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Influence of Drying Techniques on the Physicochemical and Mechanical Characterization of Scallion (Allium Schoneprasum) Leaves

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Abstract: Effect of different drying methods on selected mechanical, physical and chemical properties on the scallion leaves was studied. The green edible part of this plant was subjected to shadow, convective oven (50°C) and microwave (630 W) to evaluate the drying kinetic, surface color, maximum bending force, failure strain, toughness, pH, total phenol content (TPC) and total soluble solid (TSS) of samples. Results demonstrated that the microwave and oven drying shortened the drying time over than approximately 86 and 99% when compared to the shadow drying. The microwave method can make a balance between drying time and product quality. The total color difference (ΔE) was ranged from 7.86 to 12.58. The lowest value of ΔE (7.86) belonged to microwave dried leaves indicating good resistance to color degradation. The highest value of toughness was recorded in shadow samples (6.84×10^{-4}) showed that failure of leaves needs more energy; however a straight crack path was easily produced in microwave dried leaves. Drying processes generally results in a depletion of pH, TSS and TPC of fresh plant. The obtained data accentuated that the maximum amounts of TSS (0.13) and TPC (19.83) were recorded in plants dried in shadow.

Keywords: Scallion Leaves, Drying Method, Color Difference, pH, Total Soluble Solid, Total Phenol Content

1. Introduction

Herbs and vegetables are considered as one of the first food products with different applications all around the world [11]. Since herbs are abounding in natural antioxidants, vitamins, mineral substances and essential oils, they have been used not only for flavor seasoning but also for medicinal, pharmaceutical and cosmetic industries [37, 51]. Scallion (*Allium schoenoprasum L.*) of the *Liliacea* family is one of the aromatic plant spices from central Europe and because of its leafy and tubular shape can be grown in sunny and dry habitats perennially [31] from 20 to 50 cm high [11]. Scallion similar to other members of *Allium* genus such as leek, garlic and onion contains high amounts of flavonoids [14]. These flavonoids have an anti-oxidative effect, and they prevent or delay some diseases such as colorectal cancers cardiovascular, malignant neoplastic diseases and incidence of the stomach [14]. In the food industry, scallion leaves are being used fresh, frozen or alternately, powdered after being dried. When it comes to food preservation, dehydration is one of the oldest methods and was used by pre-historic people in sun-drying seeds [20]. Dehydration, in food processing, means by which many types of food can be preserved for indefinite periods by extracting the moisture, thereby inhibiting the growth of microorganisms like bacteria, yeasts and mold through the removal of water [20, 38, 36]. It is well-known that in all different drying methods, numerous physical, mechanical, chemical and nutritional changes occur in plants and affect the quality features [25]. Antioxidant capacity and nutritional and physical quality of the herbs cab be influenced by drying process [1, 41]. Dehydrated scallion powder has great commercial value due to its culinary, folk medicinal and pharmaceutical applications [35]. Grinding is considered as an important unit operation in the processing of herbs in which the size of dried product is reduced and their surface area is increased. Thus, preservation of quality of the dried plant to increase the availability of their constituents such as flavouring components is essential to produce the commercial powder.

Power consumption in grinding, quality attributes of flavoury herb powder such as surface area, size, color, chemical properties and powder nutrition are highly affected by drying method [40]. Some physicochemical properties of herbs were evaluated by researchers, which were mentioned in the following. Four leafy vegetables of Apiaceae family, celery, coriander, dill and parsley were used to assess the effect of different drying methods on antioxidant capacity. No significant difference was observed in the content of total phenol between fresh and dried samples [48]. Chinese chive leaves were subjected to different combination of microwave-vacuum, hot air and freeze drying to measure the chlorophyll retention. This study resulted in big difference from conventional hot air drying in chlorophyll of chive leaves [54]. To describe selected physico-chemical properties of basil, mint, oregano, parsley and rocket undergoing microwave-convective drying, an investigation was done. The highest retention of total phenol and good resistance to color degradation has belonged to lovage and parsley [34]. However, investigations on the mechanical properties of herbs are scarce, some references were found, in particular, to the mechanical properties in tensile, shear and bending tests of some leaves of various plants [7, 24, 27, 28, 32, 38, 43], or some grasses [50]. Although, moisture sorption data on plant powder are very rare in published literature; this paper presents data on heat treatment characteristics of scallion powder prepared by different drying techniques.

This paper aimed in selecting the most effective drying process of scallion leaves in the view of grinding and producing plant powder. Dried samples were analyzed in terms of drying kinetic, surface color, maximum bending force, rupture strain, toughness, pH, total soluble solid compounds (TSS) and total phenol content (TPC) to obtain the best heat processing method.

2. Materials and Method

2.1. Plant Material

Fresh scallion leaves were purchased from the local market in Hamedan, west part of Iran. To reduce the amount of respiration, biological and chemical changes, the material was stored in plastic bags at temperature of 4°C in a refrigerator until to use. Stajner et al. [13] found that in vegetables belonged to *Allium schoenoprasum*, leaves have the highest antioxidant activity in comparison with bulbs and stalks due to the high activity of enzymes related to the antioxidant system and the high levels of flavonoids, vitamin C, and carotenoids, So that, before any treatment, the physically similar leaves in color, texture and diameter were taken out of refrigerator and after cutting and discarding the bulb and stalk of the samples, only the remained green mid parts were dried. Each sample had 1 (±0.01) g in weight, 14 (±0.01) cm in length and 6 (±0.01) mm in diameter and about 10 of them were put together on a container (16×16 cm^2) for each test.

2.2. Drying Process

In the shadow drying process, the scallion fresh leaves were evenly spread on a tray uncovered and turned occasionally and left to dry in shade room (ambient temperature of 25±1 ºC, humidity of 42±2%) in an adequate natural air flow. For oven drying process, samples were spread on a tray and placed in the oven (ULE500 oven, Memmert GmbH, Germany). The temperature of oven was calibrated to 60°C. In the microwave drying process, fresh leaves on plastic containers were placed in the domestic digital microwave (Sharp, R-196 T(S), Thailand) with the power of 630 W. In all heat processing methods in appropriate time intervals, samples were weight until the vegetables were brittle enough to grind purposes (moisture content of 9% wb). An electronic balance with an accuracy of (± 0.01) was utilized for manually weighting of samples. After drying, the dehydrated scallion leaves were packed immediately in plastic bags and stored in refrigerator for further analysis. Temperature and relative humidity of the laboratory were 22±2°C and 42±2%, respectively. This research was down at the biophysical properties and rheological laboratory of agricultural faculty, Bu-Ali Sina University, Hamedan, Iran.

2.3. Physical Properties

2.3.1. Moisture Ratio and Drying Rate

The moisture content of scallion vegetables was obtained by oven drying manner [8]. The 57 (±0.01) g samples were dried in an oven at the temperature of 105°C for 24 h. By averaging three replications, moisture content of fresh scallion was obtained 11.67% (w.b) and the final moisture content was determined 9% (w.b).

Scallion leaves were dried under microwave, oven and shadow conditions. For this reason moisture ratio and drying rate during drying were computed as follows:

$$M_R = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

$$\text{Drying Rate} = \frac{M_t - M_{dt}}{dt} \quad (2)$$

Where M_R is moisture ratio (dimensionless), M is moisture content at time t (db), M_e is equilibrium moisture content, M_o is initial moisture content (db), M_t moisture content at t, M_{t+dt} moisture content at t+dt (db) and t is drying time (min), respectively. The mass of sample was measured in every 1 h during oven and shadow drying [3, 33, 49] and every 15 s during microwave drying [26] using the digital balance.

2.3.2. Color

The color is one of the most related features with respect to the quality of dried foods because it is part of their visual appearance and it is, therefore, most of the time one of the first criteria is considered by purchasers when choosing a new product. Color changes occur during drying because of chemical and biochemical responses. The rates of such reactions depend strongly on the processing parameters and the drying procedures. Fresh and dried leaf color was measured with a colorimeter (Portable colorimetric, HP-200, Guangdong, China) using a white standard and standardized light type D65. Color measurements were expressed in the L^*, a^* and b^* scales. Where L* denotes luminescence on a 0 to 100 scale from black to white, a^* (+) red or (-) green and b^* (+) yellow or blue (-) light [18, 52]. To assess the color difference between fresh and dried samples in each method color difference parameter was used.

The total color difference ΔE is calculated as follows [29]:

$$\Delta E = \sqrt{(L_0^* - L_t^*)^2 + (a_0^* - a_t^*)^2 + (b_0^* - b_t^*)^2} \quad (3)$$

Where ΔE is the difference between fresh and dried product colors; L_0^*, a_0^* and b_0^* are the color values of fresh scallion and L^*, a^* and $b^*$are the color specifications of dried scallion leaves. The measurement was done 10 times for each drying process.

2.3.3. Mechanical Properties

To evaluate the mechanical properties of dried scallion leaves an axial test device (Zwick/roell universal testing machine, Bbt-1-Fro. 5^{th}. D14, Germany) equipped with a force gauge (X Force Hp nominal Force: 500 N Capacity) was applied. The dried scallion leaves were subjected to three-points bending test with speed of 10 mm/min and support separation of 30 mm. A load was applied to the leaves by a servomotor actuator and measured by a load cell and recorded in a computer that produced a force-deformation graph (Figure 1). Bending moments which may be imposed alone or in combination with other kinds of loads occur due to wind load or other side loads and is more critical [30]. Moreover, in this study for bending tests on one dried leaf, the average maximum force and the actual deformations at break and fracture toughness were determined. The measurement was done 10 times for each drying process.

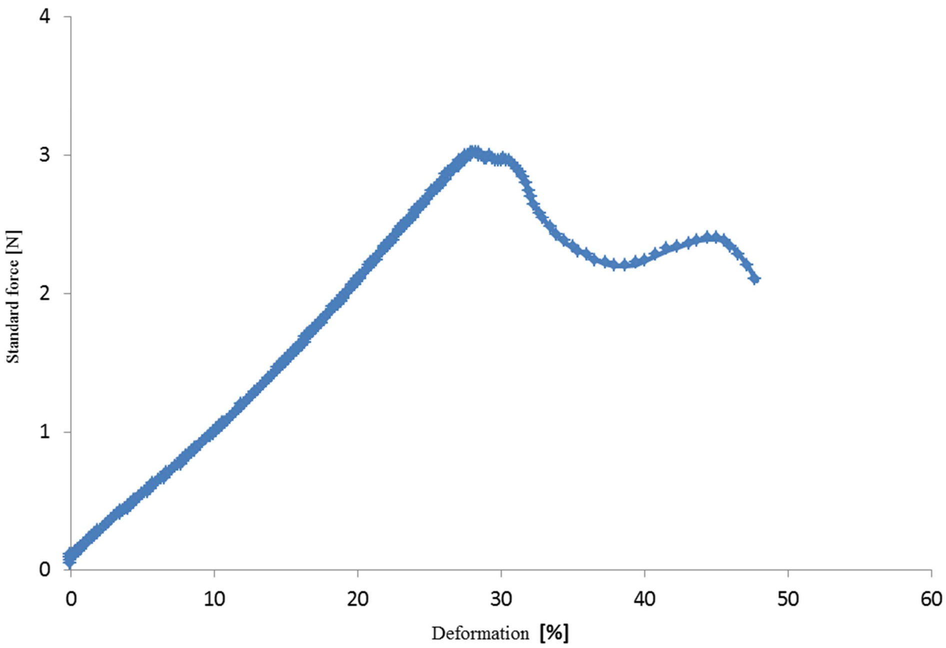

Figure 1. *Force-deformation curve of the three-points bending test for a scallion leaves sample.*

2.4. Chemical Properties: Total Content of Phenols, Soluble Solid Compounds (TSS), pH

Using scallion juice extracted from 5 (±0.01) g of dried and 30 (±0.01) g of fresh leaves, total phenol content, total soluble solid compounds and pH were measured. To evaluate selected chemical properties of plant leaves, Maceration method was used. Using this method, 5 (±0.01) g of dried samples with 30 cc of Methanol solvent (96%) were poured in sealed glass container and mixed regularly for about 4 days. Then the mixture was smoothed to separate extract from plant. Afterward, the obtained distillate was filtered again. The measurement of pH and soluble solids of fresh and dried samples were carried out by a handheld pH meter (Sartourius 12v ps/PB/20, Germany) and a refractometer (Digital refractometer PR-1, Atago, Tokyo, Japan). The measurement is based on capacity of sugar in a juice to gives the proximate sugar content in % Brix. To determine total content of phenols, Boyer and Hai Liu [22] reported a method. Using this method 2 ml of extract was mixed with 10 ml of distilled water. The samples were put in an UV-visible spectrometer (UV2700, Shimadzu, Japan) at room temperature. The absorbance at 765 nm was measured in three replications. Means were calculated from three parallel analyzes as gallic acid equivalents in g/100 g of dry plant material using the following equation:

$$C = a * \gamma * \left(\frac{V}{m}\right) * 100 \quad (4)$$

Where c is total amount of phenol compounds, mg/100g is gallic acid, a is dilatation number, γ is concentration obtained from the calibration curve (mg/ml); V is volume of methanol used for extraction (100 ml) and m is the weight of sample (g).

2.5. Statistical Analysis

The data are expressed as the mean ± standard deviation. Data analyses were performed using Statistical Package for the Social Sciences (SPSS v20). The variance analysis of the data was conducted. The data were collected by three controlling factors: the shadow drying process, the oven drying process and the microwave drying process in order to quality evaluating the drying process of scallion leaves (chemical: pH, TSS, TCP; physical: color, Moisture ratio, drying rate; mechanical: force, deformation, toughness). The least significant difference (LSD) tests was used to compare the means.

3. Results and Discussion

3.1. Drying Characteristic of Scallion Leaves

Drying curves of scallion leaves undergoing different heat processing methods are shown in Figures 2 and 3. Figure 3 illustrates the moisture ratio of scallion samples against time. The drying time is needed up to the moisture content of 9% (w.b) were 370 s, 12.6 h and 92.5 h by using microwave, oven and shadow methods, respectively. Microwave method due to its high and uniform energy level can take the moisture out of the sample more rapid than other methods. The time was too longer for shadow method due to low and fluctuating temperature and humidity during the drying period. Kowalski and Mierzwa [47] reported that although time could be a constraint, but it gives a better preservation of nutrients. The moisture content was very high during the initial phase of the drying which resulted in high drying rates due to the higher moisture diffusion. Generally, the drying rate reached its maximum value after a short heating period then drying took place in the falling rate and constant rate periods in shadow. There was no constant drying rate in microwave and oven methods.

The microwave method is a more effective process because shortens drying time and it can make a balance between drying time and product quality. Moreover, microwaves are able to penetrate a dry surface layer and heat the food throughout all high-moisture regions. This promotes mass transport and increases drying rate [3]. It was mentioned that microwave-assisted drying of biological material can be very risky in order to achieve the best quality of product as microwave ability to localize in the moistest material regions can lead to the destruction of sensitive biological tissue [4]. As expected, drying time and drying rate are highly affected by drying air temperature and when drying air temperature increases it causes increment in the rate of moisture reduction and short drying time, subsequently. On the other word when temperature of air as a drying medium increases, the drying time decreases and drying rate increases. The increase in the drying air temperature makes more temperature difference between the inside of drying product and the surrounding. Therefore, not only the moisture absorption capacity of air but also the rate of water movement increases. Similar results were observed in the previous studies such as: coconut press cake [46], carrot and pumpkin [2], onion slice [21], pomegranate aril [10], nectarine slices [9] and in herbs such as green laird lentil [16] basil, lovage, mint, oregano, parsley and rocket [34].

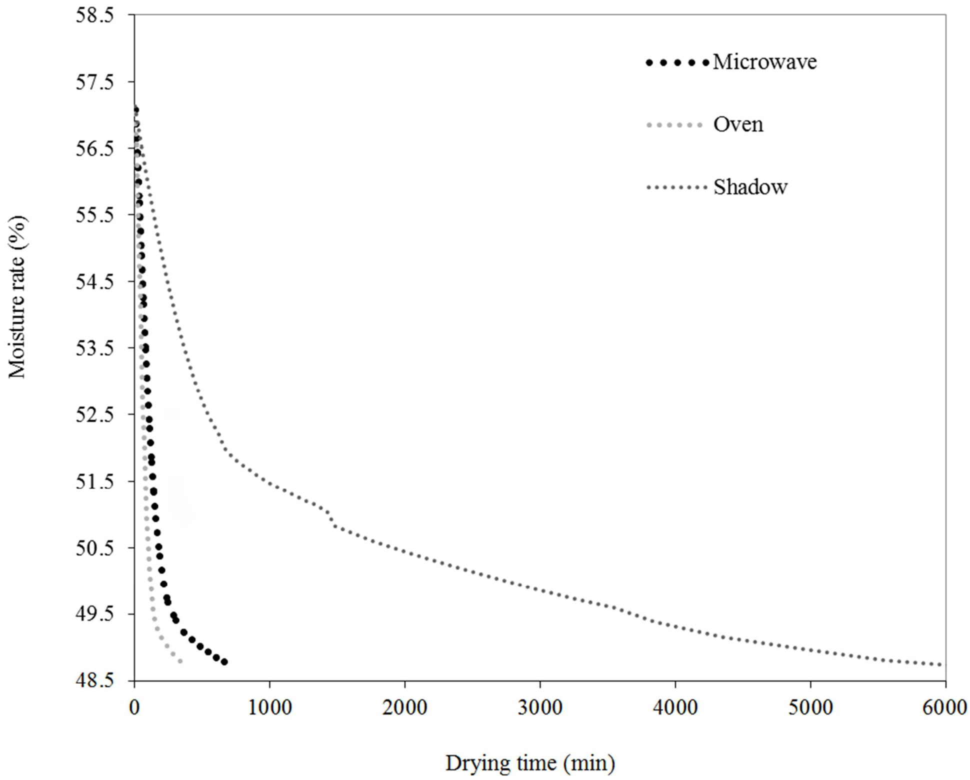

Figure 2. *Effect of different heat processing methods on plant drying time.*

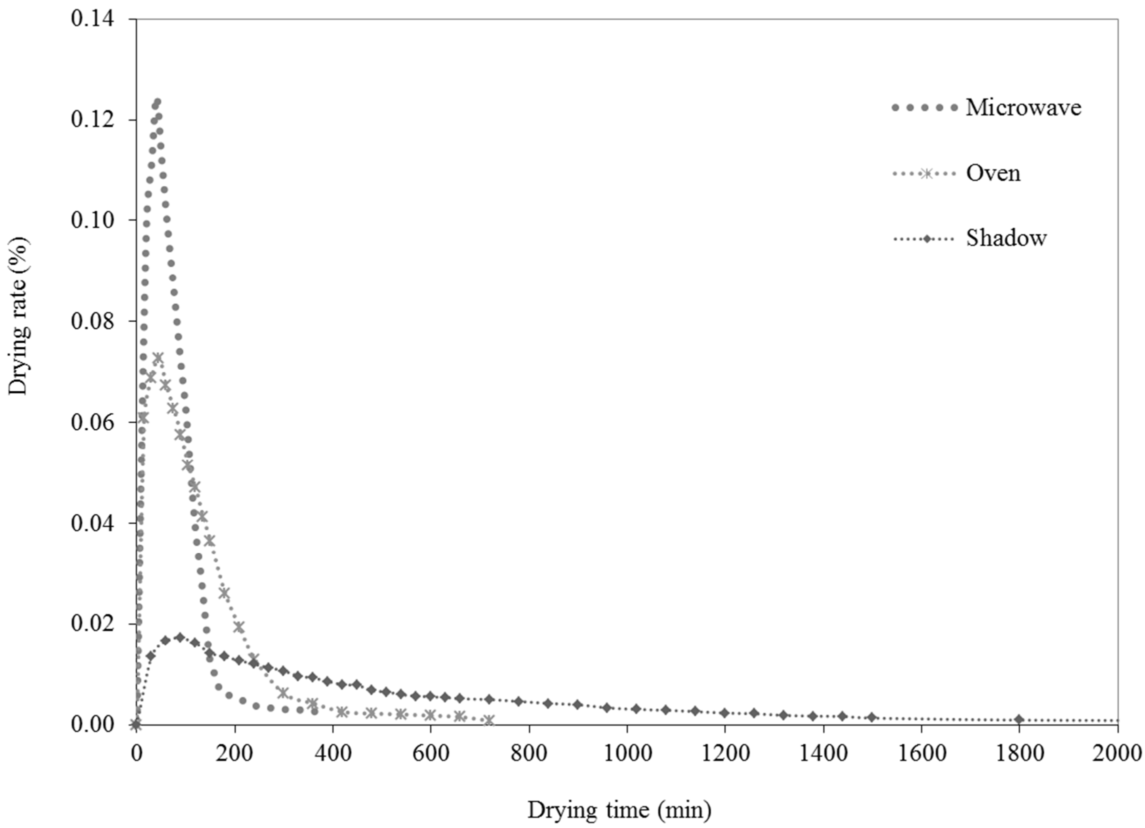

Figure 3. *Effect of different heat processing methods on plant drying rate.*

3.2. Color

Values of color specification of fresh and dried samples in the forms of Hunter L^*, a *, b^* as a result of each drying method are shown in Figure 4. Color changes during drying; occur due to chemical and biochemical reactions. All the color value of scallion leaves increased by drying. The values of ΔE were gained in this study, varied within the range of 7.86 to 12.58. The lowest value of total color difference (7.86) belonged to microwave drying method and the maximum value (12.58) was related to samples subjected to shadow drying. In the case of green leaves of plants, a* has the most importance of green-red color [34]. Green color values (-a*) of fresh and microwave, oven and shadow dried scallion leaves were 15.13, 20.07, 20.45 and 21.93 respectively. Values of L^*, a^* and b^* in shadow dried samples were the highest among the other dried leaves. Leaves were subjected to shade characterized by the remarkable change of color compared with other methods. Generally most of the shadow dried leaves were brighter (high L*), less green (higher –a*) and more yellow (higher +b*) values. The change of green color of dried vegetables is related to the loss of chlorophyll in them. It was found that greater retention of chlorophyll of type was obtained by less change of green color in the direction of red [34]. Results obtained from color-meter showed that microwave drying process causes the least total color difference between fresh and dried plant and keeps the quality of dried leaves in the view of color, so leaves exposed to microwave had the most similar color to fresh ones. It was reported by Krokida and Maroulis [36] that microwave drying method prevented color damages during drying meaning that the final product preserved its greenness in a greater ratio. Doymaz [19] reported that higher L* value is desirable in the dried products, but in the present study, microwave dried samples had most similarity to fresh ones in term of color. Infante et al. [44] reported that color changes in fruits and vegetables can be considered as a result of the magnesium of chlorophyll and it is easily replaced by two hydrogen atoms in the presence of mild acids such as oxalic or acetic acid to produce a compound called pheophytin thus affect the color during the process. Vadivambal and Jayas [45] stated that the color changes that occur in vegetables are generally related to browning reactions which could be either enzymatic or non-enzymatic. They also stated that microwave drying resulted in less browning reactions compared to convective air-drying. These results are similar to the data concerned microwave dried mint [39], coriander [5] and parsley [52].

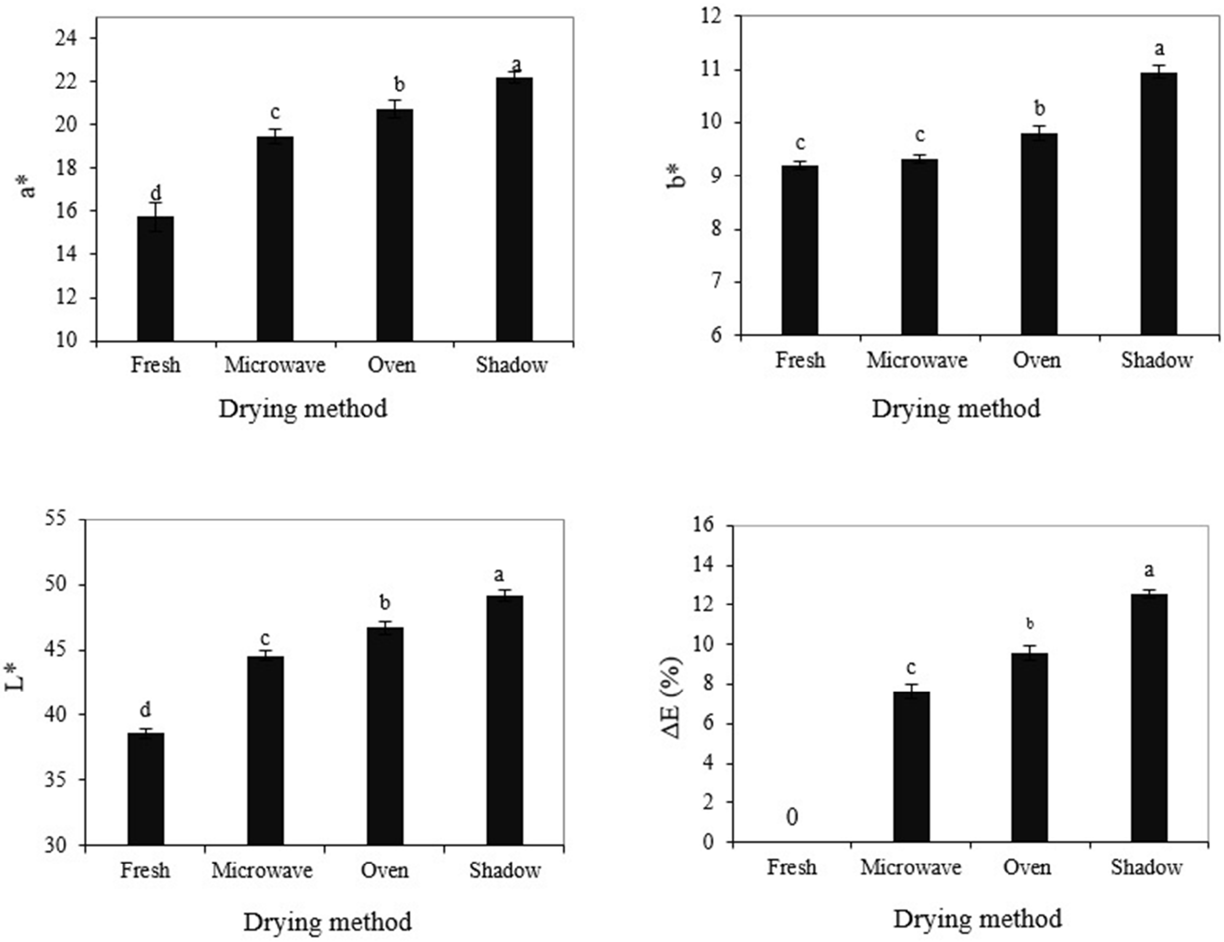

Figure 4. *Color specifications of fresh and dried scallion samples.*

3.3. Maximum Bending Force, Failure Strain and Toughness

The functional relationships (force-deformation curves) obtained from bending test of every dried sample were shown in Figure 5. The force-deformation curve gave a reliable indication of the nature of the failure. Force-deformation curves of microwave and oven dried leaves showed that complete failure occurs with some sudden force drops without notable deformation changes while this curve for shadow dried samples reduced continuously till to zero. In other words, the first maximum force is achieved when the first tissues of leaf are broken; then, it falls instantaneously to grow again after bending the next leaf side.

The relationship between force and deformation of shadow dried sample under three point bending load is downward concavity. It can be mentioned that inside hole of fresh samples subjected to microwave and oven method changed from circular to oval, but shadow dried samples had blunt flat cross-section. The maximum bending force was 0.48 N, belonged to microwave method, and the minimum value was 0.18 N related to shadow dried samples. The results showed that scallion leaves subjected to microwave fractured in lowest amount of deformation (10.88 mm) while the oven dried scallion leaves showed failure in deformation of (12.33 mm) and the failure deformation of shadow dried ones was (17.26 mm). As it shown in Table 1, shadow drying method has the maximum value of toughness and the minimum value was related to microwave process. Toughness is well defined as an energetic measure not a force and fracture toughness (specific work of fracture) is considered as the work needed to produce unit area of surface through propagating a crack at a constant velocity [42]. With this description, shadow produced tougher leaves comparing with microwave and oven. It can be justified in such a way that hollow scallion leaves exposed to shadow, changes to thick flat leaves so the view of energy consumption, shadow samples are energy consuming in failure and grinding, subsequently, however crack in microwave dried samples were deflect more easily. The tubular shape of plant minimizes stresses, but equally important is that it also maximizes flexural rigidity, i.e. minimizes the lengthwise curvature when the tube is subjected to a given bending moment. Aranwela et al. [38] and Niklas [28] stated that determination of the fracture characteristics in tubular type of biomaterial is complex; the values of the forces are relatively small and the leaves are composite materials, the laminar tissues and veins have a variable proportion of cellulose, hemicelluloses, lignin, pectin, and, like the majority of biological materials, are anisotropic and viscoelastic and also depend on the size of biological structures in the test samples.

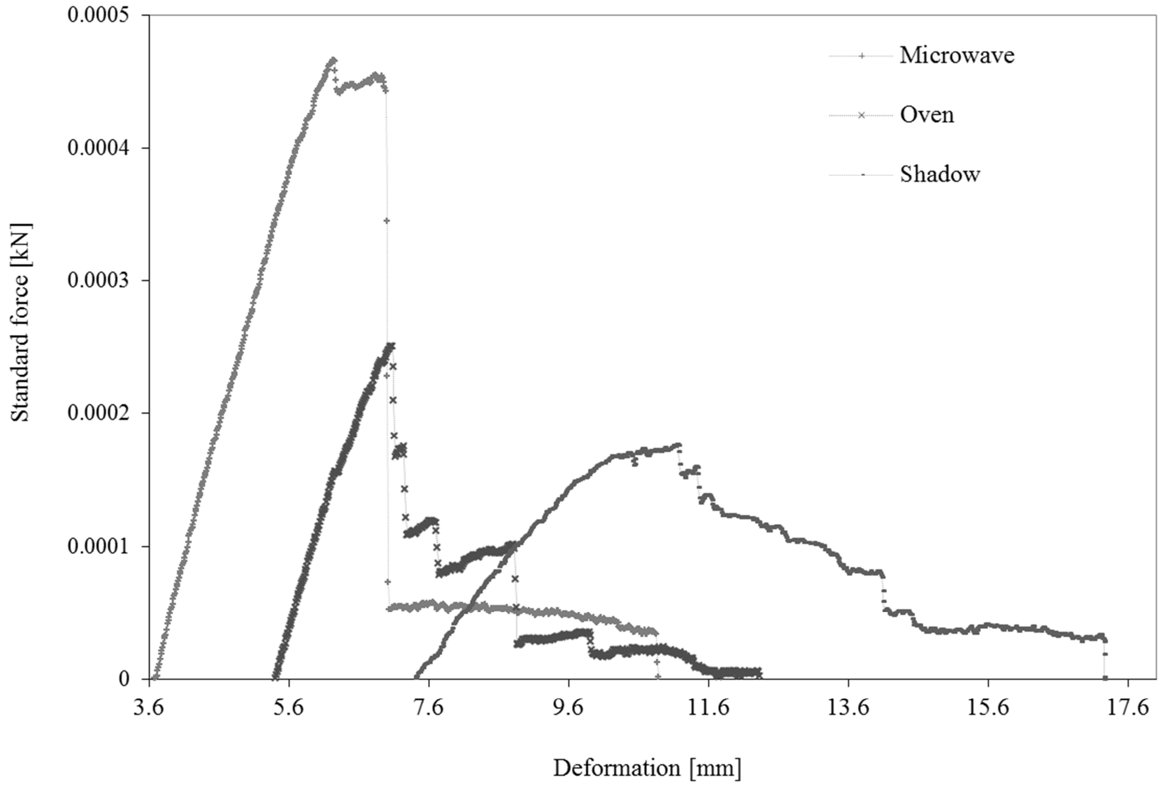

Figure 5. *Effect of different drying methods on rupture force and toughness of dried scallion leaves.*

Table 1. *Maximum force, rupture force and toughness (±sd) of scallion leaves subjected to different drying methods.*

Drying methods	Maximum Force (N)	Rupture Strain	Toughness (N/mm^2)
Microwave	0.48±0.03a	10.88±0.05c	(6.19±0.05)*10-4c
Oven	0.25±0.02b	12.33±0.04b	(6.68±0.07)*10-4b
Shadow	0.18±0.02c	17.26±0.07a	(6.84±0.06)*10-4a

Mean values in a column with different letters are significantly different at p<0.05

3.4. pH, Total Soluble Solid and Total Phenol Content

Drying processes generally resulted in a depletion of pH, soluble solid compounds and total phenol content of fresh plant (Table 2). pH is an important measurement of acidity which impacts the flavor or taste of product. The pH values of microwave, oven and shadow dried samples are about 17.98, 18.14 and 19.74% less than fresh leaves, respectively. The most acidity was observed in shadow dried samples TPC values of microwave, oven and shadow dried samples are about 3.5, 4.3 and 1% less than fresh leaves, respectively.

Table 2. *pH, soluble solid compounds and total phenol content (±sd) of fresh and dried scallion leaves.*

Drying methods	pH	TSS (%Brix)	TPC (mg of 100g gallic acid)
Fresh	6.23±0.06a	20.03±0.15a	0.2±0.1a
Microwave	5.11±0.01b	19.33±0.06c	0.09±0.01c
Oven	5.10±0.02b	19.17±0.06c	0.1±0.01c
Shadow	5.00±0.05c	19.83±0.12b	0.13±0.03b

Mean values in a column with different letters are significantly different at p<0.05

Quantitative evaluation of total phenol in methanolic extracts of fresh scallion leaves revealed that it possessed high TPC; however, different drying treatments were shown to reduce the TPC of dried leaves, significantly. The highest TPC was recorded in plants dried by shadow (0.13 mg/g of fresh plant) and was 35% less than fresh leaves whereas the lowest content was shown by microwave drying (0.09 mg/g of fresh plant) with degradation percent of 55%. It is notable than no significant difference was observed between the values of TPC and TSS of microwave and oven samples. Drying process results in a reduction of naturally occurring antioxidants in raw materials from plants [6]. There could be some explanations for the decrease in TPC of the extracts. Loss of TPC after ambient air assisted drying methods (sun and shadow drying) may be caused by enzymatic processes that occurred during treatment. Air drying cannot immediately deactivate degradative enzymes such as polyphenol oxidases; since, they are able to reduce phenolic compounds before the plant materials are completely dry. Air drying is also affected by climatic factors, which leads to an uneven loss of TPC. Oven heating was found to rapidly inactivate polyphenol oxidases present in plants; however, some of their initial activities may have occurred earlier and caused some polyphenols to be degraded. Microwave heating, brought about by absorption of microwave energy by water molecules, is more energy efficient than conventional heating and it could inactivate degradative enzymes very much faster than oven heating and yet the drastic loss of TPC was observed. Heating treatments not only deactivate enzymes but are also able to degrade phytochemicals. The heat generated from microwave is intense and that may be responsible for the large decline in TPC [53]. Drying of plant and vegetable could result in a decrease or in an increase of the TPC. Thus, Chan et al. [17] stated that all heat processing methods (microwave, oven, and sun drying) resulted in sharp declines in TPC in dried leaves of *Kaempferia galanga*, *Alpinia zerumbet*, *Curcuma longa* and. *Etlingera elatior* also, these authors reported that in the non-thermal drying methods, significant losses were observed in air-dried leaves. Similar results were reported by López et al. [23] described important losses of vitamin C and TPC in 'O'Neil' blueberries as air drying temperature increased. In another investigation, the highest TPC was shown by microwave drying of *Phyllanthus amarus* extracts and the lowest TOC belonged to air dried extracts [53]. TPC increased considerably in oregano and peppermint leaves when they were subjected to drying at ambient air. The obtained data are also in accordance with [1, 12, 17]. No significant difference was observed for lemon balm [15]. This investigation clearly explains that the drying process resulted in low levels of TPC depending on the type of drying method.

4. Conclusion

Microwave drying of plants can be considered as a technique permitting the obtainment of material with high quality. The very short time of the drying process in microwave can be an economic factor and incentive for the application of this heat processing method on an industrial scale. In the view of physical attributes, fresh scallion subjected to microwave method, has the least total color difference after drying. Mechanically, fracture toughness of microwave dried samples is less than others; however from the point of preservation of leaves ingredients, shadow method is most effective The results indicated that the microwave drying was the most effective drying process since the best conditions of dried scallion leaves is accessible to grind to produce powder. Using microwaves leads to a substantial improvement of the product quality.

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