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Influence of soil type and storage conditions on sensory qualities of fresh-cut cantaloupe (*Cucumis melo*)†

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Abstract: On-farm cantaloupe (*Cucumis melo*) production as well as fresh-cut storage duration can affect postharvest fruit sensory attributes. Both effects of soil type during production of cantaloupe fruits and storage temperature after fresh-cut processing on sensory flavour and texture attributes were determined. Melons grown in sandy loam vs heavy clay soil were lower in sweet aromatic and sweet taste and higher in moisture release and fermented flavour. Fruity/melon, sweet aromatic, surface wetness, hardness and moisture release attributes decreased while fermented and sour flavour increased during storage regardless of soil type. During storage an increase in peroxidase activity occurred in fruits produced in sandy loam soil but decreased in fruits produced in clay soil. Clay soil appeared to have some advantages over sandy loam soil in producing cantaloupe fruits with better sensory quality attributes. Storage temperature conditions in this experiment (4 °C for 10 days or 4 °C for 4 days plus 10 °C for 6 days) did not have a statistically significant effect on these sensory attributes.
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INTRODUCTION

Undesirable qualities develop during storage of cut fruits.[1,2] Appearance, aroma, flavour and texture drive consumer perception of fresh-cut fruit quality. Studies indicate that fruit appearance is a major determining factor in consumers' decision to purchase fresh-cut fruits,[3] but repeat sales are driven by eating quality. Fruit flavour is usually the first quality parameter to be altered during storage.[4] Short-term (14 days) refrigerated storage does not affect key parameters such as fruit soluble solids content, total acidity and pH,[5] in spite of changes in flavour attributes.

The storage temperature of cut fruits influences their physicochemical, microbiological and sensory parameters.[6,7] Gorny *et al*[8] reported the effect of storage temperature on the eating quality and deterioration rate of fresh-cut peach and nectarine slices: lower temperatures tended to maintain quality. Concerning cantaloupe, studies on the effects of higher temperatures (>10 °C) on microbial growth, fruit composition and the effectiveness of preservative treatments have been reported,[9,10] but little has been published on sensory quality.

Pre- and postharvest handling, transportation and storage factors are known to influence the quality of fresh-cut fruits and vegetables in the retail market.[2] Cultivation of cantaloupe melon requires well-drained soil for maximum fruit quality.[11] Cantaloupe melon is, however, also very sensitive to water stress and has low nitrogen (N) use efficiency.[12] Soil texture influences the mobility/efficiency of N and mineral uptake, which in turn impacts the quality of fruits.[13,14] Ascorbic acid and folic acid in honeydew melon[15] and β-carotene in cantaloupe melon[16] are affected by soil type, probably owing to increased or decreased nutrient uptake. β-Carotene is the main pigment in cantaloupe melon,[17] and its concentration affects fruit colour and appearance. Additionally, differences in the amount of β-carotene that occur as a result of soil type may affect fruit flavour owing to carotenoid involvement in the synthesis of some volatile aroma compounds.[18]

In the USA, recommendations on soil requirements for cantaloupe production differ between the eastern

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and western regions. Cantaloupes grown in the eastern USA are usually cultivated on well-drained sandy loam soils[11] because of the relatively high rainfall and cooler climates, and because clay soils hold more water, thus increasing the potential for plant pathogen activity. In the southwestern USA, sandy soils are recommended for the early plantings because they warm rapidly in the spring, while loam and clay loam soils are preferred for the main-season production owing to their higher water-holding capacity, which favours a prolonged harvest period.[19]

Although the relationship between production conditions and some cantaloupe quality parameters, such as soluble solids, was established long ago, there appear to be no documented studies on soil types and their effects on sensory attributes of cantaloupe fruits. In this study, sensory evaluation of cantaloupe fruits grown in two soil types (sandy loam and heavy clay) is reported using sensory lexicons previously determined for cantaloupes in this laboratory.[20] In addition, differences in the shelf life of fresh-cut cantaloupe from fruits grown on these two soil types were determined by descriptive sensory evaluation of cut fruits stored at 4 °C for 10 days or at 4 °C for 4 days plus 10 °C for 6 days. The role of peroxidase enzymes as an indicator of stress adaptation of cantaloupe fruits[21,22] was also determined and monitored during storage of the fresh-cut fruits.

EXPERIMENTAL

Fruit source

Cantaloupe melon (cultivar Nitro) was produced at two separate locations (sandy loam soil and heavy clay soil) near Weslaco, TX, USA. The two locations were approximately 50 miles apart and approximately 2.8 °C difference in temperature. All other factors (fertiliser, irrigation, etc) were constant. Fully mature fruits were harvested in mid-May from both locations 38–40 days after pollination (at abscission). After harvesting, the melons were cooled to 25 °C, packed in insulated ice-chests, shipped overnight to the Southern Regional Research Center (New Orleans, LA, USA) and stored for 2 days at 4 °C before processing into fresh-cut product.

Fresh-cut processing and sample preparation

Whole fruits were inspected carefully for bruises, compression damage and the presence of fungus on the rind, and discarded if not in optimum condition. Fruits were washed thoroughly in cold running tap water, then sanitised in $100\,mg\,l^{-1}$ sodium hypochlorite solution, rinsed and uniformly peeled with a Muro CP-44 Melon Peeler (Tokyo, Japan). The stem and blossom portions (~2–3 cm) were cut off and each melon was sliced once longitudinally with a 20.3 cm food knife. The seed cavity was gently scraped with a spoon to remove the seeds, each half was placed cut-side down on a cutting board and roughly cut into 2.5 cm thick slices using a thin 12.7 cm food knife, and all seed integument tissues (1–2 mm thick) were cut away. Approximately 2–3 cm × 2.5 cm chunks were cut from the slices. Good manufacturing practices and strict sanitary conditions were followed during processing and storage to simulate commercial processing conditions. Four to six melons from each location were processed for the experiment. Approximately 300 g of chunks were randomly placed in 24 oz (~1 l) low-profile rigid polyethylene terephthalate (PET) Juice Catcher containers (SRW-24-JC, Winkler Forming Inc, Carrollton, TX, USA). The containers were stored at 4 °C for 3 days in two separate incubators. After the fourth day, one incubator was adjusted to 10 °C to represent a higher temperature that could occur during transportation and distribution, while the other remained at 4 °C. Fresh-cut chunks were assessed after 0, 4, 7 and 10 days of storage.

Descriptive sensory analysis

Twelve experienced descriptive sensory panellists (having from 1 to 8 years of experience)[23] participated in the sensory evaluation. Sensory descriptors (six flavour and three texture attributes—Table 1) were fruity/melon, sweet aromatic, musty, fermented, sweet, sour, surface wetness, hardness and moisture release.[24] Five chunks equilibrated to room temperature (24 °C) were placed in glass custard cups and covered with inverted watch glasses that extended over the edge of the cups. The cups were labelled with three-digit random numbers. An initial sample (a sufficient quantity of a locally purchased unidentified variety of melon) was presented first to reduce the first-sample position bias. Thereafter the experimental samples were presented monadically in random order within a session. All panellists received the samples in the same order. All samples for a given storage day (eg day 0) were presented at one session. Panellists slid the watch glass back to allow the headspace aroma compounds to enter their nose. They evaluated the intensities of the various aromas emitted from the samples, then placed one chunk in their mouth and chewed to prepare for swallowing, but expectorated the sample. All descriptors were evaluated for intensity. Panellists were required to use at least three chunks for the evaluation. If the intensity of a flavour descriptor differed from that of the related aroma, or if the intensity differed between chunks, then an estimated average was recorded by the panellists. Intensity was rated on a 0–15-point anchored scale with 0 being not detectable and 15 being more intense than most foods,[23] including tropical fruits. Panellists rinsed their palate with filtered water between samples and used unsalted saltine crackers to cleanse their palate.

Statistical analysis

The experimental design was a randomised complete block design with panellists as blocks with a three-way treatment structure, location, storage temperature and storage days. Analysis of variance was performed with

Table 1. Melon flavour and texture descriptors and definitions

Descriptor	Definition
Aromatics	
Fruity/melon	A mixture of aromatics associated with melons (cantaloupes, honeydews, watermelons, etc) and other fresh fruits
Sweet aromatic	The aromatic associated with materials that also have a sweet aroma of honey, caramelised sugar and cotton candy
Musty	The aromatic associated with mould or dirt such as geosmin and 2-methylisoborneol
Fermented	The aromatic associated with fermented fruits or sugars such as dried peaches, prunes and wine
Taste	
Sweet	The taste on the tongue associated with sugars
Mouthfeel	
Sour	The taste on the tongue associated with citric acid
Texture	
Surface wetness	The amount of moisture, due to an aqueous system, on the surface: 3.0, internal surface of raw carrots ⇒ 15.0, water
Hardness	The force to compress between molars upon first bite: 1.0, cream cheese ⇒ 11.0, shelled almonds
Moisture release	The amount of wetness/juiciness released from the sample after first bite: 2.0, Betty Crocker Gushers ⇒ 12.0, grapes

panellists as a random effect and the other effects fixed. Standard errors of means (SEM) were calculated and included with means in text and tables. Pairwise mean comparisons for fixed effects were computed with Tukey's adjustment method at $p < 0.1$. Data were analysed using SAS PROC MIXED (Release 8.2, 1999–2001, SAS, Cary, NC, USA).

Peroxidase assay

The Melon Peeler was used to cut slices (about 2 mm thick) from the peeled fruit. The fruit was cut into smaller pieces (about 6 cm long) and about 50 g was randomly placed in a Juice Catcher. The sealed Juice Catcher containers were stored as described above. On each sampling date the entire contents of each Juice Catcher were used as one replication of three that were analysed. Guaiacol peroxidase (POD) activity in enzyme extracts was assayed by monitoring changes in absorbance at 470 nm in mixtures consisting of 0.02 M Na_2HPO_4, 0.08 M NaH_2PO_4, 20 mM guaiacol, 4 mM H_2O_2 and enzyme extract (10 µl), pH 6, in a total volume of 3 ml, as previously described.[21,22]

RESULTS AND DISCUSSION

Effect of days of storage

Seven of the nine cantaloupe fruit sensory attributes changed during storage. Sweet taste and musty flavour did not change. Fruity/melon, sweet aromatic, surface wetness, hardness and moisture release decreased while fermented flavour and sour taste increased during storage (Table 2). Bett[20] observed that the changes in these attributes can vary between 0 and 7 days depending upon variety. Recently, it was demonstrated that refrigerated storage of cut cantaloupe melon allows for a loss of volatile aliphatic and aromatic esters.[25,26] Esters constitute one of the classes of compounds that impact the aroma of fruits, and a decrease in fruitiness and sweet aromatic flavour might be related to their loss during time in storage. Textural quality retention is an important parameter in fresh-cut fruits.[10,27] Tissue softening and associated loss of integrity and surface dehydration are common degradative changes that occur during storage of cut fruits.[28]

Effect of production location

Cantaloupe growers prefer sandy soil in some locations and at certain times of the year, because yields are better compared with those of clay soil.[11] However, melons grown on sandy loam vs heavy clay soil were significantly different for sweet aromatic, fermented, sweet taste and moisture release attributes (Table 2). Sweet aromatic flavour and sweet taste were more intense in clay- vs sandy loam-produced melons. Fermented flavour (an off-flavour) was more intense in sandy loam- vs clay-grown melons. Based on this off-flavour being less intense and sweet aromatic and sweetness being more intense in clay- vs sandy loam-produced melons, it can be concluded that heavy clay soil produced a better-flavoured melon. The textural attribute 'moisture release' was slightly more intense in sandy loam- vs clay-grown melons. This is possibly due to higher ion exchange or water retention properties of clay. Although moisture release intensity in fruits grown in clay (6.9 ± 0.35) vs sandy loam (7.5 ± 0.32) would not likely change acceptability, acceptability changes based on texture tend to occur when an attribute deviates considerably from what is expected. Based on comparisons with commercially produced melons in a previous study,[20] the clay- and sandy loam-grown melons' moisture release intensities in this study are within the expected range. Flavour acceptability was dependent upon the existence of a balance of desirable flavours and the lack of off-flavours.[24] Low intensity of sweet taste is one of the critical flavours that consumers deem less desirable in fresh fruit. Therefore fruit soluble solids are routinely measured at harvest as an indicator of sugar content, ie sweet taste.

'Musty' describes flavours similar to that of damp soil, wet foliage or undercooked potato.[24] Musty flavour in melon fruits was not significantly affected by temperature or storage time. Musty intensity was slightly less in fruits grown in clay (0.5) vs sandy loam (0.8). Although the magnitude was small, it is a flavour that can be easily detected in some commodities at

Table 2. Means and probabilities from analysis of variance for location, days of storage and temperature, and two-way interactions

Treatment	Sensory attributes								
	Fruity/melon	Sweet aromatic	Musty	Fermented	Sweet	Sour	Surface wetness	Hardness	Moisture release
Location (Soil)									
Heavy clay	3.7 ± 0.25[a]	2.3 ± 0.24	0.5 ± 0.12	0.1 ± 0.02	5.4 ± 0.20	0.3 ± 0.06	7.2 ± 0.28	3.9 ± 0.18	6.9 ± 0.35
Sandy loam	3.4 ± 0.23	1.7 ± 0.20	0.8 ± 0.17	0.2 ± 0.05	4.5 ± 0.24	0.4 ± 0.09	7.6 ± 0.28	3.8 ± 0.17	7.5 ± 0.32
Temperature (Temp)									
4 °C	3.6 ± 0.24	2.0 ± 0.22	0.7 ± 0.14	0.1 ± 0.03	4.8 ± 0.23	0.4 ± 0.08	7.3 ± 0.27	3.9 ± 0.17	7.3 ± 0.35
4 °C/10 °C	3.5 ± 0.25	2.0 ± 0.23	0.6 ± 0.16	0.1 ± 0.04	5.1 ± 0.23	0.4 ± 0.08	7.4 ± 0.30	3.8 ± 0.19	7.1 ± 0.33
Days of storage (Days)									
0	4.2 ± 0.34a	2.2 ± 0.32a	1.0 ± 0.28a	0.1 ± 0.04b	5.0 ± 0.23a	0.2 ± 0.06b	8.7 ± 0.38a	4.6 ± 0.23a	8.4 ± 0.43a
4	3.3 ± 0.32b	2.2 ± 0.33a	0.4 ± 0.11a	0.1 ± 0.05b	4.9 ± 0.30a	0.2 ± 0.08b	7.7 ± 0.26b	4.0 ± 0.20b	6.8 ± 0.42ab
7	4.0 ± 0.34a	1.9 ± 0.30b	0.6 ± 0.17a	0.0 ± 0.02b	4.9 ± 0.42a	0.3 ± 0.09a	6.7 ± 0.34c	3.4 ± 0.22c	6.7 ± 0.48b
10	2.7 ± 0.31b	1.5 ± 0.27c	0.5 ± 0.23a	0.2 ± 0.10a	5.0 ± 0.38a	1.0 ± 0.17a	5.8 ± 0.37d	3.1 ± 0.26c	6.6 ± 0.52b
Soil	**0.09**[b]	**<0.01**	**0.06**	**0.01**	**<0.01**	0.37	0.15	0.50	**0.03**
Temp	0.67	0.92	0.82	0.35	0.39	0.97	0.82	0.57	0.73
Days	**<0.01**	**0.01**	0.29	**<0.01**	0.93	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Soil × Days	0.77	0.16	0.82	**0.02**	0.78	0.29	0.90	0.99	0.96
Temp × Days	0.75	0.76	0.88	0.69	0.52	0.67	0.45	0.12	0.97
Soil × Temp	0.013	0.77	0.88	0.60	0.73	0.73	0.65	0.58	0.14

[a] Mean ± standard error of the mean. Means within a column followed by the same letter were not significantly different at $p < 0.10$ based on least square (Tukey) mean comparisons.
[b] Probabilities in bold type are significant at $p < 0.10$.

less than 1 ppb by a portion of the population[29] and therefore warrants monitoring.

Results of soil analysis (Table 3) indicated that texture, organic matter, phosphorus, potassium and magnesium differed between the clay and sandy loam soil production sites. Golden[30] reported that cultivation in clay soil may result in relatively higher sucrose production in crops than cultivation in silt loam soil owing to the higher potassium fertiliser uptake from the clay soil. However, other production conditions can also affect soluble solids content. Isaacs *et al*[31] and Li *et al*[32] found that the effects of insufficient water during cantaloupe germination may also increase glucose, disaccharide and/or trehalose levels in the fruits. The higher sweetness level determined by sensory evaluation in the clay-grown fruits suggests that increased nutrient uptake from the more humus-rich clay soil may contribute to improved fruit sensory quality.

Table 3. Soil analysis for two locations of cantaloupe production

Property	Location	
	Sandy loam	Heavy clay
Texture[a]	2	6
Organic matter	0.18% humus	0.65% humus
PH	7.7	7.7
Nitrate (NO_3)[b]	48.2 (medium)	34.7 (medium)
Phosphorus (P_2O_5)[b]	179.2 (high)	85.1 (medium)
Potassium (K) (CO_2)[c]	218 (high)	92 (high)
Sodium (Na) (CO_2)[c]	150 (normal)	270 (high)
Calcium (Ca) (H_2O)[d]	40 (sufficient)	50 (sufficient)
Magnesium (Mg) (H_2O)[d]	12 (low)	14 (marginal)
Na/Ca	4 (sufficient)	5 (sufficient)
Na/Mg	13 (high)	19 (high)

[a] Soil texture range from 1 = sand through 3 = loam to 6 = heavy clay.
[b] kg ha^{-1}.
[c] mg kg^{-1} (carbonic acid extract).
[d] mg kg^{-1} (water-soluble extract).

Production location × days of storage interaction

Fermented flavour in sandy loam-grown melons increased during storage from 0.1 ± 0.05 at day 0 to 0.4 ± 0.2 at day 10, while fruits grown in heavy clay soil remained near 0.1 ± 0.1 (data not shown) during storage. The melons grown on sandy loam soil developed more off-flavours than those grown on clay, and did so after 7 days of storage. Even though the magnitude is low, the reality is that some panelists (sensitive to this flavour) perceived it while the others did not, which left a mean near imperceptible. It is a phenomenon worthy of consideration.

Temperature effect

The temperature at which fresh-cut fruit is held is critical for maintaining product quality and should be between 1 and 4 °C.[33–35] The temperature during processing, transit and marketing can easily range from 5 to 20 °C. Respiration rates dramatically increase as temperatures increase, which usually results in greater water loss and increased microbial activity.[2,36] Our experiment was designed to observe sensory changes that occur when ideal temperatures are exceeded. Although decreased fruit quality typically occurs with increased storage temperature, in our study the deterioration rate was not significantly affected by an increase in storage temperature. This could be due to the initial storage at 4 °C before going to 10 °C, which may indicate that maintaining the temperature at 4 °C for a few days may have some preserving affect when later temperature abuse occurs, but further research is needed. There were no significant interaction effects for soil type (production location) × storage temperature or storage day × storage temperature.

Peroxidase activity

POD activity has been linked to oxidative stress in plant tissues.[37] It has been demonstrated that the dominant POD in cantaloupe melon is the ascorbate type.[21] In the same study it was suggested that the relatively high POD in cantaloupe melon could contribute to the fruit's relatively short shelf life when compared with vegetables such as lettuce. There also appears to be an empirical relationship between residual POD activity and the development of off-flavours and off-odours in foods.[38] POD activity in cantaloupe melons grown in sandy loam soil was higher than the activity during storage in fruits grown in clay soil (Fig 1). Activity decreased during storage in clay-grown fruits and increased in sandy loam-grown fruits. Higher ion exchange properties of clay may have reduced peroxidase activity. Storage temperature did not affect POD activity as much as soil type. The effect of storage time on POD extracts from cantaloupe melon differed based on soil type. While POD in clay-grown fruits decreased with storage time as previously reported,[22] POD activity increased in sandy loam-grown fruits after 4 days of storage and remained constant for the remainder of the storage study. An increase in ascorbate POD normally indicates increased stress;[37] therefore our results indicate that a possibly higher stress level occurred in fruits grown in sandy loam vs clay soil. Higher POD levels in fruits from sandy loam vs clay soil, and coincident physiological effects, may have contributed to differences observed in some sensory attributes evaluated during storage.

CONCLUSIONS

Soil type (heavy clay vs sandy loam) had a significant effect on the initial quality of cantaloupe fruits. Fruits grown in sandy loam vs clay soil were less sweet and had greater potential for off-flavours. Storage as fresh-cut fruit resulted in a significant change in several sensory attributes. Sweet taste was not affected by storage, but sour taste increased significantly in sandy loam- vs clay-grown fruits after day 7. A change in storage temperature to 10 °C after 4 days at 4 °C had no significant effect on fruit quality during this experiment.

The two different soil production types did not appear to affect the initial POD activity after cutting the fruit, but did have an effect on POD activity during storage of the fresh-cut fruit product. Higher POD activity, which occurred during storage of fresh-cut melon from fruits grown on sandy loam soil, indicated an increased stress level and consequent biological changes that likely affected the resultant fruit flavour in sandy loam- vs clay-grown fruits. It appears that cantaloupe melons grown in clay soil produced better-tasting fruits with superior fresh-cut quality.

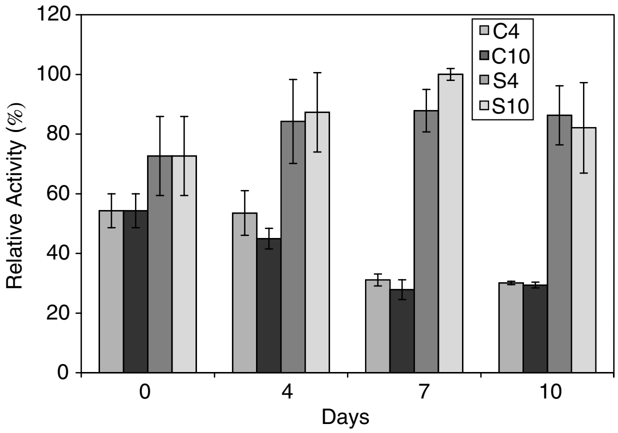

Figure 1. Effect of storage temperature on peroxidase activity (means with standard error bars) in fresh-cut cantaloupe melon: C4 = fruit grown in heavy clay soil, with fresh-cut chunks stored at 4 °C; C10 = fruit grown in heavy clay soil, with fresh-cut chunks stored at 10 °C after 4 days at 4 °C; S4 = fruit grown in sandy loam soil, with fresh-cut chunks stored at 4 °C; S10 = fruit grown in sandy loam soil, with fresh-cut chunks stored at 10 °C after 4 days at 4 °C.

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