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SENSORY PROPERTIES AND FURANONE CONTENT OF STRAWBERRY CLONES GROWN IN FLORIDA

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Abstract. **Strawberries (*Fragaria* × *ananassa* Duch., cv 'Sweet Charlie', 'Camarosa', 'Rosa Linda', 'Earlibrite', 'FL 95-41', '95-256') grown at Dover, Fl were harvested over three dates and evaluated by a trained taste panel for sweetness, sourness, texture, strawberry flavor, and strawberry aroma. Furaneol (2,5-dimethyl-4-hydroxy-3(2H)-furanone), Furaneol glucoside and Mesifuran (2,5-dimethyl-4-methoxy-3(2H)-furanone) were quantified using HPLC to correlate analytical with sensory data. Cultivar evaluation demonstrated varied sensory characteristics at all harvests. Furaneol content was highest in 'Camarosa' throughout all harvests while 'Earlibrite' contained the least amount of Furaneol during two harvests. 'Sweet Charlie' consistently rated high in strawberry aroma intensity and sweetness but was somewhat softer. 'FL 95-41' consistently rated high in strawberry flavor intensity. 'Camarosa' and 'FL 95-41' were rated higher in texture (firmness) and in sourness. 'Rosa Linda' and 'Sweet Charlie' were generally the least firm cultivars. All cultivars had good color and color uniformity. Strong correlation between furanone content and strawberry aroma could not be found (r = 0.36). However, strong correlation (r = 0.90) was found between strawberry flavor and sweetness.**

Strawberry production in Florida has increased approximately 13 percent from the 1995-96 to the 1996-97 season and is currently valued at $146,119,000. Flavor development is an important quality factor for consumer preference and significant changes in flavor occur during ripening. The composition and concentration of the volatile aroma compounds found in strawberries will inevitably vary between clones, harvest dates, maturity, and between the individual berries. Strawberry flavor can be defined as a combination of taste, the impression on the tongue, mainly determined by the acid-sugar ratio, and aroma for the impression in the nose. Previous studies have concluded that significant differences in flavor can be found between strawberry clones grown in Florida. Strawberries have an aroma matrix consisting of alcohols, acids, carbonyl, aldehydes, ketones, lactones, acetal, furans, terpenes, and sulfur compounds. To date, over 360 volatile compounds have been identified. Among these volatiles, organic esters and volatile acids are suggested as having a major impact on aroma. However, the compounds 2,5-dimethyl-4-hydroxy-3(2H)-furanone (Furaneol) and 2,5-dimethyl-4-methoxy-3(2H)-furanone (Mesifuran) have gained attention and are thought to have a more significant impact on the aroma due to their low thresholds for detection, 0.04 parts per billion and 0.03 parts per billion, respectively. Therefore, it is important to study strawberry flavor to characterize the key impact aroma compounds that may correlate with sensory data.

Furaneol is characterized by a fruity, sweet aroma at low concentrations, and at higher concentrations, a burnt caramel aroma. Mesifuran has been described as having a more sherry-like aroma. In general, Furaneol is hydrophilic in nature and has not been shown to be present in all strawberry clones; however, Furaneol is considered an important contributor to the strawberry aroma. High Performance Liquid Chromatography (HPLC) has been a common method for furanone analysis in fresh or frozen strawberries (Montero et al., 1996; Mayerl et al.; 1989; Sanz et al., 1994). To date, no research has reported the presence of the furanones 2,5-dimethyl-4-hydroxy-3(2H)-furanone (Furaneol) or 2,5-dimethyl-4-methoxy-3(2H)-furanone (Mesifuran) in Florida strawberry clones using HPLC.

The objectives of this research were to determine the sensory properties and furanone levels in several cultivars/clones of strawberries produced in Florida, and to determine if the furanone content is related to sensory characteristics.

Materials and Methods

Strawberries were harvested in 1999 on 25 Jan., 8 Feb. and 1 March from the Gulf Coast Research and Education Center in Dover, Florida. Strawberries were grown on raised beds using drip irrigation following standard strawberry horticultural practices. The strawberries were transported within 24 hours to the University of Florida's Food Science and Human Nutrition building where they were kept at 3°C overnight for sensory analysis the next day. Prior to sensory analysis, a 100 g sample from each clone was prepared for quantification of furanone content.

Samples from each clone were divided into approximately 100 g portions and blended with 320 ml of methanol (Fisher Scientific), in duplicate. Once the samples were ready for extraction, 100 ml of the methanol puree was combined with approximately 3.0 g diatomaceous earth (Celite 545, Fisher Scientific, Springfield, NJ) and shaken thoroughly. Samples were then filtered (under vacuum) using filter paper (Wattman #1) and subsequently rinsed three times with distilled water. 0.4 ml of Carrez I (15% w/v potassium ferrocyanide in water) was added and the mixture was mixed thoroughly and allowed to stand for 5 min. 0.4 ml of Carrez II reagent (30% w/v zinc sulfate in water) was then added, mixed thoroughly, and again allowed to stand 5 min. After adding Carrez I and II, samples were centrifuged (Damon model SII, Needham, MA) at 355 g for 15 min, discarding solids. After centrifuging, samples were concentrated by rotoevaporation (water bath

35°C, condenser -10°C) and brought to a volume of 25 ml with Mill Q water. The 25 ml samples were filtered through a 0.45 μm membrane and then through a 0.2 μm membrane under vacuum, then injected onto the HPLC.

Solutions of Furaneol and Mesifuran ranging from 2.0 μg/ml to 63.0 μg/ml (in water) were used to produce standard curves. The Furaneol glucoside was not commercially available and therefore quantitation of Furaneol glucoside was obtained using the standard curve for Furaneol. Identification of Furaneol glucoside was performed by adding 2 mg of 5 units/mg ß-glucosidase (Sigma) and incubating at 37°C for two hours. The samples were filtered as previously stated and injected. Analysis was carried out on a Phenomenex (Torrance, CA) reverse phase C18 column (ODS (5 μm) 250 × 4.6 mm) coupled to a Phenomenex Security Guard cartridge system. The mobile phase consisted of (A) 100% methanol and (B) 0.02 M sodium acetate/acetic acid buffer (pH 4.0) using the following gradient: 0-10 min 10% methanol; 10-40 min 12% methanol. The analysis was carried out at room temperature (~25°C), flow rate was 1.25 ml/min, detection was preformed at 280 nm, injection volume was 20 μl, and Tubrochrome (version 6.1) chromatography integration software was utilized.

A trained panel consisting of seven males and six females, from 22 to 70 years old, were used for sensory analysis; all but two panelists were members of the Food Science and Human Nutrition Department and had participated on prior trained descriptive panels. In three training sessions the panelist developed the following nine descriptive attributes: strawberry aroma intensity, other berry aroma, color intensity, color uniformity, texture, sweetness, sourness/acidity, strawberry flavor, and other berry flavor. Panelist evaluated two berries cut into quarters per cultivar on coded plates in individual taste booths using a 150 mm continuous line scale (with 0 being low and 150 being high).

Sensory data were subjected to analysis of *variance* (ANOVA) using SAS version 6.11 (Cary, NC). Data from each harvest date were analyzed separately, with the sources of variation in the study including panelists, clone, panelists and clone interaction, and replication. Duncan's Multiple Range Test was used to separate means when a significant difference (p = 0.05) was indicated in the ANOVA.

Results and Discussion

All three harvest dates revealed considerable difference between clones and between harvest dates for sensory attributes. Throughout all three harvests, 'Sweet Charlie' consistently scored higher among panelists in strawberry aroma intensity while FL 93-100 was consistently rated lower in strawberry aroma intensity (Table 1). However, all clones consistently scored high in strawberry aroma indicating all clones are of good aroma quality. Other berry aroma was not a distinguishing factor for sensory attributes. Strawberry aroma intensity of Florida strawberry clones has not been previously studied therefore, no sensory data was available to compare aromas from previous years.

The clones rated most intense in color (darkest red) were 'Camarosa' and FL 95-41 for all three harvests (Table 1). However, FL 95-256 was rated the darkest red for the first harvest but was not assayed during harvest two or three. Generally, 'Sweet Charlie', 'Rosa Linda' and FL 93-100 tended to be the clones rated the least intense or lightest red. These

Table 1. Aroma and color sensory means[z] for all harvests.

01/27/99	Strawberry aroma intensity	Other berry aroma	Color intensity	Color uniformity
Cultivar	p = 0.0347	*p* = 0.4791	p = 0.0001	p = 0.0080
Sweet Charlie	90 a	*26*	86 c	97 c
FL95-256	89 a	*25*	117 a	121 a
FL95-41	79 ab	*20*	115 a	117 ab
FL 93-100	77 ab	*24*	101 b	104 bc
Camarosa	75 b	*31*	108 ab	108 abc
Rosa Linda	71 b	*32*	90 c	100 c
02/10/99	Strawberry aroma intensity	Other berry aroma	Color intensity	Color uniformity
Cultivar	p = 0.0001	p = 0.0104	p = 0.0001	p = 0.0001
Sweet Charlie	89 a	19 b	78 b	87 bc
FL 95-41	76 a	19 b	115 a	107 a
FL 93-100	54 b	32 a	67 c	82 c
Camarosa	88 a	22 b	120 a	116 a
Rosa Linda	82 a	17 b	79 b	95 b
03/03/99	Strawberry aroma intensity	Other berry aroma	Color intensity	Color uniformity
Cultivar	p = 0.0172	*p* = 0.9238	p = 0.0001	p = 0.0076
Sweet Charlie	92 a	*20*	90 b	99 b
FL95-41	74 b	*18*	121 a	118 a
FL 93-100	73 b	*17*	95 b	92 b
Camarosa	78 ab	*21*	94 b	91 b
Rosa Linda	93 a	*23*	91 b	94 b

[z] = Means with same letter are not significantly different ($p < 0.05$) using Duncan's Multiple Range Test ($\alpha = 0.05$). Ratings on a scale of 0-150mm, with a higher value indicating a higher intensity.

results were in good agreement with previous work by Sims *et al.* (1997). FL 95-41 was determined to be the clone with the highest color uniformity throughout all three harvests. However, all clones rated consistently high in color uniformity.

Panelists rated 'Camarosa' and FL 95-41 as being the firmest strawberries and 'Sweet Charlie' and 'Rosa Linda' were rated among the softest (Table 2). These results are in good agreement with sensory work reported by Sims et al. (1997) where panelists also rated 'Camarosa' as the firmest and 'Sweet Charlie' the softest strawberries. Instron firmness measurements in this study were generally in agreement with sensory data obtained. However, 'Sweet Charlie' was typically the least firm berry among panelists, but FL 93-100 was least firm according to Instron measurements throughout all harvest dates.

Strawberry flavor intensity for FL 95-41 was strong throughout all harvests (Table 2). To date, FL 95-41 had not been previously studied for flavor and aroma but already shows good promise. FL 95-41 has been shown to posses excellent flavor and excellent firmness needed for shipping in the commercial market throughout the growing season. Sims et al. (1997) concluded 'Sweet Charlie' rated high in flavor intensity and was the sweetest berry among the clones sampled. During this study, 'Sweet Charlie' again scored well among the clones assayed for flavor intensity and consistently rated the highest in sweetness.

There were no significant differences in sweetness among clones except for harvest two, where FL 93-100 was rated the lowest in sweetness, which is in agreement with soluble solids (SS) measurements (Table 3). In previous studies (Sims et al. 1997; 1998) 'Sweet Charlie' generally had the highest SS/acid ratio, which is consistent with this study.

Sims et al. (1997) concluded that 'Camarosa' rated high in sourness among the panelists, which also was in agreement with this study (Table 2). Results indicated FL 95-41 and 'Camarosa' were rated most sour among the clones which were in agreement with titratable acidity measurements (Table 3). 'Sweet Charlie' and FL 93-100 were perceived by the taste panelists as the least sour throughout all harvest dates. 'Sweet Charlie' was quantitatively the lowest in acidity for harvest one only, while FL 93-100 was lowest in acidity for harvests two and three.

Using HPLC, linear responses ($r^2 = 0.9999$) were obtained for standard curves of Furaneol and Mesifuran standards dissolved in distilled water. Identification of Furaneol and Mesifuran were determined by using retention time, sample spiking, and spectral data of standard compounds (97% purity). Spectral analysis indicated the UV max for Furaneol glucoside, Furaneol, and Mesifuran in water was 279nm, 285nm, and 280nm, respectively (data not shown).

Through out all harvest dates, 'Camarosa' was consistently the highest in 2,5-dimethyl-4-hydroxy-3(2H)-furanone concentration while FL 93-100 was consistently the lowest (table 4). No real trends for Furaneol glucoside and 2,5-dimethyl-4-methoxy-3(2H)-furanone concentration could be established for clones assayed in this study. Strong correlation between furanone content and strawberry aroma could not be found ($r = 0.36$). However, strong correlation ($r = 0.90$) was found between strawberry flavor and sweetness.

Table 2. Texture, Sweetness, Sourness, and Strawberry Flavor Intensity Sensory Means* for All Harvests.

1/27/99	Texture	Sweetness	Sourness	Strawberry flavor	Other berry flavor
Cultivar	p = 0.0001	*p* = 0. 6401	*p* = 0.4982	p = 0.0070	p = 0.0420
Sweet Charlie	58 d	67	63	53 bc	20 a
FL 95-256	81 bc	60	76	51 c	17 b
FL95-41	88 ab	72	72	79 a	15 b
FL 93-100	76 c	67	70	69 ab	13 b
Camarosa	95 a	69	74	63 abc	18 b
Rosa Linda	71 c	68	73	58 bc	29 a
03/03/99	Texture	Sweetness	Sourness	Strawberry flavor	Other berry flavor
Cultivar	p = 0.0007	*p = 0.2610*	p = 0.0428	p = 0.2739	p = 0.8839
Sweet Charlie	82 bc	86	50 b	80	9
FL 95-41	115 a	85	72 a	85	13
FL 93-100	97 ab	62	66 ab	61	10
Camarosa	99 ab	58	72 a	56	10
Rosa Linda	72 c	73	64 ab	77	10
03/03/99	Texture	Sweetness	Sourness	Strawberry flavor	Other berry flavor
Cultivar	p = 0.0007	*p = 0.2610*	p = 0.0428	p = 0.2739	p = 0.8839
Sweet Charlie	82 bc	86	50 b	80	9
FL 95-41	115 a	85	72 a	85	13
FL 93-100	97 ab	62	66 ab	61	10
Camarosa	99 ab	58	72 a	56	10
Rosa Linda	72 c	73	64 ab	77	10

[z] = Means with same letter are not significantly different ($p < 0.05$) using Duncan's Multiple Range Test ($\alpha = 0.05$). Ratings on a scale of 0-150mm, with a higher value indicating a higher intensity.

Table 3. Soluble Solids, pH, Acidity, Soluble Solids to Acid Ratio, and Firmness of Strawberry Clones for All Harvests.

1/27/99	pH	% Soluble solids	Acidity (% citric acid)	SS: Acid	Firmness (N)
Cultivar	p = 0.0052	p = 0.0002	p = 0.0177	p = 0.0088	p = 0.0002
Sweet Charlie	3.60 a	8.9 a	0.73 c	12.0 a	2.61 bc
FL 95-256	3.42 b	7.8 b	0.84 bc	9.1 c	2.65 abc
FL 95-41	3.35 bc	8.7 a	0.92 ab	9.4 c	2.70 ab
FL 93-100	3.30 c	7.9 b	0.80 bc	9.9 bc	2.17 c
Camarosa	3.54 b	8.7 a	0.97 a	8.9 c	2.95 a
Rosa Linda	3.45 b	8.6 a	0.78 c	11.0 ab	1.60 d
2/10/99	pH	% Soluble solids	Acidity (% citric acid)	SS: Acid	Firmness (N)
Cultivar	p = 0.0072	p = 0.0001	p = 0.0001	p = 0.0005	*p = 0.0525
Sweet Charlie	3.60 a	8.9 a	0.79 b	11.3 a	2.55
FL 95-41	3.35 bc	7.5 b	0.99 a	8.16	2.78
FL 93-100	3.30 c	6.3 d	0.56 d	11.2 a	2.19
Camarosa	3.45 b	6.6 c	0.86 a	7.6 b	1.91
Rosa Linda	3.45 b	7.6 b	0.70 c	10.7 a	1.53
3/3/99	pH	% Soluble solids	Acidity (% citric acid)	SS: Acid	Firmness (N)
Cultivar	p = 0.0004	p = 0.0001	p = 0.0001	p = 0.0001	p = 0.0001
Sweet Charlie	3.44 a	8.9 a	0.72 c	12.3 a	2.94 b
FL 95-41	3.27 d	7.5 b	0.92 b	8.0 d	4.94 a
FL 93-100	3.40 b	6.3 d	0.65 d	9.5 c	1.99 c
Camarosa	3.36 c	6.6 c	0.96 a	6.84 e	3.30 b
Rosa Linda	3.33 c	7.6 b	0.71 c	10.6 b	2.86 b

[z] = Means with same letter are not significantly different ($p < 0.05$) using Duncan's Multiple Range Test ($\alpha = 0.05$).

Table 4. Furaneol Glucoside, Furaneol and Mesifuran Concentrations (mg/L) for All Harvests.

Furaneol glycoside	Harvest 1 (p = 0.0001)	Harvest 2 (p = 0.0001)	Harvest 3 (p = 0.0848)
Sweet Charlie	2.72 b	4.19 a	2.86
95-256	2.63 b	N/A	N/A
95-41	4.80 a	3.37 b	2.23
93- 100	Not detected	2.14 d	2.71
Camarosa	4.45 a	2.70 c	2.93
Rosa Linda	1.98 c	2.54 cd	2.47
Furaneol	Harvest 1 (p = 0.0001)	Harvest 2 (p = 0.0001)	Harvest 3 (p = 0.0001)
Sweet Charlie	3.40 e	4.77 b	3.35 c
95-256	4.81 b	N/A	N/A
95-41	3.92 d	4.27 c	2.95 c
93-100	2.41 f	2.16 e	2.68 c
Camarosa	6.82 a	5.89 a	5.95 a
Rosa Linda	4.34 c	2.95 d	5.10 b
Mesifuran	Harvest 1 (p = 0.0001)	Harvest 2 (p = 0.0001)	Harvest 3 (p = 0.0001)
Sweet Charlie	2.26 c	2.69 a	1.96 c
95-256	5.57 a	N/A	N/A
95-41	2.05 c	2.18 c	2.19 b
93-100	3.89 b	1.92 d	2.20 b
Camarosa	2.23 c	2.17 c	2.62 a
Rosa Linda	5.38 a	2.41 b	2.33 b
Total Furanone content	Harvest 1 (p = 0.0001)	Harvest 2 (p = 0.0001)	Harvest 3 (p = 0.0001)
Sweet Charlie	8.38	11.65	8.18
95-256	13.51	N/A	N/A
95-41	10.78	9.83	7.38
93-100	6.30	6.22	7.59
Camarosa	13.50	10.76	11.49
Rosa Linda	11.70	7.90	9.89

[z] = Means with same letter are significantly different ($P < 0.05$) using Duncan's Multiple range Test $\alpha = 0.05$ N/A = Clone was not available for assay.

Literature Cited

Dirinck, P., L. Schreyen and N. Schamp. 1977. Aroma quality evaluation of tomatoes, apples, and strawberries. J. Agric. Food Chem. 25:759-763.

Hochmuth, G. J. 1988. Strawberry production guide for Florida. Fla. Coop. Ext. Serv. Circular 142c.

Latrasse, A. 1991. Fruits III. Marcel Dekker, New York.

Mayerl, F., R. Naef, and A. F. Thomas. 1989. 2,5-dimethyl-4-hydroxy-3(2H)-furanone glucoside: isolation from strawberries and synthesis. Pytochemistry 28:631-633.

Montero, T. M., E. M. Molla, R. M. Esteban and F. J. Lopez Andreu. 1996. Quality attributes of strawberry during ripening. Scientia Horticulturae 65:239-250.

National Agriculture Statistics Service. 1997. Agricultural Statistics 1997. United States Printing Office, Washington.

Perez, A. G., R. Olisa, C. Sanz and J. Olias. 1996. Furanones in strawberries: evolution during ripening and postharvest shelf life. J. Agric. Food. Chem. 44:3620-3624.

Sanz, C., A. G. Preze and D. G. Richardson. 1994. Simultaneous HPLC determination of 2,5-dimethyl-4-hydroxy-3(2H)-furanone and related flavor compounds in strawberries. J. Food Sci. 59:139-141.

Sims, C. and C. Chandler. 1997. Sensory evaluation of Florida strawberries. Citrus and Vegetable Magazine. 61:40-41.

Sims, C. A., C. K. Chandler, J. S. Eastridge and R. Golaszewski. 1997. Changes in the fruit quality of several strawberry genotypes grown in Florida. Advances in Strawberry Research 16:48-56.

Zabetakis, I. and M. A. Holden. 1997. Strawberry flavour: analysis and biosynthesis. J. Sci. Food Agric. 74:421-434.

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EFFECT OF SEVERAL SHINY COATINGS ON THE INTERNAL GASES AND QUALITY OF APPLE FRUIT

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Abstract. **Zein, starch, polyvinyl acetate (PVA), carnauba, and carnauba-polysaccharide (CPS) coatings were applied post controlled atmosphere storage to 'Red Delicious' apples for comparison to a commercial shellac coating. Coated apples were stored in air at 2°C for two weeks and then removed to 21°C for an additional two week simulated marketing period. Gloss, internal gases, weight loss, flesh firmness, sugars and acid content were measured. Starch and carnauba coated apples showed high initial gloss, which were comparable to the shellac coating. Other coatings showed moderate initial gloss. Gloss decreased during storage to similar levels for all coatings after the 4 week experimental period, although all of the coated fruits remained significantly glossier than uncoated controls. For uncoated apples, the difference in internal O_2 and CO_2 concentrations at ambient atmosphere was 1 to 2 percent at 2°C, and increased one more percent after transfer to 21°C. Fruits coated with shellac and starch showed higher than 10 percent internal CO_2, and lower than 10 percent O_2 at 21°C. Zein-, PVA- and carnauba-coated apples showed moderate internal gases (6-7%CO_2, 11-15%O_2). There was an inverse relationship between internal O_2 and CO_2 for most coatings, except for the CPS coating, for which levels of both CO_2 and O_2 were low. Coated fruits exhibited less weight loss than uncoated except for those treated with the CPS coating. The carnauba coating was the most effective water barrier of the coatings tested, but lost this property when the polysaccharide was added. Starch-, shellac-, and CPS-coated fruit were firmer than those from other coating treatments, and all coated fruits were firmer than uncoated controls. Titratable acidity was higher in the fruits coated with CPS, starch, and shellac than in uncoated controls.**

Most 'Red Delicious' apples marketed in the United States are coated with shellac or shellac-carnauba waxes. Shellac is associated with non-food uses, which might some day be viewed negatively by consumers; therefore alternative coatings must be found and provided to the apple industry. Furthermore, shellac is currently not listed as GRAS by FDA.

High gloss is considered by the industry as the primary factor for red apple coatings. Reducing water loss and respiration rate also have benefits for extending post controlled atmosphere (CA) storage life of apples. Respiration rate of apple depends on the storage temperature and atmosphere. Coatings affect the internal atmosphere of fruit and, therefore, decrease the respiration rate. Internal O_2 and CO_2 of uncoated 'Red Delicious' apples at ambient temperature are 17 to 20% and 2 to 4% respectively (Alleyne and Hagenmaier, 2000; Bai et al., 1990). Increasing internal CO_2 and decreasing O_2 levels in coated fruit is expected, due to fruit respiration, resulting in a modified atmosphere (MA) similar to MA packaging. Fruit coated by shellac accumulated CO_2 to about 10%, and reduced O_2 to about 9% at ambient temperature, leading to ethanol accumulation of about 10 times that of uncoated control and other coatings. The gas changes caused by shellac coating were moderated more or less by adding carnauba or candelilla wax to the formulations (Alleyne and Hagenmaier, 2000). Ueda et al. (1993) stored 'Starking Delicious' apple in MA packaging at 8°C, and indicated that the resulting 6% CO_2 in the package caused off-flavor under a moderate O_2 concentration (7-9%). Since the differences of O_2 and CO_2 concentrations between in-fruit and in-package are 1-3% (Bai et al., 1990), then when internal CO_2 levels exceed 7-9%, off-flavor may result.

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