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Effect of Permeable Modified Atmosphere Packaging on Quality and Shelf Life of Fresh 'Khenaizy' Dates Stored at Low Temperature

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Abstract This study aimed to assess the effect of selectively permeable Modified Atmosphere Packaging (MAP) films on quality and shelf life stability of "khenaizy" fresh dates stored at 1°C. MAP gas system with 20% CO_2 in nitrogen and a semi-permeable films enabled the diffusion of moisture and gases creating an equilibrium state which was able to slow down the ripening progression and significantly preventing weight loss and color darkening. Fresh dates packaged in low barrier laminated film (F3) allowed more moisture loss indicated by their high-water vapour transmission rate compared to dates enclosed in packages inhibiting water loss. MAP treatments initially flushed with 20% CO_2 in N continued to record low penetration values (high firmness) at 30 days. The skin of "khenaizy" fresh dates is original red. Dates stored in medium barrier laminated film (F2)+Normal air and F3+MAP showed significant retention of fruit firmness after 20 days of storage compared with other treatments. The use of MAP with F2 films had some potential to reduce rate of color change of "khenaizy" fresh dates packed at the "Khalal" stage of maturity stored for 30 days at 1°C. Only a slight increase in water activity (a_w), indicating better resistance against fruits deterioration during storage, for both MAP and Normal air treatments over storage period compared with control. The change in quality appeared to be a function of storage atmosphere, sealing films' permeability rates and a_w.

Keywords: *fresh dates, modified atmosphere packaging, permeable films, quality, shelf life, storage*

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1. Introduction

Saudi Arabia is ranked as the fourth largest date producer in the world [1]. Because of surplus date production in Saudi Arabia, domestic marketing of the product needs to be enhanced; moreover, exports have not reached the expected level [2]. There is a vast diversity in date palm cultivars in Saudi Arabia. "khenaizy" is one of the most notable cultivars. Such cultivar has export potential, due to its physical and chemical properties, as well as its abundant availability. Recently, there are increasing consumer concerns about fresh date availability in Saudi market. In view of keeping quality extending shelf life, there is also importance of exports [3].

The date fruit goes through four distinct ripening stages. These four stages are "Kimri", "Khalal" (sometimes referred to as "Bisr"), "Rutab", and "Tamr" to represent the immature green, the mature full colored, the soft brown, and the hard raisin like stages respectively [4]. During the "Khalal" stage, the rate of gain in size and weight decreases slightly and the fruit reach full size and weight. Also, "Tamr" stage fruit has the longest potential storage life (many months) compared to "Khalal" (several days to weeks' maximum) [3,4]. Fresh dates harvested at "Khalal" stage stored at 1-4°C under MAP conditions could provide maximum economical extension of shelf life and preserves edible product quality [5]. Fresh date fruit continues to respire, consuming oxygen and producing carbon dioxide and water vapor. In general, low levels of O_2 and high levels of CO_2 usually employed to reduce the produce respiration rate, with the consequence of prolonging shelf life [6]. On the other hand, high CO_2 concentrations inhibit several enzymes of the Krebs' cycle [7]. The use of Modified Atmosphere Packaging leading to an atmosphere higher in CO_2 and lower in O_2 than atmospheric air retards ripening and slow down rates of respiration, ethylene production, softening, and compositional changes [8].

Aleid et al [9] examined the use of MAP to extend the shelf life of "Khalal" dates from "Khalas" cultivar under refrigerated conditions. The results showed that MAP with 10% or 20% CO_2 in air was successful in reducing the rate of the ripening processes while control-packaged dates showed signs of ripening development such as significant weight loss and darkening in date color, similar to that

observed in "Tamr" stage fruit. In another study, fresh "Barhi" dates at the "Khalal"stasge stored under 20% CO_2 showed significantly longer storage period (lasted for 182 days) compared to control (lasted for 49 days) [10]. "khenaizy" fresh dates variety is produced in large quantities in Alahsa region, Saudi Arabia. This variety exhibited low tannins, high sugar, red color and can be harvested at the "Khalal" stage of maturity. However, this stage has a short shelf life for few days under refrigerated temperature [3]. There is importance of exploring new practices to preserve this variety in its fresh state to extend its shelf life.

The aim of this work was to utilize selectively defined MAP films to preserve quality and extend shelf life of "khenaizy" fresh dates and to slow the ripening rate of "Khalal" stage to retain the "Khalal" crunchy texture and appearance.

2. Materials and Methods

2.1. Sample Preparation and Initial Testing

Fresh khenaizy date plam (*Phoenix dactylifera* L.) samples at "Khalal" stage were obtained from local farms located in Alahsa, Saudi Arabia. The fresh dates were washed at harvest, pre-cooled, sorted, prepared, packaged and stored at 0ºC within a day of harvesting to remove the field heat of the harvested fruits. All date fruit were pre-cooled prior to being randomly assigned to treatments. Once pre-cooled, dates were placed into either unsealed cardboard boxes or a single layer of at least 25 fruits in MAP trays (37mm x 137mm x 187mm) obtained from VC999 Packaging Systems AG (Melonenstrasse 2, CH - 9100 Herisau, Switzerland). Modified atmosphere tray pack sealed with 20% CO_2, balance nitrogen (N) gas treatment were then actively applied with MAP by introducing the gas mixture to the date samples using a VC999 TS300N tray sealing machine supplied with packs sealed with packaging films. The experiment consisted of seven treatments as follows: The first was control-unsealed cardboard box. The rests utilized three selectively permeable MAP films as follows: Three films packed with 20% CO_2 + balance air, and the same three films packed with 20% CO_2 + balance N.

2.2. Sealing Films

Three sealing films (VC999 Packing Systems AG, Herisau, Switzerland) with different permeability rates were used. The films were tested for water vapor transmission rate (WVTR), oxygen transmission rate (OTR) and carbon dioxide transmission rate (CO_2TR) at School of Packaging labs, Michigan State University. All films were tested using a 50cm^2 test area of film and run in duplicate. The measured WVTR, OTR and CO_2TR results for the tested packaging films are provided in (Table 1).

Target atmospheric concentrations of the gas mixture for treatments were filled from a premixed cylinder. CO_2 and N. Gas levels of treatments were measured immediately on the completion of packaging prior to storage and quality assessments using an Oxybaby® M^+ (Witt-Gasetechnik, Germany). Samples were retained at 1°C for assessment at 0, 10, 20 and 30 days of storage.

2.3. Postharvest Storage Assessment

Five containers from each of the six treatments were randomly selected for initial quality assessments. Assessments for moisture content, water activity (a_w) and total soluble solids (TSS) were made according to AOAC [11]. Color was measured as described in Aleid et al [9] and AL-Saikhan [12]. Firmness measurements were conducted to determine fruit firmness according to Aleid and Dogan [13] using a penetrometer (Stanhope-Seta Setamatic Penetrometer, Surrey, UK) with a cone weight of 102.3g and a 45° cone angle. Measurements were conducted on five individual fruit per replicate.

2.4. Statistical Analysis

The experiment was established as a 2-way factorial design with five replicates; there were six packaging treatments applied and four storage periods of 10, 20 and 30 days. A multiple comparison statistical procedure using Fisher's least significant difference (LSD) procedure using PC-SAS software [14] was used to determine the significance of the differences among various experimental treatments, and statistical significance levels were $P < 0.05$ unless otherwise stated.

Table 1. Some characteristics of tested packaging films, WVTR, OTR and CO_2TR.

Film Type	Property	Thickness (micron)	Water vapor transmission rate (g/m^2/24 h)	O_2 transmission rate (CC/m^2/24 h)	CO_2 transmission rate (CC/m^2/24 h)
Film 1 (F1) High Barrier	(320mm PA/PP 65my)	65	3.74	8.65	323.04
Film 2 (F2) Medium Barrier	(PETX/PP 62my AF 305mm)	62	3.86	8.90	299.99
Film 3 (F3) Low barrier laminated	(OPA/PP 65my 320mm)	65	6.39	50.37	288.87

AF = Anti Fog, My = Micron (thickness), Mm = Width mm, Pp = Polypropylene High Barrier, PET = polyethylene terephthalate, OPA = biaxally orientated polyamide, OPA/PP = Medium-barrier laminated film.

3. Results and Discussion

3.1. Moisture (Weight loss)

Weight loss of all treatments after 20 days of storage were not significant (>5% weight loss) (Figure 1). Slight increase in moisture content over 30 days' storage period was observed compared with 20 days for all treatment except control, which could be attributed to the initially low level of moisture and the high TSS content in date fruits that would bound water leaving very little if free water to be lost [9]. However, F3+Normal air dates lost weight due to their loss in moisture as they were packaged in low barrier laminated film allowing more moisture loss. Both MAP and Normal air treatments showed fluctuations in moisture loss, preventing water loss in some degree compared to control.

3.2 TSS

There was a combined effect of TSS and moisture content on a_w in fresh dates fruits, whereas TSS was positively related to fruit a_w and moisture content at harvest and during storage. Initial TSS for fresh "khenaizy" were 24.3ºBrix, with TSS increasing slowly after 10-day storage period to 36°Brix for control dates, almost doubled for F1+Normal air treatments. TSS was 28.8, 27.3, 29.9 for F1+MAP, F2+MAP and F3+MAP (20% CO_2 and balance nitrogen) respectively. Slow increases in control date fruit TSS may have been as a result of the fresh dates being stored at their optimum storage temperature of 1ºC [15] or due to the addition of altered gas atmospheres for MAP treated fruit [16]. An increase in TSS levels over time occurred through the alteration in date cell wall structure and breakdown of complex carbohydrates into simple sugars during storage [17, 18]. No significant changes in TSS for 20 and 30 days MAP treatments compared with control and F1+Normal air. Storage for 30 days showed low TSS less than 26 ºBrix for F2+Normal air and F2+MAP (Figure 2). Pareek [19] reported that TSS for each of the three main developmental stages of fresh dates with "Khalal" dates ranging between 30-45ºBrix, rutab dates between 55-60ºBrix and "Tamr" dates between 60-84ºBrix. In this study, only control and F1+Normal air TSS readings were within the "Khalal" Brix range after 30 days' storage.

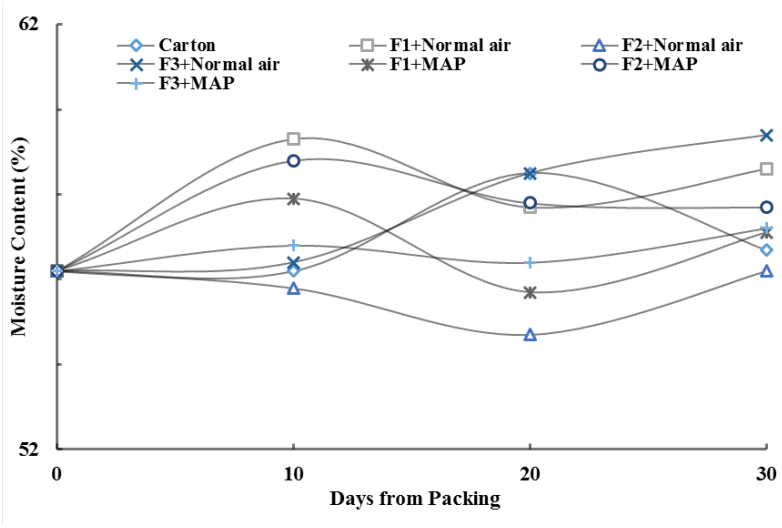

Figure 1. Effect of MAP on moisture changes in fresh "khenaizy" dates at Bisr ("Khalal") stage after 10, 20 and 30 days from storage at 1°C (Moisture LSD=2.02)

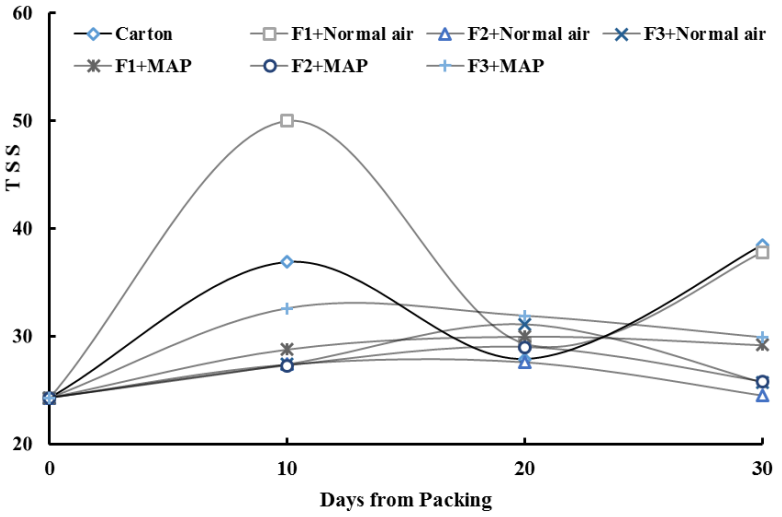

Figure 2. Effect of MAP on TSS changes in fresh "khenaizy" dates at Bisr ("Khalal") stage after 10, 20 and 30 days from storage at 1°C (TSS LSD= 3.8)

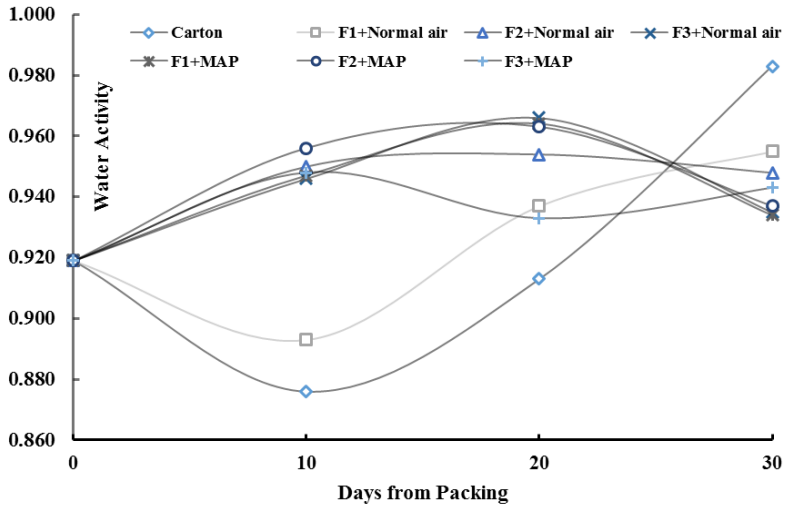

Figure 3. Effect of MAP on water activity changes in fresh "khenaizy" dates at Bisr ("Khalal") stage after 10, 20 and 30 days from storage at 1°C (water activity LSD=0.0002)

3.3. Water Activity

It is generally accepted that a_w is more closely related to physical, chemical and biological properties of foods and other natural products than to its total moisture content. Date fruits with reduced a_w displayed greater resistance against fruits deterioration [20]. Initial a_w recordings were 0.92, with a_w for "khenaizy" fresh dates slightly increasing for both MAP and Normal air treatments over 10-day storage period except control and F1+Normal air treatments. In general, a_w was slightly fluctuating in the range from 0.88 to 0.98 over 30 days' storage (Figure 3). Dehghan-Shoar et al [21] reported gradual increase in a_w during storage. There was a positive linear relationship between a_w and TSS (R^2 = 0.98) at all storage periods. The correlation of a_w to TSS is very good for MAP stored fresh dates, and this relationship seems to be influenced by moisture content.

3.4. Firmness

Firmness is a significant physical quality attribute of dates. The penetrant sinks more deeply into soft samples than hard samples. Therefore, higher penetration numbers are associated with softer samples. Lower penetration values indicate greater hardness of date flesh [22]. Loss of firmness after 10 and 20 days of storage was observed for "khenaizy" fresh dates packed for all treatments (Figure 4). Cardboard boxes and F2+MAP scored the lowest penetration values After 30 days storage; but this was most likely due to the fruit being firmer through dehydration and weight loss rather than the control packaging preserving the firmness from the initial fresh fruit. However, this progression in control fruit ripeness from "Rutab" to "Tamr" is not supported by the TSS readings. MAP treatments initially flushed with 20% CO_2 in N continued to record low penetration values at 30 days (Figure 4). Dates stored in F2+Normal air and F3+MAP showed significant retention of fruit firmness after 20 days of storage compared with other treatments; this may have been due to the changed atmospheric conditions slowing enzymatic reactions relating to softening [16,23]. Al-Shaibani [24] reported an increase in pectinesterase activity during the "Khalal" stage of date ripening which subsequently lead to the breakdown of pectin, or softening of fruit. Interestingly, fruit firmness displayed by the F2+MAP dates was considerably higher than control packaged dates, but unlike control dates, firmness was not caused by dehydration as MAP treatments displayed minimal weight loss over the 30 day storage period and looked full bodied, unlike the visually dehydrated control fruit. There was a positive effect of a_w and TSS on fruits firmness (R^2 = 0.98) at all storage periods. This might be due to the fact that TSS might cause a higher osmotic potential being able to demonstrate more flesh firmness. In common, the physical properties of fresh dates were distinctly influenced by moisture content, a_w and TSS.

Dates packaged in F3+Normal air and F3+MAP were notably softer than other treatments after 30 days storage suggesting an increase in pectinesterase. There may have been an increase in cellulase enzyme activity which can lead to the breakdown of insoluble cellulose into shorter chain substances causing textural changes to fruit [25]. Even though consumers may find these softer fruit desirables at later date ripening stages such as in the "Rutab" and "Tamr" stages, they would not be considered "crunchy" as expected from "Khalal" stage fruit and therefore would not be a suitable fruit quality.

3.5. Color

The CIE color coordinates (CIE L^*, a^* and b^* values) were determined. Total color difference (ΔE^*) which provides the value of the entire difference of the three coordinates (L^*, a^* and b^*) was also projected. Measurements were conducted on three replicates. Fresh "khenaizy" dates harvested and packed at the "Khalal" stage of maturity changed in color throughout storage (Table 1). The skin of "khenaizy" fresh dates is original red. Fruit was losing its bright redness increasingly turning to dark red brown color during storage (Table 2). At day 10, all treatments for "khenaizy" fruits had a significantly preserved its bright red appearance (Referred to high CIE L^* and b^* values). After 10 days storage, the degree of lightness, redness and yellowness was high on dates treated with F2+Normal air and F3+Normal air.

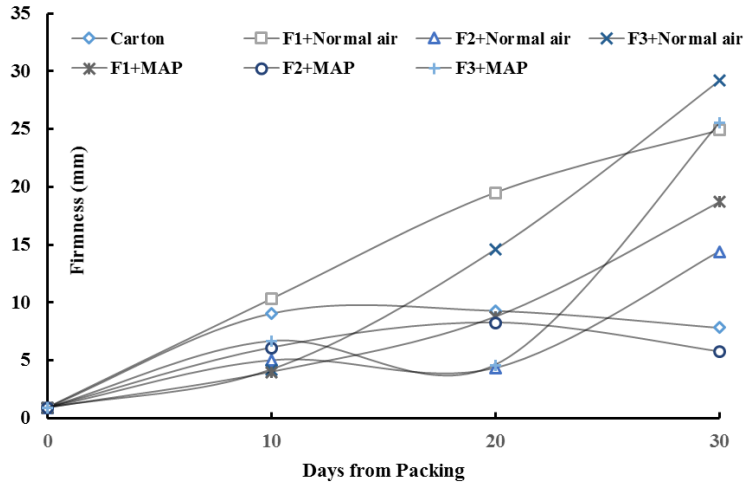

Figure 4. Effect of MAP on firmness changes in fresh "khenaizy" dates at Bisr stage after 10, 20 and 30 days from storage at 1°C (Firmness LSD=1.98)

Table 2. Effect of MAP on color changes in "khenaizy" fresh dates at "Khalal" stage after 10, 20 and 30 days from storage at 1°C*.

Treatments		CIELAB Color attributes**			
		Lightness (*L**)	Redness (*a**)	Yellowness (*b**)	Δ*E**
Initial (just before storage)		18.5	41.2	31.4	00.0
Storage period by MAP treatment interaction***					
10 days	Cardboard (control)	26.9 fg	37.9 d	36.9 gh	17.2 gh
	F1+ Normal air	35.9 e	32.5 e	43.2 de	37.9 c
	F2+ Normal air	53.3 a	49.7 a	51.3 ab	63.2 a
	F3+ Normal air	51.7 ab	47.7 ab	51.9 a	60.2 a
	F1+ MAP	39.1 d	28.6 fg	39.4 fg	41.2 c
	F2+ MAP	49.5 bc	44.8 bc	48.3 bc	51.5 b
	F3+ MAP	48.5 c	41.8 c	46.7 cd	45.9 b
20 days	Cardboard (control)	22.5 hi	44.5 c	38.7 fgh	14.6 h
	F1+ Normal air	19.1 jk	24.3 hi	27.1 j	21.8 fg
	F2+ Normal air	33.6 e	31.6 ef	43.2 de	36.5 de
	F3+ Normal air	21.4 ij	26.9 gh	35.4 h	21.2 g
	F1+ MAP	27.2 fg	30.2 ef	43.3 de	31.7 e
	F2+ MAP	29.1 f	30.8 ef	45.8 cd	35.4 de
	F3+ MAP	33.1 e	28.7 fg	46.1 cd	41.8 bc
30 days	Cardboard (control)	19.1 jk	43.9 c	31.4 i	3.2 i
	F1+ Normal air	15.8 l	26.2 ghi	26.7 j	22.4 fg
	F2+ Normal air	29.6 f	23.2 i	41.9 ef	36.9 d
	F3+ Normal air	16.7 kl	24.3 hi	16.9 k	33.2 de
	F1+ MAP	24.7 gh	24.4 hi	40.2 efg	31.8 e
	F2+ MAP	23.8 hi	42.7 c	39.8 efg	15.2 h
	F3+ MAP	23.8 hi	25.8 ghi	26.8 j	25.3 f
LSD (5%)		2.8	3.0	3.4	4.0

*All dates were assessed in air at room temperature.
***L** scale: Light vs. dark where a low number (0-50) indicates dark and a high number (51-100) indicates light; *a** scale: Red vs. green where a positive number indicates red and a negative number indicates green; *b** scale: Yellow vs. blue where a positive number indicates yellow and a negative number indicates blue; ΔE: indicates total color difference value. $\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$.
***Data are averages of replicates with different letters within the same storage period denoting significant differences at ($P \leq 0.05$) using a LSD test.

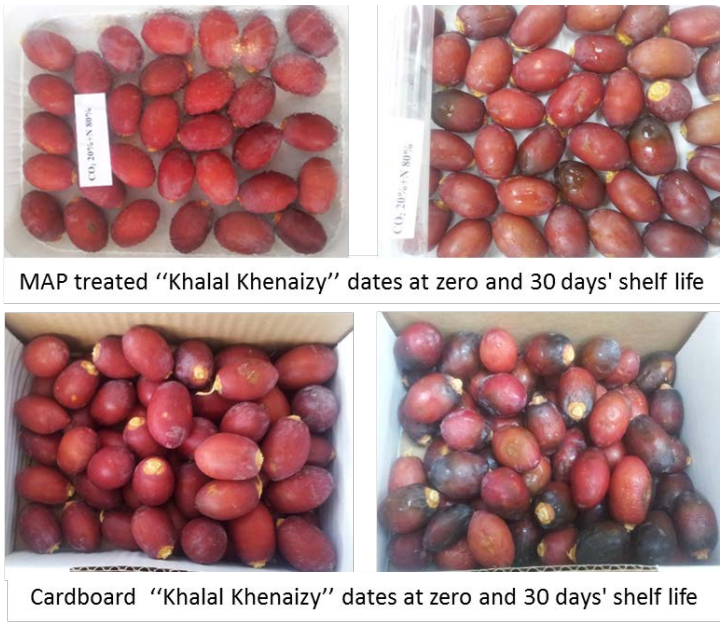

Figure 5. MAP treated fresh "khenaizy" dates at 30 days' of chilled storage (1°C)

After 20 days storage, lightness change was least on dates treated with F2+Normal air and F3+MAP , while *a** and *b** values had no significant differences for MAP treatments with a color appearance associated with dark red/brown color [26]. Finally, after 30 storage, all MAP and F2+Normal air treated dates had significantly higher *a** value than control dates, suggesting that by this time MAP dates were notably brighter in appearance than control dates. Control and F2+MAP dates stored for 30 days showed high *b** values indicating the possession of their originally red color compared to other treatments which show dark brown color. F2+MAP dates stored for 30 days significantly scored high *L**, *a** and *b** values indicating that the use of F2+MAP had some potential to reduce rate of color change of "khenaizy" fresh dates packed at the "Khalal" stage of maturity and stored at 0°C, representative of "Rutab" stage dates [26, 27].

Total color difference (ΔE^*) designates the magnitude of color difference between stored and control samples. As a result, the Initial (ΔE^*) value was (0.0) compared with stored treatments. Control date fruits sowed less variation in color differences (ΔE^* 17.2, 14.6 and 3.2) for 10, 20 and 30 day respectively (Table 2). The variation in ΔE^* values for MAP treatments was less compared with date fruits packed in air (ΔE^* 41.2-51.5, 31.7-41.8, and 15.2-31.8 respectively) among the 10, 20 and 30-day storage period as could be seen from Table (2). MAP treated fresh dates retained their initial "Khalal" red color longer than Air packaged fruit. Kader [28] reported packaging dates in nitrogen reduced darkening of dates. Similarly, Vandercook et al [29] found slow browning in fresh, oxygen depleted dates.

Retention of a greater amount of the oxygen for a greater period of time could have been achieved through the selection of more mature fruit (later in "Khalal" or early in the "Rutab" stage) or through the use of a more permeable film than the non-permeable film. When the initial atmosphere contained 20% carbon dioxide with the balance nitrogen, the lack of oxygen in the pack slowed the production and build-up of carbon dioxide due to anaerobic respiration during storage [22]. The use of MAP with F2 films had some potential to reduce rate of color change of "khenaizy" fresh dates packed at the "Khalal" stage of maturity stored for 30 days at 1°C. (Figure 5).

4. Conclusions

This study focussed on the important "khenaizy" date variety and looked at holding dates in the "Khalal" stage of development for an extended period of time using modified atmosphere packaging. "Khalal" stage dates placed into selectively permeable modified atmosphere packaging with CO_2 levels of 20% demonstrated reduced over ripening signs including "red" coloring retention compared with product stored in cardboard packaging.

Acknowledgments

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