

Gas Composition and Temperature Affect Quality of Fresh-cut Fennel

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Abstract. Freshly harvested bulbs of fennel (*Foeniculum vulgare* var. *dulce*) ‘Clio’ were sliced at 5 °C, dipped in 100 mg·L⁻¹ NaOCl solution, and packaged in passive modified atmosphere packaging (MAP) by using trays covered and thermal sealed with unperforated or perforated polypropylene film. According to common commercial needs a shelf life of 14 d at 0 and 5 °C was applied. The respiration rate of fresh-cut fennel was 1.3- to 1.7-fold higher at 5 °C than at 0 °C, and was 1.4- to 1.8-fold higher than that reported for whole bulbs. MAP did not prevent the declines in SSC and TA that occurred during storage, while pH did not change. Water loss was lower than 0.1% in all treatments, and no decay or physiological disorders developed during storage. The gas compositions of 16 to 18 kPa O₂ plus 2 to 4 kPa CO₂ generated within the perforated packages at 0 and 5 °C or 1.5 to 2 kPa O₂ plus 18 to 20 kPa CO₂ in unperforated packages at 5 °C did not inhibit browning on the cut surface or other sensory changes of the slices. However, atmospheres in unperforated packages of 4 to 6 kPa O₂ plus 10 to 14 kPa CO₂ at 0 °C maintained the sensory quality like at harvest.

Over the last decade, fennel bulbs have developed in Spain as a relatively important vegetable. Cultivation of fennel with reasonable profits for producers is increasing in the Mediterranean southeastern areas of Spain due to the favorable agricultural conditions. Bulbs are mainly shipped to European countries (United Kingdom, Germany, France, Italy and others) while domestic consumption is still very low. Competitive results for cultivation of this vegetable have induced new research about production and postharvest handling (Artés et al., 2000; León et al., 1992; Maroto, 1995; Namesny 1993; Pico, 2001).

Low temperatures (0 to 1 °C) high relative humidity (RH 90% to 95%) and an intermediate air change should be used during storage, transport, and distribution (Namesny, 1993). Use of modified atmosphere packaging (MAP) as a physical treatment to avoid browning development on the butt end cut zone and on external leaves of fennel bulbs has been recommended (Artés et al., 2000, 2002b). Gas compositions with low O₂ (3 to 5 kPa) and high CO₂ (15 to 20 kPa) levels decreased browning in the cut zone of whole ‘Orion’ fennel during 2 weeks of storage at 0 or 5 °C (Artés et al., 2000, 2002a). This physiological disorder is caused by polyphenol oxidase and other oxidative enzymes during cold storage of whole as well as of fresh-cut fruits and vegetables (Artés et al., 1998; Vamos-Vigyazo, 1981).

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Operations involved in preparing fruits and vegetables as fresh-cut products generally increase their rate of deterioration. It is essential to keep these items at the lowest temperature feasible throughout the cool chain, usually in the range 0 to 5 °C, for keeping quality and to extend their shelf-life. Additionally, modified atmospheres benefit fresh-cut products, mainly by reducing respiration rate, retarding microbial growth, and inhibiting disorders such as browning (Ahvenainen, 1996; Artés, 2000; Cantwell, 1992; Hamza et al., 1996). Fresh-processed fennel could be considered as a new product and its postharvest behavior has received very little attention in the scientific literature.

Fresh-cut fennel has been reported as being difficult to process, mainly due to its susceptibility to enzymatic browning, and a combination of partial vacuum packaging with a low concentration of citric acid and storage at 4 °C was effective in prolonging the shelf life of an unknown fennel cv. up to 10 d (Albenzio et al., 1998). However from the best of our knowledge no scientific information is available about optimal conditions for fresh-cut processing and distribution of fennel.

The aim of the present work was to study the fresh-cut processing of fennel and to determine the main quality attribute changes and losses throughout a relatively prolonged shelf life at two storage temperatures as affected by different atmospheres in MAP.

Materials and Methods

Preparation of fennel bulbs. ‘Clio’ fennel bulbs grown under Mediterranean Spanish climate were hand harvested by cutting the base with a sharp knife, and eliminating dirty and decayed external leaves. Bulbs were obtained

from a commercial farm of Torre Pacheco (Murcia, Spain) in the middle of April and transported the same day over 30 km to the laboratory, where they were stored at 0 °C. Next morning, bulbs were carefully selected to ensure that they were free from defects and with similar visual appearance and size. Individual weight was between 300 to 450 g and equatorial diameter ranged from 10 to 12 cm. Before processing, sound bulbs were cleaned by dipping them for 1 min in a 50 mg·L⁻¹ aqueous NaOCl solution at pH 7.5 and at about 20 °C. In an isolated and clean room at 5 °C, the bulbs were sliced in pieces of 8 mm thickness by cutting them perpendicular to the long axis with a commercial slicing machine (Jata, Slim model, Vizcaya, Spain). Immediately after cutting, the slices were dipped for 1 min in a 100 mg·L⁻¹ aqueous NaOCl solution at 5 °C and pH 7.5, rinsed with tap water at 5 °C for 1 min, and drained for 1 min.

Respiratory activity. Rates of CO₂ emission were determined by using a closed system (Escalona et al., 2002). Four glass jars each containing 200 g of fennel slices were placed in clean rooms at 0 or 5 °C for 14 d. The increases in CO₂ were monitored daily after closing the jars for 2 to 3 h. Gas samples were taken with a plastic syringe from the headspace. In order to avoid CO₂ accumulation (≤0.3%) (Watada et al., 1996) and to maintain a high RH within the jars, between each measurement a continuous air flow (3 to 4 L·h⁻¹ and 95% RH) with a gas mixing system (Flowboard, Davis, Calif.) was applied. CO₂ emission was determined by using a 0.5 mL gas sample injected in a gas chromatograph (GC) (GC-14B; Shimadzu, Tokyo, Japan) equipped with a thermal conductivity detector (TCD).

Modified atmosphere packages. Samples of 150 ± 5 g of fennel slices were packed into polypropylene (PP) trays of 17 × 11 × 4 cm (Plasal-Isap, Alcira, Valencia, Spain) and covered with an antimist unperforated oriented PP film of 35 µm thickness (OPP) (Plásticos del Segura S.L., Murcia, Spain), or with one (OPPI) or two (OPP2) perforations of 0.7 mm each. The film was heat sealed to the tray on the edges (model Befor; Barket, France) to generate a passive modified atmosphere. The film permeability at 23 °C and 75% RH was 5000 to 6000 mL·m⁻²·d⁻¹·atm⁻¹ for O₂ and 8000 to 12000 mL·m⁻²·d⁻¹·atm⁻¹ for CO₂ (data provided by Plásticos del Segura S.L., Murcia, Spain). Five packages were used per film/temperature combination.

To simulate maximum commercial needs for shipment, distribution and retail sale, a storage period of 14 d was applied.

Gas composition within packages. Gas composition (O₂, CO₂, and N₂) within packages was monitored throughout storage by a GC (Perkin Elmer Autosystem, Norwalk, Conn.) equipped with a TCD. For analysis, a 0.5-mL gas sample was taken from each package by using a plastic syringe through a silicone septum.

Chemical attributes evaluation. Slices randomly taken from each sample were squeezed with a commercial blender (Moulinex, Barcelona, Spain). The juice was analyzed for

soluble solids content (SSC), pH, and titratable acidity (TA). SSC was measured with a hand refractometer (Atago N1, Tokyo, Japan) and expressed as °Brix at 20 °C. The pH was determined by using a digital pH meter (Crison 501; Barcelona, Spain). For TA, 10 mL of juice was titrated with 0.1 N NaOH to an endpoint of pH 8.1 (AOAC, 1984) and expressed as oxalic acid in g·L⁻¹. Quality attributes were determined at the beginning and after shelf life.

Sensorial evaluation. A panel of five persons familiar with sensory properties of fennel evaluated visual appearance, aroma, flavor, and texture. A nine-point scale (9 = excellent, 7 = good, 5 = acceptable, limit of marketability, 3 = poor, and 1 = extremely poor) adapted from Kader et al. (1973) was used to score each sensory property. Sensorial panel evaluated a representative sample coming from each treatment.

Weight loss, decay, and browning evaluation. Weight loss was determined by using a scale (PC model; Mettler Instruments, Zurich, Switzerland) with an accuracy of 0.01 g. Values were expressed as percentage of initial fresh weight. Decay and browning were subjectively evaluated by using the scale (1 = none, 2 = slight, 3 = moderate, 4 = severe, 5 = very severe). Slices that scored higher than 3 were considered as unacceptable for consumers (Escalona et al., 2002). Values correspond to a mean of five packages per treatment.

Statistical analysis. The experiment followed a completely randomized design (n = 5). Statgraphic Plus version 2.1 software was used for analysis of variance and least significant difference test (at the 5% level) to compare means.

Results and Discussion

Respiratory activity. Mean values of respiration rate (CO₂ production) of fennel slices were between 20 to 24 mg·kg⁻¹·h⁻¹ at 5 °C and between 14 to 16 mg·kg⁻¹·h⁻¹ at 0 °C. Throughout the storage period a slight decline in respiratory activity at both temperatures was found. The respiration rate was 1.3- to 1.7-fold higher at 5 °C than at 0 °C. This result indicates 1.4- to 1.8-fold higher respiration rate than that reported for whole 'Clio' bulbs stored in air at 0 °C, which reached moderate respiration rates of 9 to 10 mg·kg⁻¹·h⁻¹ (Artés et al., 2002a). This increase in the respiration rate due to processing agrees with results reported for other fresh-cut vegetables, which exhibit 1.2- to 7-fold higher respiration than the whole product, depending on the produce, cutting grade, and temperature (Ahvenainen, 1996; Artés, 2000; Brecht, 1995; Cantwell, 1992; Watada et al., 1990).

Modified atmosphere packaging. Gas composition within packages. No steady state was reached in unperforated OPP, and after 14 d of storage gas atmospheres were 4 to 6 kPa O₂ plus 10 to 14 kPa CO₂ at 0 °C and 1.5 to 2 kPa O₂ plus 18 to 20 kPa CO₂ at 5 °C (Fig. 1). Differences in O₂ and CO₂ levels between 0 and 5 °C were very probably due to the greater respiratory activity of sliced fennel at 5 °C than at 0 °C.

Levels of O₂ and CO₂ within packages

were quite similar when OPP film with either 1 or 2 perforations were used. Steady state gas compositions were about 16 to 18 kPa O₂ plus 2 to 4 kPa CO₂ in both packages at 0 and 5 °C (Fig. 1). This atmosphere contrasts with the range commonly recommended (Cantwell, 1992) for fresh-cut vegetables (2 to 8 kPa O₂ plus 5 to 15 kPa CO₂), although the use of 1 or 2 perforations could be suggested when temperature abuse (over 5 °C) during transport, distribution and, particularly, retail sale periods, could occur.

Chemical attributes. After storage in all treatments, a decrease in SSC was detected and no differences among them were found (Table 1). At the end of storage at both temperatures, except for a slight increase in both OPP treatments, no changes in pH levels compared to values at harvest were found (Table 1). After storage, the lowest TA was found in slices un-

der the highest CO₂ levels (unperforated OPP treatments) at both temperatures. Quite similar values for SSC, pH, and TA for whole 'Clio' bulbs stored under controlled atmosphere have been recently reported (Artés et al., 2002a).

Sensory attributes. Unperforated OPP at 0 °C was the only treatment able to maintain the quality attributes of slices like at harvest for 14 d. When the temperature was increased to 5 °C, visual appearance after storage was significantly lower, but there were no differences in aroma, flavor, texture, and browning of the cut surface between slices at 0 or 5 °C (Table 2). After storage in OPP1 or OPP2 packages at 0 or 5 °C, similar quality attributes of fennel slices, lower than at harvest but higher than the limit of marketability, were reached. At the end of storage, no differences in sensory quality between OPP1 and OPP2 at either temperature were found. After 14 d at 5 °C no

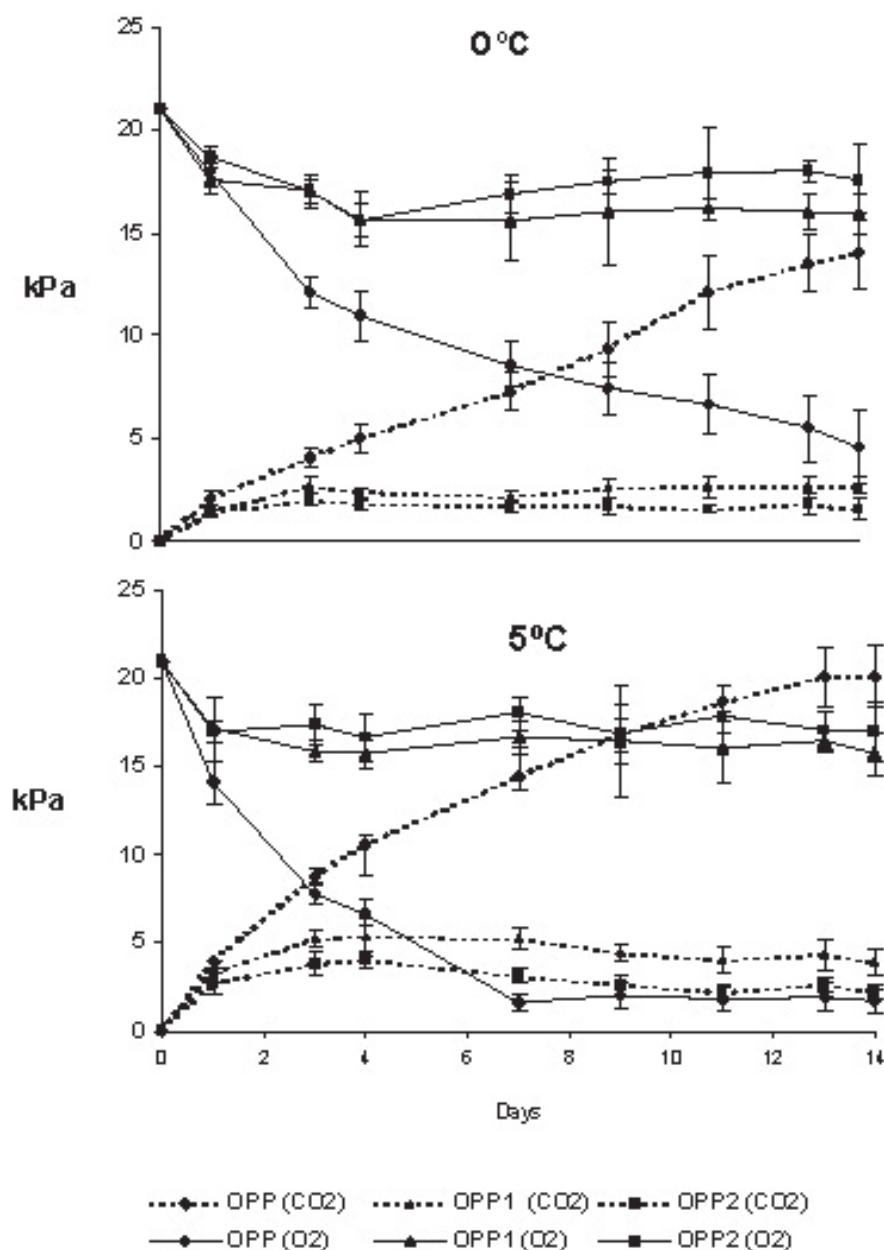


Fig. 1. Changes in O₂ and CO₂ levels in passive MAP storage of fresh-cut fennel during 14 d at 0 and 5 °C. Five repetitions of 150 g per treatment were used. Bars represent standard error.

Table 1. Soluble solids content (SSC), pH, and titratable acidity (TA) of fresh-cut fennel stored in passive MAP for 14 d at 0 or 5 °C.

Treatment	SSC (°Brix)	pH	TA (g of oxalic acid/L)
At harvest	5.5 a ^z	6.2 b	0.61 a
After 14 d at 0 °C			
OPP ^y	4.8 b	6.4 a	0.42 c
OPP1	4.6 b	6.2 b	0.48 bc
OPP2	4.4 b	6.2 b	0.46 bc
After 14 d at 5 °C			
OPP	4.6 b	6.4 a	0.44 c
OPP1	4.6 b	6.2 b	0.53 b
OPP2	4.6 b	6.2 b	0.53 b

^zData within a column followed by the same letter are not significantly different ($P \leq 0.05$) according to LSD ($n = 5$).

^yOPP = unperforated film; OPP1 and OPP2 = 1 or 2 0.7-mm perforations, respectively.

Table 2. Sensory attribute changes of fresh-cut fennel stored in passive MAP for 14 d at 0 or 5 °C.

Treatment	Visual appearance	Aroma	Flavor	Texture	Browning on the cut surface
At harvest	8.4 a ^z	8.0 a	8.2 a	8.8 a	1.0 a
After 14 d at 0 °C					
OPP ^y	8.4 a	7.6 ab	7.6 ab	8.0 ab	1.2 a
OPP1	6.0 b	5.6 c	6.8 b	7.6 b	2.0 a
OPP2	5.0 b	7.4 ab	6.6 b	7.4 b	2.2 a
After 14 d at 5 °C					
OPP	6.4 b	7.0 b	7.4 ab	7.6 b	2.1 a
OPP1	6.2 b	6.0 bc	7.0 b	7.8 ab	2.1 a
OPP2	5.2 b	6.4 bc	7.0 b	7.2 b	2.3 a

^zData within a column followed by the same letter are not significantly different ($P \leq 0.05$) according to LSD ($n = 5$).

^yOPP = unperforated film; OPP1 and OPP2 = 1 or 2 0.7-mm perforations, respectively.

differences among perforated and unperforated OPP treatments were found.

Weight loss, decay, and browning. Weight loss was lower than 0.1% after 14 d at both 0 and 5 °C. No physiological disorders nor decay developed at any time, although a slight browning on the cut surface occurred for slices in OPP1 and OPP2 packages at both temperatures and in unperforated OPP at 5 °C (Table 2). Results for browning development contrast with those reported by Albenzio et al. (1998), who considered enzymatic browning as the main cause of postharvest deterioration of fresh-cut fennel. This could be due to different sensitivities to browning of fennel cultivars. In fact, a higher sensitivity to browning of the butt end cut zone on whole bulbs of 'Orion' than that shown by whole 'Clio' bulbs during controlled atmosphere storage has been recently reported (Artés et al., 2002a).

These results suggest that low temperature maybe more important than altered atmosphere since a less extreme atmosphere at 0 °C was

more beneficial than a more extreme atmosphere at 5 °C.

Conclusions

The use of MAP with low O₂ and high CO₂ concentrations could be useful to avoid browning in fresh processed fennel. MAP with 2 to 6 kPa O₂ plus 10 to 20 kPa CO₂ at 0 and 5 °C maintained good quality of fennel slices, although the best results for keeping overall quality of fresh-cut 'Clio' fennel for 14 d was found in MAP of 4 to 6 kPa O₂ plus 10 to 14 kPa CO₂ at 0 °C.

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