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Effect of Different Drying Methods and Storage on Physico-chemical Properties, Capsaicinoid Content, Rehydration Ability, Color Parameters and Bioactive Compounds of Dried Red Jalapeno Pepper *(Capsicum annuum)* Slices

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ABSTRACT

Red Jalapeno pepper has been recognized as an excellent source of antioxidants, being rich in ascorbic acid and other phyto-chemicals. Drying conditions, particularly temperature, pretreatment and drying method leads to pepper modifications that can cause quality degradation. The present study aimed at the stability evaluation of the major capsaicinoid contents of the fresh and rehydrated red Jalapeno pepper slices after different drying methods and during storage for 12 months. For this purpose, freshly harvested red Jalapeno pepper slices were immediately dried by Refractance Window Drying (RWD_1 and RWD_2); Oven Drying (OD_1 and OD_2) and Sun Drying (SD_1 and SD_2) methods. Effects of these drying methods in terms of physico-chemical properties, rehydration ability, color parameters, ascorbic acid, total phenolic content and antioxidant activity of red Jalapeno pepper slices were also studyed. Four capsaicinoid analogues (capsaicin, dihydrocapsaicin, nordihydrocapsaicin and homocapsaicin) were identified in the tested samples. Pretreatments and different drying methods resulted in a 13.69% to 19.72% degradation of the initial capsaicinoid content. The proportion of capsaicin and dihydrocapsaicin almost (2:1) did not change during processing. During 12 months of storage at room temperature, further degradation of the pungent principles by 8.30% for blanched sample dried with RWD_2 method, and by 36.73% for unblanched sample dried with SD_1 was observed. On the other hand, the maximum Rehydration Ratio (RR) and Water Holding Capacity (WHC) values were 6.89 ± 0.337 g absorbed water/g d.m and 0.61 ± 0.023 g retained water/g water, respectively for the unblanched sample dried by RWD_1 method. Chromatic parameters (L^*, a^*, b^*, C^* and H^O), extractable color (ASTA) and Non-Enzymatic Browning index (NEB) were affected by drying methods and pretreatments, which contributed to the discoloring of the original red Jalapeno pepper color during this process. Moreover, the refractance window dried samples preserved the color with a value of 79.8% and 84.6% (ASTA) for the dried samples by RWD_1 and RWD_2 methods, respectively. Both Ascorbic Acid (AA) and Total Phenolic Contents (TPC) decreased during the six drying experiments, thus, a maximum loss of 89.3% AA in dried sample by SD_1 method was observed. In terms of drying method, the highest and lowest TPC contents were detected in the dried samples by RWD and SD methods, respectively. Furthermore, the RWD_2-dried samples showed better color parameters and the highest amounts of capsaicinoids, SHU, AA and TPC in comparison with the other drying methods after drying and during storage period.

Key words: Red pepper; Drying methods; Storage; Capsaicinoids; Pungency; Rehydration Ability Color Parameters; Bioactive compounds; Total phenolic and Ascorbic acid.

Introduction

Red peppers (*Capsicum annuum* L.) are one of the most important spices, widely cultivated and used all over the world. This crop is widely consumed as fresh vegetable or condiment and used for pharmaceutical and cosmetic purposes (Bosland, 2003). The amounts and characteristics of flavoring, coloring and especially pungent principles of *Capsicum* fruits are important quality parameters. Their strong pungency has been attributed to capsaicinoids, of which capsaicin and dihydrocapsaicin constitute more than 80% (Giuffrida *et al*., 2013; Vega-GaLvez *et al*., 2009). Their quantities vary

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with genotype and maturity and are influenced by growing conditions and losses after processing (Zewdie and Bosland, 2001). Several minor capsaicinoids and related compounds have also been Identified (Schweiggert *et al*., 2006; Thompson *et al*., 2005), but are present at very low levels and not expected to contribute greatly to overall pungency (Schweiggert *et al*., 2006a).

A part from their role as flavor ingredients, medical applications, from increasing appetite, relieving pain associated with arthritis, to diuretic effect, toxicological and repellent applications of these compounds have also been described (Reilly *et al.,* 2005). Capsaicinoids have also strong physiological and pharmacological properties, which may be used in treating sensory nerve fiber disorders, including cystitis, and human immune-deficiency virus, among others (Robbins, 2000; Tsuchiya, 2001). Although their using at low levels in the diet, they decrease the myocardial and aortic cholesterol levels. It was also reported that they have an antioxidant and antibacterial effects on certain group of bacteria (Deepa *et al*., 2007; Loizzo *et al*., 2013).

Furthermore, red pepper is an excellent source of ascorbic acid (Guil-Guerrero *et al*., 2006; Topuz and Ozdemir, 2007) and polyphenols, particularly flavonoids, quercetin and luteolin (Chuah *et al*., 2008; Materska and Perucka, 2005). Thus, all the mentioned compounds show antioxidant activity as potential action against certain cancers, stimulate the immune system, prevent cardiovascular diseases and delay the aging process, amongst other biological activities (Chuah *et al*., 2008; Podsedek, 2007).

Capsaicinoids are synthesized and accumulated in the epidermal tissue of the placenta (Topuz *et al*., 2011). Capsaicin production increases with maturity until a maximum is reached, and then decreases through a rapid turnover and degradation up to 60% (Yaldiz *et al.*, 2010), due to photooxidation or oxidizing enzymes. A recent study has shown that capsaicin and dihydrocapsaicin diminish after cellular disruption of the fruits, which is apparently due to temperature-dependent oxidation (Reyes-Escogido *et al.,* 2011).

The degree of pungency is another quality parameter of hot red pepper and very important for consumers and for industrial purposes, since a defined value is required to be employed as ingredient for food production. The pungency is considered subjective, and an universal scale has been built by the American Spice Trade Association (ASTA) based on ppm of capsaicinoids, instead than on human perception as it was in the past by the Scoville Organoleptic Test. The degree of pungency expressed by ASTA units is a measure directly related to capsaicinoids amounts and can be easily converted approximately to the more common Scoville Units by multiplying the amount of each capsaicinoid expressed in ppm by a calculated conversion factor (Ziino *et al.* 2009). The occurrence of capsaicinoids in berries is highly variable, and strongly depends on the cultivar, but also on many parameters such as ripening stage, season and irrigation (Giuffrida *et al.*, 2013; Reyes-Escogido *et al.*, 2011).

Dehydration is one of the most widely used methods for fruits and vegetables preservation. Its main objective is the removal of water to the level at which microbial spoilage and deterioration reactions are minimized. However, it is well known that during drying, vegetables undergo physical, structural, chemical and nutritional changes that can affect quality attributes like texture, color and nutritional value (Di Scala and Crapiste, 2008). Dehydrated pepper has commonly been obtained by hot air drying (oven drying), which allows rapid and massive processing, although the maintenance of nutritional and commercial quality of this pepper through the process has presented some serious problems in the past. Some studies cited in the literature have addressed the influence of drying conditions on the quality characteristics of the dehydrated product (Simal *et al*., 2005). Conventional drying of pepper causes a major loss of color quality of the final product. Undesirable changes in the color may lead to a decrease in its quality and marketing value, therefore, the surface color of the pepper is an important criterion (Vega-GáLvez *et al*., 2008a).

Amongst others, the acceptability of dried products depends mainly on their structural properties. Destruction of the cellular system is one of the most important physical and structural changes that occur during drying (Yadollahinia *et al*., 2009). Moreover, dehydrated pepper must be rehydrated for consumption of prepared foods like soups, sauces, pizzas and other foodstuffs. Rehydration behavior has been considered as a measure of the induced damage in the material during drying, such as integrity loss and reduction of hydrophilic properties, which decrease the rehydration ability (Marques *et al*., 2009). Theoretically, if there are no adverse effects on the integrity of the tissue structure, it should absorb water to the same moisture content as the initial product before drying

(Scala and Crapiste, 2008; Soysal *et al*., 2009). Rapid and complete rehydration is very important for dried products. Rehydration capacity is affected significantly by drying conditions, pretreatments prior to drying and textural characteristics of dried products. Likewise, drying can diminish the osmotic properties of cell walls; as a result, an increase in water absorption and volume occurs due to the swelling of hydrophilic materials such as starch, cellulose, and pectic materials (Nasıroglu and Kocabıyık, 2009).

Traditional drying methods (sun drying) are known to be associated with microbial proliferation and quality deterioration in red pepper (Condori *et al*., 2001). It is a lengthy process, taking up to 4-10 days to bring moisture content to 9.9 % (wet basis) (Oberoi *et al*., 2005). Since paprika is susceptible to fungal proliferation, this process creates favourable conditions for mycotoxins contaminations. In order to prevent fungal proliferation and improve the quality of paprika, different drying methods have been employed. There is always a tendency towards the use of improved drying methods which require low energy, and are more rapid, uniform and hygienic. Besides, the increasing demand for high-quality shelf-stable dried products requires the optimization of the drying process conditions, especially temperature, with the purpose of accomplishing not only the efficiency of the process but also the final quality of the dried product (Di Scala and Crapiste, 2008).

Refractance Window™ Drying (RWD) is a new technique of drying method featured by a relatively short processing time, low energy cost, and improved product quality (Nindo *et al*., 2006). It utilises circulating water at 95–97 °C under atmospheric pressure to provide thermal energy via a transparent plastic film to a layer of wet product on the film. It has been suggested that the water bearing product on the transparent plastic belt creates a ‘‘ window ’’ allowing infra-red radiation passing from hot water through the belt to reach the food. As the product loses its moisture through evaporation, the ‘‘window’’ slowly closes, leaving mainly conducted heat to finish the drying process. This reduced heat transfer in the final stage of the drying helps to prevent quality degradation of the product (Abonyi *et al*., 2002). Since the RWD is a relatively new technology, there are only a few publications reported its effect on the quality characteristics of dried products (Topuz *et al*., 2009; Cadwallader *et al*., 2009).

Therefore, the present study aimed at the stability evaluation of the major capsaicinoid contents of the rehydrated red Jalapeno pepper slices after different drying methods and during storage for 12 months in detail. Furthermore, the Refractance Window Drying (RWD_1 and RWD_2), Oven Drying (OD_1 and OD_2) and Sun Drying (SD_1 and SD_2) methods were used to dry red Jalapeno pepper slices. Effects of these drying methods in terms of physico-chemical properties, rehydration ability (Rehydration Ratio (RR) and Water Holding Capacity (WHC)), color parameters, Ascorbic Acid (AA), Total Phenolic Content (TPC) and antioxidant activity of red Jalapeno pepper slices were also studied.

Materials and Methods

Materials:

1. Samples:

Freshly harvested red Jalapeno pepper (*Capsicum annuum* L.) was from organic production in El-Khatatba, Egypt and stored at 4±2°C before processing for a maximum time period of three days. The samples were selected visually by color, size and freshness, and with no sign of mechanical damage.

2. Chemicals (Reagents):

All reagents and solvents used were purchased from Merck (Germany) and were of analytical or HPLC grade. Capsaicin and dihydrocapsaicin were obtained from Extra- synthese (Lyon, France). Hydrochloric acid, *ortho*-phosphoric acid, ascorbic acid, gallic acid, 2,6-dichlorophenol indophenols, Folin–Ciocalteu’s phenol reagent, 6-hydroxy-2,5,7,8-tetra methylchroman-2-carboxylic acid and 2,2,-diphenyl-2-picryl-hydrazyl (DPPH) were obtained from Sigma–Aldrich, Inc. (Louis, USA) and Fisher Chemicals (Pittsburgh, PA, USA).

Methods:

1. Production of Dried Red Jalapeno Slices:

1.1. Preparation of Samples:

Briefly, the fresh red Jalapeno pods were stored at 4 ± 2 °C and immediately analyzed for physico-chemical and qualitie parameters. The fresh red Jalapeno pods were washed with water, de-stemmed and cut into slices of approximately 6.0±1.0 mm thickness with a slicing machine (type K20, Seydelmann, Germany). The fresh red Jalapeno slices were separated into three groups for the drying tests. Samples from each group were subdivided into two. The first half was pretreated with submerging for 10 min at 25 °C in an aqueous solution of 15% (w/w) NaCl, 1.0% (w/w) $CaCl_2$ and 0.3% (w/w) $Na_2S_2O_5$ (treatment No.1: unblanched sample) before drying and the other half was blanched in hot water at 85 °C for 4 min and pretreated with the same solution at the same conditions (treatment No.2: blanched sample) before drying with three different methods.

1.2. Drying Methods of the Pepper Slices:

The pretreated red Jalapeno slices (treatments No.1 and 2) were dried by three different methods as follows:

1.2.1. Refractance Window™ Drying (RWD):

A pilot scale Refractance Window Dryer (RWD) with an effective length of 2.85 m was used, and the conveyor belt velocity was in the range of 0.25–0.30 m/min. Twenty kilograms of pretreated red Jalapeno slices for each treatment (unblanched (RWD_1) and blanched (RWD_2) samples as described above) were distributed uniformly as a layer on the conveyor belt of the dryer (MCD Technologies, Tacoma, WA, USA) and the plastic belt was moved over hot water of about 95 °C to dry the slices. The pretreated samples thickness on the belt was about 2.0 cm (A load density of pretreated sample about 7.0±0.5 kg m^{-2} was used). The pretreated samples (RWD_1 and RWD_2) were dried to constant weight. The drying process for each run was completed in 9.5 – 11.5 min (Topuz *et al*., 2011).

1.2.2. Oven Drying (OD):

Ten kilograms of pretreated red Jalapeno slices for each treatment (unblanched (OD_1) and blanched (OD_2) samples as described above) were distributed uniformly as a layer onto the stainless steel trays of size 40 x 50 cm and dried in an oven (Nuve FN055 Seydelmann, Germany, 100 L volume) at 60 °C. The pretreated samples (OD_1 and OD_2) were dried to constant weight. The drying process for this method was carried out in 10-12 h (Arslan and **Ö**zcan, 2011).

1.2.3. Sun Drying (SD):

Ten kilograms of pretreated red Jalapeno slices for each treatment (unblanched (SD_1) and blanched (SD_2) samples as described above) were distributed uniformly as a layer onto the stainless steel trays of size 40 x 50 cm and dried under direct sunlight at temperatures between 30 and 45°C in August. The pretreated samples (SD_1 and SOD_2) were dried to constant weight. The drying process for this method was carried out in 4-5 days (Arslan and Özcan, 2011).

2. Storage of Dried Red Jalapeno Slices:

After drying, all products (aliquots of 250 g of the dried red Jalapeno slices) were packed in polyethylene (PET) bags under reduced pressure and stored at room temperature for 12 month. On each sampling date 150–200 g were taken for analysis.

3. Analytical Methods:

3.1. Physico-chemical Analysis:

The crude protein content was determined using the Kjeldahl method with a conversion factor of 6.25 (AOAC No. 960.52). The lipid content was analysed gravimetrically following Soxhlet extraction (AOAC No. 960.39). The crude fibre was estimated by acid/alkaline hydrolysis of insoluble residues (AOAC No. 962.09). The crude ash content was estimated by incineration in a muffle furnace at 550 °C (AOAC No. 923.03). The available carbohydrate was estimated by difference. The equilibrium moisture content was determined by means of AOAC method No. 934.06. All methodologies followed the recommendations of the Association of Official Analytical Chemists (AOAC, 2000). The pH was measured using an EXTECH Instruments microcomputer pH-vision 246072 (Waltham, Massachusetts, USA) and the level of titratable acidity was expressed as malic acid. The water activity (a_w) was measured at 25 °C by means of a water activity instrument (Novasina, model TH-500, Pfaffikon, Lachen, Switzerland). Soluble solids were measured using a refractometer (ABBE, 1T, Tokio, Japan) which measures refraction indices both of solid and liquid samples in a fast and accurate way and its scale ranges from 0.0 to 95 °Brix. All measurements were done in triplicate.

3.2. Determination of Capsaicinoid:

Capsaicinoids were extracted from the samples of fresh and dried red Jalapeno slices by applying the technique described by a previous study (Topuz *et al.,* 2011). The capsaicinoids were extracted from 0.5 g of red Jalapeno pepper in 8 ml acetonitrile by heating at 80 °C for 4 h. The suspensions were periodically shaken every 30 min throughout the extraction process. The suspended material was allowed to cool and settle.The supernatant was filtered into a 2 ml glass vial using a 0.45 µm membrane filter (Millipore) and used for HPLC injections.

Liquid chromatography was performed using a pump unit (Hitachi L 6200 A) solvent equipped with an autosampler (Hitachi AS 2000), a fluorescence detector (Hitachi FL) and an integrator (HP 3393 A). The separation was performed on a column (Phenomenex ODS, 5 µm, 250 x 4.6 mm i.d.) at room temperature.

The following HPLC operating conditions, used by Schweiggert *et al.* (2006a), were employed. The eluent was a mixture of acetonitrile/water/acetic acid (100:100:1) at a flow rate of 1.2 ml/min. Total run time was 35 min. The injection volume was 10 µL. All capsaicinoids were monitored at 280 nm at a flow rate of 0.4 mL/min. Additionally, UV/Vis spectra were recorded in the range of 200–600 nm at a spectral acquisition rate of 1.25 scans/s (peak width 0.2 min).

3.3. Quantification of Individual Compounds:

Individual capsaicinoids were identified and quantified using calibration curves of the corresponding standard compounds of capsaicin (98%), dihydrocapsaicin (90%) and a mixture of capsaicinoids (60% capsaicin). Since nordihydrocapsaicin and homocapsaicin were not available as a reference substance, the calibration of the structurally related dihydrocapsaicin was used with a molecular weight correction factor. All determinations were performed in triplicate. Total amounts of capsaicinoids were calculated as the sum of nordihydrocapsaicin, capsaicin, dihydrocapsaicin and homocapsaicin.

3.4. Determination of Pungency:

Scoville Heat Unit (SHU) of samples was calculated by the method of Ziino *et al.* (2009). The method involved multiplication of each capsaicinoid concentration, determined by HPLC, by their individual dilution factors of burning sensation. Additionally, the SHU calculation was made for isodihydrocapsaicin as equivalent of homodihydrocapsaicin (homocapsaicin).

3.4. Rehydration Analysis:

The dried red Jalapeno slices were placed in distilled water at 40 °C for 6 h, using a solid to liquid ratio of 1:50. The samples were then removed, drained for 30 s, and weighed. All measures were done in triplicate. The Rehydration Ratio (RR) was calculated according to Eq. (1) and expressed as grams of water absorbed per gram dry matter. The Water Holding Capacity (WHC) was determined by centrifuging the rehydrated samples at 3500×g for 15 min at 20 °C in tubes fitted with a centrally placed plastic mesh which allowed water to drain freely from the sample during centrifugation. The WHC was calculated from the amount of water removed following Eq. (2), according to Vega-Gálvez *et al.* (2008b):

$$\text{RR} = \frac{W_{reh} * X_{reh} - W_{dried} * X_{dreid}}{W_{dried} * (1 - X_{dried})} \quad \ldots\ldots (1)$$

$$\text{WHC} = \frac{W_{reh} * X_{reh} - W_l}{W_{reh} * X_{reh}} \times 100 \quad \ldots\ldots (2)$$

where W_{reh} is the weight of the sample after the rehydration process, X_{reh} is the corresponding moisture content on a wet basis, W_{dried} is the weight of the sample after the drying process, X_{dreid} is the corresponding moisture content on a wet matter and W_l is the weight of the drained liquid after centrifugation.

4. Color Parameters:

4.1. Surface Color Measurement:

Surface color of the rehydrated dried red Jalapeno slices was measured using a colorimeter (Hunter Lab, model MiniScan™ XE Plus, Reston, VA, USA). Colour was expressed in CIE L^* (brightness), a^* (redness) and b^* (yellowness) coordinates, standard illuminant D_{65} and observer 10° (Vega-Gálvez *et al.,* 2008b; Ashour *et al.*, 2014). Five replicate measurements were performed and results were averaged. In addition, color intensity (Chroma), total color difference *(ΔE)* and Hue angle were calculated using the following Eqs. (3) – (5), where: L_o, a_o and b_o are the control values for peppers (Sigge *et al.*, 2001).

$$\text{Chroma } (C^*) = (a^{*2} + b^{*2})^{0.5} \quad \ldots\ldots (3)$$

$$\Delta E = [(a^* - a_0)^2 + (b^* - b_0)^2 + (L^* - L_0)^2]^{0.5} \quad \ldots\ldots (4)$$

$$\text{Hue angle } (H^O) = tg^{-1}(b^*/a^*) \quad \ldots\ldots (5)$$

4.2. Extractable Color (ASTA):

The determination was carried out according to the methodology proposed by the American Spice Trade Association (ASTA, 1995). Rehydrated sample (5.0 g) was kept in about 100 ml acetone in 250 ml screw-cap jars maintained in the dark for 16 h at ambient temperature. An aliquot of this solution was used for the spectrophotometric measurement (*Spectronic*® 20 Genesys™, Illinois, USA) at 460 nm. ASTA units were calculated as follows:

$$\text{Color value } (Cv) = \frac{A * 16.4 * I_f}{W_{reh}} \quad \ldots\ldots (6)$$

where A is the absorbance of the acetone extract; I_f is the instrument correction factor calculated from a pattern solution of potassium dichromate and W_{reh} is the sample weight. The color loss value (%) was calculated according to the following equation:

$$(\%) \text{ Color loss value} = \frac{Cv_o - Cv_T}{Cv_o} \text{ X } 100 \quad \ldots\ldots (7)$$

Cv_o is the ASTA color value of the fresh pepper and Cv_T is the ASTA color value of the rehydrated peppers dried with different drying methods.

4.3. Determination of Non-enzymatic Browning (NEB):

The methodology applied for determination of non-enzymatic browning compounds (NEB) solubilized in the rehydration water was that proposed by El-Hamzy and El-kholan (2014). The rehydration water was first clarified by centrifugation at 3200xg for 10 min. The supernatant was diluted with an equal volume of ethanol (Sigma Chemical CO., St. Louis, MO, USA) at 95% and centrifuged again at 3200xg for 10 min. The browning index (absorbance at 420 nm) of the clear extracts was determined in quartz cuvettes using a spectrophotometer ($Spectronic$ ® 20 $Genesys^{TM}$, Illinois, USA).

5. Bioactive Compounds:

5.1. Determination of Ascorbic Acid (AA):

Ascorbic Acid (AA) was determined based upon the quantitative discoloration of 2,6-dichlorophenol indophenol titrimetric method as described in AOAC methodology No. 967.21 (AOAC, 2000). Comparative evaluations of Ascorbic acid stability in fresh and rehydrated pepper slices (dried by different methods) were carried out, where 5.0 ± 0.1 g of each sample was weighied, crushed and diluted in 1 L distilled water. The Ascorbic acid content was expressed as mg AA retained/100 g dry matter.

5.2. Determination of Total Phenolic Content (TPC):

Total Phenolic Content (TPC) was estimated as Gallic Acid Equivalents (GAE) as described by Folin–Ciocalteau's (FC) method with modifications (Ashour and Shaaban, 2014). An aliquot (0.5 ml) of the pepper extract solution is transferred to a glass tube; 0.5 ml of reactive FC is added after 5 min; 2 ml of Na_2CO_3 (200 g/l) are added and shaken. After 15 min of incubation at ambient temperature, 10 ml of ultra-pure water was added and the formed precipitate was removed by centrifugation during 5 min at 4000xg. Finally, the absorbance was measured in an spectrophotometer ($Spectronic$® 20 $Genesys^{TM}$, Illinois, USA) at 725 nm and compared to a GA calibration curve. Results were expressed as mg gallic acid/100 g dry matter.

6. Evaluation of Antioxidant Activity:

6.1. Extraction for Antioxidant Measurements:

Methanolic extracts were prepared as reported previously by Luthria *et al.* (2006). Approximately 400±1mg of ground dried pepper sample was placed in a 15mL centrifuge tube with 5 mL of the solvent mixture MeOH:H_2O (80:20, % v/v). The vials were then placed in a sonicator bath at ambient temperature for 30 min. The mixture was centrifuged and the supernatant was transferred into a 10 mL volumetric flask. The residue was resuspended in 5mL of MeOH:H_2O (80:20, %v/v), gently mixed manually and sonicated for an additional 30 min followed by centrifugation. The supernatant was combined with the initial extract and the volume of combined supernatant was made up to 10 mL with the extraction solvent and appropriate aliquots of extracts were filtered and assayed for antioxidant activity. For each sample, triplicate extractions and analyses were carried out.

6.2. DPPH Radical Scavenging Activity:

Antioxidant activity was evaluated by measuring the radical scavenging effect of dried peppers methanolic extracts towards the 2,2-diphenyl-1-picrylhydracyl ($DPPH^{\bullet}$) as reported previously by Bamdad *et al.* (2006) and El-Hamzy *et al*. (2013). Five mL of a 0.1 mM methanol solution of DPPH were added to 0.1 mL of several concentrations of methanol extracts of fresh and dried pepper samples. The tubes were allowed to stand at 27 °C for 20 min. The decrease in absorbance at 517 nm was recorded in a spectrophotometer (Shimadzu UV–vis mini spectrophotometer 1240). Radical

scavenging activity was expressed as inhibition percentage and was calculated using the following formula:

(%) Radical scavenging activity = $[\ 1 - \frac{Abs_{sample}}{Abs_{control}}\ ] \times 100$…….. (8)

6.3. Total Antioxidant Activity Assay:

Total antioxidant activity was determined using the ABTS method adapted from Miller and Rice-Evans (1997). Decolorization of the $ABTS^{\bullet+}$ radical cation by sample extract was measured at 734 nm in relation to a Trolox® (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) standard. Results were expressed as Trolox® equivalent antioxidant capacity (µmol TEAC/100 g DM).

7. Statistical Analysis:

The effect of different drying methods and storage on each quality parameter was estimated using Sigma-Plus 13 (Statistical Graphics Corp., Herndon, VA, USA). The results were analyzed by an analysis of variance (ANOVA). Differences amongst the media were analyzed using the least significant difference (LSD) test with a significance level of $\alpha = 0.05$ and a confidence interval of 95% ($p < 0.05$). In addition, the multiple range test (MRT) included in the statistical program was used to demonstrate the existence of homogeneous groups within each of the parameters.

Results and Discussion

1. Effect of Different Drying Methods on Physico-chemical Properties:

Proximate analysis of red Jalapeno pepper (on 100 g of fresh weight) presented an initial moisture content of 89.11 ± 1.23 g; crude protein of 1.34 ± 0.19 g; total lipids of 0.59 ± 0.09 g; crude fiber of 1.16 ± 0.18; crude ash of 2.14 ± 0.10 g and available carbohydrates (by difference) of 4.91 ± 0.22 g.

Table 1 shows the mean values and standard deviations of the moisture content (g water/100g d.m), soluble solids (°Brix), pH, acidity (%) and water activity of both fresh and dry-rehydrated red Jalapeno pepper slices. Significant differences were found between different drying methods and the properties mentioned ($p < 0.05$). A maximum value of moisture content of 10.75 ± 0.18 g water/100 g dry matter (d.m) was observed in red Jalapeno pepper slices dried by SD_1 method; however, samples with lower moisture contents were obtained in red Jalapeno pepper slices dried by OD_2, RWD_2 and OD_1 methods, respectively. Soluble solids and acidity (%) exhibited a decreasing tendency in all the different drying methods respect to the fresh sample. In the same table, pH increased slightly from its original value, showing the same tendency of acidity. Values of water activity, which is an indicator of water availability, were high for all the samples, as expected for rehydrated samples. Similar results were found by Miranda *et al* (2009a), working with dehydrated hot pepper.

Table 1: Effect of different drying methods on physico-chemical properties of fresh and dry-rehydrated red Jalapeno pepper slices.

Drying Method	Moisture Content (g water/100g d.m)	Soluble Solids (°Brix)	pH	Total Acidity (%)	Water Activity (a_w)
Fresh	----	11.18 ± 0.19^{a}	4.66 ± 0.08^{a}	0.361 ± 0.011^{a}	0.971 ± 0.003
RWD_1	9.20 ± 0.11^{c}	$3.19 \pm 0.41^{b,c}$	4.97 ± 0.06^{b}	0.140 ± 0.010^{b}	0.981 ± 0.002
RWD_2	$8.87 \pm 0.24^{c,d}$	4.41 ± 0.22^{b}	5.20 ± 0.04^{c}	0.125 ± 0.014^{c}	0.977 ± 0.002
OD_1	$8.92 \pm 0.43^{c,d}$	2.59 ± 0.28^{c}	5.22 ± 0.11^{d}	0.121 ± 0.015^{d}	0.984 ± 0.004
OD_2	8.59 ± 0.15^{d}	$3.39 \pm 0.34^{b,c}$	5.24 ± 0.10^{d}	0.118 ± 0.016^{d}	0.979 ± 0.002
SD_1	10.75 ± 0.18^{a}	2.98 ± 0.44^{c}	5.04 ± 0.06^{b}	0.136 ± 0.018^{b}	0.979 ± 0.003
SD_2	9.88 ± 0.12^{b}	3.78 ± 0.16^{b}	5.18 ± 0.06^{c}	0.129 ± 0.012^{c}	0.976 ± 0.001

Different letters in the same column indicate that the values are significantly different ($p < 0.05$).

2. Effect of Different Drying Methods on Capsaicinoid Contents and Pungency:

2.1. Effect of Different Drying Methods on Capsaicinoid Contents:

The HPLC separation of the four major capsaicinoids (capsaicin, dihydrocapsaicin, nordihydrocapsaicin and homocapsaicin) extracted from fresh red Jalapeno pods is presented in Fig 1. The studies had demonstrated that the capsaicinoid profile of red Jalapeno pods is considerably more complex than considered so far (Schweiggert *et al.,* 2006b). However, since the minor capsaicinoids are present at very low levels and are not expected to contribute greatly to overall pungency, only the predominant compounds listed above were quantified. Previous reports on the HPLC determination of capsaicinoids demonstrated high relative standard deviations in pepper fruits, due to the large variation of the pungent principles in the raw material even of the same variety (Minami *et al.*, 1998). Therefore, Kirschbaum-Titze *et al.* (2002b) suggested that a minimum of 5 fruits should be used for capsaicin analysis based on a coefficient of variation of 6 %. In the present study, the amount of fresh red Jalapeno pods used and the replication of sample preparation in triplicate ensured sufficient product homogeneity, which was reflected by coefficients of variation below 6% for all samples analyzed.

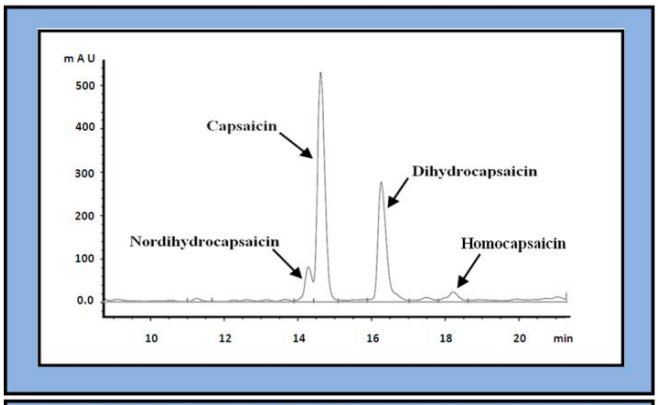

Fig (1): HPLC Separation of the major capsaicinoids extracted from the red Jalapeno pods (Detection at 280 nm).

In this study, the capsaicinoid contents of the samples were analyzed to determine their stability during drying, as shown in (Table 2 and Fig. 2). The total capsaicinoid content of fresh red Jalapeno slices was 326.6 mg/100g (dry matter), which included capsaicin (60.6%), dihydrocapsaicin (31.3%), and nordihydrocapsaicin (6.0%), and homocapsaicin (2.1%). It can be seen that capsaicin and dihydrocapsaicin are the major capsaicinoids. The ratio of (capsaicin + dihydrocapsaicin) to the total capsaicinoids was 91.9% in the red Jalapeno pepper. These results agree with those of previous studies on mature fruits of *C. annuum* varieties (Topuz and Özdemir, 2007; Ziino *et al*., 2009). The capsaicinoid concentrations of the red Jalapeno slices were decreased by 13.69 to 19.72% after drying processes irrespective of the drying method. Similar results could be observed in other studies describing losses of 14.1–25.7% during blanching and drying (Orak and Demirci, 2005; Topuz and Özdemir, 2004). Susceptibility of the Four major capsaicinoids to different drying methods were similar, with capsaicin, dihydrocapsaicin, nordihydrocapsaicin and homocapsaicin decreasing on average by 13.7%, 14.0%, 15.3% and 4,4%, respectively, when the samples were dried with RWD_2 method, and by 18.7%, 21.2%, 20.9%% and 20.3%, respectively, when the samples were dried with SD_1 method. The proportion of capsaicin and dihydrocapsaicin almost (2:1) were did not change during processing, which was also observed by Topuz and Özdemir (2004).

The concentration of the individual capsaicinoid analogues were all significantly changed ($p < 0.05$) by the different drying processes (Fig. 2 and Table 2). The samples from the RWD_2 and OD_2 methods had the highest concentrations for every capsaicinoid analogue in dry basis as well as the samples from the SD_1 and OD_1 methods had the lowest concentrations for every capsaicinoid analogue in dry basis. Considering the unblanched red Jalapeno slices before drying by the RWD_1, OD_1, and SD_1 methods, the lower capsaicinoids amount in these samples may be caused by the

catalytic activity of oxidising enzymes on capsaicinoids, especially peroxidase. Contreras-Padilla and Yahia (1998) reported that peroxidase was more active at low capsaicinoids concentrations in red pepper and this may indicate that capsaicinoids degradation is aided by the catalytic activity of peroxidase.

Table 2: Relative capsaicinoid contents of the fresh and dried red Jalapeno slices obtained by different drying methods.

Dying Method	Capsaicinoids (mg/100g d.m)	Capsaicin		Dihydrocapsaicin		Nordihydrocapsaicin		Homocapsaicin	
		(mg/100g d.m)	%	(mg/100g d.m)	%	(mg/100g d.m)	%	(mg/100g d.m)	%
Fresh	326.6	197.8 ± 2.81[a]	60.6	102.2 ± 1.55[a]	31.3	19.6 ± 3.11[a]	6.0	6.9 ± 3.11[a]	2.1
RWD_1	272.7	166.8 ± 4.22[b]	61.2	83.6 ± 5.04[c]	30.7	16.1 ± 4.86[c]	5.9	6.2 ± 4.86[c]	2.3
RWD_2	281.9	170.8 ± 2.19[b]	60.6	87.9 ± 2.33[b]	31.3	16.6 ± 2.14[b]	5.9	6.6 ± 2.14[b]	2.4
OD_1	269.9	165.3 ± 4.78[c]	61.2	82.8 ± 6.11[c]	30.7	16.0 ± 4.58[c]	5.9	5.8 ± 4.58[d]	2.2
OD_2	277.1	168.1 ± 2.88[b]	60.6	86.6 ± 3.46[b]	31.3	16.4 ± 3.75[b]	5.9	6.2 ± 3.75[c]	2.2
SD_1	262.2	160.7 ± 5.76[d]	61.2	80.5 ± 8.66[d]	30.7	15.5 ± 4.78[d]	5.9	5.5 ± 4.78[d]	2.1
SD_2	271.2	164.3 ± 2.89[c]	60.6	84.8 ± 5.77[c]	31.3	15.9 ± 2.96[c]	5.9	6.2 ± 2.96[c]	2.2

Different letters in the same column indicate that the values are significantly different ($p < 0.05$).

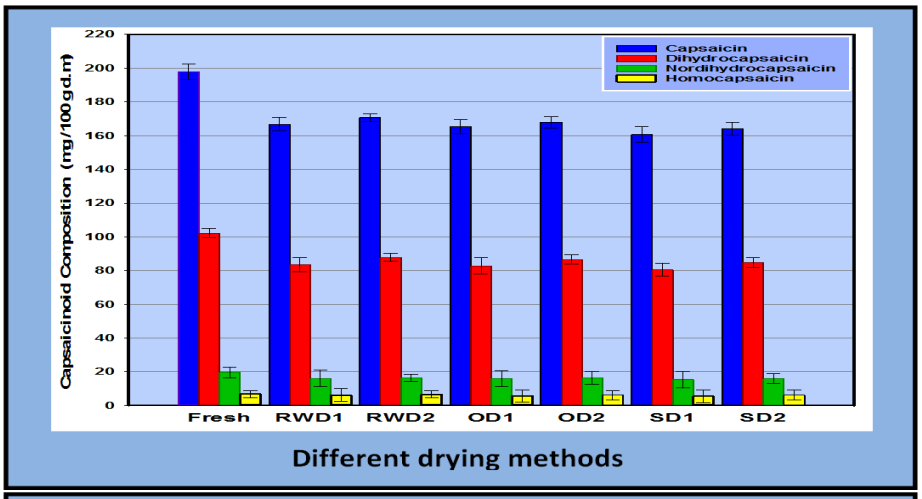

Fig (2): Capsaicinoid contents of the red Jalapeno slices obtained by different drying methods.

All the drying processes did not differ in their residual capsaicinoid concentrations of red Jalapeno slices. The proportion of (capsaicin + dihydrocapsaicin) in all the dried red Jalapeno slices to the total capsaicinoids (91.9 - 92.0%) remained almost unchanged by the drying processes.

2.2. Effect of Different Drying Methods on Pungency:

It is well known that the capsaicinoid analogues are responsible for the pungency of red Jalapeno pepper. In order to determine the pungency of *Capsicum* powders, several methods were developed over the years using a dilution factor of each of the capsaicinoids analogues for minimum perceivable burning sensation, which was termed as Scoville Heat Unit (SHU) (Ziino *et al.,* 2009).

In this study, the SHU of the samples was calculated from the capsaicinoids data to examine the effect of the drying methods on the pungency level of red Jalapeno slices, as shown in Fig (3). Among the drying methods, the SD_2 and SD_1 samples possessed the lowest SHU values. In comparison, the RWD_2 and RWD_1 samples had the highest SHU values, followed by that of OD_2 and OD_1 samples. The SHU results are more or less correlated with the capsaicinoids results. The relatively low SHU values of the SD_2 and SD_1 samples may be caused by a removal of the DHC (Dihydrocapsaicin) and NDHC (Nordihydrocapsaicin) analogues from the red Jalapeno slices during the drying processes (Fig. 3).

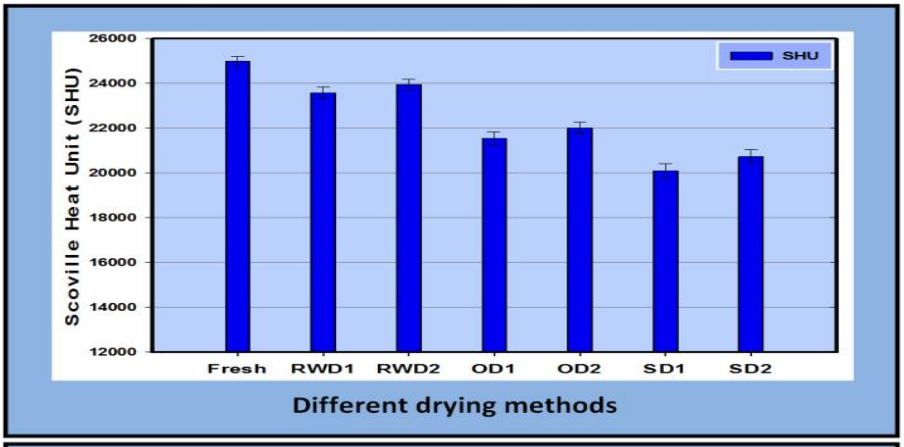

Fig (3): Effect of different drying methods of the red Jalapeno slices on the pungency.

2.3. Effect of Storage on Capsaicinoid Contents and Pungency:

Since rehydration during storage may result in enzyme regeneration, permeability of the packaging material was assessed by determination of the water content of the dried red Jalapeno slices before and during storage. A significant increase could not be observed.

In this investigation on the storage stability of unblanched and blanched red Jalapeno slices and dried by different drying methods, higher capsaicinoid contents in blanched samples before drying processes were found in those samples that were blanched in water at 85 °C for 4 min. On the other hand, blanching in water at 85 °C for 2 and 4 min resulted in slightly decreased capsaicinoid contents (Orak and Demicri, 2005), confirming the results obtained in our study. After 12 months of storage the unblanched red Jalapeno slices that dried by the RWD_1, OD_1 and SD_1 methods were contained 230.7, 213.8 and 165.9 mg/100 g capsaicinoids on a dry matter basis corresponding to 15.40, 20.79 and 36.73% degradation based on the concentration respectively, determined at the beginning of storage. In contrast, in blanched red Jalapeno slices and dried by the RWD_2, OD_2 and SD_2 methods were contained 258.5, 237.8 and 194.7 mg/100 g capsaicinoid concentrations on a dry matter basis corresponding to 8.30, 14.18 and 28.21% degradation based on the concentration respectively, as shown in Fig (4).

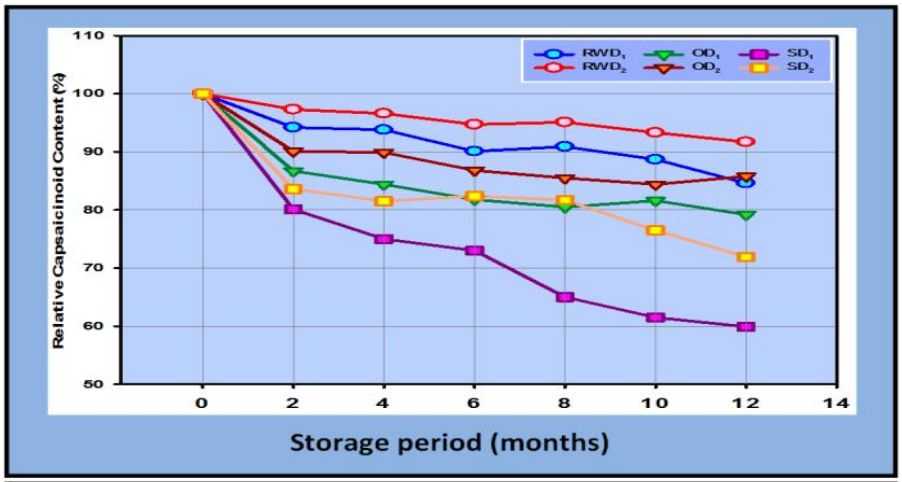

Fig (4): Effect of different drying methods of the red Jalapeno slices on the capsaicinoids during storage period at room temperature.

Fig 4 exemplifies relative capsaicinoid levels during storage period of red Jalapeno slices dried by Refractance Window Drying (RWD_1 and RWD_2); Oven Drying (OD_1 and OD_2) and Sun Drying (SD_1 and SD_2) methods. Capsaicinoid degradation was initiated within the first 2 months, especially when red Jalapeno slices were dried by (SD_2 and SD_1) methods. During 12 months of storage at room temperature, further degradation of the pungent principles by 8.30% for blanched red Jalapeno slices and dried with RWD_2 method, and by 36.73% for unblanched red Jalapeno slices and dried with SD_1 was observed. Drying of the red Jalapeno slices by (RWD_2 and RWD_1), and (OD_2 and OD_1) methods, respectively, results in an improved disintegration of the pepper tissue and release of the capsaicinoids, which are located in small vesicles and vacuoles of epidermal cells of the placenta (Schweiggert *et al.,* 2006b). Therefore, the pungent principles (Fig. 5) may be susceptible to degradation processes from the beginning of the storage. This decomposition stagnated and did not change significantly during ongoing storage.

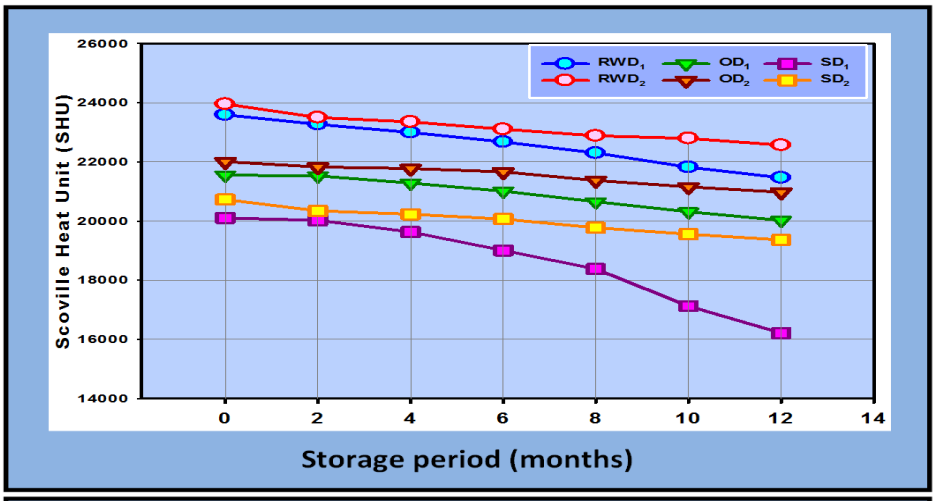

Fig (5): Effect of different drying methods of the red Jalapeno slices on the pungency during storage period at room temperature.

3. Effect of Different Drying Methods on Rehydration Ratio (RR) and Water Holding Capacity (WHC):

Rehydration process depends on structural changes in pepper tissues and cells of vegetal material during drying, which produces shrinkage and collapse (Kaymak-Ertekin, 2002). The interaction between Rehydration Ratio (RR) and Water Holding Capacity (WHC) for rehydrated red Jalapeno slices was evaluated in order to evaluate the influence of the different drying methods and the pretreatment on RR and WHC.

Fig. 6 shows the inability of the dried samples to imbibe sufficient water to become fully rehydrated. The WHC was decreased for samples that were blanched in hot water at 85 °C for 4 min before submerging in an aqueous solution (as described in method) and drying by RWD_2, OD_2 and SD_2 methods in comparison with unblanched samples before drying by RWD_1, OD_1 and SD_1 methods. The maximum RR and WHC values of the unblanched samples before the pretreatment and drying were 6.89 ± 0.337 g absorbed water/g d.m and 0.61 ± 0.023 g retained water/g water, respectively for red Jalapeno slices dried by RWD_1 method; thus, the red Jalapeno slices dried by this method retained a great amount of water.

On the other hand, dried samples by SD_2 method have reduced their WHC, thereby preventing the complete rehydration of the dried product. Similar investigations reported that blanching in hot water at high temperature before drying is the main factor affecting the WHC (Vega- Gálvez *et al.*, 2008b). In the same figure, RR was affected by the blanching in hot water at high temperature before drying, since absorbed water decreased with the blanching at high temperature. However, the lowest RR value was 5.56 ± 0.35 (g absorbed water/g d.m) for the red Jalapeno slices dried by OD_2 method,

this could be explained due to cellular structure damage resulting in modifications of osmotic properties of the cell as well as lower diffusion of water through the surface during rehydration (Kaymak-Ertekin, 2002). Moreover, pretreatments of the samples with saline or sweet solutions such as $CaCl_2$ or saccharose and unblanching at high temperature before drying allowed to maintain the initial texture, leading to cellular structure stability and retained a greater quantity of water (Lewicki, 2006; Papageorge *et al.,* 2003).

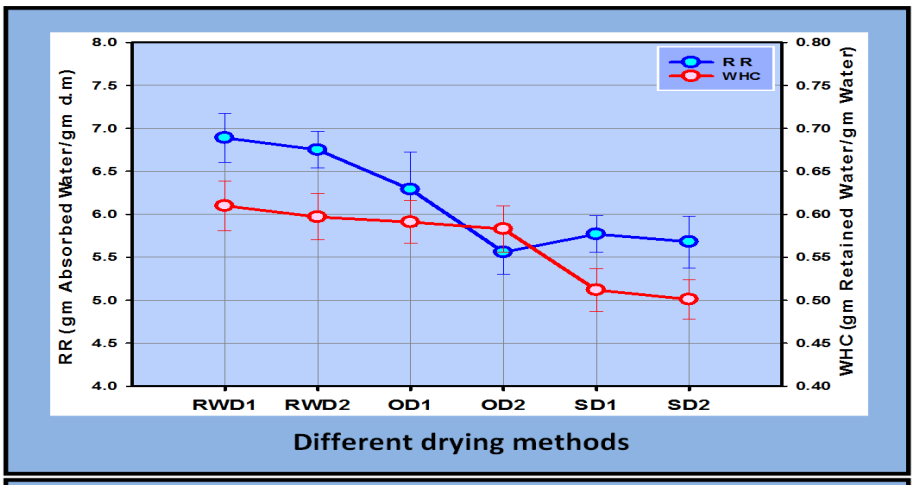

Fig (6): Interaction between rehydration ratio (RR) and water holding capacity (WHC) of the rehydrated red Jalapeno slices dried by different drying methods.

4. Color Parameters:

4.1. Effect of Different Drying Methods and Storage on Surface Color:

The color change of a food product during drying is an indication of how severe the drying conditions are related to its pigment composition/concentration. Different drying methods and pretreatments exert a significant effect on the color changes of red Jalapeno slices. Fig. 7 shows the color data in terms of *L**, *a** and *b** values of fresh and dried red Jalapeno slices.

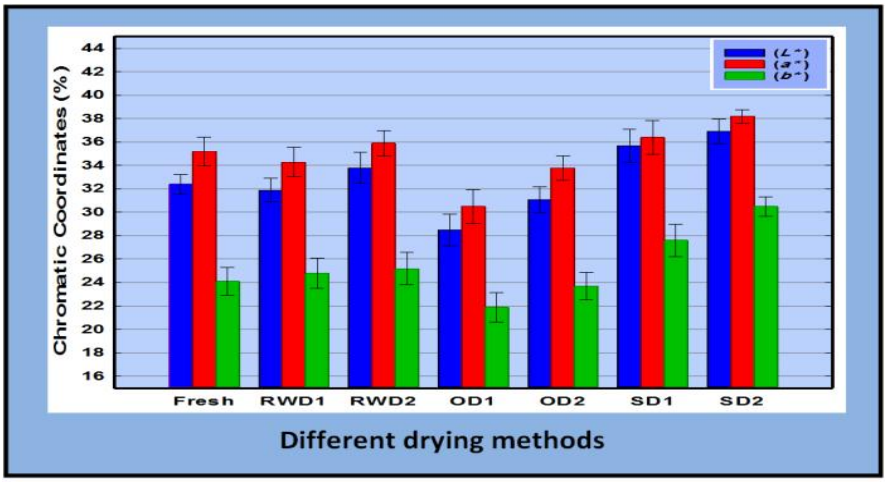

Fig (7): Effect of different drying methods of the red Jalapeno slices on the chromatic coordinates (*L, *a** and *b**) values.**

Coordinate L^* (whiteness) values of dry-rehydrated red Jalapeno slices decreased with oven drying (OD_1 and OD_2 methods). It can be observed that coordinate L^* presents the lowest values 28.50 ± 1.16 for the unblanched sample before preteatmenr and dried by OD_1 method indicating that fresh peppers presented a darker color compared to the dry-rehydrated samples that dried by OD_1 and OD_2 methods. For drying by RWD_1 and RWD_2 methods, the differences in lightness are not so evident ($p < 0.05$). Coordinate L^* values of dry-rehydrated red Jalapeno slices that dried by RWD_1 and RWD_2 methods had almost remained unchanged when compared to the fresh sample. Rehydrated red peppers became darker probably due to a larger extension of the Maillard reaction, especially using sun drying method (Acevedo *et al*., 2008; Manzocco *et al*., 2001). Pretreatments, like addition of different compounds, can enhance the chromatic coordinates (Garau *et al*., 2007; Sigge *et al*., 2001). The decrease in L^* values can be attributed to brown pigment formation during drying as Vega-Gálvez *et al*. (2008a) reported that brown pigment in dried red peppers was due to their high levels of reducing sugars and amino acids in red pepper. Sun dried samples (SD_2 and SD_1 methods) had the highest L^* values whichmeant these samples were lighter in colour than the fresh peppers, indicating a more pale appearance in dried samples (SD_2 and SD_1 methods). Similar result was also reported in a previous study, which was attributed to an increase in bright pigment concentrations (Schweiggert *et al*., 2005a).

Modifications in coordinate a^* (redness) for dry-rehydrated samples are also presented in Fig. 7, where there was a decrease of this coordinate (13.35%) for the unblanched samples and dried by OD_1 method respect to fresh samples ($p > 0.05$). This could be explained due to the presence of carotenoids as well as other components (vitamins, carbohydrates, amino-acids, etc.) in the pepper affecting the final product color (Miranda *et al*., 2009b). Coordinate a^* values of sun dried samples (SD_1 and SD_2 methods) were higher than the other dried samples. Oven dried samples (OD_1 and OD_2 methods) had lower a^* values than the fresh and refractance window dried samples (RWD_2 and RWD_1 methods). The longer drying time and high temperatures involved in oven drying might lead to reductions in the redness of the samples. Shi *et al*. (1999) reported that color degradation of tomato was less severe when the drying temperature was lowered from 90 to 55 °C. Topuz *et al.* (2009) showed that refractance window drying (RWD) prevented color damages during drying. Pott *et al.* (2005) reported that high temperatures and excessive sun drying resulted in a noticeable increase in redness in mango slices. The change of color could be attributed to the browning reactions (Maillard) that occur during drying (Adam *et al*., 2000).

Coordinate b^* (yellowness) showed a slight decrease in its values of 1.66 and 9.13% for the blanched and unblanched samples dried by OD_2 and OD_1 method, respectively (Fig. 7) as a result of generation of brown products due to enzymatic reactions ($p > 0.05$). Sun dried samples (SD_2 and SD_1 methods) showed the highest b^* values. Refractance window dried samples (RWD_2 methods) followed the dried samples (RWD_1 methods) in terms of b^* values.

Non-enzymatic browning and carotenoid loss occurring during drying are major causes for the colour degradation in the red pepper (Perez-GǐAlvez *et al.*, 2005). The increase in L^* could be due to an increase of the moisture content after rehydration. The increase in b^* could be caused by the development of some brown pigments related to non-enzymatic reactions activated during drying process. Doymaz and Pala (2002) reported the L^*, a^* and b^* values of dried red peppers some of which were treated with dipping solutions (cold aqueous alkali emulsion of ethyl oleate) between 21.83–41.12, 18.18–38.04 and 3.33–10.02. The L^* and a^* values determined in the present study, fall between the ranges reported by Doymaz and Pala (2002), while b^* values were higher. Kim *et al.* (2006) reported the colorimetric values of red pepper cut pods dried at 70 °C for 6 h as L^* (36.09), a^* (38.78), and b^* (30.71), while whole pods dried at 80 °C for 5 h as L^* (34.62), a^* (29.61), and b^* (26.26). The values measured for the dried red Jalapeno slices in this study were between the ranges of values reported by Kim *et al.* (2006).

The less color alterations in RWD samples may be linked to less carotenoids decomposition and/or less formation of undesirable pigments as a result of mild drying conditions. It was found that RWD drying is the most suitable drying method for maintaining the red Jalapeno color quality (Park and Kim, 2007). Schweiggert *et al.* (2005a) blanched chili (unnamed *Capsicum* cultivars) to inactivate enzymes before drying by RWD method and claimed that enzyme inactivation was the main reason for high color quality of red Jalapeno produced with RWD method. No research has been reported on color quality of RWD dried Jalapeno pepper slices. It is postulated that the less color degradation in

RWD dried Jalapeno pepper was due to prevention of pigment oxidation and decomposition due to less exposure to oxygen when an intensive vaporization takes place on the surface of the product on the plastic belt, as well as a reduced heating at the final stage of RWD drying. The short drying time in RWD might also contribute to the less color alteration in dried red Jalapeno slices.

Since total color difference (ΔE) is a function of the three *CIE L*, a*,* and *b** coordinates (Eq. (4)), changes from 5.33 ± 1.99 to 8.61 ± 1.78 were estimated in sun dried samples (SD_1 and SD_2 methods), respectively. Similar results were obtained by Miranda *et al* (2009b), where high ΔE values were found in blanched samples and dried by sun drying method due to the effect of long drying time on sensitive components like proteins and carbohydrates, amongst others.

The saturation index or chroma (C^*) and the hue angle (H^O), as shown in Fig. 8, provide more information about the spatial distribution of colors than direct values of tristimulus measurements (Sigge *et al*., 2001; Rico *et al*., 2010). It is observed that the values of both indices were affected by drying method in opposite ways ($p > 0.05$) for both fresh and dry-rehydrated red Jalapeno slices. Estimated chroma values (C^*) of the dry-rehydrated samples retained the 96.77% and 90.37% of the oven dried samples (OD_1 and OD_2) methods, respectively, the hue angle (H^O) showed an increase of 9.43% and 5.86% in the same samples, respectively compared to fresh sample indicating discoloration of the original red Jalapeno slices color. The H^O values of the dried red Jalapeno slices were in the range of 33.41±2.01 to 39.28±3.05, which were significantly ($P<0.05$) different from samples obtained with different drying methods.

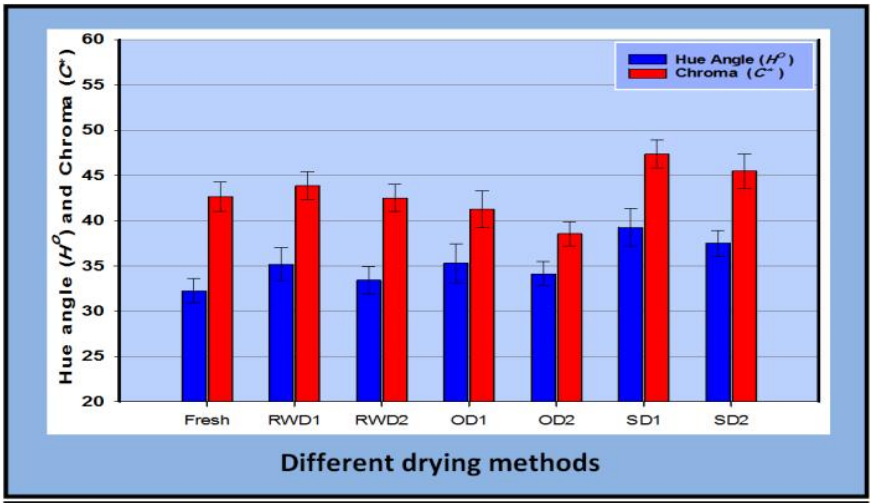

Fig (8): Effect of different drying methods of the red Jalapeno slices on the hue angle (H^o) and the chroma (C^*).

Effect of Storage on Surface Color:

Variance analysis of the color parameters was conducted to examine the effect of main factors, i.e., drying method, storage period, and their interactions. The refracted color parameters were significantly ($P < 0.05$) affected by the main factors. The color parameters of the dried red Jalapeno slices after drying and during storage period are presented in Figs 9, 10 and 11. On day zero, dried samples by RWD_2, SD_1 and SD_2 methos immediately after drying had the highest values of *L**, *a**, *b** and *C**. Storage stability of the color of dried red Jalapeno slices was also evaluated. The chromatic coordinates *L**, *a** and *C** values were significantly reduced in OD_1, SD_1 and SD_2 samples after 2 months of storage for the dry-rehydrated red Jalapeno slices, while for RWD_1, RWD_2 and OD_2 samples the reduction was not significant (Figs 9, 10 and 11). In addition to the dried red Jalapeno slices by all methods (RWD, OD and SD), the color parameters of *L**, *a** and *C** were also significantly decreased during 12 months of storage. Meanwhile, the dried red Jalapeno slices by all methods (RWD, OD and SD), the coordinate *b** value was significantly increased during 12 months of storage. Similar result was also reported in a previous study, which was attributed to an increase in *b** value during storage period (Schweiggert *et al*., 2005b; Kim *et al*., 2008).

It appears that a fast reduction in those color parameters took place in the first 2 months. After 2 months, the color changes were slightly significant ($P > 0.05$). This may be caused by depletion of oxygen in the polyethylene (PET) bags thereby a reduction in ongoing carotenoids oxidation of dried red Jalapeno slices. Since the values of a^* and b^* changed in a similar pattern during the storage, the H^O values were not significantly affected by storage period (Ayuso *et al*., 2008). Finally, the color of dried red Jalapeno slices by WRD_2-mthod was the most stable for coordinates L^*, a^*, b^* and C^*.

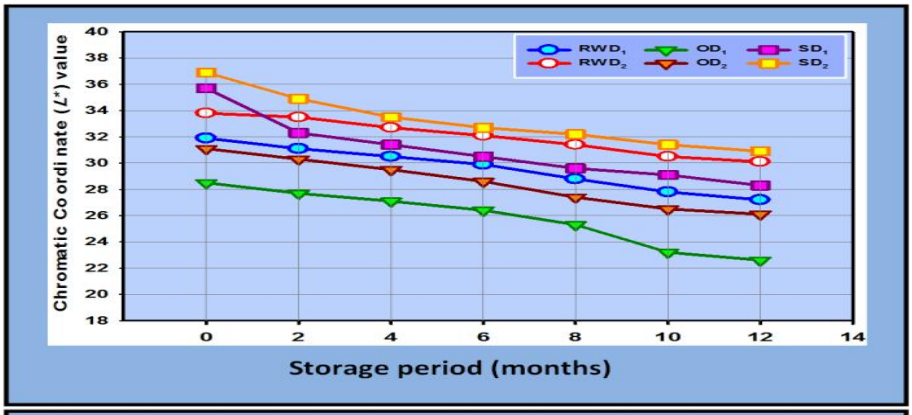

Fig (9): Effect of different drying methods of the red Jalapeno slices on the chromatic coordinate (L^*) value during storage period at room temperature.

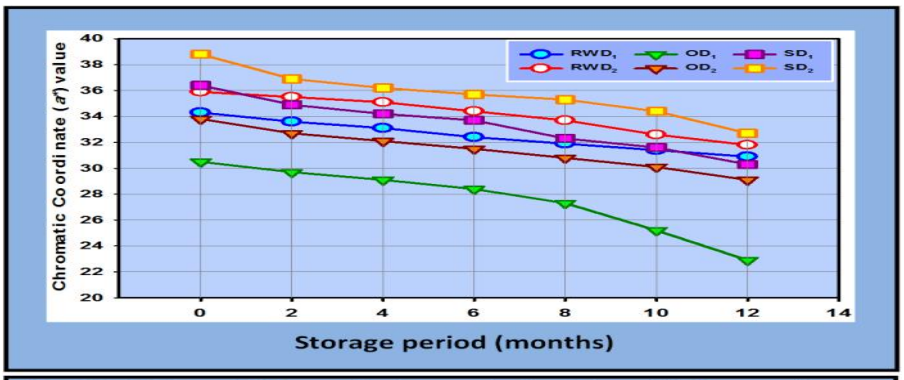

Fig (10): Effect of different drying methods of the red Jalapeno slices on the chromatic coordinate (a^*) value during storage period at room temperature.

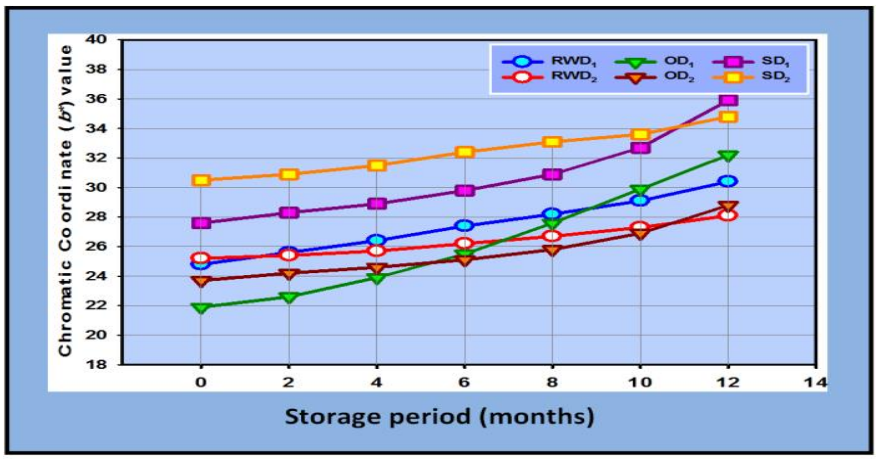

Fig (11): Effect of different drying methods of the red Jalapeno slices on the chromatic coordinate (b^*) value during storage period at room temperature.

4.2. Effect of Different Drying Method and Storage on Extractable Color (ASTA):

The extractable color value is generally noted as ASTA color value. The present study showed that the ASTA color values significantly ($P < 0.05$) changed by different drying methods, and storage period (Fig. 12). The ASTA color value for the fresh red Jalapeno slices was 528.12 ± 2.92 ASTA units/ g d.m. When the different drying methods were evaluated, the ASTA color values of the dry-rehydrated red Jalapeno slices were ranged between 309.88 ± 3.04 and 487.43 ± 4.01 ASTA units/g d.m. The highest ASTA color values were recorded in blanched samples (as described in method) before pretreatment and dried by RWD_2 and OD_2 methods with the values of 487.43 ± 4.01 and 446.23 ± 3.03 ASTA units/g d.m, respectively. In contrast, the dried samples by sun drying (SD_1 and SD_2 methods) were yielded the lowest ASTA color values (309.88 ± 3.04 and 359.67 ± 2.03 ASTA units/g d.m), respectively. The refractance window dried samples (RWD_2 and RWD_1 methods) gave a significantly ($P < 0.05$) higher ASTA values than the oven dried samples (OD_1 and OD_2 methods) and the sun dried samples (SD_1 and SD_2 methods). The highest ASTA values of the refractance window dried samples (RWD_2 and RWD_1 methods) thus could be attributed to biosynthesis of carotenoids in living tissues. This phenomenon was also reported in previous research for drying processes (Minguez-Mosquera *et al*., 2000).

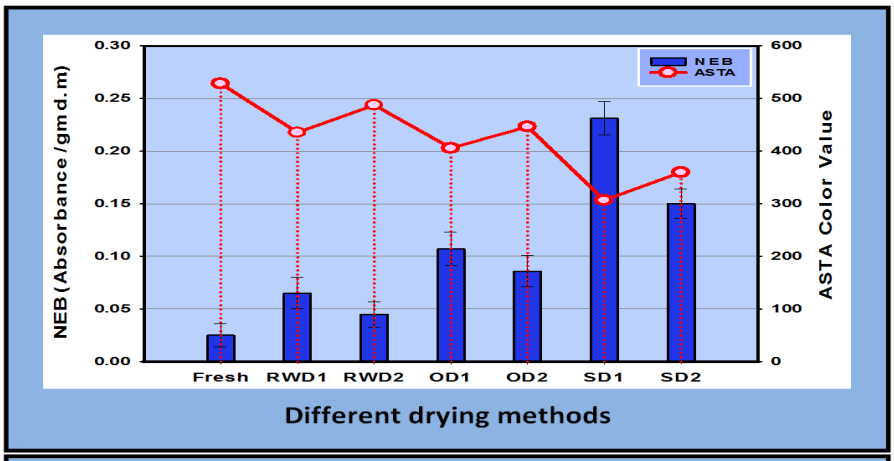

Fig (12): Effect of different drying methods of the red Jalapeno slices on the non-enzymatic browning (NRB) and ASTA color value.

Moreover, the degree of the carotenoids synthesis thereby ASTA color values were obviously changed by the different drying methods. ASTA color content is mainly attributable to endogenous carotenoids such as capxanthine, capsorubin, β-carotene and others (Vega-Gálvez *et al*., 2008b). In consequence, the behavior of this parameter is directly related to deterioration in these pigments due to sun drying methods (Ergunes and Tarhan, 2006). Furthermore, discoloration of carotenoids during processing might occur through enzymatic or non-enzymatic oxidation (Rodriguez-Amaya *et al*., 2008). Both non-enzymatic browning (NEB) and ASTA color presented significant differences ($p < 0.05$).

The ASTA color values of the dry-rehydrated red Jalapeno slices were significantly ($P< 0.05$) decreased by 14.1–29.6% during 12 months of storage at room temperature, except for that of dry-rehydrated red Jalapeno slices dried by RWD_2 method. Similar reduction in ASTA values of the red papper during storage was reported in the literature (Park and Kim, 2007; Tepic and Vujicic, 2004).

It is interesting to note that the changes in ASTA values were not followed by changes in the values of reflected color parameters, especially in the dried samples with RWD_2 and RWD_1 methods. The lowest ASTA values were determined in the sun dried samples (SD_1 and SD_2 methods) which had the highest values of the apparent color parameters. Considering that the ASTA value is an indication of the total carotenoids content, the reflected color degradation in the dry-rehydrated red Jalapeno slices was thus not only related with the carotenoids decomposition. Likewise, in a previous research,

there was a very poor positive linear correlation between *CIE* Lab color parameter and ASTA values of hot red papper (Nieto-Sandoval *et al*., 1999; Tunde-Akintunde *et al*., 2005).

4.3. Effect of Different Drying Method and Storage on Non-Enzymatic Browning (NEB):

The non-enzymatic browning (NEB) is another criterion used to evaluate the dried red Jalapeno slices quality. The NEB values of the dry-rehydrated red Jalapeno pepper slices were significantly ($p < 0.05$) affected by the different drying methods, and storage period. Figs. 12 and 13 present the color changes of red Jalapeno pepper slices related to both non-enzymatic browning (NEB) and the ASTA color value. The red pepper color was dependent on the pretreatment and using method in the drying of the red Jalapeno pepper slices.

In terms of drying method, the highest and lowest NEB values were detected in sun drying (SD) and refractance window drying (RWD) methods of red Jalapeno slices, respectively (Fig. 12). It may indicate that the RWD_2, RWD_1 and OD_2 methods produced less non-enzymatic browning reaction in the samples after drying. It is expected that the browning reactions would be minimized by a RWD method. The low level of NEB values of RWD method is worthy of more attention. It may be attributed to the short drying time of RWD method which suppressed the browning reaction. In addition, although the blanching in hot water temperature for the RWD_2 method was high (85°C for 4 min.), the product temperature was relatively low (Nindo *et al*. 2003). The importance of drying time is evidenced by the very high NEB value of dried sample by SD_1 method in which the drying was finished in 4–5 days under direct sunlight.

Fig. 13 showed that the refractance window dried samples preserved the color with a values of 79.8% and 84.6% for the dried samples by RWD_1 and RWD_2 methods, respectively, while the sun dried samples (SD_1 and SD_2 methods) preserved it only between 16.7% and 30.0%, respectively. In addition, it is observed that the blanched samples before pretreatment and dried by RWD_2 method showed browning pigments values lower (0.045 ± 0.026 Abs/g d.m) than unblanched samples and dried by RWD_1 method (0.065 ± 0.045 Abs/g d.m). The color loss value (CLV) may be related to the formation of browning compounds, since red pepper contains considerable amounts of reducing sugars and amino acids (Lee *et al*., 1991).

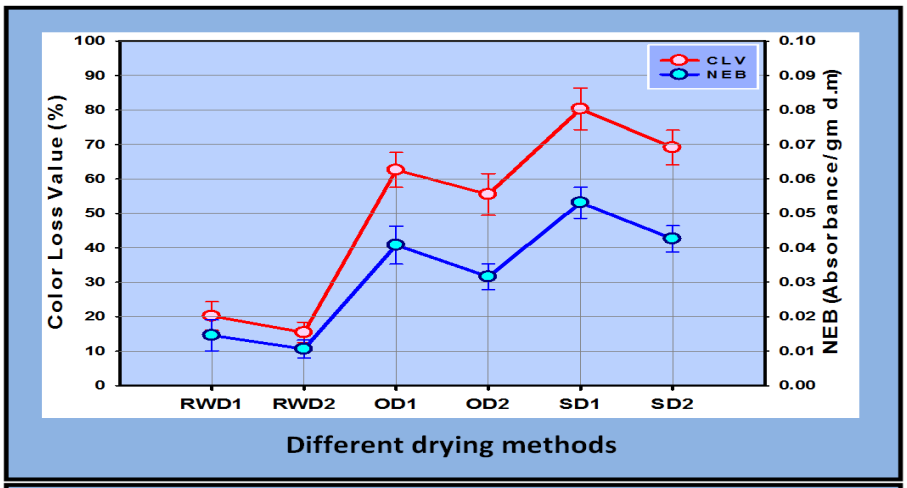

Fig (13): Effect of different drying methods of the red Jalapeno slices on the color loss value (CLV) and the non-enzymatic browning (NEB).

It can be observed that an increase in the drying time led to an important formation of brown products.This could be explained due to an increase in the kinetic reaction rate that showed a maximum NEB value of 0.231 ± 0.016 Abs/g (d.m) for the unblanched samples that dried with SD_1 method. Furthermore, it is well known the effect of water on chemical reactions, via a_w or by plasticizing amorphous systems (dehydrated systems) since the inhibitory effect of water seems to be a decisive factor in the NEB reaction rate (Acevedo *et al*., 2008). Turhan *et al.* (1997) showed that a

major color change in red pepper during drying was due to the large increase in the content of brown pigments. Kim *et al*. (2004) reported that brown pigments in dried red peppers were due to their high levels of reducing sugars and amino acids in fresh red pepper. In addition, the development of the Maillard reaction frequently occurs in concomitance with other events, which can contribute to change both color and the overall antioxidant capacity of pretreated foods (Manzocco *et al*., 2001).
The NEB values of all the dried red Jalapeno slices were significantly ($p < 0.05$) increased throughout the storage period. Kim *et al*. (2006) also noticed that first few months of storage played a crucial role in the formation of brown pigments but it slowed down for an extended storage period. In this study, the dried samples that had initially lower NEB values experienced a faster increase in NEB during storage, indicating a continued non-enzymatic browning activity under storage conditions. For instance, the NEB values of the sun dried samples (SD_2 and SD_1 methods) increased about 31–47% during the storage period. However, the increase in the NEB values of the dried sample by RWD_2 method in this period was about 16.6%.

5. Bioactive Compounds:

5.1. Effect of Different Drying Methods on Ascorbic Acid Content (AA):

Fig. 14 shows the ascorbic acid (AA) as well as the total phenolic content (TPC) for the fresh and dry-rehydrated red Jalapeno slices during the six drying experiments. The initial content of ascorbic acid in fresh red Jalapeno pepper was 190.2 ± 3.12 mg AA/100 g d.m, which was within the ranges found in this study for dry-rehydrated red Jalapeno slices dried by different drying methods (20.6 ± 4.34 to 65.1 ± 3.22 mg AA/100 g d.m). It can be seen that an increase in the drying time and temperature treatment has an important effect on ascorbic acid ($p < 0.05$), thus, a maximum loss of 89.3% AA in dried sample with SD_1 method is observed. All dried samples contained less AA than the fresh red Jalapeno pepper due to a combination of oxidation and thermal destruction of AA during pretreatment before drying and subsequent rehydration (Inchuen *et al*., 2010). This could be explained due to irreversible oxidative processes either during drying or rehydration water lixiviation of this water-soluble vitamin (Sigge *et al*., 2001; Vega-Gálvez *et al*., 2008b). In addition, AA is considered as an indicator of the quality of food processing due to its low stability during thermal processes (Podsedek, 2007). Similar results were obtained by other authors working with red peppers (Di-Scala and Crapiste, 2008). Pretreatments like blanching or additives like SO_2 and $CaCl_2$ can improve the retention of this ascorbic acid (Vega-Gálvez *et al*., 2008b).

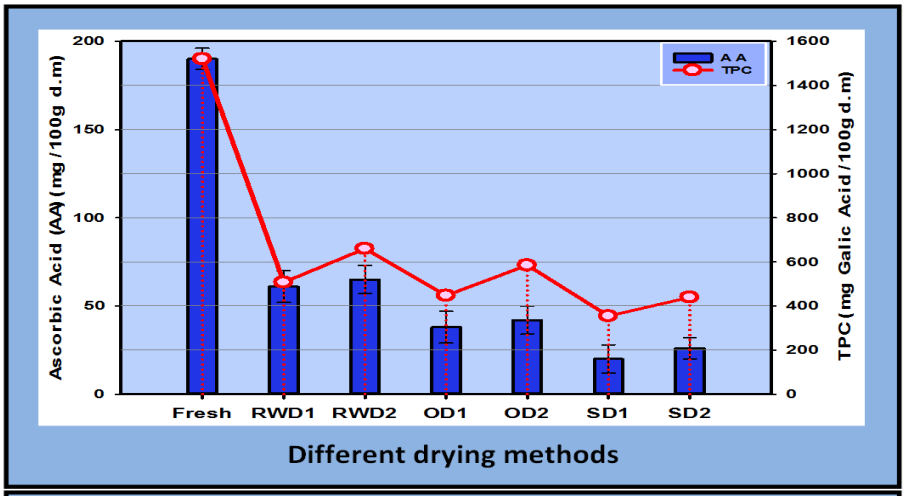

Fig (14): Effect of different drying methods of the red Jalapeno slices on the ascorbic acid (AA) and total phenolic content (TPC).

5.2. Effect of Different Drying Methods on Total Phenolic Content (TPC):

Phenolic compound which constitutes one of the major groups of compounds acts as primary antioxidants or free radical terminators (Tabart *et al*., 2009). The initial phenolic content (TPC) of fresh red Jalapeno pepper was 1521 ± 148 mg galic acid/100g dry matter. The red Jalapeno pepper contained numerous phenolic compounds, and not all of the genotypes may contain a similar profile or relative proportions of these compounds within the profile. Differences in these profiles may subsequently result in complex changes in antioxidant activity or other bioactivities (Deepa *et al*., 2007).

It can be observed from (Fig. 14) that an increase in the drying time and temperature treatment had an important effect on the total phenolic content ($p < 0.05$). In terms of drying method, the highest and lowest TPC contents were detected in RWD and SD methods of red Jalapeno slices, respectively. It may indicate that the RWD_2 and OD_2 methods produced high TPC contents (660 ± 14.23 and 585 ± 16.53 mg galic acid/100g d.m), respectively for dry-rehydrated red Jalapeno slices after drying. The high level of TPC contents of RWD method is worthy of more attention. It may be attributed to the short drying time of RWD method which suppressed the browning reaction. The importance of drying time is evidenced by the very low TPC contents of SD method in which the drying was finished in 4–5 days under direct sunlight. This could be explained due to an increase in the kinetic reaction rate that showed a minimum TPC contents of 354 ± 21.24 mg galic acid/100g (d.m) for the unblanched sample that dried by SD_1 method. The formation of phenolic compounds in blanched samples at high temperatures (85 ºC) might be related to the availability of precursors of phenolic molecules by non-enzymatic inter conversion between phenolic molecules (Que *et al*., 2008).

6. Effect of Different Drying Methods on Antioxidant Activity:

Fig (15) shows the average antioxidant activity and radical scavenging capacity of fresh and dried red Jalapeno pepper slices. The antioxidant activity of pepper samples was significantly affected by the drying conditions. Drying methods showed a significant increase in antioxidant activity of red Jalapeno pepper. The antioxidant activities of the all dried samples were higher than the fresh samples. The radical scavenging capacity and antioxidant activity were investigated based on different drying methods ($p < 0.05$) as observed in Fig. 15, where the trolox equivalent antioxidant capacity (TEAC) values for dried red Jalapeno pepper slices varied between 3770.89 and 5564.55 µmol TEAC/100 g d.m and DPPH radical scavenging capacity of the dried samples were in the range of 60.97–89.14%. The sun dried samples (SD_1 and SD_2) and oven dried sample (OD_1) gave the lowest TEAC and DPPH radical scavenging activity. Meanwhile, refractance window dried samples (RWD_2 and RWD_1) and oven dried sample (OD_2) exhibited the highest TEAC and DPPH radical scavenging activities.

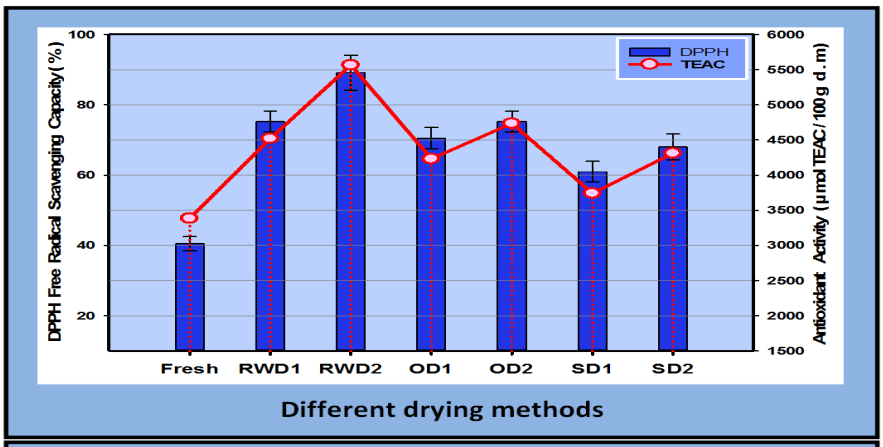

Fig (15): Effect of different drying methods of the red Jalapeno slices on the DPPH radical scavenging activity and the Trolox equivalent antioxidant capacity.

Similar results have been reported by various researchers such as Madrau (2009) who reported a significant increase in antioxidant activity of apricots from Cafona variety after oven drying at 75 °C, Inchuen *et al.* (2010) reported an improved antioxidant activity of the red curry powder after drying process, and Oboh and Akindahunsi (2004) reported that sun-drying caused significant increases in the antioxidant properties of the green leafy vegetables. This behaviour could be related to drying process at low temperatures, which implies long drying times that may promote a decrease of antioxidant capacity (Garau *et al*., 2007). It was previously reported that long dehydration times together with high temperatures (Perez-GǐAlvez *et al.*, 2005) lead to poor quality products due to caramelization, Maillard reactions, enzymatic reactions, pigment degradation and L-ascorbic acid oxidation (Howard, 2001; Rufián-Henares *et al.*, 2013).

Kim *et al.* (2006) reported that modified drying, which is short time and low temperature drying of cut red pepper pods, was certainly more effective than conventional drying in reducing the destruction of the antioxidant activity, ascorbic acid and color. Furthermore, generation and accumulation of Maillard derived melanoidins having a varying degree of antioxidant activity could also enhance antioxidant properties at high temperatures (i.e. 80 and 90 ºC) (Miranda *et al*., 2009; Que *et al*., 2008). Increasing correlation between antioxidant activity and total phenolic content has been reported during food dehydration (Deepa *et al*., 2007). However, data on the effects of drying on TPC and antioxidant activity of vegetables are conflicting due to several factors, like drying method, pretreatment, antioxidant assays used as well as interactions of several antioxidant reactions (Manzocco *et al*., 2001; Que *et al*., 2008).

Conclusion

In conclusion, drying conditions, particularly temperature, pretreatment and drying method led to pepper modifications that could cause quality degradation. The present study aimed at the stability evaluation of the major capsaicinoid contents of the fresh and rehydrated red Jalapeno pepper slices after different drying methods and during storage for 12 months in detail. For this purpose, freshly harvested red Jalapeno pepper slices were immediately dried by Refractance Window Drying (RWD_1 and RWD_2); Oven Drying (OD_1 and OD_2) and Sun Drying (SD_1 and SD_2) methods. Effects of these drying methods in terms of physico-chemical properties, rehydration ability, color parameters, ascorbic acid, total phenolic and antioxidant activity of the red Jalapeno pepper slices were evaluated. Four capsaicinoid analogues (capsaicin, dihydrocapsaicin, nordihydrocapsaicin and homocapsaicin) were identified in the tested samples. Different drying methods resulted in a 13.69% to 19.72% degradation of the initial capsaicinoid contents. Among the drying methods, the RWD_2 and RWD_1 samples had the highest SHU values, followed by that of OD_2 and OD_1 samples. During 12 months of storage at room temperature, further degradation of the pungent principles by 8.30% for blanched red Jalapeno slices dried with RWD_2 method, and by 36.73 % for unblanched red Jalapeno slices dried with SD_1 was observed. On the other hand, the maximum Rehydration Ratio (RR) and Water Holding Capacity (WHC) values for the unblanched samples before drying were 6.89 ± 0.337 g absorbed water/g d.m and 0.61 ± 0.023 g retained water/g water, respectively for red Jalapeno slices dried by RWD_1 method; thus, the red Jalapeno slices dried by this method retained a great amount of water.

Chromatic parameters (L^*, a^*, b^*, C^* and H^O), extractable color (ASTA) and Non-Enzymatic Browning index (NEB) were affected by drying methods and pretreatments, which contributed to the discoloring of the original red Jalapeno pepper color during this process. Moreover, the RWD dried samples by RWD_1 and RWD_2 methods preserved the (ASTA) color with a value of 79.8% and 84.6%, respectively. In terms of drying method, the highest and lowest NEB values were detected in SD and RWD methods of red Jalapeno slices, respectively. It is expected that the browning reactions would be minimized by a RWD process. It may be attributed to the short drying time of RWD method which suppressed the browning reaction. Both (AA) and (TPC) decreased during the six drying experiments, thus, a maximum loss of 89.3% AA in dried samples by SD_1 method was observed. In terms of drying method, the highest and lowest TPC contents were detected in RWD and SD methods of red Jalapeno slices, respectively. Furthermore, the RWD_2-dried red Jalapeno slices showed better color parameters and the highest amounts of capsaicinoids, SHU, AA TPC and antioxidant activity in comparison with the other drying methods after drying and during storage period.

In consequence, the results obtained in this work are essential for the processing of dried red pepper slices in order to obtain the optimum benefits of bioactive compounds present in red Jalapeno pepper during drying.

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