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Research Paper

Effect of controlled atmosphere on the storage potential of Ottomanit fig fruit

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ABSTRACT

Fig fruit are highly perishable due to softening and decay. Controlled atmosphere (CA) was studied as a potential tool to extend the shelf life of Ottomanit figs. The figs were stored for 30 days at 0 °C and 2 days of shelf life under four storage regimes (O_2/CO_2 in kPa): 5/5, 5/10, 5/15, and 20/0 representing ambient atmosphere in the cold room. Ripening, expressed as total soluble solids, acidity and color, was retarded by the CA but recovered after shelf life. Firmness was retained to a higher level under the 5/5 kPa CA. CO_2 injury was observed at the higher CO_2 levels and decay was lowest under the 5 kPa CO_2 condition. Fruit fluorescence indicated on significant differences among the CA treatments in the anthocyanin index after cold storage and an increase in the flavonoid index after shelf life of the CA treatments. Fluorescence imaging of the fruit suggested that exposure to CA conditions of 5/5 kPa O_2/CO_2 retains fruit integrity whereas under the other conditions, fruit integrity is compromised.

1. Introduction

Figs have been an important part of the traditional Mediterranean diet with origins in the eastern Mediterranean region and southern Arabia (Khoshbakht and Hammer, 2006; Stover et al., 2007). The total global production of figs is 1.14 million tons annually, with Turkey ranking first in production with about 0.3 million tons (FAOSTAT, 2014). Most of the current production is of dried figs; fresh production is limited by the high perishability of the fruit and the lack of techniques and facilities to allow sustainable distribution to local and global markets. Despite these limitations, in recent years, the total production and market value of fresh fig has increased, necessitating the development and adoption of new means to store them. With an export value of \$2–3 kg^{-1} for fresh figs, they are considered one of the highest income sources in Turkey's fresh fruit sector.

Taxonomically, figs (*Ficus carica* L.) belong to the family Moraceae and botanically, they are a closed flower. The edible part is made up of condensed female flowers termed syconium, and the tissue consists of a small drupe-shaped fruit and pedicels that connect it to the receptacle (Flaishman et al., 2008). The fig is pollinated by the wasp *Blastophaga psenes*, which enters through an opening at the bottom of the fruit termed ostiole (Galil and Neeman, 1977). Fig fruit production is asynchronous and it can yield two crops a year.

As is the case with other fruit, figs exhibit a double-sigmoid curve which involves a phase of rapid cell division, a transition phase, and a cell-expansion phase (Marei and Crane, 1971). At the end of this last phase, the fruit volume is two to three times larger than in the second phase, and there is rapid accumulation of anthocyanins (Solomon et al., 2006). Based on its responsiveness to ethylene and postharvest ripening, including color and sugar accumulation and softening, fig is considered a climacteric fruit (Freiman et al., 2012). A unique aspect of fig tree physiology is that it can produce either parthenocarpic or pollinated fruit, with the latter being rounder and of higher quality, as manifested in part by better firmness and less spoilage (Rosianski et al., 2016).

Fruit firmness and peel color are considered the main harvest indicators for fresh figs (Crisosto et al., 1998; Freiman et al., 2012). The high perishability of figs is attributed to their delicate epidermal tissue, which is very sensitive to wounding and spoilage by molds (Colelli et al., 1991), as well as extensive softening. To reduce losses, it is acceptable practice to harvest the figs just before full ripeness (Türk, 1989) although in general, the customers prefer to buy fully mature fresh figs.

The number of studies dealing with postharvest technologies for fresh figs is rather limited, but it is generally accepted that storage temperature should be low (0–2 °C) and relative humidity (RH) should be high (Colelli et al., 1991; Gözlekçi et al., 2005). Forced-air precooling reduced weight loss of 'Bursa Siyahi' figs during storage at 0 °C

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and doubled the storage potential of the fruit from 2 to 4 weeks (Celikel and Karacali, 1998). With respect to controlled or modified atmosphere (CA and MA, respectively), (Mathooko et al., 1993) stored 'Masui Dauphine' figs for 3 days under MA packaging (MAP) and enriched CO_2 at 0 °C and found it to better maintain fig quality. In another study, (Bouzo et al., 2012) packed 'Brown Turkey' figs with different films and reported that after 21 days at 0 °C, MAP reduced the rate of respiration and prolonged the shelf life of the fruit, although accumulation of CO_2 was rather low. MAP of three cultivars for 21 days showed cultivar-dependent retention of quality after storage (Villalobos et al., 2016).

In contrast to MAP which depends entirely on fruit respiration, under CA, CO_2 and O_2 levels are continuously monitored and controlled to the desired level with the aim of limiting respiration without inducing anaerobic respiration to the point of off-flavors and fruit damage. Colelli et al. (1991) placed 'Mission' figs in jars enriched with 15 or 20 kPa CO_2 at 0–5 °C for 28 days of cold storage. The bright appearance of the peel was better maintained, decay was completely inhibited, and fruit firmness was improved under the enriched CO_2 atmosphere. Acetaldehyde increased under high CO_2 levels from the beginning of storage and then decreased, whereas ethanol increased in the fourth week of storage. Türk et al. (1994) studied the effect of CA at O_2-to-CO_2 ratios of 3:3, 5:5, 10:5, 20:2 and 20:0 on 'Bursa Siyahi' figs stored for 40 days at 0 °C and 3 days of shelf life. While technical details on the CA system used and statistical analysis were lacking, the authors suggested that the 3:3 and 5:5 treatments result in better fruit quality. In another study, mature 'Mavra Markopoulo' figs were stored at −1 °C in 2 kPa O_2 or under ambient atmosphere for 29 days (Tsantil et al., 2003). The low O_2 reduced fruit respiration and ethylene emission, and had a major effect on fruit firmness and delay in color accumulation. However, no effect was observed on titratable acid (TA) or SSC (soluble solid content), nor was any fruit decay reported. CA was also tested in California on three fig cultivars—Brown Turkey, Kadota and Mission—stored for 31, 31 and 19 days, respectively, at 0 °C (Crisosto et al., 2009). Storage conditions included a CA of 6 kPa O_2 and 17 kPa CO_2, a control that was not under CA, and shelf life at 20 °C for up to 3 days. CA conditions had a major positive effect on decay reduction: for example, after 1 day of shelf life, the control 'Kadota' fruit suffered 72% decay compared to those held at 0 °C under CA conditions, but after 3 days of shelf life, 86% of the fruit from the CA suffered decay.

Addressing the high variability among and within reports and varieties, our objective was to determine the effects of different CA conditions on the storage of the major fig cultivar grown in Israel and to test new methodologies to assess its quality.

2. Materials and methods

2.1. Fruit source

Figs termed Ottomanit or Cyprus fig (Brazilian type) were purchased from a grower in Arugot, Israel, toward the end of the production period spanning June to September 2016. The planting system was vase-shaped with planting distances of 5 m × 4 m. The overall quality of the fruit was not high, and only uniform-size fruit with no external damage were selected. The figs were transported 40 km to the Department of Postharvest Science at the Volcani Center in an air-conditioned van. The initial weight of each fruit was determined before it was placed in the tray and a set of 20 fruit were measured for firmness, color, TSS, acidity and fluorescence as described below.

2.2. Experimental plan

Figs were arranged in plastic "egg" trays for small fruit in a 4 × 5 array, and these were placed in cardboard trays. One replication contained five fruits and four replications were used for each treatment. The treatment was composed of two trays, one for analysis after cold storage and the other for shelf life analysis. Cold storage was carried out for 1 month at 0 °C, RH 95%, and shelf life was examined for 2 days at 20 °C and RH 85%.

The experiment was carried out in an experimental CA system (SCS, Paddok Wood, UK) in 400-L cabinets. The treatments included three CA conditions: all had a constant O_2 level of 5 kPa, and the CO_2 levels were 5, 10 or 15 kPa. The control treatment was placed in the same cabinets without sealing the cabinet door.

2.3. Determination of quality traits

Measurements of fruit weight, diameter, firmness, total soluble solids (TSS) and acidity at harvest were performed on five fruits in four replications. Fruit firmness was measured using a fruit texture analyzer (Inspekt 5 Table Blue, Germany) equipped with a 25-mm flat tip. The tip moved at a speed of 5 mm s^{-1} to a depth of 2 mm and the maximum recorded force value was expressed in Newton (N). TSS and TA were measured in juice prepared by maceration with a juice extractor (Sachs, Model F-800, Israel) and filtration through four layers of cheesecloth. TSS was determined with a digital refractometer (Atago, Tokyo, Japan). TA was determined by titration to pH 8.2 with 0.1 N NaOH in an automatic titrator (Metrohm, Herisau, Switzerland), and results were expressed as percentage citric acid equivalents. Skin color was measured with a Minolta chroma meter (Model CR-400, Osaka, Japan). The recorded values were: luminocity (L), showing the change in brightness on a scale of 0 (black) to 100 (white); chromaticity (C), which is the color intensity (low values represent darker colors); hue (h°), i.e., the angle of the color cycle with 0° in the red–violet zone, 90° in the yellow zone, 180° in the blue–green zone and 270° in the blue zone.

The percentage weight loss of each fruit was determined and pooled to the replication level. Decay was quantified by subjective evaluation with a value of 0 for fruit with no decay and 1 if decay covered the entire fruit surface. Internal decay was also determined by cutting the fruit and inspecting flesh integrity and color.

2.4. Detection and measurement of fruit fluorescence

Fruit fluorescence was also quantified using the Multiplex III system (Force A, Orssay, France) (Ghozlen et al., 2010). Measurements were carried out for each fruit on both sides of the fruit surface with a 3-cm diameter hole through which fluorescence was recorded and the instrument was placed on each fruit with the surface of the fruit centered below the hole. The indices used in this study are listed in Table 1.

Fluorescence imaging was carried out with the IVIS system (IVIS® Lumina LT Series III, PerkinElmer). Excitation was at 465 nm epi-illumination and emission was set by a Cy5.5 filter. Field of view was set to D and camera level was set to high to capture a set of 16 fruits in one image.

All fruit were photographed in a studio equipped with a dual halogen light source and reflectors (SLS-DL1000, Tokina, Hong Kong).

Table 1
Fluorescence signals used in this study.[a]

Ratio	Expression[b]	Primary signal at denominator	Index
SFR_R	FRF_R/RF_R	Red fluorescence excited by red	Chlorophyll
FLAV	Log (FRF_R/FRF_UV)	Far-red fluorescence excited by UV	Flavonols[c]
FER_RG	FRF_R/FRF_G	Far-red fluorescence excited by green	Anthocyanins
ANTH_RB	Log (FRF_R/FRF_B)	Far-red fluorescence excited by blue	Anthocyanins

[a] According to Ghozlen et al. (2010).
[b] FRF_R – Far-red fluorescence excited by red light: the common value of all numerators in the expression.
[c] Compounds which absorb at 375 nm.