Effects of Harvest Date and Specific Gravity on Storage Behavior and Raw and Processed Quality of 'Jonathan' Apples[1]

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Abstract. The composite specific gravity (SG) of 'Jonathan' apples decreased and size increased with each of 3 successive harvest dates. The SG of all but the least dense fruit decreased during storage. Correlation *r* values of some raw product attributes are shown. Analysis of sauce made from fruits of different SG and stored for up to 4 months showed that separation according to SG at early and late harvest dates may have some value in obtaining a higher quality product.

Previous research (7, 8, 9, 10, 11, 12, 13) has demonstrated the possibility of using fruit or vegetable specific gravity (SG) characteristics as a means of "mass grading" for different quality attributes. This procedure would be especially desirable because of the potential low cost per unit. To establish procedure for apples, more data on the effects of storage, harvest date and their interaction with fruit specific gravity was needed.

Materials and Methods

Representative 'Jonathan' trees, about 25 years old on standard rootstocks in a local commercial orchard were chosen and each tree was separated into 6 wedgeshaped sections. Two opposite sections of each tree were harvested at dates corresponding to 2 weeks before the optimal commercial harvest date (OCHD), at OCHD, and 3 weeks after OCHD. Fruit was being harvested commercially from this orchard at each harvest date. No attempt was made to separate fruit according to cluster position. Westwood et al. (16) have shown that cluster position affects fruit density.

The apples were brought to the laboratory and separated by ethanol flotation into 4 density classes: those floating in 95% (F95), 90% (F90), and 85% (F85) ethanol, and those sinking in 85% ethanol (S85). These corresponded to average densities of .0857, .8254, .8420, and .8569, respectively. Samples (approx 3 kg) were withdrawn from each lot and placed in perforated polyethylene bags. The bagged samples were placed in storage at approx 1.5°C (35°F). Two replications were made by using 2 different storage rooms set for the same temp for comparable lots of fruit.

At harvest and monthly intervals thereafter for 4 months, a sub-sample of fruits was removed, one fruit at a time for analysis of internal atmospheres. A hole was bored into each core with a No. 1 cork borer, the cylinder of tissue was removed and the hole was plugged with a serum stopper through which 2 half ml samples were removed for analysis of CO_2 and C_2H_4. Internally pressurized apples fitted with serum stoppers as described showed no gas exchange around the stopper. All gas exchange was through the lenticels or the calyx (Fig. 1). Both CO_2 and C_2H_4 were analyzed by gas chromatography using standard procedures.

The same fruit were then used for measurements of firmness, size, percent blush, and soluble solids content. Firmness was measured by a Magness-Taylor pressure tester with an 11 mm (7/16 inch) tip. Tests were made on de-skinned sections of the blush and non-blush sides. Size measurements were made across the widest lateral section. Blush ratings were made by visual estimation of the percent of skin colored red. The soluble solids content was measured with a Bausch & Lomb Abbe-3L refractometer on a composite juice sample extracted during the pressure tests from both the blush and non-blush sides of each fruit. The remaining fruit from each sample were separated into the 4 density classes by alcohol flotation and the changes in density within each original density class, and during storage were measured. The apples were then sliced, placed in 'C'

Fig. 1. Apple prepared for sampling of internal atmosphere. The air bubbles show points of gas exchange when the fruit is pressurized. Notice that no gas exchange occurs around serum stopper.

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enamel 303 x 211 cans, steam exhausted for 10 min, closed, and processed in boiling water for 30 min. This procedure was followed for each harvest date and storage sampling.

The processed slices were then made into sauce with a No. 101 Foley Food Mill[3] for measurement of all objective indices of quality except consistency. The percentages of dry wt and AIS were determined by modifications of the AOAC methods (1). The percentage of soluble solids was measured on a Bausch & Lomb Abbe-3L refractometer. Titratable acidity was determined by titration of a known wt (approx 5 g) of puree in 100 ml of distilled water to pH 8.1 with 0.1 N NaOH. The pH and the color were determined on undiluted puree; the color determination was made by using a Gardner color difference meter with a white tile reference having tristimulus values of L=93.8, a_L=-1.2, and b_L=2.8. Consistency and subjective measurements of color, taste, and appearance acceptability were made on sauce made from 0, 2, and 4 month samples with a Cefaly[4] pulper-finisher using a Bostwick consistometer and an 8 member panel respectively.

Results

Specific gravity distribution. Since SG was determined by alcohol flotation classes rather than as a specific value determination for each fruit, the discussion will be in terms of SG classes rather than by density per se. The relationship between percent ethyl alcohol and SG is slightly curvilinear (Fig. 2). For the purposes of discussion, however, a linear relationship is assumed.

The percentage of less dense fruit (F95 & F90) tended to increase with a concomitant decrease in the percentage of more dense fruit (F85 & S85) as harvest was delayed (Fig. 3). Overall

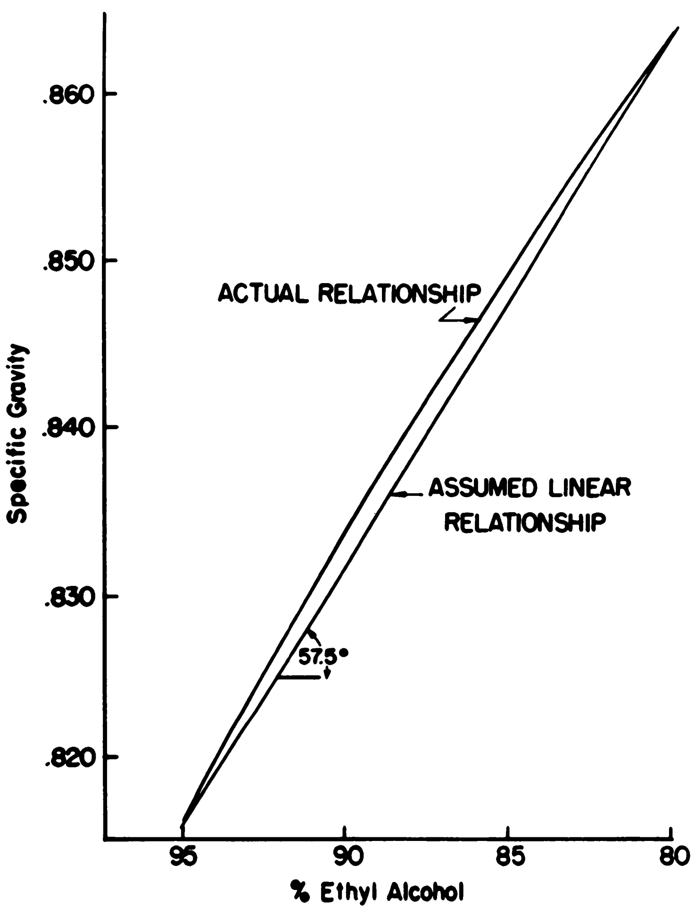

Fig. 2. Plot of specific gravity vs. percent ethanol showing the actual linear relationship.

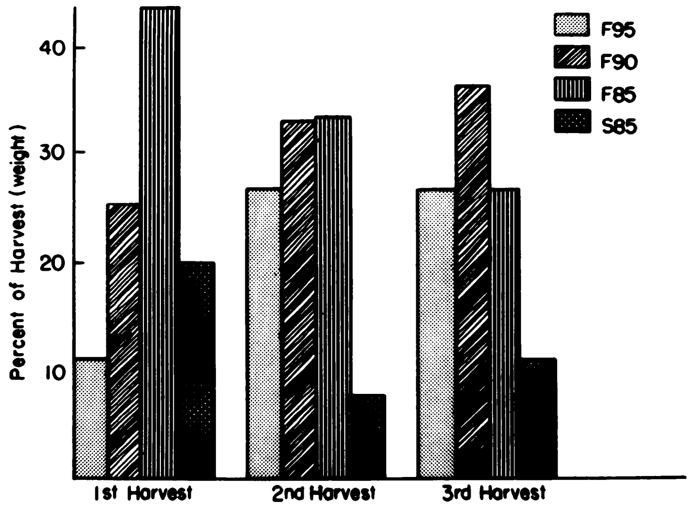

Fig. 3. Distribution of the 4 density classes of 'Jonathan' apples at each of 3 harvests dates.

SG decreased with harvest from approx .8366 at first harvest (H_1) to approx .8273 at third harvest (H_3). The small increase in the percentage of S85's at the last harvest date may be due to the beginning of some watercore in the larger fruit. Individual fruits were cut to study watercore which occurred in all SG classes. But its occurrence was sporadic and of limited development throughout the experiment.

Larger fruits occurred in the lower SG classes (Fig. 4). Fruit size was negatively correlated with SG but positively correlated with delay of harvest date.

Fruit SG changes were influenced by SG at harvest, harvest date, and storage. All main effects and interactions were significant at the 1% level (Fig. 5). Fruit of the F95 SG class from H_1 increased in SG during storage to a greater extent than fruit from H_2, while no change was observed with the F95 fruit from H_3. Apples of the other SG classes became less dense during storage, the magnitude of the change being related to the delay in harvest and the initial fruit SG.

Internal atmosphere analysis. Analysis of the internal atmospheres showed marked differences in the CO_2 and C_2H_4 content at the different harvest and storage intervals (Fig. 6). Mean values for both CO_2 and C_2H_4 concn were higher at H_2 than at H_1 or H_3. Data obtained from H_1 and H_3 showed that CO_2 and C_2H_4 content of the internal atmospheres plotted against storage time followed the typical climacteric-type pattern. The magnitude of the change during storage, however,

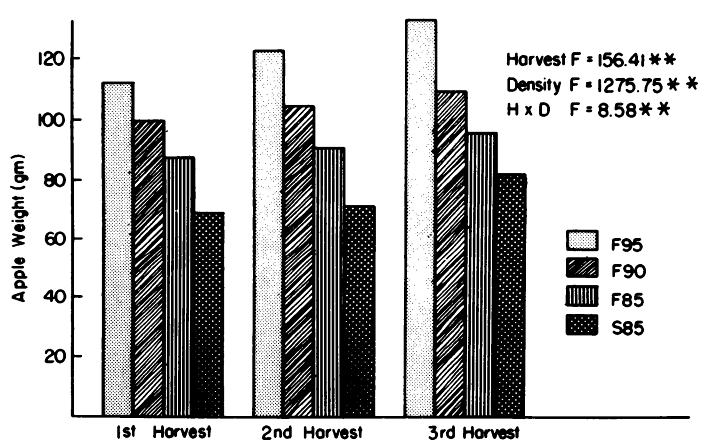

Fig. 4. Apple weight (g) of 'Jonathan' apples as related to density class at each of 3 harvest dates.

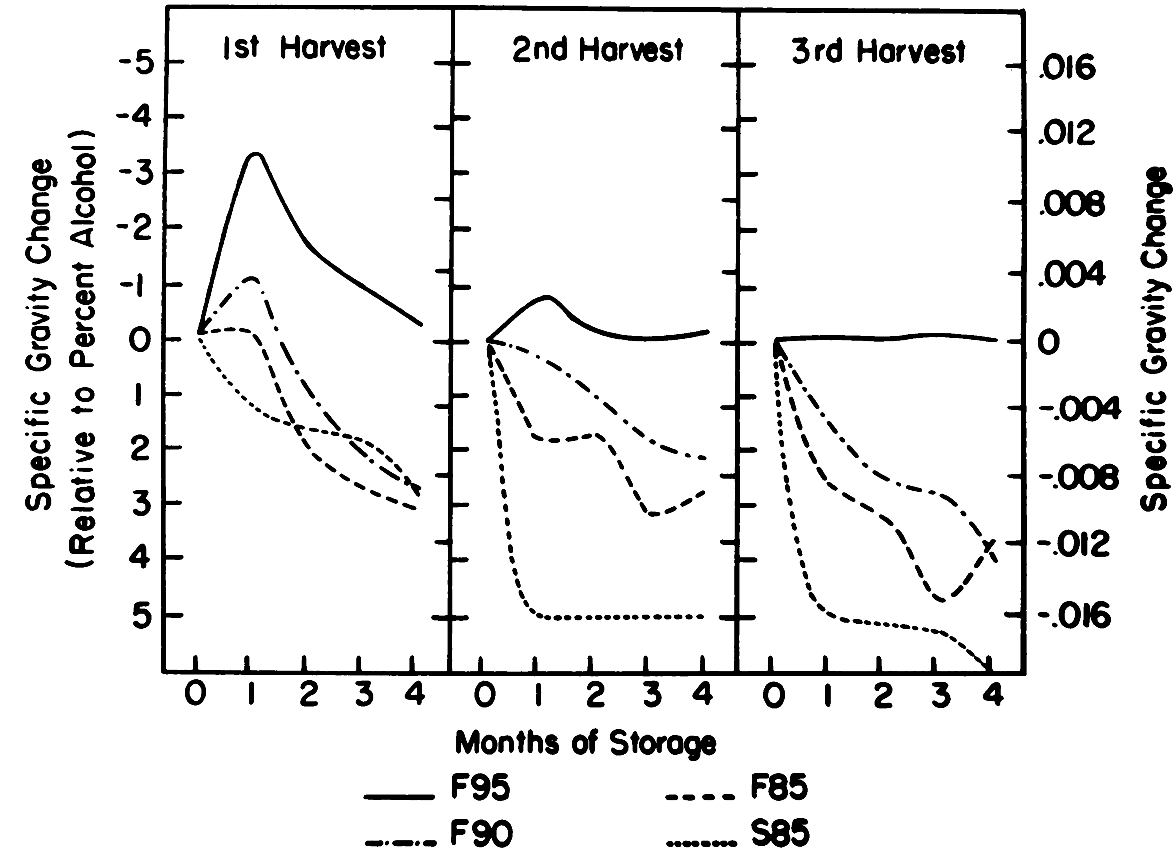

Fig. 5. Fruit specific gravity changes of 'Jonathan' apples during storage within density classes as determined at each of 3 harvest dates.

was unexpected. For example, mean CO_2 concn for all density classes at both H_1 and H_3 were approx 0.06%, or only twice that of the surrounding atmosphere. There were no differences due to SG as measured by analysis of variance of data for the whole experiment. However, when data for only H_3 were examined, the S85 fruit did contain significantly higher amounts of CO_2 (Fig. 6) than other density classes.

Raw product quality. The firmness F value for the storage x SG interaction was significant only for firmness values taken on the blush side. Since all other F values were approx equal, the firmness values of the blush side will be used for discussion. As expected, firmness decreased with succeeding harvest date and increasing length of storage (Fig. 10). Fruit from the first harvest showed a larger decrease in firmness than fruit from the last harvest while the second harvest was intermediate in firmness loss.

Firmness values were greater in fruits of higher SG. Apples in the S85 class lost firmness at a slower rate during storage, and maintained their higher firmness values throughout the storage period tested.

The data from means of each harvest show that with each harvest delay of approx 2 weeks, there was an approx gain of 0.5% soluble solids, the differences being greater, however, at harvest. Fruit from the first harvest showed a marked increase in soluble solids during storage (Fig. 10), probably due to starch hydrolysis. Apples harvested later remained more or less constant with respect to the soluble solids percentage. No definite relationship of SG with percentage of soluble solids was noted during storage even though the SG x Storage interaction was significant. In general, the more dense fruit (S85 & F85) tended to remain constant in soluble solids percentage during storage whereas the less dense fruit (F95 & F90) tended to reach a peak value sometime during storage.

At H_1, the F95 fruit had the greatest amount of blush while the F90 fruit had the least (Table 1). By H_2, both the F95 and F90 fruit were covered by more blush than were the F85 and S85 fruit. At H_3, however, the S85 fruit were more highly colored than those in the other density classes. So, although the means for the density main effect did not differ, there was a significant harvest x SG interaction.

Raw product data were correlated by computer using the University of Arkansas Correlation - Regression program (CORREG). Selected calculated r values for each SG class within each harvest date are graphically presented in Fig. 8.

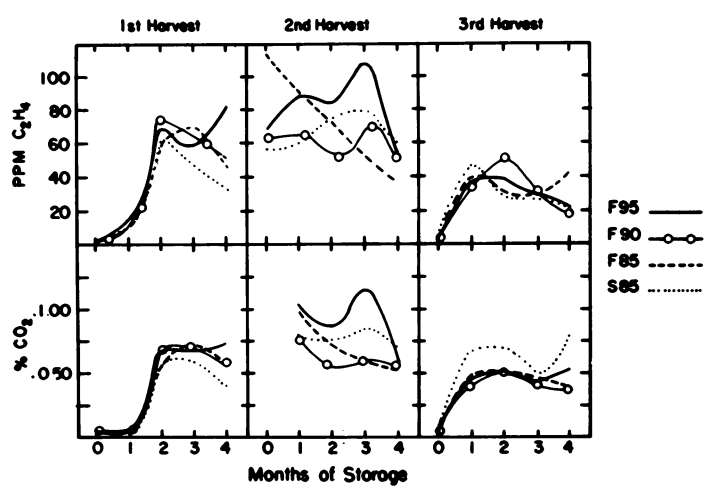

Fig. 6. Effect of harvest date, specific gravity (as determined at harvest), and storage duration on the % CO_2 and ppm C_2H_4 in the internal atmospheres of 'Jonathan' apples.

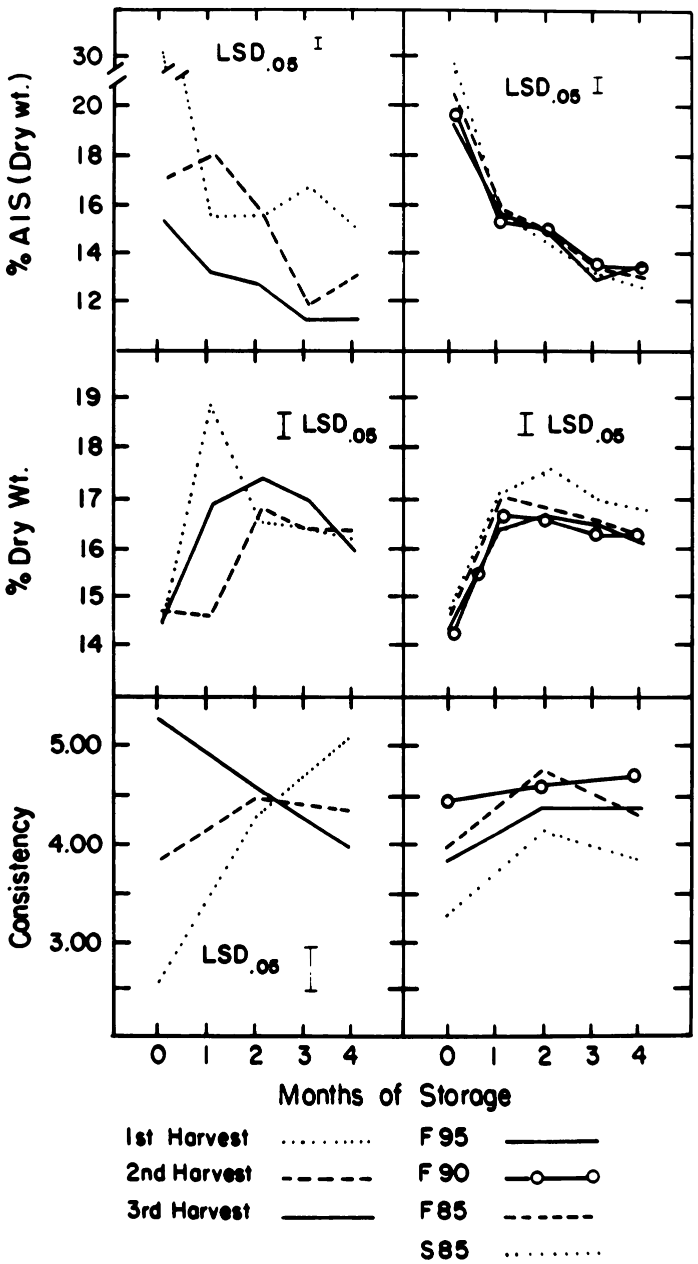

Fig. 10. Effect of harvest date, specific gravity, and storage duration on the quality of 'Jonathan' apple sauce.

Although several of these values were significant at the 1% level, these correlations are presented to illustrate certain analytical trends and are not intended to suggest predictability. For example, internal CO_2 and ethylene were positively correlated, especially in H_2 and H_3 fruit. With exception of the F95 density class, internal CO_2 was positively correlated with blush and non-blush firmness in H_1 fruit. In contrast, H_3 data exhibited negative correlations, while *r* values from H_2 showed no significance.

Processed product quality. Objective quality evaluation of the sauce made from the canned slices showed, as expected, marked differences due to harvest date and storage duration (Tables 2 and 3 and Figs. 7 and 9). The effects of these variables on % soluble solids, titratable acidity, consistency and % AIS were noteworthy. Some differences related to SG also existed. Sauce from fruit with the highest SG (S85) exhibited the highest consistency and total and soluble solids.

Table 1. **Effect of harvest date and fruit specific gravity on percent blush of 'Jonathan' apples.**

Density class[z]	Percent blush 1st Harvest	2nd Harvest	3rd Harvest	Mean
F95	16.8	35.3	59.1	37.1
F90	8.8	38.8	59.9	35.8
F85	12.0	29.1	61.0	34.0
S85	11.4	25.6	72.2	36.4
Mean	12.3 a[y]	32.2 b	63.0 c	
$LSD_{.05}$ for interaction = 7.8				

[z]F95 - floated in 95% Ethanol; F 90 - floated in 90% Ethanol; F85 - floated in 85% Ethanol; S85 - sank in 85% Ethanol

[y]Mean separation in row by Duncan's multiple range test, 5% level.

In general, quality increased with each successive harvest date. Sauce made from H_1 fruit was definitely inferior. If these fruit were stored for 1 - 2 months, however, sauce of acceptable quality could be made from them.

Fruit separation by SG was of little or no benefit on fruit from H_1 or H_2. Some differences due to SG were evident from H_3 fruit. The more dense fruit from this harvest were higher in titratable acidity, percent soluble solids, percent dry wt and color score as calculated according to Kramer and Twigg (11) (Tables 2 and 3 and Figs. 7 and 9). Sauce made from S85 fruit

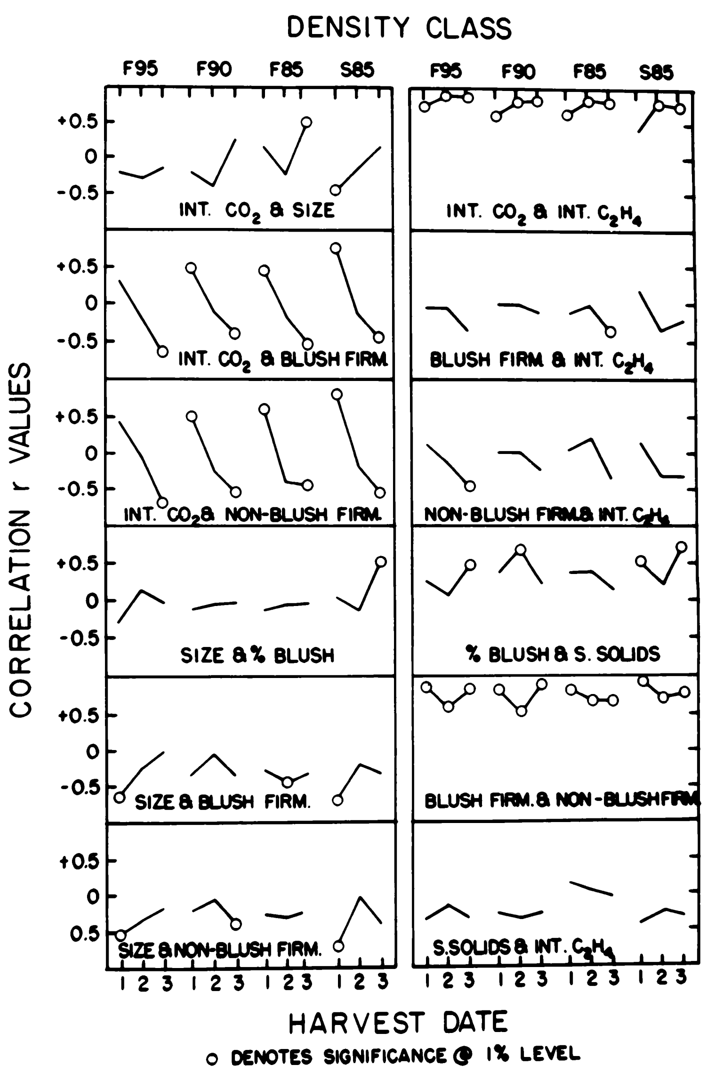

Fig. 8. Effect of harvest date and specific gravity (density class) on correlation *r* values of several raw 'Jonathan' apple characteristics.

Table 2. Effect of harvest date and fruit specific gravity on quality attributes of apple sauce.

Density[z]	Harvests 1st	2nd	3rd	Mean[y]	Harvests 1st	2nd	3rd	Mean
Density[z]								
	Titratable acidity[x]				% Soluble Solids			
F95	5.21	4.28	2.88	4.13	12.6	12.9	12.8	12.7 a
F90	4.85	4.21	3.10	4.05	12.8	12.9	12.9	12.9 b
F85	4.87	4.27	3.49	4.21	12.8	13.2	13.5	13.1 c
S85	4.75	4.32	3.46	4.17	12.8	13.3	13.9	13.3 d
Mean	4.92 c	4.27 b	3.23 a		12.7 a	13.1 b	13.3 c	
	LSD, 5%, 0.26[w]				LSD, 5%, 0.3[w]			
	pH				% Dry wt			
F95	3.52	3.58	3.77	3.62	16.4	15.8	15.8	16.0 a
F90	3.53	3.58	3.72	3.61	16.6	15.5	16.0	16.0 a
F85	3.50	3.60	3.68	3.59	16.4	15.7	16.6	16.2 a
S85	3.55	3.65	3.64	3.61	16.5	16.0	17.3	16.6 b
Mean	3.52 a	3.60 b	3.70 c		16.5 b	15.8 a	16.4 b	
	LSD, 5%, .06[w]				LSD, 5%, .45[w]			

[z]Density Classes: F95, floated in 95% ethanol; F90, floated in 90% ethanol; F85, floated in 85% ethanol, S85, sank in 85% ethanol.

[y]Mean separation in rows and columns by Duncan's multiple range test, 5% level.

[x]Ml of 0.1 N NaOH required to titrate 5 g of puree to pH 8.1.

[w]Least significant difference at 5% level for interaction.

had the greatest, and sauce from F90 fruit the lowest, consistency values. Sauce from F95 and F85 fruit had consistency values between those of the S85 and F90 fruit (Fig. 7). Taste preference scores from the panel showed no effect of fruit density. However, the taste preference scores increased with each successive harvest date and storage period. Data from the panel evaluation showed a definite discrimination against sauce made from unstored fruit.

Discussion

Our data showed that under some conditions, separation of apples according to SG may have practical application. Higher quality fruit may be separated by using the least dense fruit from the early harvest and more dense fruit from the later harvests, particularly the latter. These trends were more evident from objective quality evaluation than from subjective evaluation, probably due to the great amount of variability in the preferences of individual panel members.

The most dense fruit of H_3 were higher in % soluble solids. Porritt et al. (13) found a high percentage of the more dense fruit to be watercored. A definite relationship of watercore to sorbitol, but not necessarily to sugars has been shown (17). Watercore occurred in all density classes, but its occurrance was so sporadic that a definite trend could not be established. The more dense fruit used in this study were also firmer.

Francis et al. (6) reported that the SG of 'Richared Delicious' apples decreased during 6 months of storage after a small initial increase following 1 month storage. Westwood (15) and Blanpied (2) reported that SG decreased with delay in harvest date. All reports, however, were from work with apples that

Table 3. Effect of harvest date and fruit specific gravity on quality attributes of apple sauce.

Density[z]	Harvests 1st	2nd	3rd	Mean[y]	Harvests 1st	2nd	3rd	Mean
	% AIS[x]				Color score[w]			
F95 17.	17.7	15.4	12.9	15.3	20.6	21.0	22.1	21.2
F90	18.0	15.3	12.9	15.4	21.2	22.0	22.2	21.8
F85	19.0	15.0	12.5	15.5	20.7	21.8	23.0	21.8
S85	18.9	15.1	12.6	15.5	20.3	21.7	24.3	22.1
Mean	18.4 c	15.2 b	12.7 a		20.7 a	21.6 b	22.9 c	
	LSD 5%, .29[t]				LSD 5%, .64[t]			
	Consistency[v]				Taste preference[v]			
F95	3.20	3.78	4.15	3.71 b	3.46	4.38	5.25	4.36
F90	3.82	3.88	4.53	4.07 c	3.46	3.71	5.00	4.06
F85	3.30	4.02	4.28	3.87 bc	3.21	3.83	5.46	4.17
S85	3.08	3.23	3.43	3.25 a	3.17	4.00	4.96	4.04
Mean	3.35 a	3.73 b	4.10 c		3.32 a	3.98 b	5.17 c	
	LSD 5%, N.S.[t]				LSD 5%, N.S.[t]			

[z]Density Classes: F95, floated in 95% ethanol; F90, floated in 90% ethanol; F85, floated in 85% ethanol, S85, sank in 85% ethanol.

[y]Mean separation in rows and columns by Duncan's multiple range test, 5% level.

[x]Percentage of alcohol insoluble solids calculated on dry wt basis.

[w]As calculated from tristimulus color values using the following equation: Score = 9.40 + 0.056L + 0.802 a + 0.252 b.

[v]As determined by spread on Bostwick consistometer for 15 sec.

[u]As determined by 8 member taste panel on basis of 1 (bad) - 10 (good).

[t]Least significant difference at 5% level for interaction.

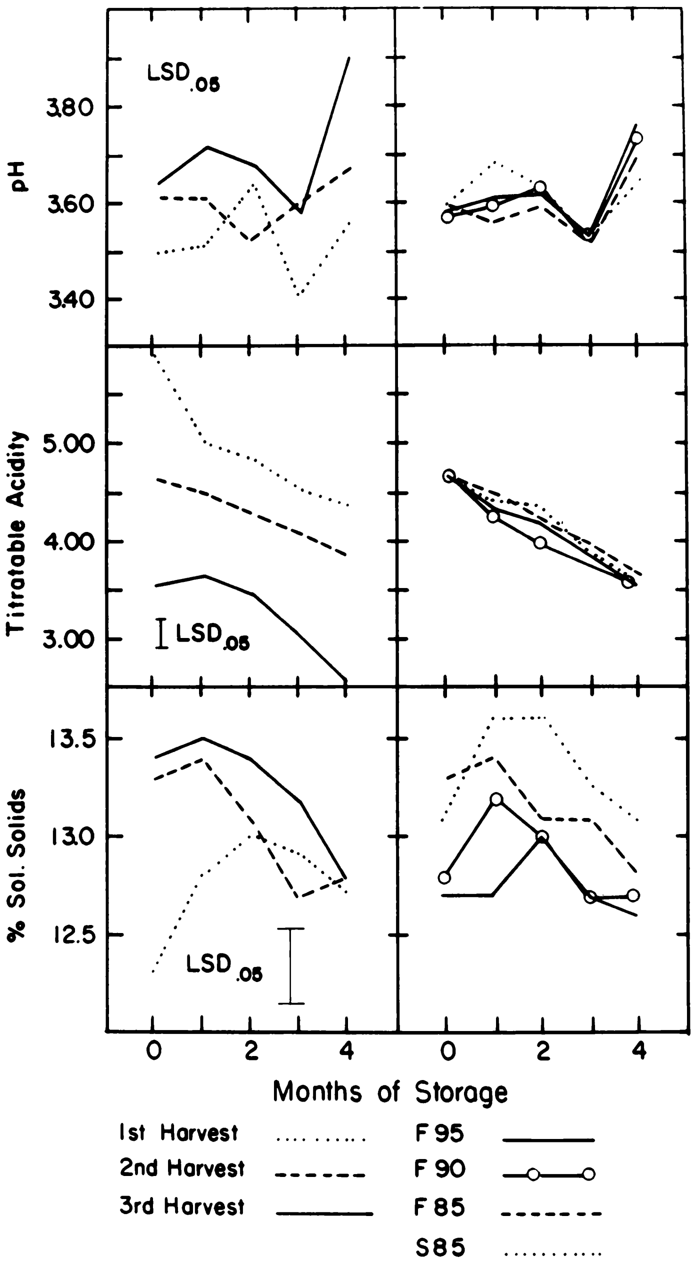

Fig. 9. Effect of harvest date, (left) specific gravity (right), and storage duration on certain quality attributes of 'Jonathan' apple sauce.

probably encompassed the entire population of fruit SG. The work reported here shows that, in general, the SG of 'Jonathan' apples decreased with delay of harvest or days after full bloom. The changes during storage, however, were related to harvest date and initial fruit SG.

The SG (.78) of 'Jonathan' apples reported by Westwood (15) is lower than that generally observed in this study (.83). By comparison, Westwood's SG determinations with 'Red Delicious', 'Rome Beauty' and 'Golden Delicious' are comparable to those of Francis et al. (6) and Blanpied (2). The fruit wt of 'Jonathan' reported by Westwood are greater than those found in this study. This may be expected as larger fruit are less dense than smaller fruit. Internal air space volume and fruit diam have been shown to be related (15). The fact that in this study fruit size was smaller and SG greater could mean that a) there was a smaller number of cells per fruit in this study, b) cell enlargement occurred to a lesser extent, or c) since core

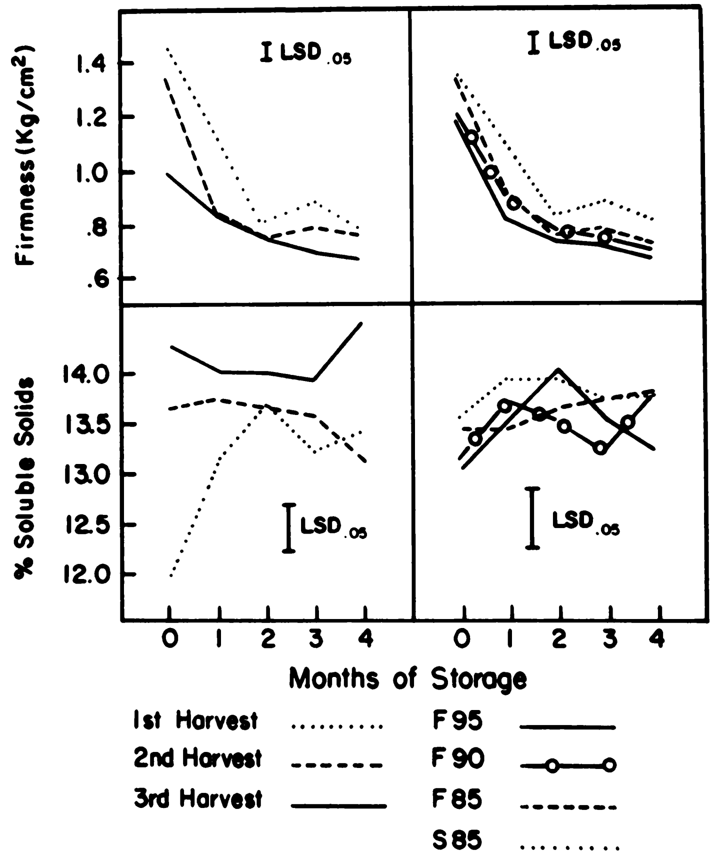

Fig. 7. Interactive effects of harvest date and specific gravity (determined at harvest) with storage duration on firmness values and percent soluble solids in raw 'Jonathan' apples.

tissue is of greater SG than flesh tissue (15), the ratio of core to flesh could be greater. None of these postulations are mutually exclusive, however.

Some evidence was obtained to suggest that the smaller, more dense, apples used in this study stored better than the less dense fruit. This was shown by the higher firmness and soluble solids (Fig. 10) maintained throughout storage by fruit from all harvests and the higher titratable acidity in the more mature fruit of H_3.

The correlation values obtained from H_2 seem to exhibit a lack of "fit" for a number of the correlations made. However, when H_1 and H_3 r values are approx equal, it may be of interest to speculate as to why H_2 r values did not equal those of H_1 and H_3. For example, the plot of blush firmness r values vs. non-blush firmness r values show this type of pattern. A possible explanation for this could be that fruit from H_2 experienced a shift in firmness patterns during storage (data not shown). All H_2 fruit at harvest were either firmer on the non-blush side or showed similar trends. As storage time progressed, however, all but S85 fruit exhibited a change in firmness patterns so that firmness values on the blush side became greater. This pattern did not develop with either H_1 or H_3 fruits.

The CO_2 content of the internal atmospheres of S85 fruit tended to be lower in H_1, but not at H_3. It is tempting to postulate that the lower C_2H_4 content of the more dense fruits' internal atmospheres at H_3 was responsible for the better storage life. While trends for this do exist, the data are not conclusive. Only correlations of C_2H_4 content with firmness (H_3, F95 and F85) or soluble solids content gave significant negative r values. To this end, it is possible that the precision of the experiment was not sufficient.

The correlations of internal CO_2 with firmness values show that, in general, a positive relationship existed at H_1. This may have been due to a limiting gas exchange rate at H_1 when fruits had only begun to ripen and CO_2 production rates were low. By H_3, the fruit tissue barrier was no longer the limiting factor to gas exchange and the CO_2 was perhaps indicative of a greater respiratory and ripening rate, as indicated by significant negative correlations of internal CO_2 with firmness.

Respiratory (5) and C_2H_4 production (4, 3) rates have been shown to be correlated with the CO_2 and C_2H_4 contents respectively of the internal atmospheres of apples. The data also show that a commonly utilized index of quality, i.e. red color, could not be used as an accurate predictor of other quality indices such as percent soluble solids and firmness as has been done with tomatoes and cherries (8, 9).

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Placental Tissue and Ovule Development in 'Lodi' Apple[1, 2]

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Abstract. The 'Lodi' apple has heavy bearing characteristics. This study shows it to have profuse numbers of ovules compared with other commercial cultivars. The principal morphological difference between 'Lodi' and other cultivars is that 'Lodi' contains numerous smaller seeds attached to the placental tissue, not only at the proximal end, but extending all the way to the distal end.

The 'Lodi' apple, known for heavy bearing, has distinct morphological differences in placentae and ovullary attachment compared to 'Delicious', which does not set heavy crops of fruit. Variability of fruit-set continues to be of great concern to commercial apple growers. The 'Lodi' apple originated in Geneva, New York in 1924 from the cross 'Montgomery' X 'Yellow Transparent'.

Studies have shown definite morphological differences in placental and ovule attachment between 'Jonared' and 'Golden Delicious' compared with 'Starking' (7, 8). These differences appear at the ovule base where it attaches to placental tissue, with the ovullary vascular strands being constricted as they enter the proximal end of the ovarian locule. A comparison of 'Jonared' and 'Golden Delicious' showed the ovules to be supported by a well-differentiated vascular system entering a thick, well-formed placental tissue. Earlier studies of fruit setting in 'Delicious' revealed embryo-sac irregularity (3).

Crane (1) states "the asymmetrical growth of other fruits in which fertilization in some of the ovules does not take place or in which abortion of some ovules occurs may be ascribed to the lack of gradient being set up by them. Conversely, the larger the number of developing seeds in a fruit, the larger the number of sinks toward which nutrients flow and the greater the growth and development of the fruit".

MacArthur and Wetmore (5) found that ovules of 'Wagener' are longitudinally oriented in bi-partite locules, with one ovule on each side of the locule. There is no such regularity of ovule orientation in 'McIntosh'. Ovules in 'McIntosh' are generally horizontal in position, stretching across the bi-partite locule or occupying the central cavity at the axis.

In aborted ovules, placentae had not developed sufficiently to be good supportive tissue for functioning normal ovules (7, 8).

Murneek (6) reported "the polyembryonic apple fruit usually does not set unless fertilization has occurred in a considerable number of the 10 ovules. With self-pollination, the average number of seeds per fruit was 3-5 or less, while with good cross-pollination it was 5-8 and up to 10. When the crop is fairly heavy, fruits with less than 3 seeds usually abscise. There is a relationship not only between seed number and fruit size but also between leaf area and fruit volume. When fruit set is relatively large, then foliage becomes the limiting factor; when it is light, seed number seems to determine size of fruit".

Crane (1) concluded that marked correlations exist between seed number and ultimate fruit size, and also between seed distribution and fruit shape.

Tukey and Young (9) reported that the cartilaginous portion of the carpels develops rapidly for 2-4 weeks after full bloom,

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