Modified Atmosphere Maintains Quality of Fresh-cut Cantaloupe (Cucumis melo L.)

J-H. Bai, R.A. Saftner, A.E. Watada, and Y.S. Lee

ABSTRACT: Fresh-cut cantaloupe cubes were placed in film-sealed containers in which the internal gas mixture was attained naturally (nMAP), was flushed with 4 kPa O₂ plus 10 kPa CO₂ (fMAP), or was maintained near atmospheric levels by perforating the film (PPF). While both nMAP and fMAP maintained the salable quality of melon cubes for 9 d at 5 °C, fMAP maintained quality better than nMAP. The benefit of fMAP was indicated by better color retention, and by reduced translucency, respiration rate, and microbial population compared with nMAP. Shelf life of cubes in PFP was only 5 to 7 d at 5 °C, and its rapid decline was due to tissue translucency and/or off-odor development.

Keywords: cantaloupe, fresh-cut, modified atmosphere packaging, storage quality

Introduction

Fresh-cut cantaloupe (Cucumis melo L. reticulatus group) and other fresh-cut products are a rapidly growing segment of the retail and foodservice horticultural industry (Anonymous 1998). Various kinds of packaged fresh-cut melons are among the most common fresh-cut fruits available in the marketplace. While fresh-cut products have met consumers’ desire for convenience, product quality and shelf life in particular are still important considerations. A shelf life of up to 10 d for fresh-cut melons is desirable in the distribution chain (Anonymous 1996), but retail stores seldom market the product for more than 3 d. Both consumers and producers would benefit from a method that would extend shelf life without adversely affecting the quality of fresh-cut products.

Fresh-cut fruits and vegetables generally are packaged in film bags or containers overwrapped with film, which creates a modified atmosphere within the package (MAP). MAP can extend the shelf life of many intact and fresh-cut horticultural products (Kader and others 1989; Gorny 1997). It can also cause the O₂ level to decrease below 1 kPa in commercial fresh-cut fruit and vegetables packages (Cameron and Smyth 1997; Qi and others 1999), which may not be desirable. A low O₂ level may retard browning and spoilage and maintain fresh appearance; however, it also can cause off-flavor and flavor loss (Cameron and Smyth 1997). A very low O₂ or an elevated CO₂ in MAP may inhibit growth of aerobic spoilage organisms, but may allow or stimulate the growth of foodborne pathogens (Farber 1991). On the other hand, growth of aerobic spoilage organisms may be considered beneficial because it warns the consumers of spoiled product. Thus, for a given product of known weight and storage temperature, proper film selection is essential for attaining a gas mixture in MAP that will maintain quality and restrict microbial growth.

The gas mixture recommended for controlled atmosphere (CA) storage of whole cantaloupe is 3 to 5 kPa O₂ and 10 to 15 kPa CO₂ (Kader 1989), and a similar gas mixture is recommended for fresh-cut cantaloupe (O'Connor-Shaw and others 1996; Portela and others 1997). With complete sanitation and meticulous laboratory care, O'Connor-Shaw and others (1996) were able to maintain a low microbial population and obtain a 28-d shelf life with fresh-cut cantaloupe held at 4.5 °C in recommended controlled atmospheres. Portela and others (1997) indicated that the recommended CO₂ concentration maintained fresh-cut cantaloupe visual quality above the limits of salability for 9 d at 10 °C and 15 d at 5 °C, and the combination of an elevated CO₂ with a lowered O₂ concentration provided additional benefit in reducing microbial counts.

A major metabolic process occurring in harvested produce is respiration. The respiration rate of produce is an excellent indicator of metabolic activity of tissue; that is, it is a useful guide to the potential storage life of the produce. Climacteric respiration, as well as the complete ripening process, indicates the end of storage life of fruit. In MAP, the equilibrium atmosphere may change rapidly to anaerobic once climacteric respiration begins.

Since the marketing period of fresh-cut fruit is relatively short, an additional benefit of MAP may be attained by actively flushing the package with the desired gas rather than allowing the MAP to develop naturally, which may take 24 h or more to equilibrate. Ayhan and Chism (1998) were able to store fresh-cut cantaloupe 15 d at 2.2 °C when the commodity was packaged in a 5 kPa O₂ and 95 kPa N₂ atmosphere; however, they did not report the gas levels present during storage. To our knowledge there are no other studies on the effect of MAP with recommended gas mixtures on the quality and microbial changes of fresh-cut cantaloupe.

We describe in this paper the quality and natural microbial population changes on fresh-cut cantaloupes when placed in film-sealed containers, where the internal gas mixture developed naturally during storage (nMAP), was rapidly attained by flushing the containers with a 4 kPa O₂ plus 10 kPa CO₂ gas mixture (fMAP), or was maintained at atmospheric levels by perforating the film (PPF).

Materials and Methods

Materials

Cantaloupes (Cucumis melo L. reticulatus group) of ‘Athena’ cv. at 3/4 to full slip maturity were harvested during July and August 1998 from a field in Maryland. The ‘Athena’ cv. was selected because it is being considered specifically for fresh-cut processing by Novartis Seeds, Inc. The fruit of two of the three trials were transported directly from the field to the laboratory, while the fruit of the third trial was shipped to the Philadelphia Wholesale Market, then to the laboratory. Thus, the fruit of the...
latter trial was in transit about two d before being available for experimenta-
tion. All fruit was kept overnight at 5 °C prior to processing on the following
morning.

For each trial, 15 cantaloupes of about 2500 g each were washed with water at 5 °C and dipped in sanitizer (200 μL L⁻¹ sodium hypochlorite solu-
tion, pH 6.5) at 5 °C for 2 min. The san-
tized fruit were peeled, dipped in the same sanitizer for 30 s, halved, cored, sliced, and cut into 2 cm-square cubes. The cubes were rinsed in 150 μL L⁻¹ so-
dium hypochlorite solution for 30 s and allowed to drain at 5 °C for 1 h, then separated into three groups, representing three replicates. Each replicate was divided into 31 uniform samples (175 g) for 3 package treatments, 2 temperature treatments, and 6 sampling times.

The cantaloupe cubes were placed in a 1-L plastic container underlaid with a Fresh R Pax TM water-absorbent pouch (Maxwell Chase Technologies, Atlanta, Ga., U.S.A.). The container was thermo-
conglutinated with the LDX-5406 film (Cryovac, Duncan, S.C., U.S.A.) using a food pack machine (Model FP Basic V/G, Ilpra, Italy). The oxygen transmission rates (OTR) of the film were 1006 and 1448 mL m⁻² h⁻¹ atm⁻¹, at 2.5 °C and 5 °C, respectively. The packages were di-
vided into 3 groups for the following: (1) the packages were allowed to naturally form a modified atmosphere (nMAP), (2) the internal atmosphere of the packages was flushed with a gas mixture of 4 kPa O₂ plus 10 kPa CO₂ (fMAP), and (3) the film was perforated with a needle to have 10 1.5-mm holes (PFP. The two tempera-
ture treatments were 5 °C continuous, or 2 d at 2.5 °C and then transferred to 5 °C. The latter was to simulate the pro-
cessing and marketing temperature con-
ditions, respectively. Samples were re-
uced for analyses of gas composition, quality, and natural microbial population.

Table 1—Equilibrated ethylene concentrations in packages and ethylene produc-
tion rates of fresh-cut cantaloupe cubes stored in 3 types of packaging at 2 temperatures over 3 trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>Ethylene concentration in package (µL L⁻¹)</th>
<th>Initial ethylene production rate at 5 °C (µL kg⁻¹ h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PFP</td>
<td>nMAP</td>
</tr>
<tr>
<td>Trial 1</td>
<td>2 ± 1 y</td>
<td>112 ± 15</td>
</tr>
<tr>
<td>Trial 2</td>
<td>1 ± 0</td>
<td>71 ± 16</td>
</tr>
<tr>
<td>Trial 3</td>
<td>1 ± 1</td>
<td>34 ± 8</td>
</tr>
</tbody>
</table>

PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O₂ plus 10 kPa CO₂ prior to storage. Maximum concentrations and steady states for PFP were not maintained.

Microbial analysis
The bacterial count was determined by incubating melon extracts on tryptic soy agar (TSA, Difco Laboratories, De-
etroit, Mich., U.S.A.). The yeast and mold

Quality analysis
Quality analyses included visual quality (VQ), aroma, translucency, texture, soluble solids content (SSC), and color. The sensory evaluations were

Figure 1—Oxygen and CO₂ concentrations in three types of packaging of fresh-
cut cantaloupe cubes over 2 temperatures and 3 trials. PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O₂ plus 10 kPa CO₂ prior to storage. Vertical lines represent SD (n = 18). SD bars were not shown when masked by the symbol.
Modified Atmosphere Effects on Cantaloupe . . .

Table 2—Probability and significance of visual quality (VQ), aroma, translucency percent, L*, shear force, SSC, bacterial and yeast and mold populations of fresh-cut ‘Athena’ cantaloupe cubes stored in three types of packaging for 0, 2, 5, 7, 9, and 12 d over 2 temperatures and 3 trials

<table>
<thead>
<tr>
<th>DF</th>
<th>VQ</th>
<th>Aroma</th>
<th>Translucency</th>
<th>L*</th>
<th>Shear force</th>
<th>SSC</th>
<th>Bacterial and yeast mold population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package (P)</td>
<td>2</td>
<td>0.0001**</td>
<td>0.0001**</td>
<td>0.0001**</td>
<td>0.7835</td>
<td>0.9106</td>
<td>0.0011** 0.0001**</td>
</tr>
<tr>
<td>Day (D)</td>
<td>5</td>
<td>0.0001**</td>
<td>0.0001**</td>
<td>0.0001**</td>
<td>0.0001**</td>
<td>0.0060**</td>
<td>0.0001** 0.1471</td>
</tr>
<tr>
<td>P × D</td>
<td>17</td>
<td>0.0001**</td>
<td>0.0001**</td>
<td>0.0001**</td>
<td>0.9712</td>
<td>0.9992</td>
<td>0.0210 0.0001**</td>
</tr>
<tr>
<td>Coef. Var.</td>
<td>6.15</td>
<td>3.69</td>
<td>119.64</td>
<td>4.50</td>
<td>16.60</td>
<td>7.74</td>
<td>11.15 20.8</td>
</tr>
</tbody>
</table>

*When next to data, * = p < 0.05; ** = p < 0.01 using Scheffe’s multiple comparison test.

Results and Discussion

Gas change in packages and respiration of fresh-cut cubes

The final gas level in a MAP system depends on film permeability and product respiration rate. Within PFP, the O₂ and CO₂ levels remained essentially the same as that in ambient air until d 9, and then changed by only 1 to 2 kPa during the next 3 d (Figure 1). In the air flow-through system, which was similar to the atmosphere within PFP, the average respiration rate based on O₂ uptake of cantaloupe cubes at 5°C was stable during the first 5 d, then increased more than sixfold during the next 5 d (Figure 2). Within nMAP, the O₂ concentration decreased to 8 kPa while CO₂ increased to 12 kPa during 12 d at 5°C, with neither gas reaching an equilibrium within the package (Figure 1). The average respiration rate within nMAP remained stable for about 9 d at 5°C, or nearly twice as long as that in PFP. While the respiration rate increased about twofold between 9 and 12 d in nMAP, the rate at 12 d in nMAP was similar to that in PFP at d 7 and was only one-fifth that in PFP at d 12 (Figure 2). Within fMAP, the O₂ concentration decreased to 8 kPa while CO₂ increased to 12 kPa during 12 d at 5°C, with neither gas reaching an equilibrium within the package. The average respiration rate within fMAP remained stable throughout the 12 d of storage at 5°C (Figure 2). The increase in the average respiratory rate by d 7 and 12 in PFP and nMAP, respectively, was correlated with and was thought to have been caused by a general deterioration of the tissue. Ethylene levels increased during the first 5 d, then remained relatively stable. Ethylene accumulated in both nMAP and fMAP, but the ethylene level in fMAP was only about 1/4 of that in nMAP (Table 1). The atmospheres within the nMAP and fMAP did not have any adverse effect on the packaged cubes.

In the CA and air flow-through syst-
Modified Atmosphere Effects on Cantaloupe . . .

Table 3—Shelf life in d of fresh-cut cantaloupe cubes stored in 3 packaging at 2 temperatures over 3 trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>Temperature</th>
<th>VQ&lt;sup&gt;z&lt;/sup&gt;</th>
<th>Aroma</th>
<th>VQ&lt;sup&gt;z&lt;/sup&gt;</th>
<th>Aroma</th>
<th>VQ&lt;sup&gt;z&lt;/sup&gt;</th>
<th>Aroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>2.5-5 °C&lt;sup&gt;x&lt;/sup&gt;</td>
<td>5.7 ± 1.2</td>
<td>7.0 ± 0.0</td>
<td>12.0 ± 0.0</td>
<td>10.0 ± 1.7</td>
<td>12.0 ± 0.0</td>
<td>11.0 ± 1.7</td>
</tr>
<tr>
<td></td>
<td>5 °C</td>
<td>5.0 ± 0.0</td>
<td>6.5 ± 1.2</td>
<td>12.0 ± 0.0</td>
<td>9.0 ± 0.0</td>
<td>12.0 ± 0.0</td>
<td>9.0 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>5 °C</td>
<td>7.0 ± 0.0</td>
<td>7.7 ± 1.2</td>
<td>10.0 ± 1.7</td>
<td>9.0 ± 0.0</td>
<td>10.0 ± 1.7</td>
<td>9.0 ± 0.0</td>
</tr>
<tr>
<td>Trial 2</td>
<td>5 °C</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>9.0 ± 0.0</td>
<td>10.0 ± 1.7</td>
<td>10.0 ± 1.7</td>
<td>10.0 ± 1.7</td>
</tr>
<tr>
<td>Trial 3</td>
<td>5 °C</td>
<td>7.0 ± 0.0</td>
<td>9.0 ± 0.0</td>
<td>9.0 ± 0.0</td>
<td>9.0 ± 0.0</td>
<td>12.0 ± 0.0</td>
<td>12.0 ± 0.0</td>
</tr>
</tbody>
</table>

<sup>x</sup>PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O<sub>2</sub> plus 10 kPa CO<sub>2</sub> prior to storage.

<sup>z</sup>VQ = visual quality

<sup>2</sup>± d at 2.5 °C and then transferred to 5 °C

tems, the corresponding average respiration rates were lower, and the respiratory increases delayed by 4 d when the fruit cubes were treated for 2 d at 2.5 °C and then transferred to 5 °C rather than being continuously treated at 5 °C (data not shown). In our MAP experiments, however, a 2-d treatment at 2.5 °C prior to 5 °C storage had little effect on the levels of gases in the packages when compared to those continuously treated at 5 °C. The ineffectiveness of the 2.5 °C treatment in MAP is due to the lowered temperature having a greater inhibitory effect on gas permeabilities of the film than on the average respiration rate of the cubes.

The initial ethylene production rate of the melon cubes for the 3 trials was variable (Table 1). However, the ethylene production rate of the cubes from all three trials decreased gradually during storage (data not shown). The declining ethylene production rates during experimentation indicate that the climacteric peak of ethylene production may have occurred before fresh-cut processing had begun. The lower initial ethylene production of cubes in trial 3 indicated a more advanced stage of ripening of those samples compared to those in the other two trials.

Quality characteristics

Packaging and storage d significantly affected the two basic quality characteristics of visual quality and aroma (Table 2). The shelf life in PFP at 5 °C was 5 to 7 d (Table 3). Storing 2 d at 2.5 °C prior to 5 °C had little additional benefit for shelf life except in trial 3, in which it prolonged storage by 1 to 2 d more than those stored continuously at 5 °C (Table 3). Deterioration was primarily due to the development of translucency—that is, lower scores of visual quality. The percent translucency of cubes in PFP was greater than 30% after 7 (Figure 3), indicating that the produce was in an advanced stage of senescence. Translucency greater than 20% may be considered the limit of salable quality. O’Connor-Shaw and others (1996) indicated that translucency occurred in all treatments not containing CO<sub>2</sub> and in some treatments having greater than 15 kPa O<sub>2</sub>.

Both nMAP and fMAP maintained the shelf life of cubes for 9 to 12 d (Table 3), and lowered translucency (Figure 3). However, translucency was detected 2 d earlier and was two- to fivefold higher between 9 and 12 d in nMAP than in fMAP, which indicated that melon cubes in nMAP were senescing faster than those in fMAP. A faint off-odor occurred by d 12 in all samples except the cubes in fMAP in trial 3, which retained a mild melon aroma. The development of off-odor was associated with the presence of fungi on the surface of the cubes, not to anaerobic respiration of the cube tissue.

A high lightness (Figure 3) and bright orange color were observed on good, high quality cube surfaces. The initial L<sup>a</sup> value, as lightness, was 59. The value in fMAP gradually increased, while it remained essentially unchanged in nMAP. The value in PFP decreased slowly during the first 5 d, then more rapidly over the next 7 d. The chroma (C<sup>a</sup>), brightness of the cube surface color, was initially 34 with a hue angle (h<sub>ab</sub>) of 72°. Due to increasing translucency, C<sup>a</sup> showed the same pattern of change as for L<sup>a</sup> in all treatments, but h<sub>ab</sub> remained constant.

Figure 3—Translucency percent and L<sup>a</sup> values of fresh-cut cantaloupe cubes stored in 3 types of packaging over 2 temperatures and 3 trials. PFP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O<sub>2</sub> plus 10 kPa CO<sub>2</sub> prior to storage. Vertical lines represent SD (n = 10). SD bars were not shown when masked by the symbol.
Modified Atmosphere Effects on Cantaloupe...

(data not shown).

The firmness of the cubes was significantly different among trials (data not shown), but was not different among package types (Table 2). The initial shear force was about 700 N for trials 1 and 2, and 500 N for trial 3 where the fruits were shipped to market for two d before laboratory analyses. Samples from trials 1 and 2 that had a relatively high initial shear force softened faster than those of trial 3 having a lower initial firmness. The average shear force loss from d 0 to d 9 of cubes prepared from field- and market-derived fruit was 34% and 10%, respectively. However, no difference was shown among package types and storage temperatures (Table 2). The soluble solids content (SSC) was about 9.5% in samples from all 3 trials and did not change during 12 d of storage in all treatments. The SSC was lower than expected, and probably was due to the influx of sanitizer into the cubes during cube dipping treatments—that is, the fruit cubes gained weight during the dipping treatments.

Microbial populations

Initial populations of bacteria (TSA) were about log 3.2 CFU g⁻¹, while those for yeasts and molds (PDA) were less than log 1.9 CFU g⁻¹. Microbial populations on both TSA and PDA increased in all samples as storage time increased, regardless of the treatment (Figure 4). However, by d 5, microbial populations were higher for PFP than for nMAP or fMAP. The total microbial population was generally between 0.2 (-35% reduction) and 0.5 (-70% reduction) log units lower in fMAP than in nMAP (Figure 4). Bacterial counts ranged from log 3 to log 10 CFU g⁻¹. The quality of the cubes in nMAP and fMAP on d 9 of storage was acceptable, even though they had bacterial counts of log 8 CFU g⁻¹. Yeasts and molds were less numerous than bacteria, which is the same pattern as that found on other fresh-cut produce (Nguyen-The and Cartin 1994). The benefit of elevated carbon dioxide in modified atmosphere is due to its fungicidal and bacteriostatic characteristics against many spoilage organisms that can grow at refrigerated temperatures (Enfors and Molin 1978). Carbon dioxide also increased the lag phase of growth curves for several spoilage organisms (Coyne 1933). Low oxygen in MAP generally inhibits the growth of aerobic microorganisms.

Conclusions

NATURALLY MODIFIED ATMOSPHERE packaging (nMAP) was beneficial for fresh-cut ‘Athena’ cantaloupe cubes, retaining salable quality for 9 d at 5°C. Rapidly flushed modified atmosphere packaging (fMAP, 4 kPa O₂ plus 10 kPa CO₂) maintained quality better than MAP; that is, better color retention and reduced translucency, respiration rate, and microbial populations. The question remains whether or not the improved quality of fresh-cut melon in fMAP relative to nMAP is worth the added cost of flushing the packaging atmosphere. Salability was limited mainly by the development of translucency and/or off-odor.

References


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Figure 4—Bacterial, yeast, and mold populations of fresh-cut cantaloupe cubes stored in three types of packaging over 2 temperatures and 3 trials. PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O₂ plus 10 kPa CO₂ prior to sheage. Vertical lines represent SD (n = 18). SD bars were not shown when masked by the symbol.