chilling (54). If this system were operative in plums, this could explain the following trends: 1) a decrease in ethylene production levels at extended storage at any harvest date due to prolonged chilling damaging the ethylene generating system; 2) the declines in ethylene production in fruits of the 1st and 2nd harvest at two weeks storage may be due to the conversion of accumulated ACC to ethylene.

The fall and rise in ethylene production from fruits of the first harvest after two weeks storage could represent the initial development of a typical ethylene climacteric following the decline of ethylene production due to the accumulation of ACC in storage. This down and up trend was also apparent in fruits of the 1st orchard, 1st harvest, at 4 weeks storage, but in this case the ethylene production was considerably less.

If accumulation of ACC occurs in plums with limited storage, it apparently is dependent on the stage of fruit maturity, as the ethylene production levels of fruits from the third harvest were lower after two weeks storage when compared to no storage.

Since it has been suggested that the ethylene-synthesizing system (conversion of ACC to C_2H_4) may be localized in cell membranes in higher plants (22), these responses of plum to chilling can be further clarified. Damage to membranes is common in chilling-sensitive tissues below their critical temperatures due to possible changes in membrane permeability and phase changes in membranes with increased activation energies of membrane bound enzyme systems (21). If the ethylene-synthesizing system in plums was localized in cell membranes then this chilling damage may have resulted in reduced ethylene levels after 4 and 6 weeks at low temperature (0^oC).

5. Carbon Dioxide Production

Date of harvest and time of storage affected CO_2 production (Figure 22). Nearly all storage treatments increased respiration compared to the non-stored control. At no storage and two weeks storage, the respiration values generally increased. However, at 4 and 6 weeks storage there was a trend for respiration rates to decline after removal from storage. This data yields interpertation according to a mechanism of chilling injury as hypothesized by Lyons (21). Below critical chilling temperatures there is a buildup of metabolic intermediates due to the slow down of membrane bound enzyme systems. However, since the phase changes that chilled membranes undergo

Figure 23. The effects of length of storage, time of harvest, length of conditioning and source of fruit on CO_2 production of 'Stanley' plums in open systems in 1980.

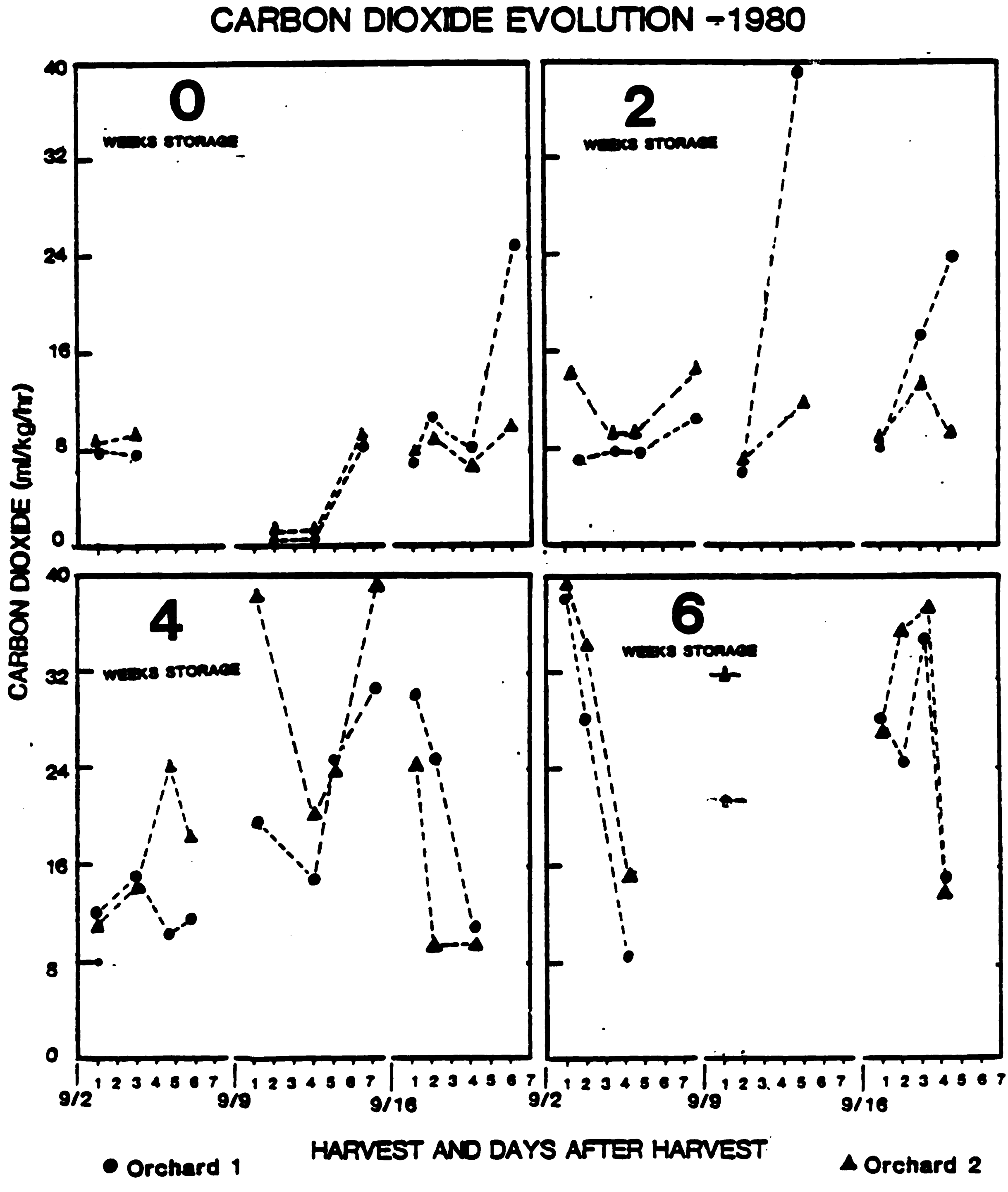

CARBON DIOXIDE EVOLUTION -1980
0
WEEKS STORAGE
2
WEEKS STORAGE
4
WEEKS STORAGE
6
WEEKS STORAGE
CARBON DIOXIDE (ml/kg/hr)
0
8
16
24
32
40
1 2 3 4 5 6 7
9/2
9/9
9/16
HARVEST AND DAYS AFTER HARVEST
● Orchard 1
▲ Orchard 2

Figure 23

are completely reversible, normal metabolism can be re-established, pending there is no degenerative injury. Upon release to ambient temperatures, the respiration increases sharply but transiently, as these built up intermediates are completely respired (21). Critical temperatures for chilling can range from 32°F (0°C) to 45°F (7.2°C) in Japanese plums (50) and is probably similar in European plums. Therefore at 4 and 6 weeks storage under plums's critical temperature this build up of intermediates would occur resulting in higher evolutions of CO_2.

6. Relationship Between C_2H_4 and CO_2 Production

Ethylene production is superimposed over that of CO_2 in Figure 23, illustrating a possible interplay between the two gasses. Plums that were not stored show a relationship between the two gasses common to climacteric type fruits. At the second and third harvest when the plums had evolved substantial levels of ethylene, increases in respiration follow soon after. However, with storage this relationship is confounded by chilling effects on the production of both gasses and also by the ripening changes that plums undergo during storage.

At two weeks storage there is a different relationship between ethylene and CO_2 production at each successive harvest.

Figure 24. The relationship between ethylene and CO_2 production in 'Stanley' plums in 1980 as affected by length of storage, time of harvest, length of conditioning and source of fruit.

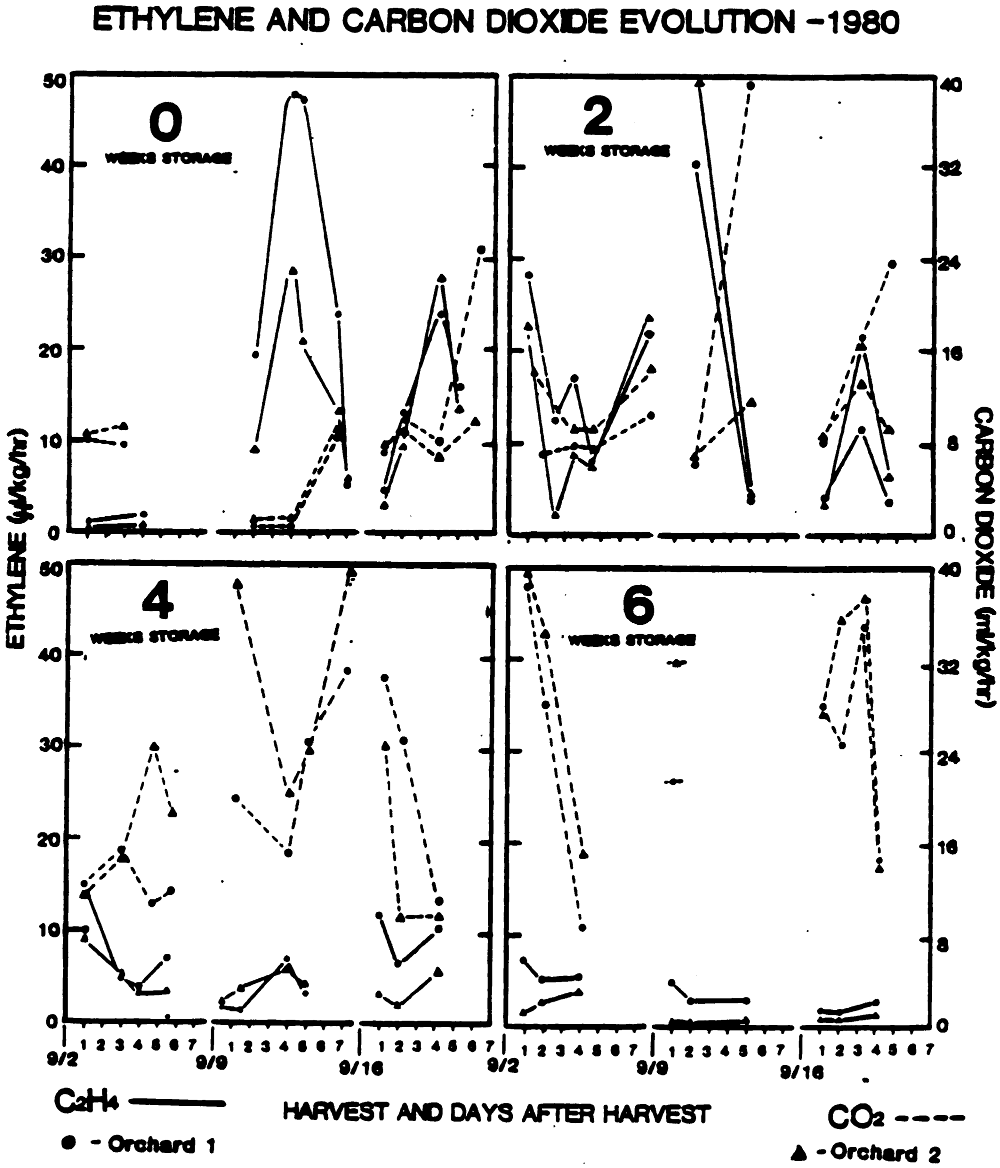

ETHYLENE AND CARBON DIOXIDE EVOLUTION -1980
0
WEEKS STORAGE
2
WEEKS STORAGE
4
WEEKS STORAGE
6
WEEKS STORAGE
ETHYLENE (µl/kg/hr)
CARBON DIOXIDE (ml/kg/hr)
9/2
9/9
9/16
C2H4
HARVEST AND DAYS AFTER HARVEST
CO2
● - Orchard 1
▲ - Orchard 2

Figure 24

In the second orchard of the first harvest it appears that both intermediates of the ethylene and CO_2 systems are rapidly converting to end products upon removal from storage, followed by increases due to a normal climacteric response. In the fruits of the second and third harvest it appears that the effects of these storage intermediates are masked by the effects of normal climacteric rises.

At four weeks storage the fruits of the second harvest also displayed a decline and rise in CO_2 production despite the low levels of ethylene production. This conforms to a pattern of respiration of accumulated metabolites followed by a normal respiratory climax. While the ethylene generating system has been hypothesized to be largely inoperative due to extended chilling, the respiratory increases in this fruit seem to follow a very slow rise in ethylene production of the surviving ethylene generating system. At the last harvest of four weeks storage and two harvests of six weeks storage the respiration rate declined continuously. Perhaps a depletion of substrate after extended storage is responsible for the absence of a recovery in CO_2 production. The advancement of ripening with extended storage is reported in this thesis and other research (18,28,30).

7. Ethylene Evolution in Closed Systems - Introduction

Ethylene production and accumulation in closed containers was observed in 1981 and 1982. The use of the closed system was chosen in 1981 because of similar successful research with apples (Dilley, D. R., personal communication). In such systems, accumulation of ethylene with time can induce ethylene action, and one of these actions is to further increase ethylene production. Thus containerization of fruit immediately after harvest can trigger climacteric responses before similar fruit left on the tree. This allows for a model by which the time of optimal maturity can be predicted. Though plums are less responsive to ethylene than most apple varieties, they are considerably affected by the gas as discussed earlier. Preliminary tests and periodic checking of fruit throughout the experiments revealed that O_2 levels remained above 14% and CO_2 levels below 2% as the fruits progressively ripened in the containers. Dry lime packets were placed next to fruits to scrub CO_2. These container gas levels predispose relatively high O_2 and low CO_2 concentrations within the fruit. If binding of ethylene to metallic receptor sites follows the model of Burg (3), then these modified atmopsheres would not likely inhibit or compete with ethylene.

8. Comparison of Ethylene Evolution in Open and Closed Systems

When open systems (Figure 22 - 1980) are compared with closed (Figures 25, 26 and 27 - 1981 and 1982), the differences between the two becomes apparent as the open system fruit showed

Figure 25. The effect of source of fruit, harvest date, and length of time after harvest on ethylene production in 'Stanley' plums in closed containers in 1981. Fruit from 4 Grand Rapids area orchards.

ETHYLENE PRODUCTION - 1981

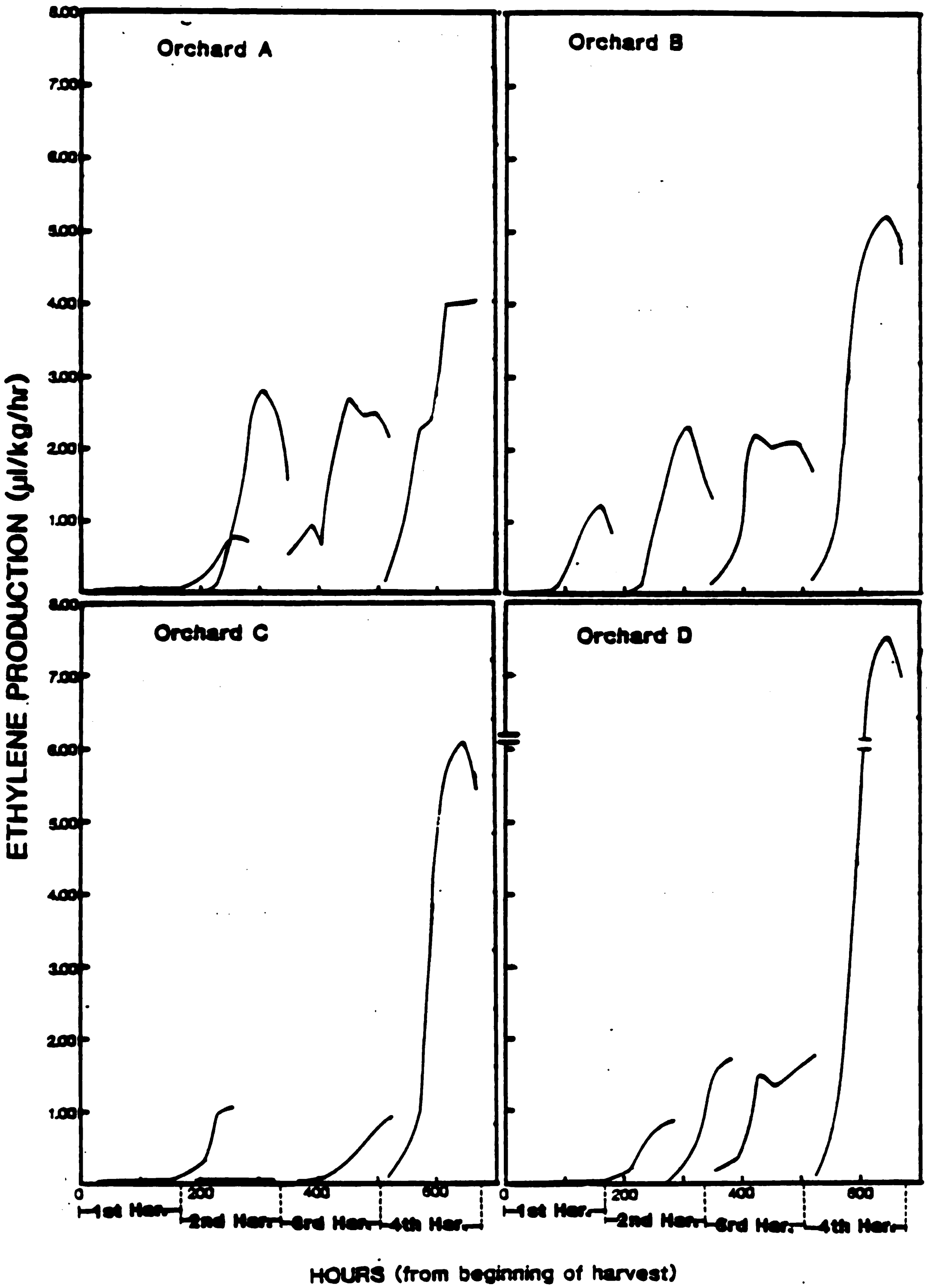


Figure 25

Figure 26. The effect of source of fruit, harvest date and length of time after harvest on ethylene production in 'Stanley' plums in closed containers in 1982. Fruit from 4 Grand Rapids area orchards.

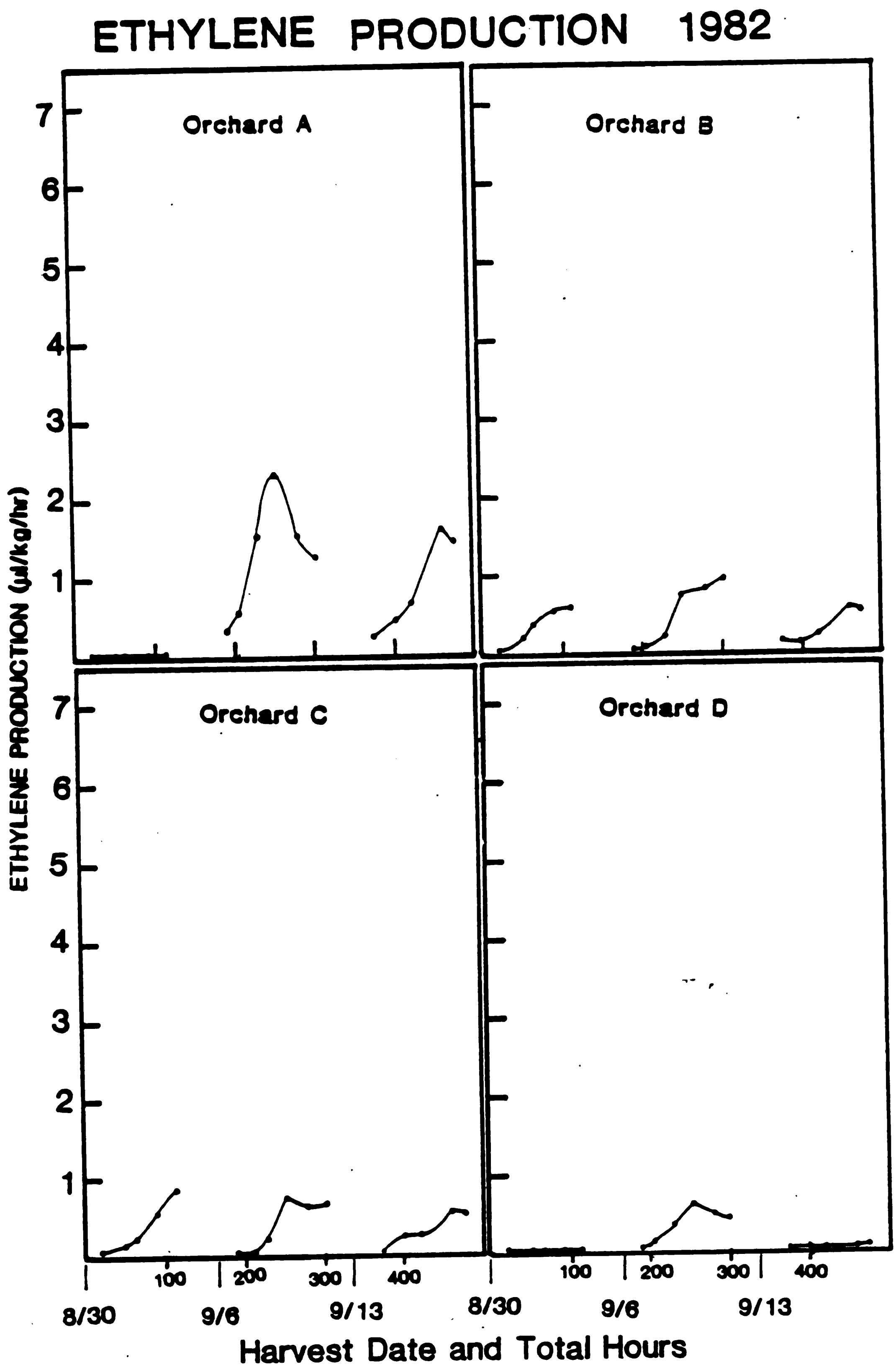

ETHYLENE PRODUCTION 1982
Orchard A
Orchard B
Orchard C
Orchard D
ETHYLENE PRODUCTION (µl/kg/hr)
7
6
5
4
3
2
1
100
200
300
400
8/30
9/6
9/13
Harvest Date and Total Hours

Figure 26

Figure 27. The effect of source of fruit, harvest date, and length of time after harvest on ethylene production in 'Stanley' plums in closed containers in 1982. Fruit from 4 Southwest Michigan orchards.

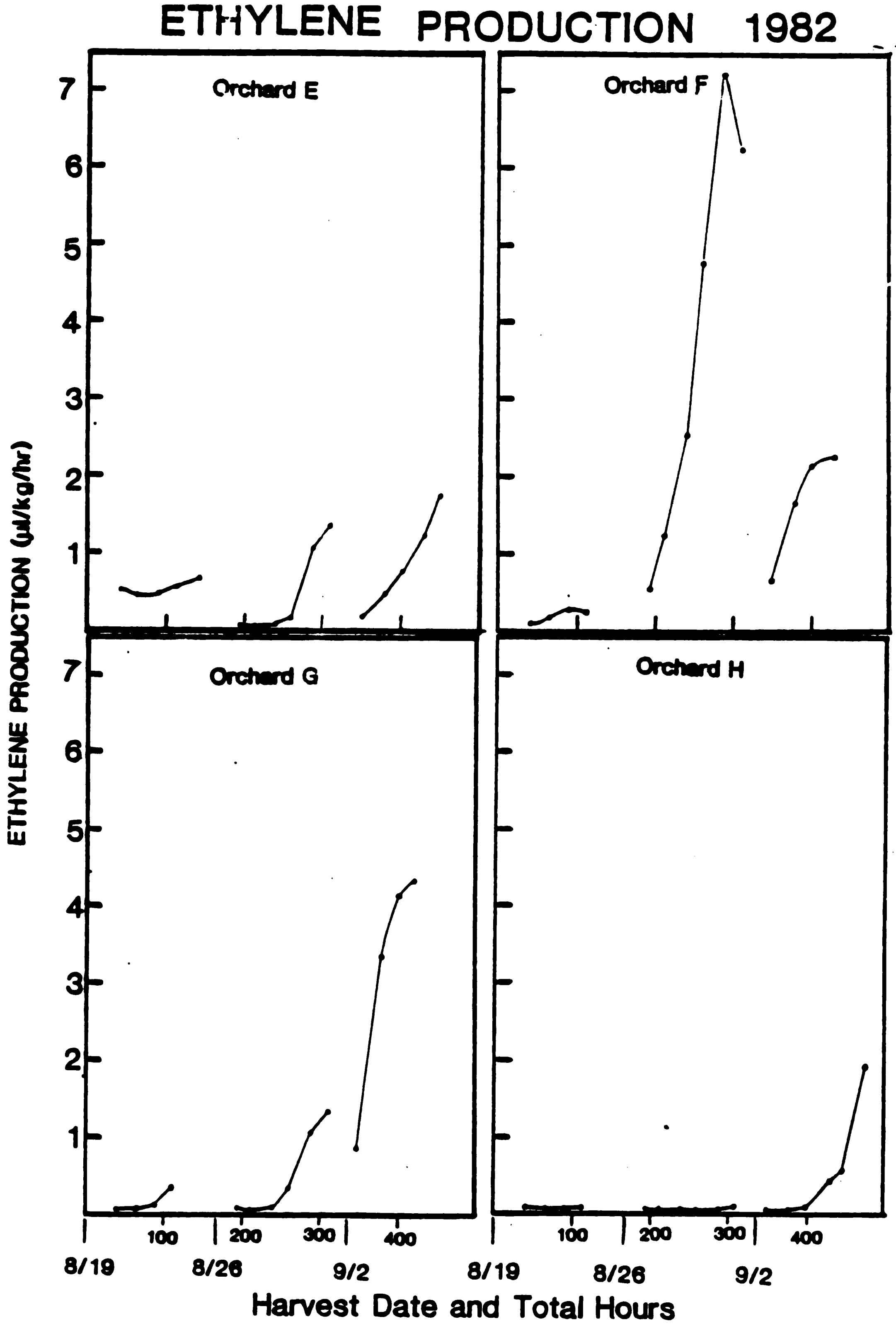

ETHYLENE PRODUCTION 1982
Orchard E
Orchard F
Orchard G
Orchard H
ETHYLENE PRODUCTION (µl/kg/hr)
1
2
3
4
5
6
7
100
200
300
400
8/19
8/26
9/2
Harvest Date and Total Hours

Figure 27

a rapid rise and fall in ethylene production (with no storage), while the closed system fruit displayed very gradual declines in ethylene production. The ethylene evolution rate of non-stored fruit in 1980 was in the range of 10-50 ul/kg/hr (2nd and 3rd harvests). In contrast, when closed systems were utilized in 1981 and 1982, the production rates were below 8 ul/kg/hr during a similar conditioning period. The decrease in ethylene production rates observed in closed systems could be due to some sort of feedback inhibition of ethylene.

9. Effects of Harvest Date on C_2H_4 Production in Closed Systems

At each location the effects of harvest upon ethylene production were different (Figures 25, 26 and 27). In all orchards but Orchard C of 1982 there was an increase in ethylene production at later harvest dates. These increases were fairly gradual with the exception of all of the final harvests in 1981 and the second harvest of Orchard F in 1982. In the first case, the plums were in an advanced state of maturity and in the second case, a brown rot infection in the plums artifically accelerated the peaking of ethylene production. The data suggests that ethylene evolution could be used as an index for determining harvest timing for optimal quality fruit. The results of such a scheme will be discussed later in conjunction with a harvest model.

F. Section 6: Taste Panels on Fresh Market Fruit

1. Discussion of Statistical Bias

Taste panels were conducted to evaluate the fresh plums in 1981 (Figure 28). Fruit from each succeeding harvest was placed in cold storage ($0^{o}C$) until all samples were harvested. Approximately five weeks after the first harvest, fruit of all four harvests were evaluated. Results from Section 2 have indicated that cold storage can advance ripening by some parameters, while results from Section 4 show that respiration was increased at longer storage periods (4-6 weeks). In view of this, the long-stored (early harvested) fruits were biased to have higher taste panel scores than they would have had if tested immediately after harvest. This bias diminished towards the last harvest where the fruit was not stored beyond one week. At earlier harvests this was reflected in an added margin of quality. Even though the earlier harvests had lower scores in general, this bias was one reason for the lack of greater mean separation between harvests. Another major factor was an insufficient sample size, a problem inherent in taste panel studies.

2. The Effects of Harvest Date, Conditioning and Location on Quality

Location and time of harvest are important determinants of quality (Figure 28). Mean separation was limited. In all

Fibure 28. The effects of harvest date and source of fruit on the quality of 'Stanley' plum in 1981 as determined by a taste panel. (High score equals high quality preference.)

Taste Panel Quality Ratings

Location and Harvest Effects Pooled over Conditioning

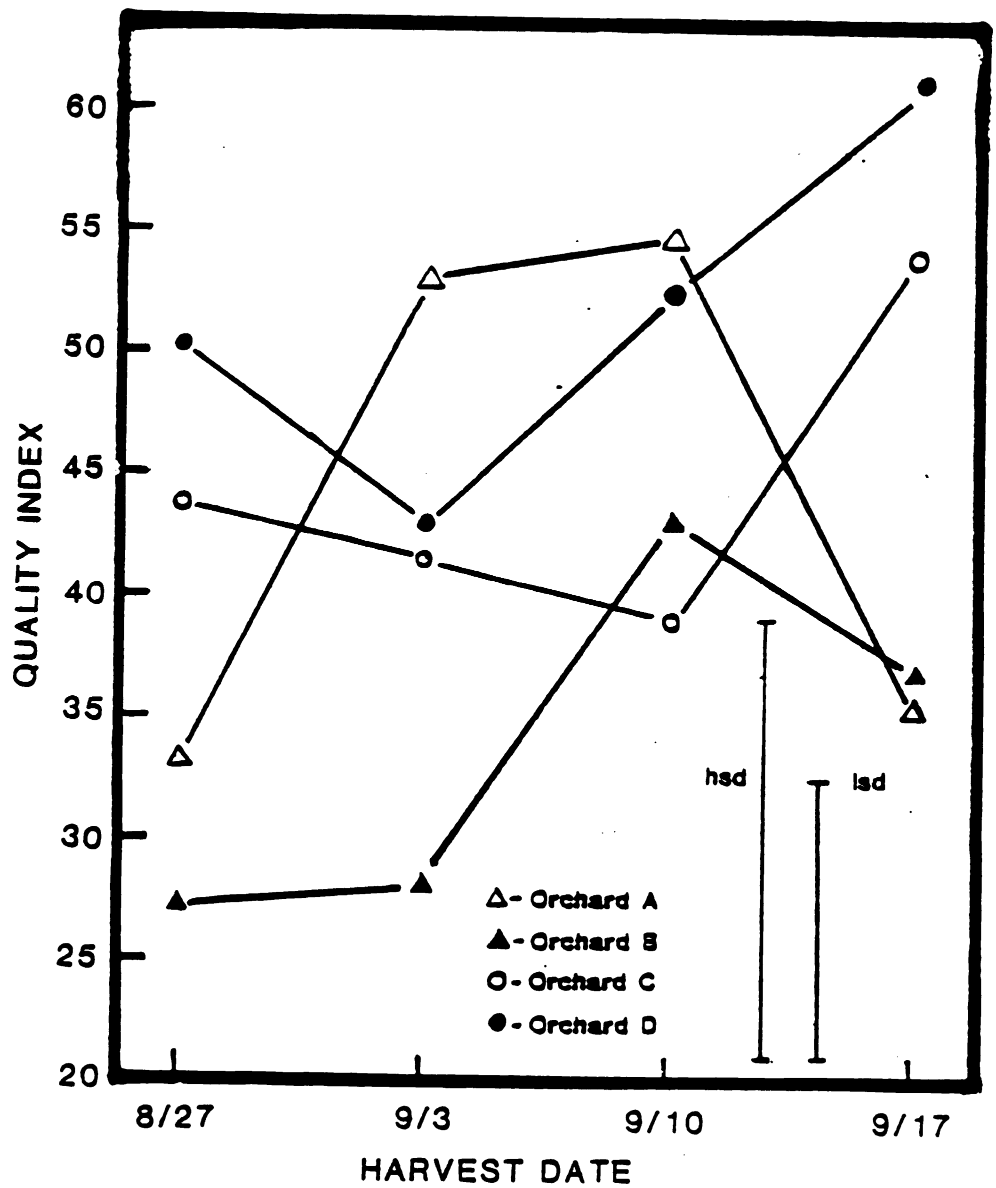


Figure 28

cases the highest and the lowest quality values within a given location were significantly different.

Figure 29 illustrates the effects of conditioning and harvest date in determining optimum fruit quality. In the two earlier harvests, ratings for the two later conditioning periods (3 and 6 days) were significantly higher than for no conditioning. For the 3rd harvest quality was lowered by conditioning for 6 days. A similar pattern exists for the 4th harvest. The results illustrate that conditioning time can greatly modify the harvest effects. These effects, however, have serious practical limitations in that the conditioning time is rarely a dependent variable in the marketing channels, and certainly not at the grower level. The shelf life, which corresponds to conditioning time in real marketing situations is usually determined by economic factors at the retail outlet rather than controlled decisions that can be made at the grower or packer level. Thus the harvest selection within an orchard remains the major applicable factor in determining fresh market quality. Storage of up to four weeks could likely play a role in quality improvement based on the maturity index changes, but this factor was not pursued in taste panel work.

3. Correlations between Quality and Maturity Indices

Since various components of the taste panel ballots (color, acid, sweetness, etc.) had corresponding ripening

Figure 29. The effect of harvest date and the length of conditioning time on the quality evaluations of 'Stanley' plum in 1981 as determined by a taste panel. Means are pooled over location.

FRESH PLUM TASTE PANEL QUALITY EVALUATIONS

Effects of Harvest and Conditioning over Location

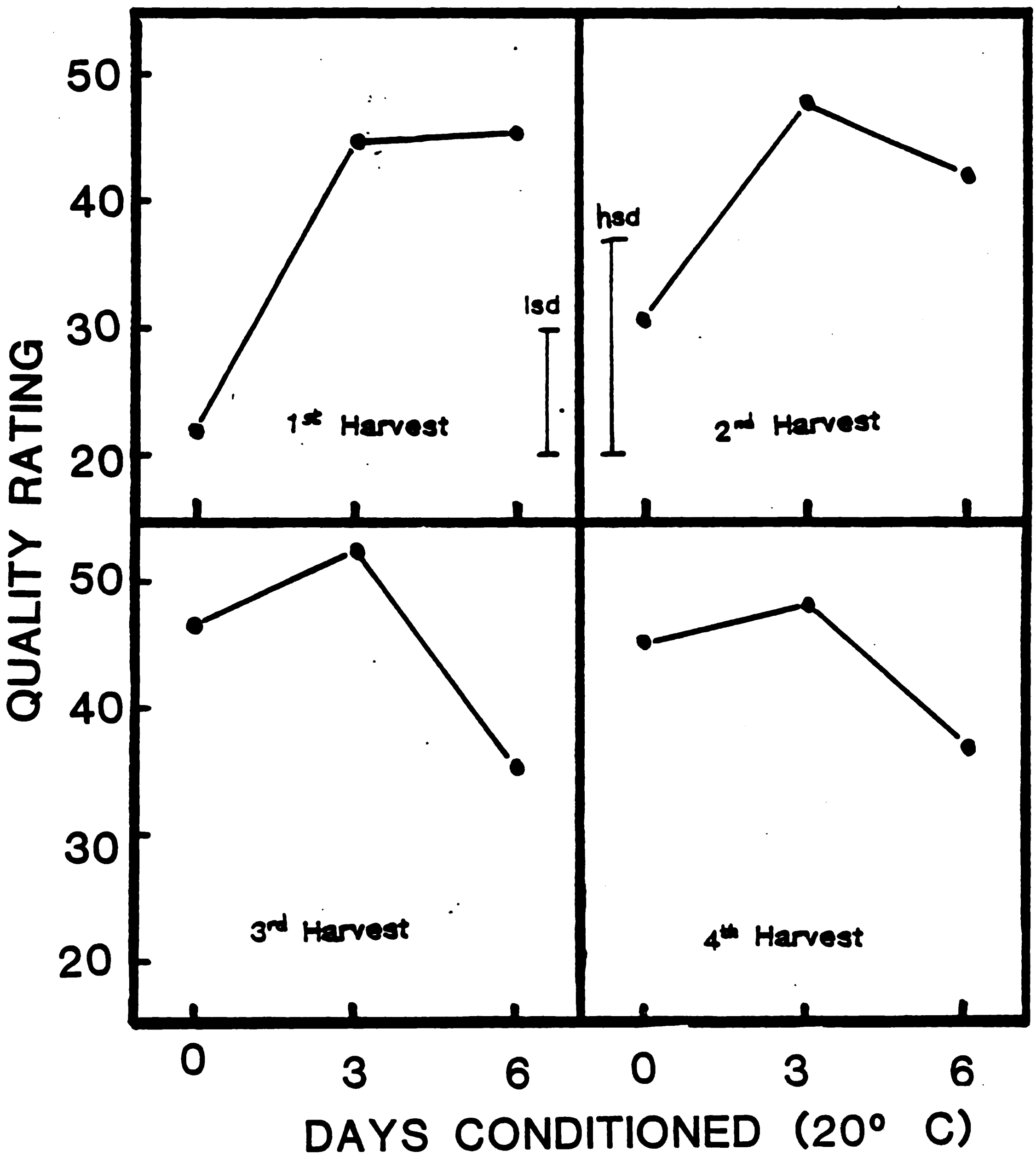


Figure 29

indices (extractable pigments, titratable acidity, soluble solids, etc.), correlations were calculated between five ripening indices and the overall quality scores from the taste panels. From the previous discussion, conditioning is not a controllable variable, so the means were pooled over the conditioning treatments and each location-harvest combination was then matched to obtain a correlation coefficient. The results are presented in Table 1.

Soluble solids, flesh firmness and ethylene production all significantly correlated with the overall quality scores of panelists with soluble solids being highly significant. Acidity and color correlated poorly with the quality preference. The two values that drop with quality (acidity and flesh firmness) had negative correlations, while the three that rise with quality (soluble solids, flesh firmness and ethylene) had positive correlations.

In addition to the correlations of single variables, correlations were run comparing quality to compound variables: 1) soluble solids readings minus flesh firmness; 2) soluble solids readings minus flesh firmness plus modified ethylene units. In both cases the correlation was significant, having a higher correlation coefficient than ethylene or flesh firmness alone, but a lower correlation coefficient than soluble solids alone. Nevertheless, since soluble solids is a factor which can change with varying harvest seasons,

TABLE 1
Correlations of Maturity Indicators with Quality Ratings

Parameter	r Value	Significance[1]
Single Factors		
SOLUBLE SOLIDS	+.734	**
FLESH FIRMNESS	-.558	*
ACIDITY	-.250	ns
COLOR	+.393	ns
ETHYLENE	+.565	*
Combination Factors		
S.S. - F.F.[2]	+.590	*
S.S. - F.F. - ETH[3]	+.608	*

Table 1 presents correlations between taste panel overall quality ratings and various physical or chemical maturation indices. Of the 16 (harvest x location) combinations, 14 means were equated for correlation coefficients. Two quality values were eliminated because the fruit were overripe.

1. ** Significant at 1% level, * Significant at 5% level, ns - Not significant

2. Soluble solids value minue the flesh firmness value.

3. SS - FF + k + 7(log 10 + C_2H_4): Soluble solids value minus flesh firmness value plue a constant plus 7 x log (10 + Integral of ethylene production from harvest till 100 hours after harvest). This is a measurement of ethylene production over time as determined by integrating production curves from 0 to 100 hours. The constant 10 was inserted to avoid values of log 0 and to more precisely delinate the function. Seven was used as a multiplier to bring the log value within a similar range of the soluble solids and flesh firmness.

its high correlation with quality was not an irrevocable testimony this it is necessarily the most reliable index. The combining of two or three indices maintained each one's individual significance but added the extra insurance that each parameter can buffer the other. This can provide a broader base for judging quality in cases where conditions would not favor correlations with one major index.

It is noteworthy that the addition of ethylene to the combination soluble solids-flesh firmness reading makes the initial correlation a little better. These correlations provide evidence that soluble solids, flesh firmness and ethylene readings should be the most reliable indicators of fruit quality as judged by this taste panel and as judged in the marketplace.

4. Correlations between Factors within the Taste Panel

Correlations between overall taste panel scores vs. the individual quality indices used for evaluations are presented in Table 2. Almost none of the components or combination of components showed a significant correlation with quality except for flavor, acid, and the combination factor, flavor plus sweetness plus texture, in Orchard B. Nonetheless, the following observations bring out some important trends: 1) flavor has the highest correlation coefficient in two of the four locations and the second

TABLE 2
Correlations of Taste
Panel Components with Quality

Location	Color	Tartness	Texture	Sweetness	Flavor	Texture + Sweetness	Texture + Sweetness Flavor
Orchard A	.279	.464	.207	.312	.092	.285	.423
Orchard B	.554	.615*	.397	.517	.769*	.524*	.686*
Orchard C	.270	.131	-.077	.166	.317	.238	.269
Orchard D	.512	.388	.381	.113	.444	.267	.350

Table 2 presents correlations from the taste panels between individual components of taste and the overall rating for quality. To obtain the most finely tuned correlation within the panels, orchards were calculated individually. All 12 treatments within an orchard were matched (4 harvests x 3 conditioning treatments) providing correlations based on 12 means for each variable.

highest in one location; 2) in three of the four locations, texture and sweetness have lower correlations than flavor; 3) when flavor readings were included with those of texture and sweetness, the correlation coefficient was raised. This "3-factor value" had the highest mean r value, indicating panelists combined several factors into an overall score.

G. Section 7: A Model for Harvest Timing of Fresh Market Plums

1. Introduction

Considering the previous discussion about the relationship of quality to three major maturity indices; soluble solids, flesh firmness and ethylene evolution, models were designed to aid growers in determining the optimal time of harvest. Tolerances were determined using data from 1981 and then extensively tested on 8 orchards in 1982 to assess their accuracy in pinpointing the best harvest date.

2. Ethylene Index

Fruits from individual orchards harvested sequentially show considerable variation in the time they initiate high ethylene production within the closed system containers (Figure 30). The time it takes fruit from each successive harvest to reach an arbitrary ethylene production rate of approximately 2 ul/kg/hr is distinctly different. At the first harvest, no fruits from any orchard attained this level. At the second harvest, fruits from two orchards had risen to this value after 120 hours. Upon the third harvest, fruits from three of the four locations had attained 2 ul/kg/hr within 83 hours and by the fourth harvest, all locations had arrived at the mark before 70 hours.

Figure 30. Effects of the time of harvest and the source of the fruit on ethylene evolution of 'Stanley' plums maintained in closed containers in 1981. (A point represents the mean of 4 containers with ten plums each).

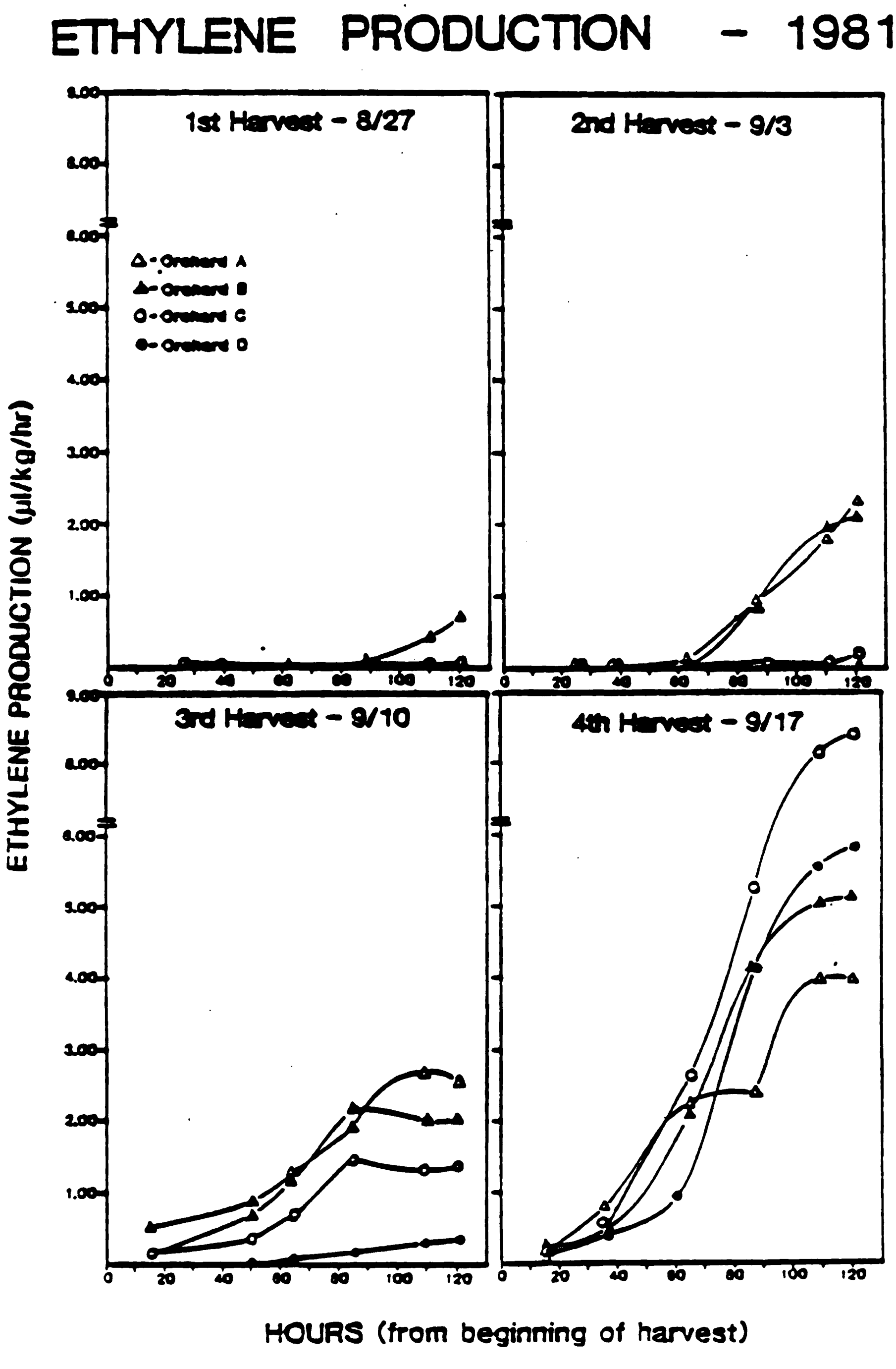

ETHYLENE PRODUCTION - 1981
1st Harvest - 8/27
2nd Harvest - 9/3
3rd Harvest - 9/10
4th Harvest - 9/17
Orchard A
Orchard B
Orchard C
Orchard D
ETHYLENE PRODUCTION (µl/kg/hr)
HOURS (from beginning of harvest)

Figure 30

Ethylene prodcution is presented again, but in relation to taste panel quality ratings (Figure 31). The four points for quality at each location represent the mean for quality at each harvest as pooled over the conditioning treatments (0, 3 and 6 days). Since growers or packers have no control over conditioning (shelf life) in the market channel, this is the most reasonable assessment of quality. Using the arbitrary tolerance of approximately 2 ul/kg/hr of ethylene evolution as a guide, this level was reached at the following times: Orchard A - 2nd harvest, 4th day; Orchard B - 2 harvest, 6th day; Orchard C - 4th harvest, 3rd day; Orchard D - 2rd harvest 8th day. The choice of these four dates would have resulted in maximum quality fruit for the first 3 orchards and high quality fruit in the last orchard. Based on this model for 1981 only, the information gathered on ethylene alone seemed to be adequate to indicate the most desirable harvest date based on quality. The precision rate for such a model would be 100% based on the four orchards.

3. Testing the Ethylene Model - 1982

The model based on a 2 ul/kg/hr tolerance was tested in 1982. Data (previously presented) graphing ethylene evolution is shown with the suggested "best" harvest dates

Figure 31. Effects of the time of harvest, the source of fruit and the length of conditioning on ethylene in relation to taste panel quality ratings of 'Stanley' plums in closed containers, 1981. (Ethylene values are the mean of four containers with ten plums each. Quality values represent the mean for each harvest as pooled over conditioning treatments. The LSD relates to the differences between quality values.)

ETHYLENE PRODUCTION - 1981

Relation to Taste Panel Quality Ratings

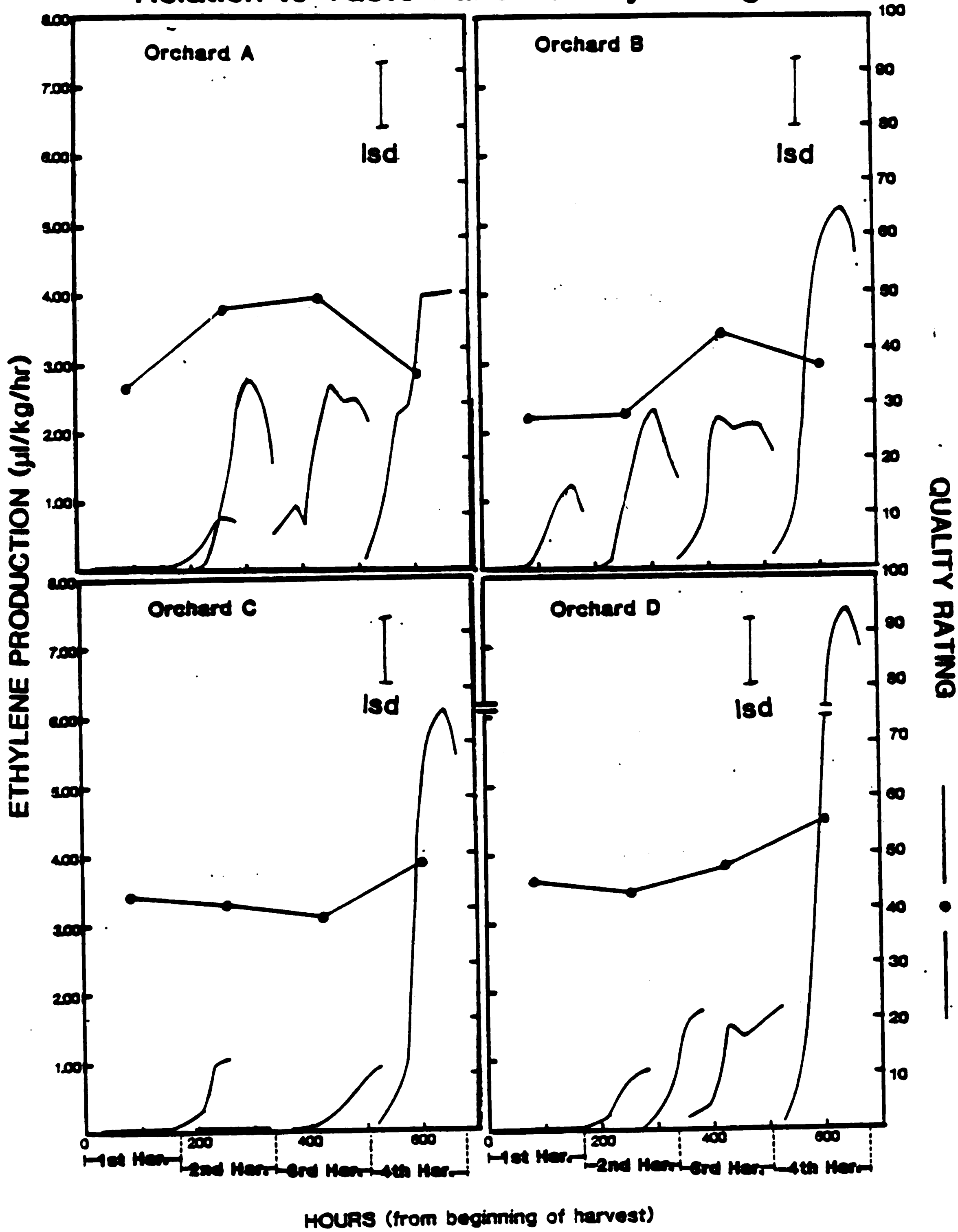


Figure 31

indicated with arrows (Figures 32A and 32B). Since time limitations restricted the use of taste panels in 1982, the ideal harvest date was qualitatively evaluated. Through casual observations, tasting, and monitoring of the soluble solids and firmness levels, fruit were evaluated at harvest and throughout the conditioning period by a team of 3 individuals. In the Grand Rapids area only one of the four orchards generated ethylene levels of about 2 ul/kg/hr (Figure 32A). This was in Orchard A and it corresponded to the suggested harvest date.

In the Southwest Michigan area, three of the four orchards were approaching the 2 ul/kg/hr level near the ideal harvest date (Figure 32B). The fourth orchard, Orchard F, was contaminated with much brown rot, and the inflated peak at the 2nd harvest (7 ul/kg/hr) was the result of this. By carefully purging any plums suspect of brown rot, this contamination was avoided in the third harvest of Orchard F. It could be hypothized by examining the trends that the second harvest of Orchard F would also have approached the 2 ul/kg/hr level near the end of the second week had it not been infected. (A dashed line on Figure 32B represents this level as roughly extrapolated from the 1st and 3rd harvests.) Based on this unsubstaniated but reasonable assumption, all four orchards from Southwest Michigan would

Figure 32A. The relationship of ethylene production rates of 'Stanley' plum in closed containers to ideal harvest dates as determined by qualitative assessment. Four orchards from the Grand Rapids area.

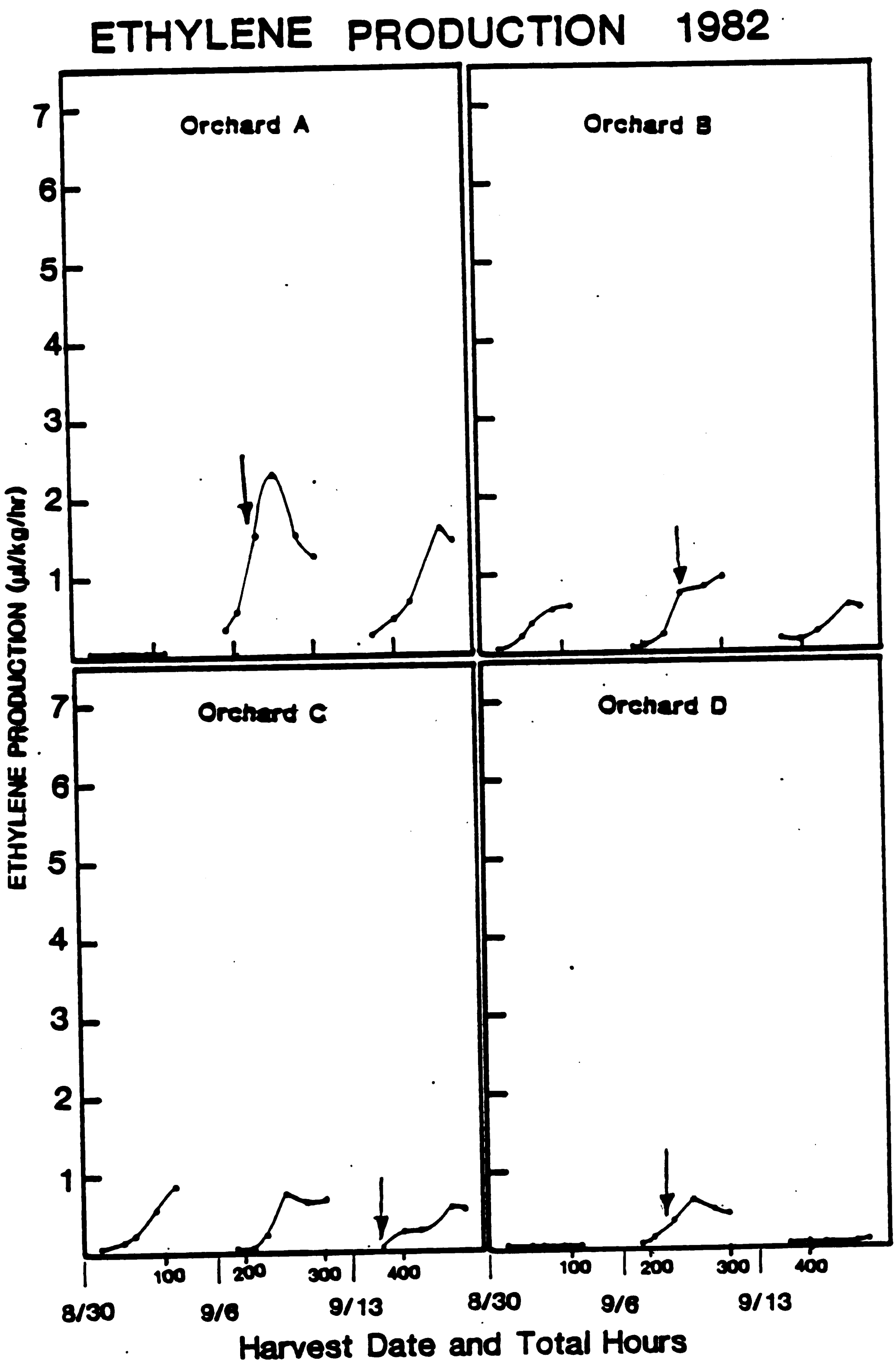

ETHYLENE PRODUCTION 1982
Orchard A
Orchard B
Orchard C
Orchard D
ETHYLENE PRODUCTION (µl/kg/hr)
1
2
3
4
5
6
7
100
200
300
400
8/30
9/6
9/13
Harvest Date and Total Hours

Figure 32A

Figure 32B. The relationship of ethylene production rates of 'Stanley' plum in closed containers to ideal harvest dates as determined by qualitative assessment. Four orchards from the Southwest Michigan area. (Dashed line in Orchard F represents the probably rate of brown rot-free plums.)

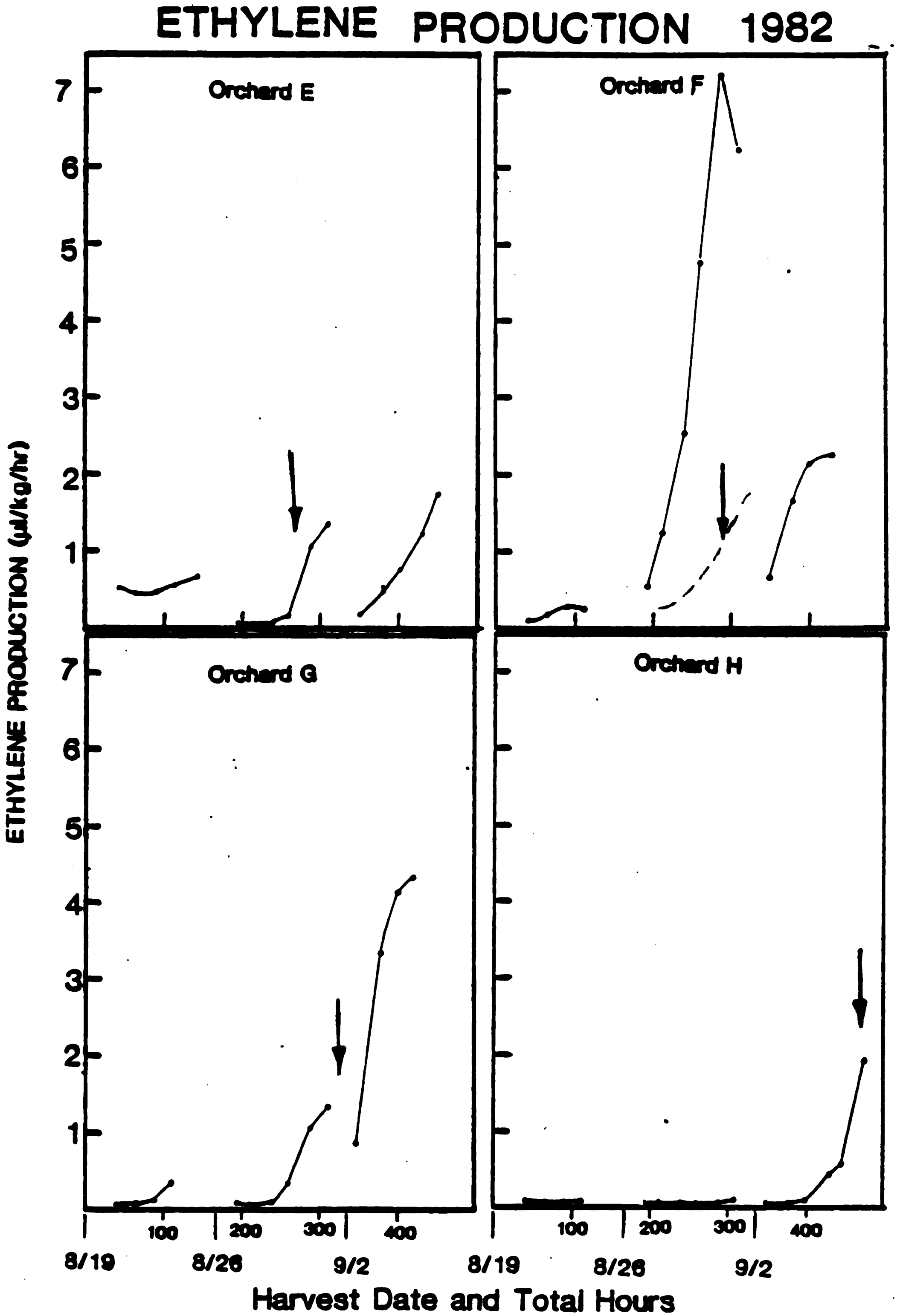

ETHYLENE PRODUCTION 1982
Orchard E
Orchard F
Orchard G
Orchard H
ETHYLENE PRODUCTION (µl/kg/hr)
1
2
3
4
5
6
7
100
200
300
400
8/19
8/26
9/2
Harvest Date and Total Hours

Figure 32B

have conformed to the model.

The use of endogenous ethylene production as a harvest indicator was successful in selecting optimal harvest dates in at best 9 of the 12 orchards in the two year study; however, ethylene levels were unable to signal the ideal harvest in three orchards during the second season of testing. This limits the applicability of ethylene as the key indicator of maturity. This does not preclude its use with other indicators, but emphasizes that ethylene readings must be interpreted with caution. Additional auxillary experiments performed in 1982, however, present some promise of the use of ethylene as a more reliable index of maturity.

4. Effects of Chilling on C_2H_4 Evolution

Various periods of chilling at various temperatures were found to affect the level of ethylene evolution in the closed containers. The results of two such treatments are presented in Figures 33 and 34. Fruits of the second harvest from the four orchards in Southwest Michigan were chilled at $0^{o}C$ for 48 hours before being placed in containers (Figure 33). In 3 of the 4 orchards the ethylene production was greatly advanced over the control fruits (no chill treatment). The other orchard, F, as discussed earlier, was infected with

Figure 33. The effects of 48 hours of $0^{o}C$ chilling on ethylene evolution (in closed containers) of 'Stanley' plums from four Southwest Michigan orchards harvested Ausust 26, 1982.

EFFECTS OF CHILLING ON ETHYLENE PRODUCTION

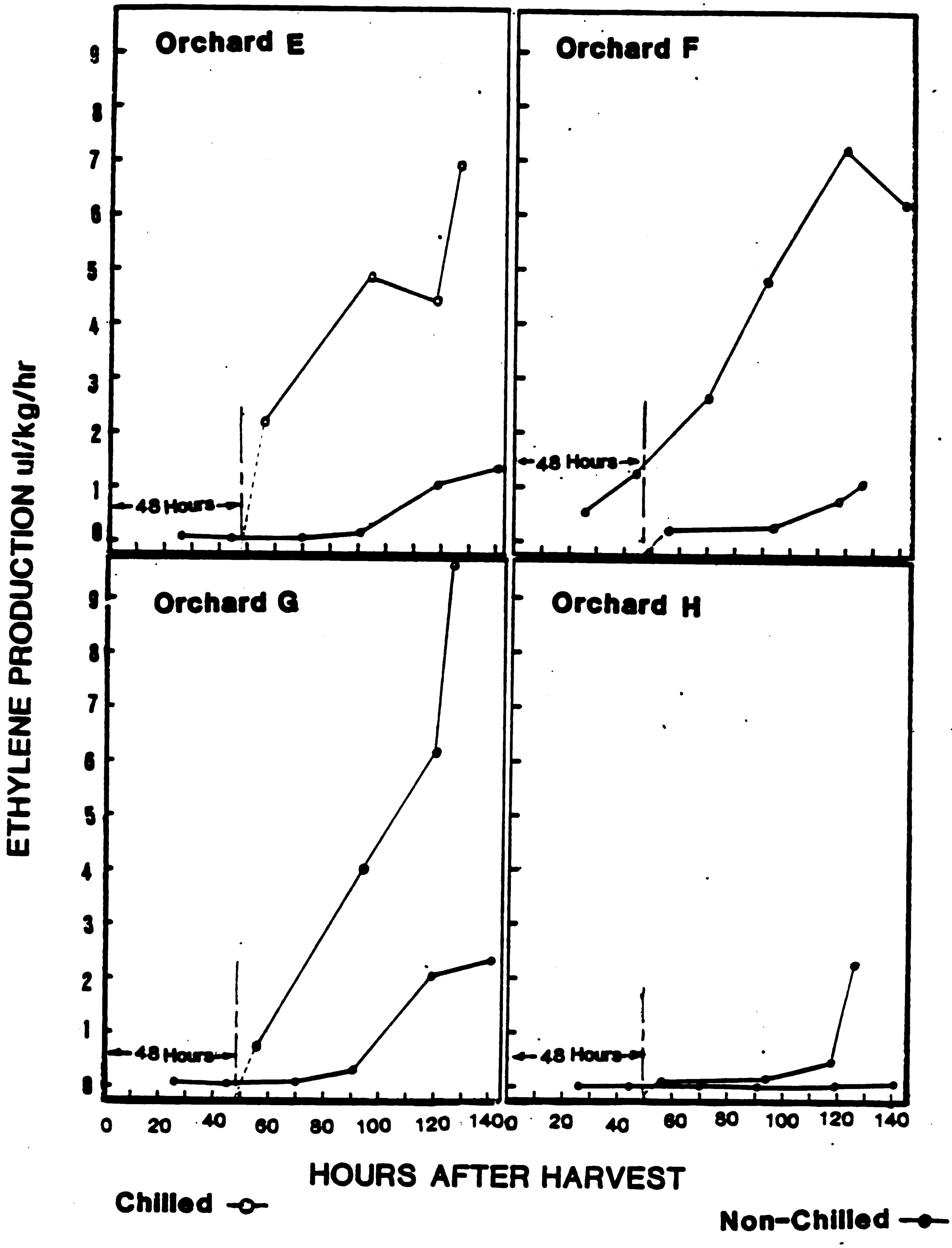


Figure 33

Figure 34. The effects of 3 hours of 5°C chilling on ethylene evolution (in closed containers) of 'Stanley' plums from four Grand Rapids area orchards harvested September 6, 1982.

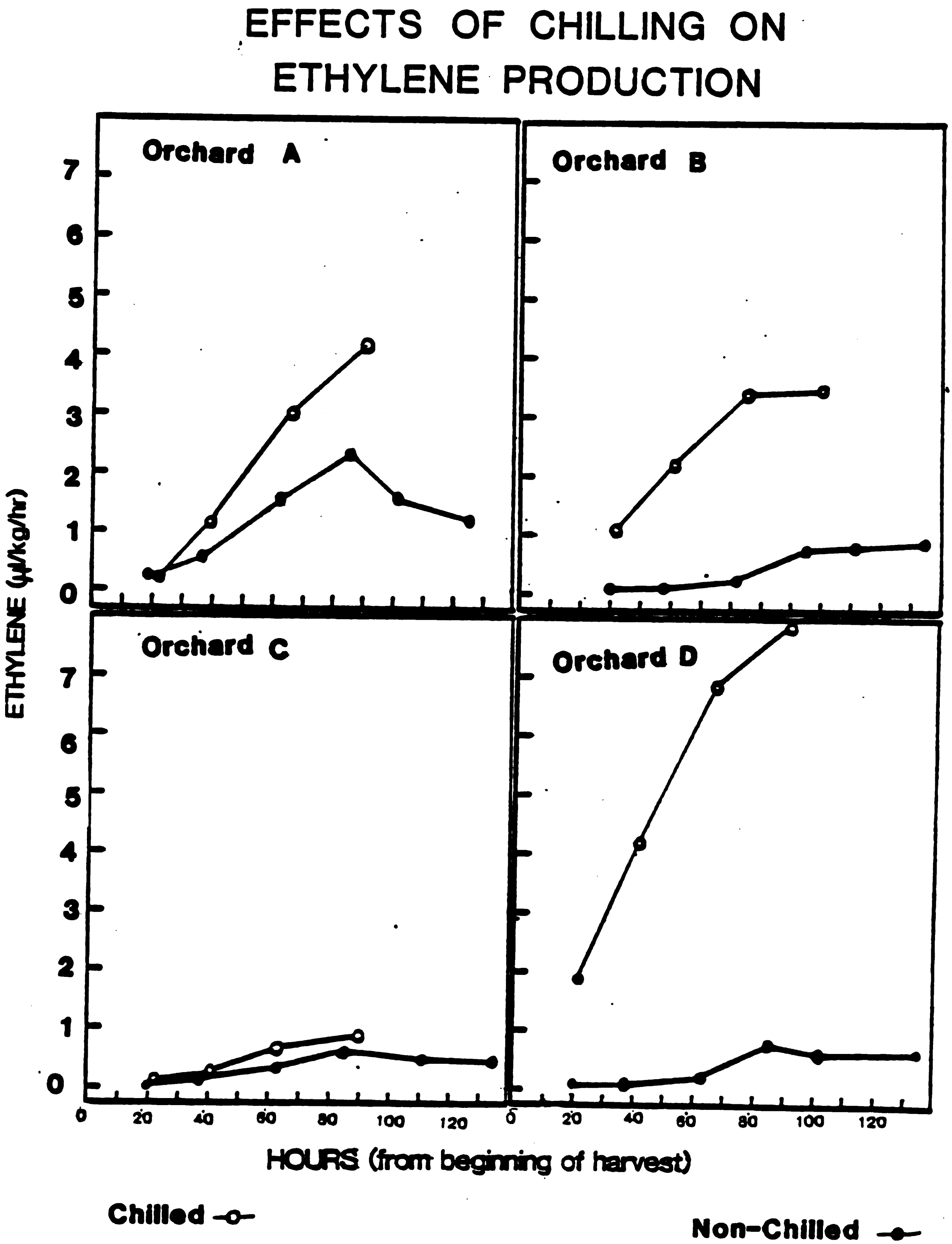

EFFECTS OF CHILLING ON
ETHYLENE PRODUCTION
Orchard A
Orchard B
Orchard C
Orchard D
ETHYLENE (µl/kg/hr)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
HOURS (from beginning of harvest)
Chilled
Non-Chilled

Figure 34

brown rot and therefore had an inflated peak in the control. It is likely that the chilling treatment of 48 hours curbed the spread of infection on the tissue and resulted in the more reduced and delayed ethylene curve in Orchard F.

Fruits from orchards in the Grand Rapids area were chilled for an even shorter duration at the second harvest producing similar results (Figure 34). After a 5°C chilling treatment for merely 3 hours, fruits were placed in containers and responded with advanced levels of ethylene production in all four orchards. In 3 of the 4 orchards ethylene production was substantially increased. Only in Orchard C were the ethylene production levels similar to the control. The fruit of this orchard failed to respond to any of the chilling or stress treatments. While these chilling treatments only advanced ethylene evolution in 6 of the 8 orchards, further experimentation may reveal that specific chilling treatments can be valuble tools in determining optimum harvest dates. The treatments appear to artifically advance the climax of ethylene production. Since during the period of plum maturation fruits are often exposed to night temperatures between 0 and 5°C for various lengths of time, there is a likelihood that chilling in storage may intensify a natural mechanism in plum ripening. Furthermore, if fruit only respond to this treatment in a short period before becomming mature, this advanced ethylene production may serve as an early signal in predicting the best harvest date.

5. Modeling for Soluble Solids and Flesh Firmness: Determination of Tolerances

Tolerances for soluble solids and flesh firmness were determined by utilizing data from the taste panels. Table 3 presents the weighted means of flesh firmness and soluble solids which were calculated for each specific orchard from the taste panel ratings of all treatments. These means were calculated by taking the sum of the products of the taste panel quality rating and the maturity index reading, and dividing by the sum of the quality readings. A simplified hypothetical example may clarify this:

Harvest	Soluble Solids	Quality Rating	Product
1	10	50	500
2	11	50	550
3	12	50	600
4	13	80	1040
		Σ=230	Σ=2690

Weighted Mean = 2690/230 = 11.69% S. S.

If however, the panelists had rated the sweeter fruit higher, the result would be:

1	10	00	000
2	11	10	110
3	12	70	840
4	13	95	1235
		Σ=175	Σ=2185

Weighted Mean = 2185/175 = 12.48% S. S.

This provides a balanced measure of what specific index-readings were collectively associated with high quality fruit via the evaluations of all the panelists. The table indicates

TABLE 3

Tolerances for Soluble Solids and Flesh Firmness as Determined by Taste Panel Quality Assessment

Orchard	Flesh Firmness	Soluble Solids
A	7.2	13.4
B	5.8	12.9
C	7.5	12.6
D	6.5	13.4
Means:	6.75	13.07

Table 3 presents tolerances for soluble solids and flesh firmness to be used in determining optimal harvest date. Each index reading for the various treatments (each harvest x orchard x conditioning treatment) was multiplied by its quality rating. Then the sum of the products for each index was divided by the sum of the quality ratings.

that a maximum flesh firmness of about 7 lbs. and a minimum soluble solids reading of about 13% are the closest integers that relate to these two parameters. When these two tolerances are applied to selecting the ideal fruit in each of the 16 (harvest x orchard) treatments, the results are shown in Table 4.

As fruits from the various locations were conditioned after their respective harvests, the conditioning period brought on decreased flesh firmness (approaching 7 lbs.) while solbule solids levels remained equal to or slightly above the level at harvest. When the fruit attained the two tolerances (13% soluble solids and 7 lbs. firmness) with conditioning, the taste panel quality score was recorded at that point. Of the 16 orchard x harvest combinations observed only 9 had advanced their indices sufficiently to have attained the two tolerances. The remainder were still too immature regardless of the maximum six days conditioning treatment.

TABLE 4

Reliability of Tolerances When Applied to Harvest and Conditioning Treatments

Orchard	Harvest	Conditioning (days)	Flesh Firmness	Soluble Solids	Quality
A	2	6	4.4	13.4	51.8
	3	3	5.1	14.2	55.1
	4	0	6.8	14.6	41.5
B	3	0	4.2	14.0	48.7
	4	0	6.2	13.1	41.4
C	3	3	5.2	13.3	42.2
	4	3	4.9	14.4	47.6
D	3	3	5.8	12.7	63.7
	4	0	6.3	16.6	45.9

Table 4 presents the quality ratings of the taste panel for fruits of treatments which satisfied the 13% soluble solids and 7 lb. firmness tolerances. For each orchard, at each harvest, the earliest conditioning treatment that brought the plums within the tolerances is recorded. Of the 16 orchard x harvest combinations only 9 treatments came within these levels.

6. Utilizing Tolerances to Indicate Optimal Harvest

As mentioned previously though, conditioning is not a controllable variable within fresh market channels. With this in mind, Figure 35 has been presented to show the reliability of soluble solids and flesh firmness tolerances in predicting the optimal harvest date.

In the graphs, flesh firmness had been converted to flesh softness with the simple equation: softness = 20 lbs. minus flesh firmness reading. Since ideal soluble solids readings are 13 and ideal flesh firmness readings are 7, ideal softness readings will also convert to 13 (20 lbs. - 7 lbs.).

The dotted line on the four orchards' graphs represents this 13 unit level common to the parameters of soluble solids and flesh firmness. Individual short lines represent the development of fruit picked from the tree at harvest and then conditioned for 2, 4 and 6 days. From earlier data on conditioning effects, it is clear that flesh firmness rapidly changed with increased conditioning while soluble solids changed slowly. Thus the convergence of the flesh firmness reading upon the slower changing soluble solids reading, at or near 13 units, focuses upon the best time to harvest fruits for maximum quality within an orchard.

Thereafter, the date of convergence of these two lines is related to the quality reading above, which is the quality

Figure 35. Effects of the time of harvest, the source of fruit, and the length of conditioning on soluble solids readings and flesh softness index in relation to taste panel quality ratings for 'Stanley' plums in 1981. (Quality values are pooled over conditioning treatments. The dashed line represents the suggested 13% soluble solids and the 13 lbs. softness index tolerance for harvest.)

RELATIONSHIP OF PLUM QUALITY TO SOLUBLE SOLIDS AND FIRMNESS READINGS

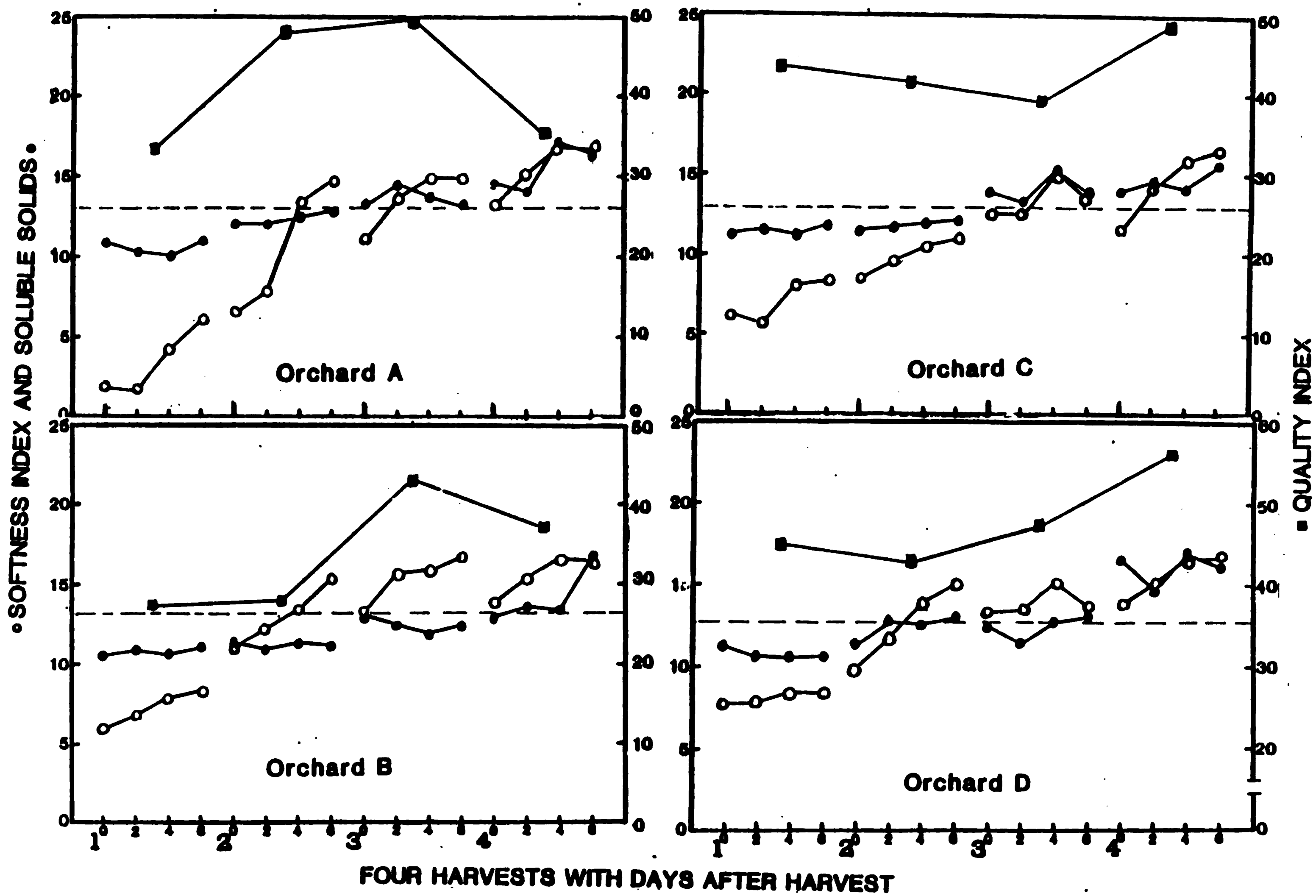


Figure 35

average of all conditioning treatments for each harvest. In Orchards A and B these tolerances indicated maximal quality. In Orchard D it indicated a climbing, but still high quality plum. In Orchard C the model was ineffective in pinpointing optimal quality. Therefore an overall precision score for the model utilizing only soluble solids and flesh firmness is 75% in the four orchards tested. As discussed earlier, there is a likelihood that quality scores at the earlier harvests were inflated upward due to longer storage treatments.

7. Testing the Soluble Solids - Flesh Firmness Model, 1982

In the 1982 season the soluble solids - softness tolerances were field tested in the same 8 locations that the ethylene model was tested. Though conditioning was obtained at 1, 3, 5 and 7 days rather than 0, 2, 4 and 6 days of 1981, the trends are similar to the 1981 results. Soluble solids generally rose gradually with each successive harvest (Figures 36 and 37). While soluble solids increased with lengthened conditioning in some cases, in many instances it decreased. The "softness index" generally increased greatly with longer conditioning treatments and also increased substantially with successive harvests. In all of the 8 locations the convergence of soluble solids and softness at the suggested 13 tolerance corresponded with a period of high quality of the fruit. Black arrows indicate the suggested time of harvest based on the qualitative assessment of our research team.

Figure 36. The effects of time of harvest, and length of conditioning on soluble solids and flesh softness readings of four orchards (Grand Rapids area) of 'Stanley' plum in 1982. (Dashed line represents ideal tolerance levels, 13% soluble solids and 13 lbs. softness, for harvest. Black arrows indicate optimal time of harvest and dashed arrows represent actual 1982 harvest.)

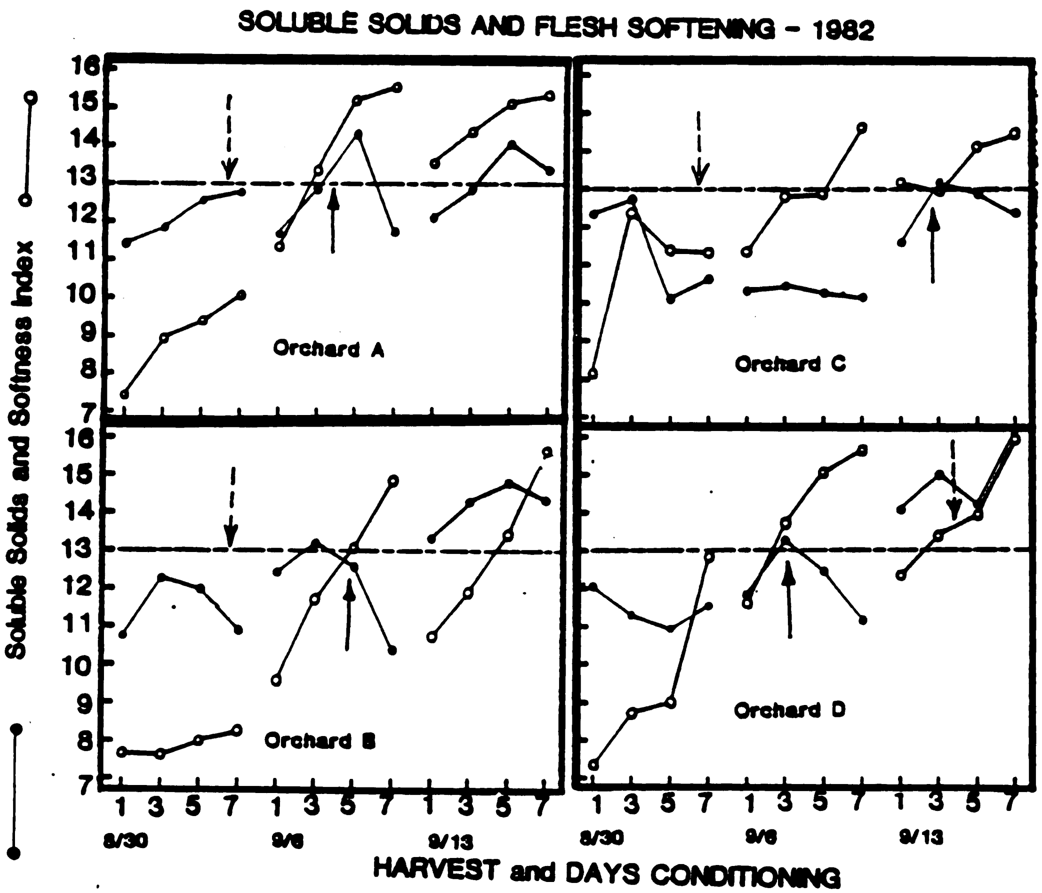

SOLUBLE SOLIDS AND FLESH SOFTENING - 1982
Soluble Solids and Softness Index
16
15
14
13
12
11
10
9
8
7
Orchard A
Orchard C
Orchard B
Orchard D
1 3 5 7 1 3 5 7 1 3 5 7
8/30
9/6
9/13
HARVEST and DAYS CONDITIONING

Figure 36

Figure 37. The effects of time of harvest and length of conditioning period on soluble solids and flesh softness readings of 4 orchards (Southwest Michigan area) of 'Stanley' plum in 1982. (Dashed line represents ideal tolerance levels for harvest, 13% soluble solids and 13 lbs. softness. Black arrows indicate optimal time of harvest and dashed arrows represent actual 1982 harvest.)

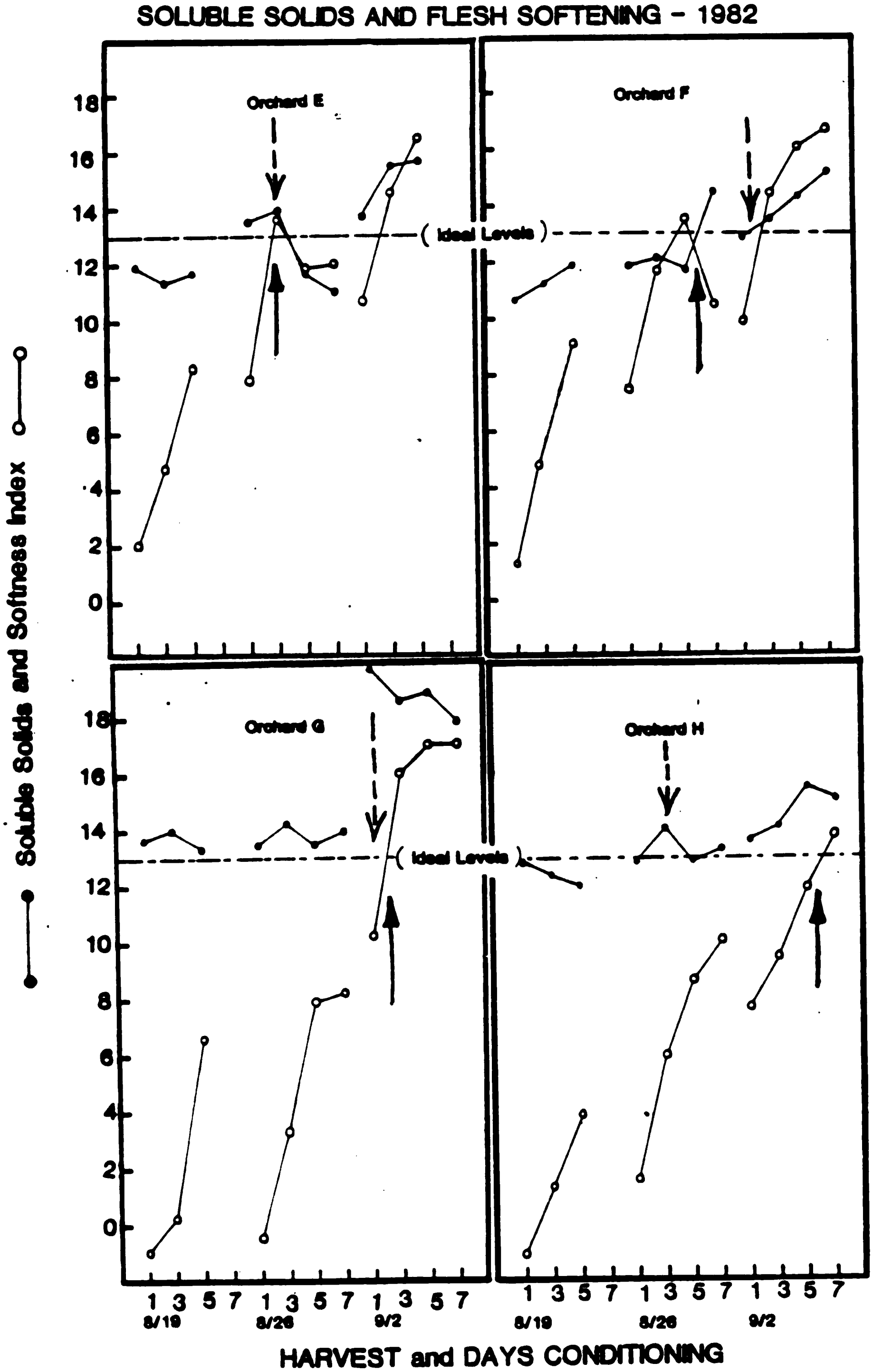

SOLUBLE SOLIDS AND FLESH SOFTENING - 1982
Orchard E
Orchard F
Orchard G
Orchard H
(Ideal Levels)
Soluble Solids and Softness Index
HARVEST and DAYS CONDITIONING
1 3 5 7 1 3 5 7 1 3 5 7
8/19 8/26 9/2

Figure 37

The dashed arrows indicate the actual time the grower harvested. In one orchard (H) from the Southwest area and in three orchards (A, B and C) from the Grand Rapids area, growers harvested before plums reached these tolerances and likely sacrificed quality for earliness, filling the market with hard, astringent and unsweet fruit. In a fifth participating orchard from the Grand Rapids area (data not shown) the grower picked early also, but because he harvested tagged research trees, data are not available. However, he did harvest when soluble solids were under 12%, firmness was higher than 11 lbs. (softness index under 9 lbs.), and fruit were extremely underripe. Orchard D was an agricultural experiment station and the management was not under the same market pressure for earliness as a commercial orchard. This site was harvested slightly after attaining optimal maturity as the fruit went to a late speciality market at a local roadside operation. This decision on harvest timing is not generally reflective of commercial marketing.

The model indicates that at least half of the cooperating growers in 1982 harvested somewhat early. In 11 of the 12 cases (1981-1982) this model seems to have been operational for Michigan 'Stanley' plums in selecting an optimal harvest date (Figures 35, 37 and 37).

H. Section 8: Canning Studies

1. Pitting Losses

Figures 38 and 39 diagram the pitting losses of halved plums during 1981. There were 3 major controlling factors, size, conditioning period and harvest date. The first graph (Figure 38) illustrates the size (weight) effects. Since size was not a predetermined variable, a correlation was used in this analysis. It was discovered that medium sized plums were most suitable for clean pit separation due largely to their tailored fit in the standard cups equipped on the pitter. When a line was fitted to the pit-loss data of the 16 orchard-harvest combinations, 32 grams in weight was projected as the ideal plum size. When plums' weights were above or below this ideal size, pitting losses increased in a linear fashion. The correlation has an r value of 0.73 and is highly significant. The majority of poor performing plums were in the heavier ranges, which was advantageous as most orchards producing large plums (over 40 grams) would be more economically suited to the fresh market.

Harvest and conditioning treatments regulated pitting losses to a greater degree than sizing. These treatments are represented in Figure 39 where the means are pooled over

Figure 38. A scatter diagram and linear regression showing the effects of size (weight) of 'Stanley' plums on the weight losses resulting from mechanical pitting in 1981. (Points are weight differences from 32 grams and the line is fitted to the 16 points, each representing an orchard x harvest combination. The r value is a correlation coefficient significant at a 1% alpha level.)

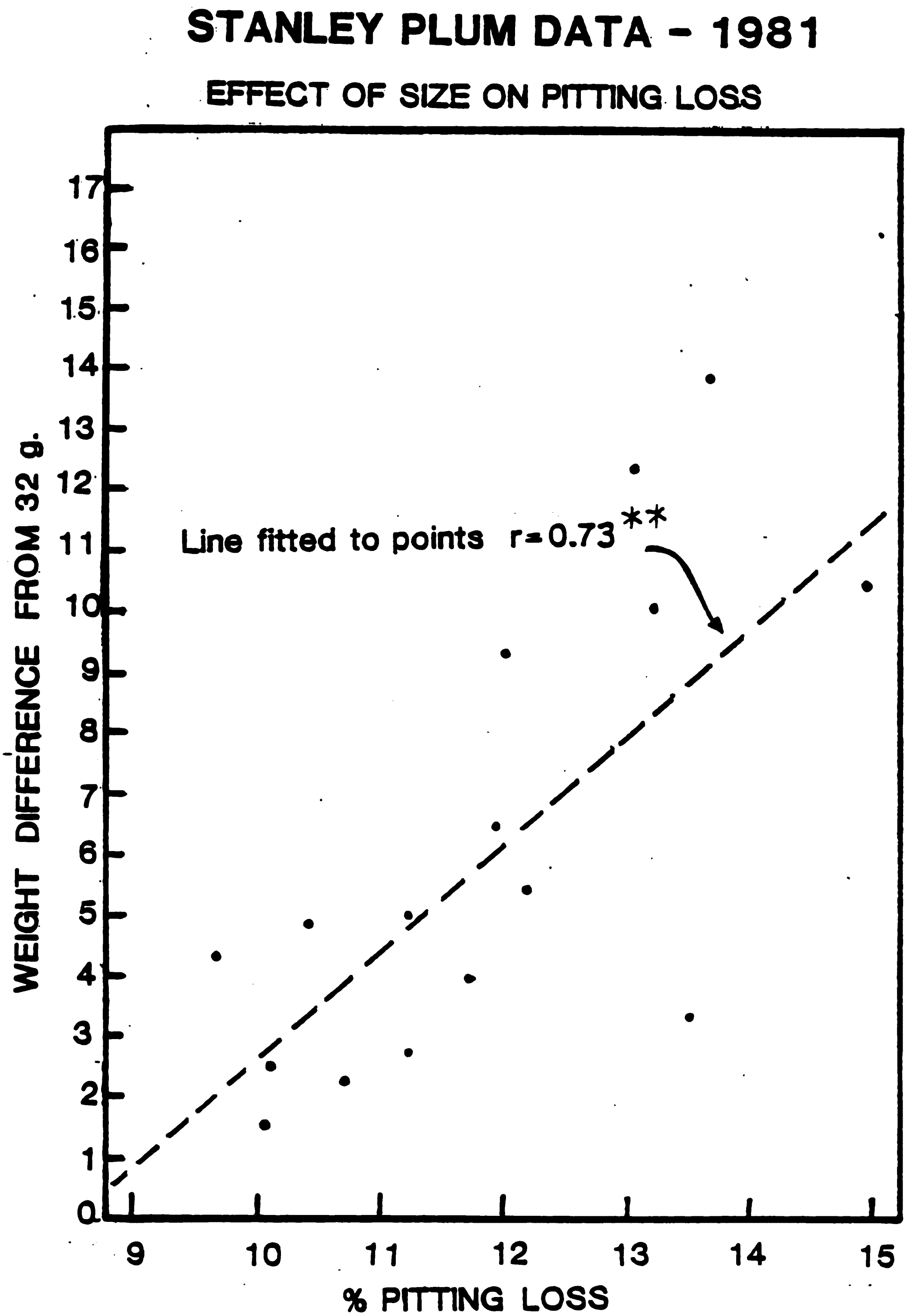

STANLEY PLUM DATA - 1981
EFFECT OF SIZE ON PITTING LOSS
WEIGHT DIFFERENCE FROM 32 g.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Line fitted to points r=0.73**
9
10
11
12
13
14
15
% PITTING LOSS

Figure 38

Figure 39. The effects of length of a 20°C conditioning period and the date of harvest on the percentage weight loss due to mechanical pitting of 'Stanley' plums in 1981.

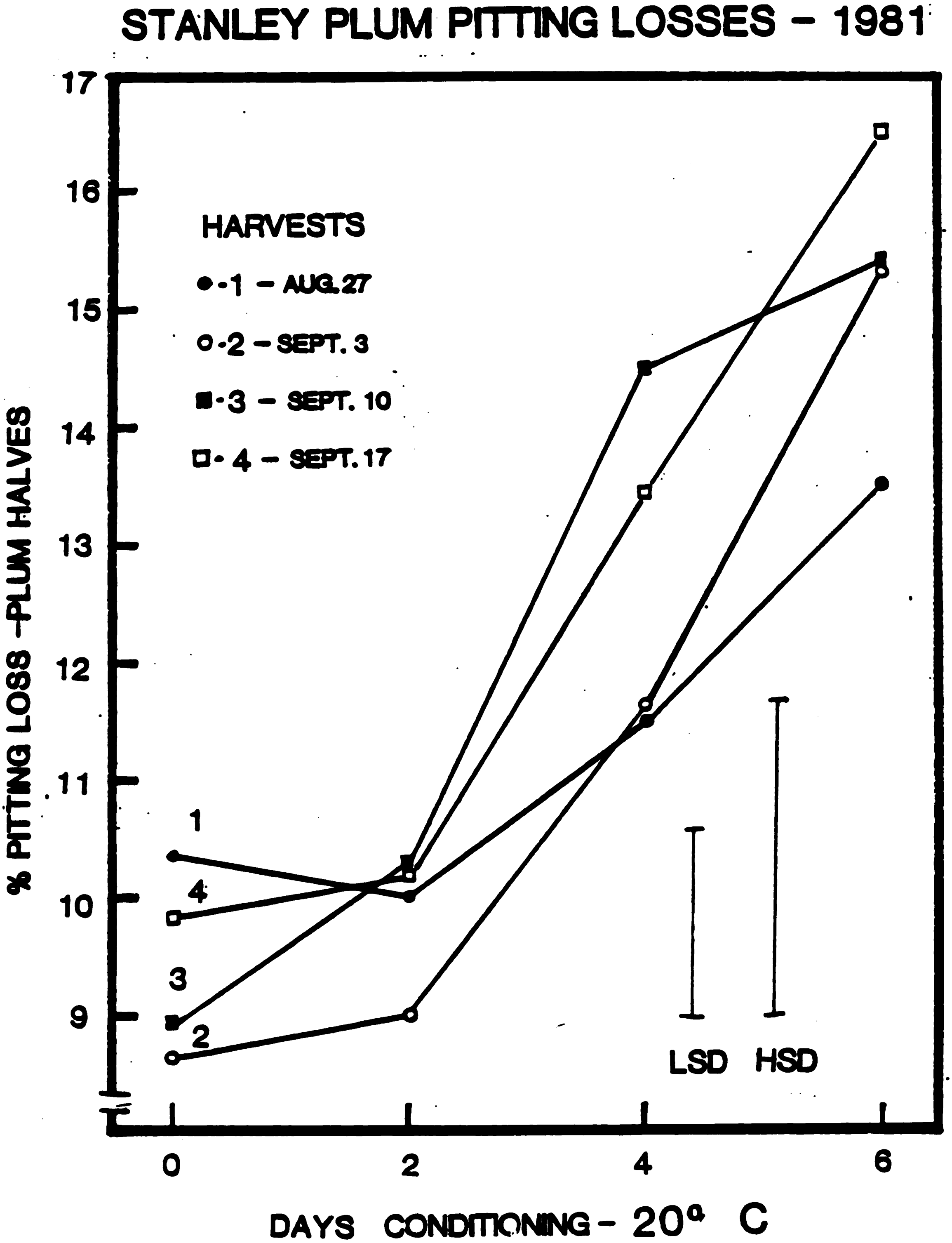

STANLEY PLUM PITTING LOSSES - 1981
HARVESTS
● - 1 - AUG. 27
○ - 2 - SEPT. 3
■ - 3 - SEPT. 10
□ - 4 - SEPT. 17
% PITTING LOSS - PLUM HALVES
17
16
15
14
13
12
11
10
9
1
4
3
2
LSD
HSD
0
2
4
6
DAYS CONDITIONING - 20° C

Figure 39

storage and location. Regardless of harvest, plums which were conditioned less than two days were subject to minimal pitting losses of less than 10.5%. While there was no significant increase in pitting losses for up to two days of conditioning, beyond two days of conditioning, pitting loss increased significantly. Later harvests tended to have more pitting debri at the later conditioning treatments. After four days conditioning, the last two harvests were significantly higher in pitting loss than the first two. Thus, pitting losses were minimized by periods of up to four days for the earlier harvests, but for only two days for the later harvests. Since fruit were more advanced in maturity at the later harvests, this would allow for high quality fruit to be canned without increasing the conditioning treatment. With less mature fruits however, this benefitial conditioning treatment could be stretched up to four days without a heavy loss in tonnage resulting from large pitting debris.

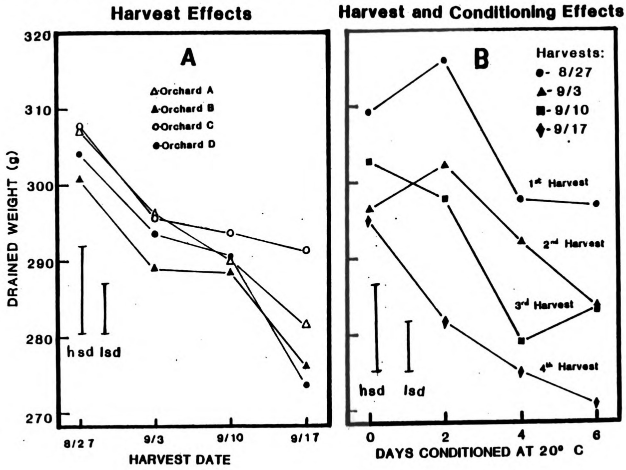
2. Drained Weights

The effect of various treatments on drained weights is presented in Figure 40. As with pitting loss, the major influencing factors were harvest and conditioning period. The harvest data is illustrated in the first graph (Figure 40-A). The four orchards were nearly parallel with respect to conditioning and the data are pooled over storage and location. With few exceptions increasing conditioning time lowered the drained weight values. For all orchards the six

Figure 40A. The effects of date of harvest and source of fruit on the drained weights of 'Stanley' plums in 1981.

Figure 40B. The effects of length of 20°C conditioning period and harvest date on the drained weights of 'Stanley' plums in 1981.

DRAINED WEIGHTS OF CANNED PLUMS - 1981



Figures 40A and 40B

day conditioning treatment was significantly different than the 0 and 2 day treatment. Advances in ripening brought on by later harvest and increased conditioning reduced drained weights. High drained weights are usually indicative of firmer, more compact fruits, often with better appearance. Low drained weight fruits are often softer and more ragged.

Decreased drained weights occurred with increasing maturity due to the cell wall breakdown accompanying ripening. The added solubility of pectic substances could permit their movement into the juice and result in lower drained weights. When the flesh is soft there could also be an added physical separation of small parts of the solid fraction into the liquid. Finally, the osmotic pressure of the syrup, which is more concentrated than cell solute, creates an osmotic gradient which draws plum cell solute out, also reducing weight.

A correlation coefficient was determined for drained weight vs. overall quality, as judged by taste panels testing the canned product. Means of the 16 harvest-conditioning combinations were compared, however due to an overripening response in the extreme conditioning treatment of the last harvest, only the first 15 were run. Drained weight was found to negatively correlate with the overall quality rating by the taste panels of the canned product. A line fitted to the points is presented in Figure 41. The correlation coefficient was highly significant. Accordingly, the panelists have

Figure 41. A scatter diagram and linear regression showing the relationship between drained weight and quality as determined by taste panels of 'Stanley' plum in 1981. (The line is fitted to 16 points, each representing a harvest x conditioning treatment pooled over location.)

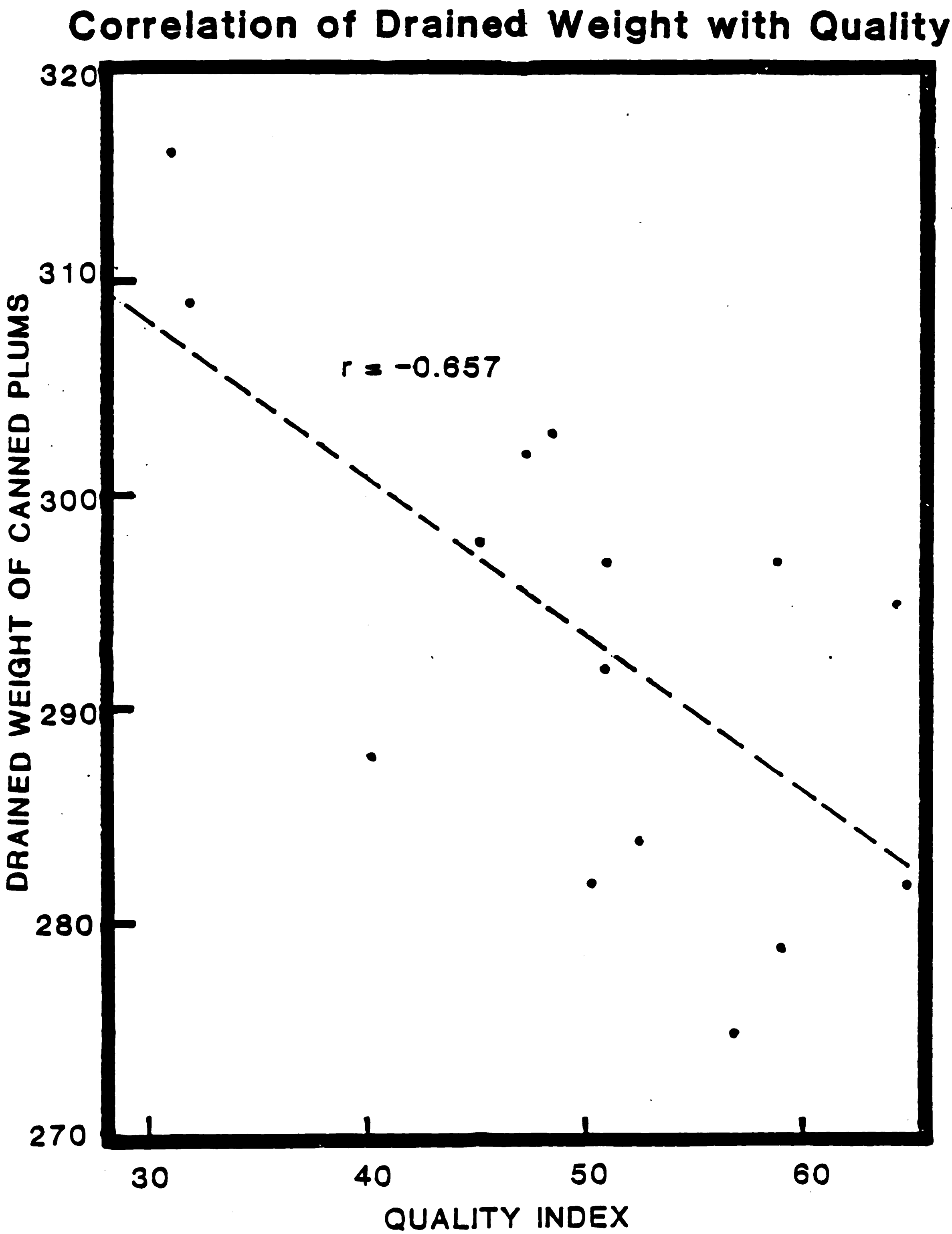

Correlation of Drained Weight with Quality
320
310
300
290
280
270
DRAINED WEIGHT OF CANNED PLUMS
r = -0.657
30
40
50
60
QUALITY INDEX

Figure 41

displayed an appreciation for improvements in fruit quality with ripening despite the textural integrity and appearance improvement which accompanied high drained weight fruits.

This should present a dilemma to canners. Higher drained weights are considered to be a favorable factor in canning economics because fruit that can maintain a minimum legal drained weight requires a smaller initial canning weight. Fruit that have low drained weights have lost weight in the can and must be packed at higher volumes to insure that they remain above the legal standards. Since high drained weights correspond to lower quality, there is a clear trade off to be made in the economic benefit of maintaining initial canning weight and the economic drawback of selling less than optimal quality fruit.

3. Taste Panels on Canned Fruit

Figures 42 and 43 display the results of the canned product taste panels. The data in the two graphs are the same but arranged differently for ease of interpretation. Figure 42 clearly illustrates quality changes as time progresses through the succeeding harvests and conditioning periods. The early harvests (1st and 2nd) show general increases in quality with more conditioning. The last harvest shows a decline with more conditioning probably due to overripening. The 3rd harvest is a compromise trend between

Figure 42. The effects of time of harvest and length of $20^{\circ}C$ conditioning period on the quality evaluation of canned, pitted 'Stanley' plums as determined by a taste panel in 1981.

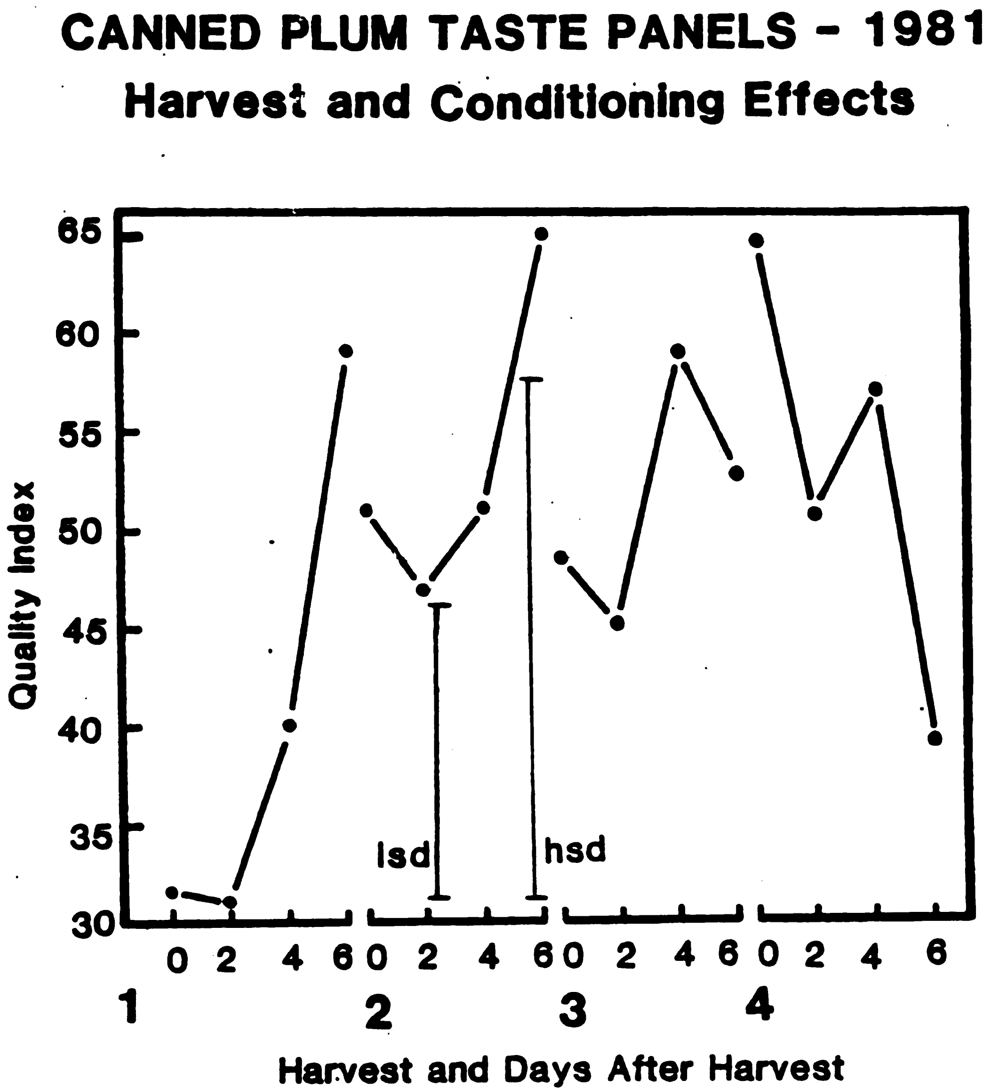
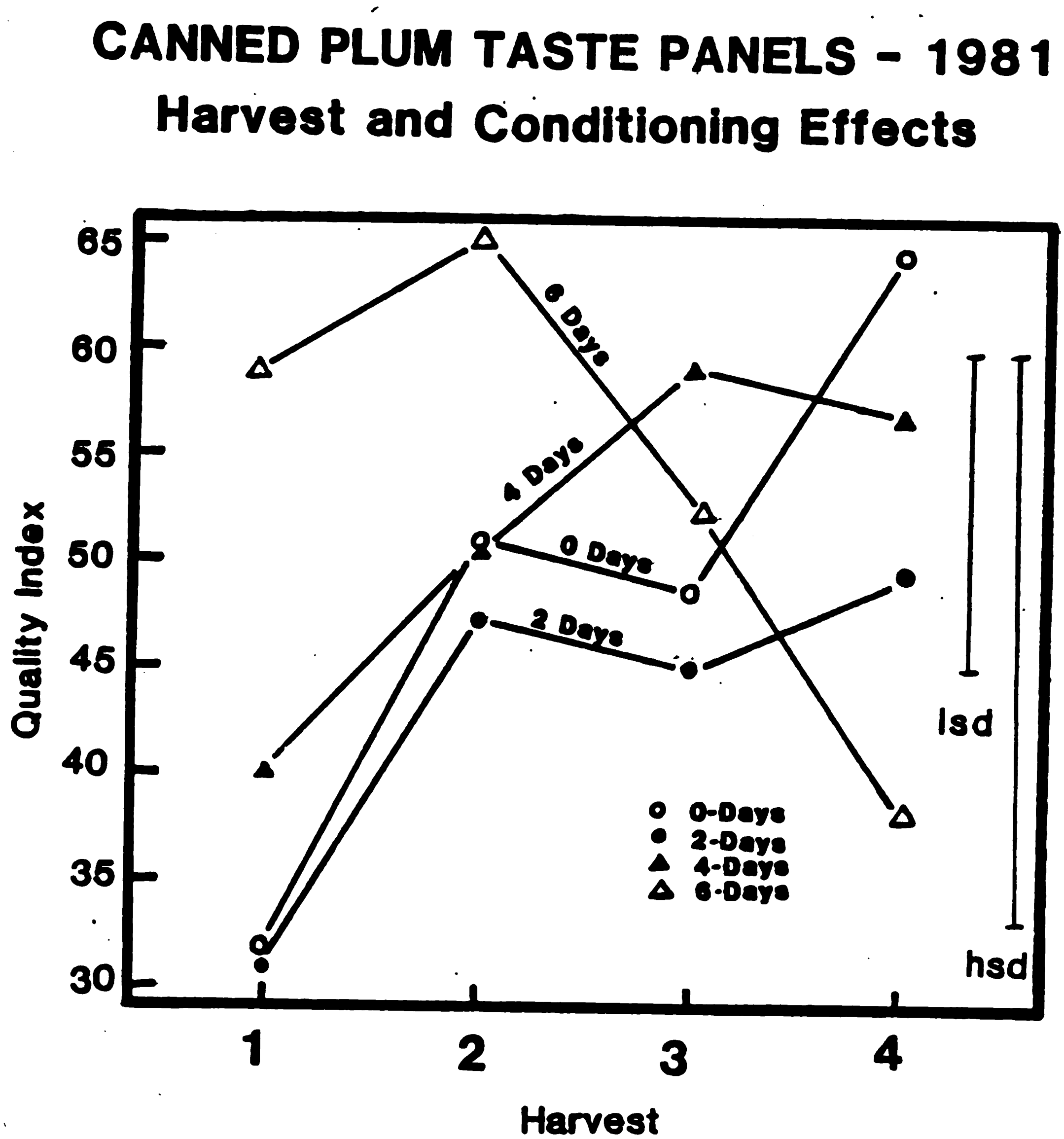

CANNED PLUM TASTE PANELS - 1981
Harvest and Conditioning Effects
65
60
55
50
45
40
35
30
Quality Index
lsd
hsd
0 2 4 6 0 2 4 6 0 2 4 6 0 2 4 6
1
2
3
4
Harvest and Days After Harvest

Figure 42.

Figure 43. The effects of time of harvest and length of 20°C conditioning period on the quality evaluation of canned, pitted 'Stanley' plums as determined by a taste panel in 1981.



CANNED PLUM TASTE PANELS - 1981
Harvest and Conditioning Effects
Quality Index
65
60
55
50
45
40
35
30
6 Days
4 Days
0 Days
2 Days
lsd
hsd
0-Days
2-Days
4-Days
6-Days
1
2
3
4
Harvest

Figure 43

the first and last harvests. While there were no significant differences with extended conditioning periods, maximum quality was obtained at a mid-range conditioning treatment (4 days). These trends are similar in nature to those of the fresh market panels as illustrated in Figure 28. LSD mean separation provides at least one major quality difference between the highest and lowest rated fruit within each harvest, except for the third harvest.

The interaction between harvest and conditioning is so influential that a discussion about harvest effects in themselves is incomplete. Given any harvest, quality can be modified to a high rating by altering the conditioning time. A look at Figure 43 gives a clearer idea of the mean separation as all points are within the same time frame. At the first and second harvest, the six day conditioning treatment is significantly greater than the three other conditioning treatments. By the 3rd harvest, while four and six days conditioning still had produced superior fruit, the ripening on the tree brought up the quality rating of the shorter conditioned fruit (0 and 2 days) to values high enough that added conditioning could not significantly improve quality. By final harvest the situation had reversed from the earlier harvests, and tree ripe fruit were superior to all conditioned treatments. The non-conditioned fruits (0 days) were significantly greater than six or two days, but not four days.

The relationship between conditioning and maturity at harvest is much more useful in the canned product than in the fresh. Because the conditioning period necessary for development of optimal fruit quality attributes can be controlled by the fruit handler, it use as a ripening regulator is important.

This scenario presents another dilemma to canners. If the fruits are harvested early and conditioning is necessary for full ripening, there will be considerable gain in the pit loss percentages as shown in Figure 39. Thus weight loss will be sacrificed for quality. If later harvested fruits are used, there is a less clear cut distinction as to the ideal conditioning time. From Figure 43 it appears that tree ripe fruit at 4th harvest and minimal conditioning performed the best of the later harvested fruit. Furthermore, this fruit would have had very low pit losses from Figure 39. This then suggests that fruit ripened well on the tree and immediately pitted has a small qualitative and quantitative advantage over all other treatments.

4. Tolerances for Canned Fruit

The setting of tolerances for canned fruit is more difficult than with the fresh market product, for two simple reasons: 1) processing alters the nature of the fruit from its original condition (forced sweetening and softening); 2) there are rapid changes in quality with conditioning that cannot be easily predicted from the orchard condition. Nevertheless, it was found that quality of the canned product showed important correlations with two main parameters, color and sweetness (Table 5).

There was a highly significant correlation to quality with color scores within the panel and with absorbance readings from the color index. Fruit with OD readings ranging from 0.86 to 1.43 had quality ratings 13% higher than the mean of all quality ratings, and 30.4% higher than any fruit whose OD readings were outside that range.

The observation that quality improvements correlate well with color absorbance in the canned product but not in the fresh plum seems contradictory; however, closer examination reveals sound reasons for this occurance. In the fresh fruit taste panel, skin color is similar in most treatments. (The exception was fruits from the earliest harvests and conditioning treatments which still had an observable green tinge.) During canning, the cooking of the fruit gives a purple-red tone to the flesh and syrup from the diffusion of the anthocyanin pigment out of the skin. Thus the intense pigmentation which is a deep purple in the skin of the fresh product becomes "thinned out" in canning and differences became apparent so that quality ratings of the canned product correlated positively with both; 1) the color rating of the same taste panels, and 2) the absorbance of the

TABLE 5

Canned Taste Panel Correlations -1981

Correlation	r Value	Significance[1]	No. of Means
QUALITY/COLOR (Panel Ratings)	.762	**	16
QUALITY/COLOR (Absorbance)	.667	**	15
QUALITY /SWEETNESS (Panel Ratings)	.786	**	16
QUALITY/SOLUBLE SOLIDS	.462	ns	15

The above correlations were determined from the base of 16 harvest-conditioning treatments pooled over location. Since harvest and conditioning were the most influencing variables, this scheme was chosen. Advances in final indices were accompanied by a low quality score, so in the case of quality/absorbance and quality/soluble solids correlations, only 15 of the 16 means were utilized in order to maximize the linearity of the responses.

1. ** = Significant at 1% level
   ns = Not significant

fresh product.

Likewise there was a highly significant correlation of quality with sweetness values but not with soluble solids readings. This later correlation was only realized at an alpha level of 8.7% rather than the 5% necessary for significance. Nevertheless, the quality to sweetness correlation does show a significant relation to the perception of sweetness and the ultimate quality. Since it has been shown that drained weights and accompanying cell solute concentrations change with conditioning and harvest treatments, perhaps an explanation exists here for the correlative significance between quality and sweetness, but non-significance between quality and soluble solids.

If fruits of the earlier harvests absorbed some of the 20% glucose syrup, they were likely to be judged sweeter and consequently of higher quality, reinforcing the quality-sweetness correlation. However, since those same fruits that were artifically sweetened had low soluble solids levels, the quality-soluble solids correlation would have a looser fit.

The relative importance of both color and sweetness both tend to further the recommendation that optimal quality can be best obtained with advanced ripening on the tree. Since both of these parameters increase with fruits on the tree, the selection of a later harvest date would be more advantageous than dealing with somewhat uncertain changes to be regulated with conditioning. Therefore recommendations for optimal fruit for canning would be along the following lines: 1) Color (O.D.) values 0.85 - 1.40; 2) Soluble solids readings 13 - 14% or higher.

5. Storage Effects Evaluated on Canned Fruit - 1980

In 1980 storage tests were evaluated with canned fruit. The samples were conditioned for 6 days, unforunately eliminating any avaluation of conditioning or storage-conditioning interactions. Another deficiency in the experimental design was a lack of an "overall quality" rating within the panel evaluation. Nevertheless, despite these two limiting factors, some interesting trends due to storage can be extracted from the data.

The results of the panel are presented in Table 6. The trends were the following: 1) texture became firmer with extended storage; 2) flavor strength and off flavor dropped; 3) tartness and color were fairly stable throughout the various storage periods. The general trend was for no quality improvements with storage, unless one could arbitrarly consider firmer fruit to be of higher quality. However, no such correlation existed in the 1981 data with canned fruit. What is impressive about the panel data however, is that it parallels some of the trends of the indices. Firmness in both panel and index dropped at the second storage period

Table 6

The Effects of Storage on the Results of Quality Assessment by Taste Panels - Canned Plums, 1980

Taste Component	Length of Storage Period			
	0 Weeks	2 Weeks	4 Weeks	6 Weeks
1. Texture	30.1_a [1]	29.1_a	59.5_b	76.5_c
2. Flavor Strength	54.0_a	51.8_a	52.5_a	44.6_b
3. Off Flavor	40.2_a	43.2_{ab}	50.0_b	34.4_a
4. Tartness	35.0_a	33.4_a	36.4_a	30.4_a
5. Flavor Acceptability	55.7_b	50.9_b	40.4_a	56.8_b
6. Color	59.3_a	62.4_a	56.8_a	51.0_a

The effects of storage time on individual components of the taste panel evaluations for canned, pitted 'Stanley' plums in 1980. All values are the storage effects pooled over location, harvest and ethylene treatments. Conditioning was six days for all treatments before canning.

1 Least significant differences (LSD's) indicated by different letters following the values. Calculated at the 5% level

and climbed at four and six weeks (Figure 11B, mean of the 1980 graph). This complimented an overall firming trend that was observable in longer stored fruit. The strongest drop in panel tartness ratings also accompanied the major drop in the acidity index at the sixth week (Figure 15). Color showed dropping trends in both panel and absorbance index (Figure 16B).

6. Tests with the Hunter Color Meter

In 1980 all the skin side of halved plums were analyzed on the Hunter Color Meter. There were no significant differences with respect to harvest, storage or ethylene treatment on the three scales, L, A and B.

DISCUSSION AND SUMMARY

A. Maturation Indices

Selection of a proper harvest date was by far the most important factor in this research that influenced ultimate plum quality for the fresh market or processing. It was found that from a handful of traditional harvest indicators, the standbys of flesh firmness and soluble solids proved to be the most revealing of changes in plum maturation. Debate surfaces in the literature as to the one most desirable index. While some researchers opt for flesh firmness (13, 17, 18, 51, 52), others stress some level of soluble solids should be incorporated into quality assessment (9, 10, 47). Since both of these indicators are accessable and useful to growers in assessing maturity, a compromise of both parameters should be used for Michigan's 'Stanley' plum crop.

The use of either color or acidity presents problems to fresh market quality assessment. Skin color changes (extractable pigments) are an ineffective tool. While rapid changes in OD readings might mildly correspond with changes in plum quality, the bulk of the OD readings do not reflect any qualitative color change perceptable by the consumer.

Color changes visible to the eye can only distinguish very immature fruit from slightly immature. The visual change of flesh color from yellow green to amber has been discussed in two reports (10, 55) and appears applicable to 'Stanley' fruit but awaits development of a reliable physical measure or color chart for research and implementation. Acidity, an index rarely prescribed in the literature, was found to be unapplicable to 'Stanley' plums, largely because of seasonal variation and a low correlation with quality. While soluble solid - acid ratios are suggested as a potential index in one report (10), the use of this ratio with 'Stanley' was less effective than soluble solids readings alone. This supports the view of La Rosa (18) that it is of limited value. Both color and acid readings also suffer from the use of complicated and time consuming instrumentation.

A high degree of seasonal variability in maturation and ripening was witnessed in this three year study, and is supportive of previous reports (10, 18, 38, 48, 55). Variations due to location were also pronounced.

B. Post Harvest Treatments

The use of two postharvest treatments, 0°C storage (2, 4 and 6 weeks) and room temperature conditioning at 20°C (2, 4 and 6 days) advanced all maturity indicators (color, texture, pit removal, soluble solids and acidity).

The only exception to this was a drop in color readings (extractable pigments) with extended storage and this may reflect pigment migration from the skin to the flesh. The most notable changes due to a postharvest treatment were:

1) flesh firmness decreases and color (anthocyanin pigment) increases with progressing conditioning periods.

2) acidity decreases with storage and conditioning, and color (anthocyanin pigment) decreases with storage.

3) small and largely non-significant soluble solids increases with both storage and conditioning.

The increases in flesh firmness and stability of soluble solids readings with conditioning are in agreement with other research (18, 34, 48) concerning the postharvest changes in these parameters. The relatively stable levels in flesh firmness despite long storage as presented in Figures 11, 13 and 14 have also been reported previously (24). Despite significant changes with postharvest treatments, harvest date selection had considerably more influence in regulating the degree of ripening.

The general maintainence of quality in plums at 0°C reported here coincides with the bulk of the literature (9, 18, 27, 44, 48) as plums retained quality 2 - 4 weeks in cold storage with a small incidence of internal browning occurring at six weeks storage. The abnormal ripening at 32°F (0°C) as reported by Gerhardt et al (10) was not witnessed in this report. While shrivelling problems are cited in some of the literature (48, 52), this was not visible until the sixth week of storage. Four weeks storage had little damaging effect on fruit quality even in the later harvested 'Stanley' fruit.

C. Weight Changes

Weight improvements with maturation were evident at the later harvests but were often erratic and unpredictable. Sampling indicated that weight losses could also occur and might be tied to environmental or physiological changes. In the majority of orchards, plums seemed to gain the greatest weight in the last week of fruit development prior to drop. In this time frame, increases of 1% per day were observed and echo the findings of other reports (9, 11, 18, 52). However, the lack of any steady weight gains in several locations suggests that harvesting for optimal quality is just as critical as harvesting for maximum tonnage. The loss of weight during storage agrees with Couey's research (8) where losses of about 5% were obtained with open storage. In 'Stanley' all of the weight loss was observed after the first storage period (2 weeks), and at extended storages (4-6 weeks) plum weight losses stabilized.

D. Ethylene Gassing

Gassing of fruits with ethylene has produced significant advancements in only two textural parameters, flesh firmness and pit removal, both in the first two harvests (Figures 19 and 20). A trend toward increased absorbance readings was witnessed but was not significant. Smith reported similar advances on another European variety, 'Monarch,' with ethylene and acetylene gassing (43). Furthermore, the use of ethephon, an ethylene generator, has also hastened flesh firmness loss and color gain in 'Early Italian' plums as observed by Proebsting et al. (29), while other researchers have reported similar effects of ethephon on oriental plums (2, 12). Gassing increased the incidence of skin cracking in 'Stanley' plums. In addition gassing treatments had no effect on the quality of the canned product or on the pitting losses of halved plums. Gassing is not recommended for either the ripening of fresh market fruit or for the pre-treatment of processed fruit.

E. Ethylene and CO_2 Production

Ethylene production of plums at harvest was a function of harvest date. This was observed in 3 years with two ethylene monitoring systems. There appeared to be a clear ethylene climacteric of the fruits in the open system and while this was paralleled in the closed system, it was confounded by the accumulation of ethylene. A respiratory climacteric followed this burst of ethylene production in the non-stored fruits. This supports Abeles classification of the plum as a climacteric fruit (1).

Short storage (2 weeks) enhanced or sustained ethylene production while longer storage (4-6 weeks) diminished it. It was suggested that this data supported a mechanism of ethylene physiology as hypothized by Wang (54) with cucumber fruits. The elevated ethylene production in fruits of short storage may be the result of increased capacity of chilled tissues to make ACC, while the depressed ethylene production by fruits after long storage may be due to the damaging of the ethylene generating system with extended chilling temperatures (54). Increased production of ethylene was observed in closed systems when fruits were subject to short chilling exposures (3 hours and 3 days). Ethylene production following chilling appeared to be dependent on both the chilling treatment and the level of fruit maturation. This advance in ethylene production in treated plums further supports the hypothesis that ACC levels increase with chilling.

Such a hypothesis could also interpret findings of La Rosa (18) and Probesting et al. (28, 30) who witnessed ripening advances in fruits subject to cold storage treatments of one and two weeks. These advances could be tied to the accumulation of ACC during storage that was sufficient to generate enough poststorage ethylene to initiate climacteric ripening responses. Smith (43) found that although ethylene gassing improved ripening of fruits after storage for 7 or 14 days, a higher proportion of ungassed fruit ripened after 14 days compared to 7. If ACC accumulated consistantly under this limited chilling, then this could explain a more complete ripening response in the ungassed fruit chilled for a longer period. Furthermore when Smith (43) gassed fruit with high concentrations of ethylene while in 31°F (-0.4°C) storage there were no effects.

Chilling temperatures have stimulated ethylene evolution in grapefruit, sweet oranges and avocados (7). Research on 'Bosc' pears has indicated that chilling periods of several days at 5°C promote earlier and greater ethylene production than at room temperature (37). In addition 'Bartlett' pears have been shown to ripen prematurely with artifically controlled warm days and chilling night temperatures (53). Both ethylene and CO_2 evolution occurred earlier in chilled samples than in non-chilled controls (53). The increased ethylene production in plum suggests that the system may be similar to pears and part of a natural ripening mechanism.

CO_2 production in plums after cold storage appeared to be influenced by: 1) normal respiratory climacteric; 2) catabolism of respiratory intermediates that have accumulated during storage. At extended storage there was a downward trend in CO_2 production with no recovery suggesting a build up of intermediates had occured along with a depletion of substrate. However, in some cases with short storages the fall in CO_2 production was followed by a recovery, suggesting normal respiration occurred after the catabolism of built up intermediates. These trends appear to fit a pattern of respiration as hypothesized by Lyons (21) where respiratory intermediates are built up due to increased energies of activation in membrane bound enzyme systems. Furthermore, plums respond favorably to intermittant warming treatments (42, 45) indicating that a period of active metabolism may have the effect of reducing the buildup of toxic intermediates and thus ameliorating chilling injury. While other hypotheses for a chilling response exist, the Lyons (21) hypothesis seems most applicable to the data.

These patterns tend to compliment the work of Uota (49) (working with Japanese plums) who was unable to obtain strong respiratory increases with high levels of ethylene and cool temperatures (35-55°F, 1.7-12.8°C). Total ethylene and respiratory increases with high levels of ethylene and cool temperatures, and chilling temperatures inhibit respiratory action even in the presence of ethylene (49). Uota was able to obtain respiratory increases in plum after ethylene gassing at high concentrations and warm temperatures (70 and 90°F, 21.1 and 32.2°C), and was also able to hasten the initiation of the respiratory climacteric by about one day (49).

F. Fresh Fruit Taste Panels

Fresh fruit taste panels revealed strong interactions between harvest and conditioning and harvest and location. At a given location fruits must be harvested at the proper time for maximal quality. Using this framework, correlations were drawn between quality as determined by taste panels and various indices. Flesh, firmness, soluble solids, and a modified log function of ethylene evolution were most significantly linked.

G. Modeling for Ethylene, Soluble Solids and Flesh Firmness

The use of closed systems for measuring ethylene showed promise for estimating the optimal harvest date in its initial year of testing. The rates of evolution had strong variations between both harvest dates and locations. Favorable results have been attained using such monitoring systems with apples (Dilley, D. R., personal communication) and pears (Mitchell, F. G., personal communication). Considering the results of the taste panels and ethylene's involvement in ripening, a harvest model was designed using two traditional parameters, soluble solids and firmness, along with ethylene. Tolerances were established utilizing changes in harvested fruit as indicators of when to harvest the fruit on the tree. Levels of 13% soluble solids, 7 lbs. flesh firmness and 2 ul/kg/hr of ethylene were set as those harvest indicators in the conditioned fruit.

The soluble solids and flesh firmness tolerances were different from recommendations of other research. The sweetness levels were somewhat lower than those recommended for Western plums (9, 10). Lower light levels and shorter growing seasons in the East are often responsible for this divergence in the soluble solids of many fruit crops. Firmness levels were lower than the 15-20 lbs. previously recommended for Michigan 'Stanleys' (17), but considering the different techniques in determing flesh firmness, this was difficult to compare. Flesh firmness and soluble solids showed considerable seasonal differences along with orchard variation as evidenced by the results of this report and others (9, 18, 47).

Upon testing in 1982, the model gave reliable assessments of optimal harvest dates with respect to the soluble solids and firmness tolerances. The ethylene tolerance though, failed to be workable in a few locations. Nevertheless, auxillary experiments indicate that exposing fruits to some chilling treatment may not only facilitate the use of the ethylene index but also enable growers to get an earlier warning of when their crop will ripen. Continuing research on this matter is recommended.

H. Canning Studies

Results of the canning studies produced several variables to consider in determing harvest and postharvest treatments of plums; drained weights, pitting losses and taste panel evaluations. Pitting losses were modulated by size, harvest and conditioning. Conditioning was the most dominant factor followed by harvest and size. The sizing relationship, though minor, was previously suggested by Cargill et al. (4). The selection of medium sized plums however, was instrumental for proper alignment of the pit in the cup, and considerably reduced the fracture of pits which leaves undesirable fragments in the can. Drained weights were found to be negatively correlated with taste panel quality. Extended storage appeared to have no benefit on the quality of the canned product and coincides with the conclusions of La Rosa (18), while diverging somewhat from the storage-induced quality improvements reported by Proebsting et al. (28, 30).

Rather than being influenced by storage, quality of the canned product was most strongly tied to the conditioning treatments, and particularly interwoven with the harvest-conditioning combination. By properly conditioning fruits of any given harvest, fruit can be brought up to a high quality level. This added conditioning however, produces an increase in pit losses so the canning of fruits from later harvests directly after picking presents the optimal tradeoff between these two factors. However, when market, or processor pressures force the canning of less mature fruit, the proper conditioning period is mandatory for high quality. Tolerances for canning are as follows: 1) minimum of 13% soluble solids; 2) minimum of 0.85 O.D. units when anthocyanin extractions (1.3 cm^2 skin tissue/10 ml of 10% oxalic acid solution) are read at 515 nm on a spectophotometer. These two indices were recommended as they showed a correlation to canned plum quality.

The basic problems with pitting of 'Stanley' plums are engineering difficulties regarding proper sizing and alignment of the plum into the cup to minimize pit fragments. If these problems can be solved, proper postharvest treatment will ensure a minimum pitting weight loss to the processor.

I. Conclusion

Determination of the best harvest date and the ideal postharvest treatments for Michigan 'Stanley' plums is a complex issue that frequently stretches beyond the borders of postharvest physiology. Many factors face the grower from the cultural, environmental and managerial problems in the orchard to the logistical and economic pressures of the marketplace. When these factors are interwoven to the results of this thesis, they can modify the application of the conclusions and recommendations. The findings of this 3 year study are thought to be representative of the mainstream of the Michigan plum industry, but their interpretation falls within a wide variety of specific cultural-marketing situations, each demanding its own particular application. The success in implementing the recomendations of this research lies ultimately in the search for higher quality by our plum producers.

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