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The Effect of Chemical Treatments and Heat on Color Stability of Frozen Machine-harvested Strawberries for Jam[1]

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***Abstract*. A study was conducted on 2 cultivars of mechanically harvested strawberries (*Fragaria* X *ananassa* Duch.) to determine the effects of chemical treatments and heat on stability of color in frozen fruit for jam. Treatment with $NaHSO_3$, citric acid or $SnCl_2$ improved color of the jam when compared to the control, as demonstrated by Color Difference Meter (CDM) values and sensory ratings. The CDM color functions were higher on jam made from frozen puree than from frozen whole fruit, yet panel scores were significantly higher on jam from whole fruit. The jam made from frozen puree browned more during storage than that made from whole fruit. There were significant differences in color between cultivars and storage temperatures, but differences among treatments were larger. Treatment with $NaHSO_3$, citric acid or $SnCl_2$ offer possibilities for stabilizing color in jam.**

Color stability of frozen strawberries in the whole, sliced, puree, and concentrate form is extremely important to their value for manufacture into preserves, jam, and jelly. Strawberries for commercial preserves, jam, and jelly manufacture are usually washed and capped, then frozen with either 5:1 or 4:1 fruit:sugar ratio, and then thawed before processing. The development of mechanical harvesting of strawberries has produced other options for preparing frozen strawberries for manufacture. These include the freezing of whole uncapped fruit which are later pureed.

Stabilization of pelargonidin-3-glucoside (P-3-G), the predominant pigment in strawberries, is necessary to maintain consumer acceptance in strawberry products (1, 9). However, a rapid change in color of strawberries and strawberry products can occur under different conditions of handling, storage, and processing (2, 5, 6, 7, 8, 14, 15, 16). Wrolstad et al. (21) attributed the color change in strawberry concentrate to the degradation of monomeric anthocyanin pigment to polymeric pigments. Earlier studies had shown that the polymeric pigment formed from degraded anthocyanins in strawberry products could only be solubilized in 1 N NaOH (8, 15), and that chemical additives can stabilize the pigments in strawberry juice and puree during storage. It has been observed that significant changes in color occur in strawberries during mechanical harvesting, washing, preparation, freezing, storage and thawing of fruit for manufacture (12, 19). Therefore, the purpose of this study was to determine the effects of certain chemical additives and heat on the color stability of jam manufactured from machine harvested, frozen strawberries.

Materials and Methods

Strawberries were grown at the Main Arkansas Agricultural Experimental Station, Fayetteville, in 1979. The fruit was harvested once-over by a commercial harvester, cleaned, washed, and size-graded into small (mostly green) and large (mostly ripe) categories described previously (11, 12). The experiment was designed as a factorial with 7 treatments at 2 levels [1) Control, no treatment; 2) $NaHSO_3$ (SO_2), 80 and 160 ppm; 3) citric acid, 0.5 and 1.0%; 4) $SnCl_2$, 100 and 200 ppm; 5) ethylenediaminetetracetate, Na salt (EDTA), 200 and 400 ppm; 6) acetaldehyde (AA), 500 and 1000 ppm; and 7) heat, 80° and 90°C]; 2 styles (whole berries and puree during freezing); 2 cultivars ('Cardinal', and A-5344); 2 storage temperatures (15° and 24°C); and 3 storage times (0, 4, 9 months) of the jam.

After washing, the ripe and green (75%, 25%) whole, uncapped fruit of each cultivar were mixed thoroughly and weighed into 2-kg lots, treated and filled into 303 × 406 R-enamel cans and sealed. The puree was made from the same fruit mixture by passing the fruit through a commercial slicer followed by a pilot plant model-pulper fitted with a 0.69-mm screen to remove the caps. The puree was mixed thoroughly and weighed into 2-kg lots, treated and filled into 303 × 406 cans and sealed. The heated lots were brought to temperature in a 20 liter steam jacketed kettle, filled into cans, sealed and cooled in tap water. Then, all cans of fruit were frozen at −18°C and stored for 2 months prior to manufacture of jam. The cans of frozen whole and puree fruit were thawed in water at 24° for 2 hr. After thawing, whole frozen fruit was made into puree by the same procedure described above. The jam was made from both styles of frozen fruit as previously described (17). A total of 58 batches of product was prepared, adjusted to 68–69% soluble solids by adding water or heating, and filled into 211 × 304 R-enamel cans. The cans were sealed, inverted for 1 min, cooled in tap water and stored at either 15° or 24°.

The samples were analyzed at 0, 4, and 9 months for color by a Gardner Color Difference Meter (CDM) that was standardized against a standard red plaque as follows: L = 24.4; a = 25.2; and b = 11.8. Chroma is represented by $(a^2+b^2)^{1/2}$. Total color (TC), or O.D. units/g fresh weight was determined as described (17). The color index, an indication of browning, was calculated as a ratio of the optical density of the extract at 510/430 nm. Reduced ascorbic acid was analyzed by the method of Morell (10).

Sensory evaluation for color intensity, freedom from discoloration, color acceptance, and flavor was conducted by a panel of 15 graduate students and faculty on a 9-point hedonic scale: 9 represented intense red color, free from browning and highly acceptable in color and flavor, whereas 1 represented extremely

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light color, extremely brown and poorly acceptable in color and flavor. The panel was instructed on the rating scale and shown samples of product that represented the different levels of quality.

The ratings were made on coded white enamel trays with 4 samples on each tray for easy comparison on an open countertop in a room designed with 2 solid banks of fluorescent lights so that the room could be lighted with average lighting and high intensity lighting. The average lighting was used since this was best for good color perception by the panelists.

The data were analyzed as factorials by the analysis of variance using the Statistical Analysis System (SAS) of the University of Arkansas Computer Center. Wherever F values were significant, Duncan's multiple range test was used to separate means of main effects. Significant differences between means of interactive effects were separated by the Least Significant Difference (18). The means of the main effects and the most important interactive effects are recorded in tables.

Results and Discussion

Three of the chemical treatments (SO_2, citric acid, $SnCl_2$) significantly improved color of the jam as compared to the control when measured by a, b, and chroma values (Table 1), and also had higher L values, indicating lighter color with less darkening. EDTA did not increase either L (lightness), or ascorbic acid as compared to the control. Ascorbic acid was stabilized somewhat by SO_2, $SnCl_2$, citric acid and heat as shown by the higher values. The pH of all jam samples was 3.2 to 3.3 except those treated with citric acid, and these averaged 0.1 pH units lower. The AA treatment was applied at concentrations similar to those used to improve color stability in strawberry juice (3). However, concentrations were too high for strawberries that are manufactured into jam since the color changed to a purplish red upon heating to high temperature. The panel rated the jams made from fruit treated with SO_2, citric acid and $SnCl_2$ higher than the control in color intensity and acceptance (Table 2). Only the SO_2 treatment was higher in TC than the control, and fruit treated with SO_2 and EDTA had a higher color index (less browning).

The levels of chemicals added to fruit before freezing significantly increased a, b, and chroma values and ascorbic acid content, yet these differences were not as discernible by the panel (Tables 1 and 2). The highest correlations between color functions and panel scores were between a, b and chroma, and color acceptance and freedom from browning ($r = 0.66$ to 0.78). Earlier studies on frozen strawberries (16), puree (15, 19), concentrate (20), and preserves and jam (17, 20) have demonstrated that the a value of the CDM was a good measure of redness and color acceptance in strawberry products. Spayd and Morris (20) found high correlations between color acceptability and CDM a, chroma, log total anthocyanins (TAcy) and log of ratio of absorbance at 520 and 430 nm. The TC did not correlate as highly with sensory color evaluations as CDM color functions. In a study where no chemicals were added, Spayd and Morris (19) obtained high correlations between TAcy and a and chroma ($r = 0.86$ and 0.85) on strawberry puree.

The style of pack had a significant effect on color. All color functions of the CDM were higher in jam made from the frozen puree than from whole frozen fruit (Table 1). The panel rated the jam from the whole packed frozen fruit higher in color (Table 2). Also, total color content was higher in jam from whole fruit. The degradation of anthocyanins in the puree during preparation and frozen storage could have contributed to the difference in pigment content since puree was not deaerated prior to freezing.

Table 1. Main effect of treatments, levels, styles of pack, cultivar, storage temperature, and storage time on quality attributes of strawberry jam.

Main effects	Color Difference Meter L	a	b	Chroma $(a^2+b^2)^{1/2}$	Ascorbic acid (mg/100g)
Treatments[z]					
Control	12.5b[y]	8.0b	2.0c	8.30b	3.02d
$NaHSO_3$	13.4a	10.5a	3.0a	10.90a	5.71a
Citric acid	13.6a	10.5a	3.1a	10.97a	4.10c
$SnCl_2$	13.7a	11.1a	3.0a	11.56a	4.69b
NaEDTA	12.8b	10.6a	2.7a	10.93a	3.31d
AA	10.9c	4.9c	0.3d	4.96c	2.55e
Heat	12.8b	8.5b	2.0c	8.74b	4.02c
Levels					
1	12.7a	8.9b	2.2b	9.23b	3.36b
2	12.9a	9.4a	2.4a	9.73a	4.46a
Style					
Puree	13.3a	10.0a	2.6a	10.33a	3.78a
Whole	12.3b	8.3b	1.9b	8.57b	4.05a
Cultivar					
A-5344	13.3a	10.3a	2.8a	10.75a	3.97a
Cardinal	12.3b	8.0b	1.8b	8.21b	3.86a
Storage temperature (°C)					
15°	12.6b	9.2a	2.3a	9.53a	4.04a
24°	13.0a	9.1a	2.3a	9.43a	3.79b
Storage time (mo.)					
0	12.2b	12.1a	2.7a	12.38a	2.25c
3	12.1b	9.6b	2.5b	9.94b	3.95b
9	14.1a	5.8c	1.7c	6.12c	5.54a

[z]Treatments: NaEDTA; ethylenediamine-tetracetic acid-Na salt; AA, acetaldehyde.

[y]Means separated by main effects within columns by Duncan's multiple range test, 5% level.

There was an interaction between treatment and style of pack on TC, color index, color acceptance and color darkness (Table 3). Since the chemicals were directly exposed to all the fruit tissues in puree, the differences in color index and color acceptance were greater between treatments in jam made from puree than from whole fruit. In color darkness and TC the whole fruit exhibited the greater differences between treatments. The smallest differences between puree and whole fruit occurred in lots treated with AA and those heated. These differences in the reaction of puree and whole fruit to the treatments caused the interaction.

Both cultivars were highly acceptable for jam (Table 1 and 2), yet color functions for A-5344 were significantly higher than those for 'Cardinal.' A-5344 was lighter in color (higher L), yet higher in a (redness) and chroma. The panel rated 'Cardinal' slightly higher in color darkness although color acceptance and freedom from browning did not differ between cultivars. The TC was higher in 'Cardinal' than A-5344, but A-5344 had less browning (higher color index). Earlier studies on preserves and jams showed that A-5344 rated higher than 'Cardinal' in color acceptance during storage (17).

The significant interaction between style of pack and cultivar on color functions was influenced by the greater differences between A-5344 and 'Cardinal' in jam made from frozen whole fruit than in jam made from puree (Table 4).

Table 2. Main effects of treatments, levels, style of pack, cultivar, storage temperature and storage time on quality attributes of strawberry jam.

Main effects	Total color (O.D. units/ g fw)	Color index (O.D.510/430nm)[y]	Sensory ratings[z] Color darkness	Color acceptance	Freedom from browning	Flavor
Treatments						
Control	18.9c	1.68b	7.0d	6.9d	6.4b	6.8bc
$NaHSO_3$	20.1a	1.86a	7.6a	7.4a	7.2a	7.6a
Citric Acid	18.8c	1.62b	7.4b	7.1c	6.6b	6.6c
$SnCl_2$	19.2bc	1.74b	7.4b	7.4a	7.3a	7.1b
NaEDTA	19.1bc	1.92a	6.9d	7.2bc	7.1a	7.0b
AA	13.8e	1.70b	7.7a	3.4f	3.6d	3.4d
Heat	17.2d	1.69b	7.2c	6.3e	5.8c	6.6c
Levels						
1	18.1a	1.70b	7.4a	6.5b	6.2b	6.5a
2	18.2a	1.78a	7.3b	6.6a	6.4a	6.4a
Styles						
Puree	16.2b	1.76a	7.2b	6.4b	6.0b	6.1b
Whole	20.1a	1.72a	7.5a	6.7a	6.6a	6.8a
Cultivars						
A-5344	16.7b	1.81a	7.2b	6.5a	6.3a	6.9a
Cardinal	19.6a	1.68b	7.5a	6.5a	6.3a	6.0b
Storage temperature (°C)						
15°	19.3a	1.68b	7.4a	6.6a	6.5a	6.6a
24°	17.0b	1.80a	7.3b	6.4b	6.1b	6.3b
Storage time (mo.)						
0	18.2b	2.04a	7.3b	6.9a	6.6b	6.7a
3	19.4a	1.66b	7.5a	6.3b	6.9a	6.6a
9	16.9c	1.52c	7.2c	5.7c	5.4c	6.0b

[z]Sensory ratings conducted by a panel of 15 members on a hedonic scale of 9 (best) to 1 (poor).
[y]A color index that indicates browning.
[x]Means separated by main effects within columns by Duncan's multiple range test, 5% level.

Table 3. Interactions of treatment × style of pack on quality attributes of strawberry jam.

Treatment	Total color (O.D. units/ g fw)	Color index (O.D.510/430nm)[y]	Sensory ratings[z] Color acceptance	Color intensity
		Puree		
Control	14.5[x]	1.65	6.7	7.2
$NaHSO_3$	16.6	1.91	7.4	7.0
Citric acid	17.1	1.61	7.1	7.3
$SnCl_2$	14.9	1.86	7.4	7.3
NaEDTA	16.0	2.08	6.8	7.2
AA	14.7	1.55	2.8	7.4
Heat	16.5	1.69	6.3	7.0
		Whole		
Control	22.1	1.72	7.0	7.6
$NaHSO_3$	24.1	1.94	7.3	8.0
Citric acid	20.8	1.63	7.1	7.5
$SnCL_2$	22.4	1.77	7.5	6.9
NaEDTA	20.3	1.77	7.5	6.7
AA	13.0	1.55	4.0	8.0
Heat	17.9	1.68	6.2	7.4
LSD 5%	1.5	0.15	0.3	0.2

[z]Sensory ratings conducted by a panel of 15 members on a hedonic scale of 9 (best) to 1 (poor).
[y]A color index that indicates browning.
[x]Means of interactive effects separated in columns by LSD, 5% level.

Storage temperature resulted in less change in jam color quality than other main effects (Table 1). The color was lighter in jam stored at 24°C as shown by higher L values. The loss in color is shown by lower TC and freedom from browning values (Table 2). This may indicate more oxidation and development of brown pigments. In addition, ascorbic acid content and flavor scores were lower in jam stored at 24° than at 15°C.

There was a significant interaction between style of pack and storage temperature (data not shown). In the color functions a

Table 4. Interactions of style of pack and cultivar on quality attributes in strawberry jam.

Style	Color Difference Meter a	b	Chroma $(a^2+b^2)^{1/2}$	Total color (O.D.units/ g fw)	Color index (O.D.510/430nm)[z]
			Puree		
A-5344	11.7[y]	3.3	12.2	15.3	1.91
Cardinal	8.3	2.0	8.5	17.2	1.61
			Whole		
A-5344	8.9	2.2	9.2	18.0	1.70
Cardinal	7.7	1.6	7.9	22.1	1.75
LSD 5%	0.4	0.1	0.4	0.8	0.08

[z]A color index that indicates browning.
[y]Means of interactive effects separated in columns by LSD, 5% level.

Table 5. Interactions of style of pack × storage time on quality attributes in strawberry jam.

Storage time (mo.)	Total color (O.D.units/ g fw)	Color index (O.D.510/430nm)[z]	Sensory[y] color intensity	Ascorbic acid (mg/100g)
		Puree		
0	14.9[x]	2.12	7.1	2.91
3	18.2	1.75	7.3	3.36
9	15.8	1.42	7.2	5.04
		Whole		
0	21.6	1.97	7.5	1.57
3	20.6	1.57	7.7	4.53
9	17.9	1.63	7.1	6.04
LSD 5%	1.0	0.10	0.2	0.54

[z]A color index that indicates browning.
[y]Sensory rating conducted by a panel of 15 members on a hedonic scale of 9 (most intense) to 1 (least intense color).
[x]Means of interactive effects separated in columns by Least Significant Difference (LSD).

and b, the values were higher in jam made from frozen puree and stored at 24°C, whereas the L function was higher in jam from frozen whole fruit. There were smaller differences in all color functions between storage temperatures in jam made from frozen puree than from whole fruit.

There was a significant cultivar × storage temperature interaction on color components. 'Cardinal' apparently lost more color than A-5344, the difference being greater at 24° than at 15°C, resulting in significantly lower "a" and chroma values and higher "L" values (data not shown). The color index was influenced by storage temperature of A-5344, yet not of 'Cardinal.'

Storage time significantly influenced all color components and sensory ratings (Tables 1 and 2). There was no change in lightness (L values) during the first 3 months of storage, although there was a shift in redness and darkness which is shown by the decrease in a and chroma values. Also, there was an increase in TC, color darkness, and freedom from browning values at 3 months of storage. Previous studies have shown an improvement in color during early storage in strawberry products (17). This could have been produced either by the chemical treatments decreasing initial browning or by leucoanthocyanins being converted to anthocyanins. The ascorbic acid was not significantly different between treatments at 0 storage (data not shown). Most of the increase in ascorbic acid at 3 and 6 months storage was attributed to the chemical treatments (Table 2). Cornwall and Wrolstad (4) showed an increase in ascorbic acid in pear concentrate during 7 months storage. They attributed the increase to the reaction of reductones formed during storage with 2,6-dichlorophenolinde-phenol dye used to measure ascorbic acid. Other workers have shown that reductones formed in an ascorbic acid-anthocyanin-flavanol system can react with the dye (13). Sistrunk and Cash (15) have shown that $SnCl_2$ reduced dehydroascorbic to ascorbic acid in strawberry puree during holding at 50°C.

A significant interaction between cultivar and storage time on color components was influenced mostly by greater changes in color of 'A-5344' during storage than 'Cardinal' (Table 5). However, in L values there was a greater increase between 0 and 9 months storage in 'Cardinal', yet A-5344 decreased more in color acceptance, freedom from discoloration, TC and color index than 'Cardinal.' The greater TC content of 'Cardinal could

Table 7. Interactions of storage temperature × storage time on quality attributes of strawberry jam.

Storage time (mo.)	Color Difference Meter L	a	Chroma $(a^2+b^2)^{1/2}$	Total color (O.D.units/ g fw)	Sensory[z] color acceptance
			15°C		
0	12.2[y]	12.0	12.4	19.9	6.9
3	12.1	9.1	9.4	20.5	7.1
9	13.5	6.5	6.8	17.7	5.9
			24°C		
0	12.2	12.1	12.4	19.5	7.0
3	12.1	10.1	10.5	18.4	6.8
9	14.6	5.1	5.4	13.0	5.5
LSD 5%	0.4	0.6	0.6	1.0	0.2

[z]Sensory ratings conducted by a panel of 15 members on a hedonic scale of 9 (best) to 1 (poor).
[y]Means of interactive effects separated in columns by LSD, 5% level.

Table 6. Interactions of cultivar × storage time on quality attributes of strawberry jam.

Storage time (mo.)	CDM L	Sensory ratings[z] Color acceptance	Freedom from discoloration	Color intensity	Total color (O.D.units/ g fw)	Color index (O.D.510/430nm)[y]
			A-5344			
0	12.8[x]	6.9	6.8	7.2	18.3	2.19
3	13.0	7.2	7.0	7.6	18.1	1.78
9	14.2	5.6	5.2	6.8	13.6	1.45
			Cardinal			
0	11.6	7.0	6.4	7.4	20.8	1.90
3	11.2	6.6	6.8	7.4	20.1	1.60
9	14.0	5.9	5.6	7.5	18.0	1.55
LSD 5%	0.4	0.2	0.3	0.2	1.0	0.10

[z]Sensory ratings conducted by a panel of 15 members on a hedonic scale of 9 (best) to 1 (poor).
[y]A color index that indicates browning.
[x]Means of interactive effects separated by columns by LSD, 5% level.

have masked some of these changes in the jam, making them more difficult to define.

The significant storage temperature and storage time interaction on color components indicated that the color changed more at 24°C than at 15°, which was expected (Table 6). Any of these measurements (L, a, chroma, TC, or color acceptance) seemed to be adequate to define the differences in strawberry jam between storage temperatures (Tables 1 and 6). This substantiates the results of earlier studies on preserves and jam (17, 20). Again, there was not much difference between 0 and 3 months of storage but the differences were accelerated between 3 and 9 months at both temperatures (Table 7).

It appears that the chemical treatments SO_2, citric acid and $SnCl_2$ had a stabilizing effect on the color of frozen strawberries for manufacture. The SO_2 and $SnCl_2$ provided a reducing environment which prevented the breakdown of anthocyanins and ascorbic acid. The citric acid treatment reduced the pH, thus inhibiting enzymatic degradation (16), which improved color as shown by "a" and chroma values. Applying the treatments to puree had more beneficial effect on color than in whole fruit. The jam made from fruit treated with SO_2 and $SnCl_2$ was significantly better in color than the control jam throughout the storage period at either 15° or 24°C.

Literature Cited

1. Abers, J. E. and R. E. Wrolstad. 1979. Causative factors of color deterioration in strawberry preserves during processing and storage. J. Food Sci. 44:75.
2. Cash, J. and W. A. Sistrunk. 1970. Anthocyanin pigment concentration and type are important for color in strawberries. Ark. Farm Res. 19(3):8.
3. Chen, W. P. and R. E. Wrolstad. 1980. A note on the influence of acetaldehyde on color of strawberry juice. J. Sci. Food Agr. 31:667.
4. Cornwall, C. J. and R. E. Wrolstad. 1981. Causes of browning in pear concentrate during storage. J. Food Sci. 46:515.
5. Decareau, R. V., G. E. Livingston, and C. R. Fellars. 1956. Color changes in strawberry jellies. Food Technol. 10:125.
6. Little, A. C. 1977. Colorimetry of anthocyanin pigmented products: changes in pigment composition with time. J. Food Sci. 42:1570.
7. Lukton, A., C. O. Chichester, and G. Mackinney. 1956. The breakdown of strawberry anthocyanin pigment. Food Technol. 10:427.
8. Markakis, P., G. E. Livingston, and C. R. Fellars. 1957. Quantitative aspects of strawberry pigment degradation. Food Res. 22:117.
9. Meschter, E. E. 1953. Effects of carbohydrates and other factors on strawberry products. J. Agr. Food Chem. 1:574.
10. Morell, S. A. 1941. Rapid photometric determination of ascorbic acid in plant material. Ind. Eng. Chem. Anal. ed. 13; 793.
11. Morris, J. R., A. A. Kattan, G. S. Nelson, and D. L. Cawthon. 1978. Developing a mechanized system for production, harvesting, and handling of strawberries. HortScience 13:413.
12. Morris, J. R., W. A. Sistrunk, A. A. Kattan, and D. L. Cawthon. 1979. Quality of mechanically harvested strawberries for processing. Food Technol. 35:92.
13. Poei-Langston, M. S. and R. E. Wrolstad. 1981. Color degradation in an ascorbic acid-anthocyanin-flavanol model system. J. Food Sci. 46:1218.
14. Robinson, W. B., F. A. Lee, G. L. Slate, and C. S. Pederson. 1957. Chemical composition and freezing adaptability of strawberries. N.Y. State Agr. Expt. Sta. Bul. 726.
15. Sistrunk, W. A. and J. N. Cash. 1970. The effect of certain chemicals on the color and polysaccharides of strawberry puree. Food Technol. 23:169.
16. Sistrunk, W. A. and J. N. Moore. 1971. Strawberry quality studies in relation to new variety development. Ark. Agr. Expt. Sta. Bul. 761.
17. Sistrunk, W. A. and J. R. Morris. 1978. Storage stability of strawberry products manufactured from mechanically-harvested strawberries. J. Amer. Soc. Hort. Sci. 103:616.
18. Snedecor, G. W. and Cochran, W. G. 1967. Statistical Methods. The Iowa State University Press, 6th ed., Ames, Ia.
19. Spayd, S. E. and J. R. Morris. 1981. Effects of immature fruit and holding on strawberry puree quality and color stability. J. Amer. Soc. Hort. Sci. 106:211.
20. Spayd, S. E. and J. R. Morris. 1981. Influence of immature fruits on strawberry jam quality and storage stability. J. Food Sci. 46:414.
21. Wrolstad, R. E., D. D. Lee, and M. S. Poei. 1980. Effect of microwave blanching on the color and composition of strawberry concentrate. J. Food Sci. 45:1573.