Effect of drying treatments on texture and color of vegetables (pumpkin and green pepper)

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Abstract

The present work evaluates the effect of different drying treatments on the color and textural attributes of green bell peppers and pumpkin, which were dried using two different methods: air drying and freeze-drying. The treatments in air drying were carried out at 30°C and 70°C.

From the results it is possible to conclude that the increase in drying temperature reduced drastically the hardness of green peppers and the freeze drying had an intermediate effect between vegetables dried at 30°C and 70°C. Moreover, the springiness was higher in dried green peppers but an opposite effect was observed on chewiness. With respect to pumpkin, any dependence between the fiber orientation and the hardness of the fresh vegetable was not found. In addition, increasing temperature from 30°C to 70°C particularly reduced the hardness and the chewiness of dried product and maintained cohesiveness and springiness approximately constant.

Regarding the color, it was possible to conclude that air drying at 30°C produced small changes in color of green pepper whereas air drying at 70°C and freeze drying originated more intense color changes. The increase of temperature on air drying augmented the color saturation of dried pumpkin while decreased the hue angle by a linear relationship. In addition, the chroma of dried pumpkin decreased significantly with the freeze drying, while the hue angle was maintained constant as compared with the fresh vegetable.

Keywords: Green pepper; Pumpkin; Hardness; Texture; Color; Air drying; Freeze drying

1. Introduction

Portuguese cuisine is rich in using fresh vegetables, such as pumpkin (Cucurbita maxima L.) and green pepper (Capsicum annuum L.), on soups, salads, sauces, packet food, desserts and many convenience foods. However, their processed form is scarce in the market. Therefore, the drying, which is one of the oldest methods for food preservation, may represent a possible method to commercialize these vegetables.

The chemical composition, associated to the antioxidants and vitamins, makes these two vegetables important in the diet, either for their nutritional value or health protective functions. The bright orange color indicates that the pumpkin is high in β-carotene, an important carotenoid precursor to vitamin A in the human body (Weinstein et al., 2004). During the last few years bell pepper has gained consumer interest due to their vitamin and antioxidant contents (Penchayya et al., 2009; Simonne et al., 1997; Vega-Gálvez et al., 2008). Bell peppers present different nutritional compositions, depending on the variety and stage of maturity, but are naturally also rich in ascorbic acid, provitamin A carotenoids and minerals that have an important health-protecting effect (Faustino et al., 2007).

Bell peppers, like other vegetables, are quite perishable, originating high losses due to storage problems and marketing, among others. An alternative to the consumption of fresh vegetables is their dried form, which allows their use during the off-season. The most popular drying process uses convection through hot air, but high temperatures can change the composition and the nutritional value as well as physical properties, density, porosity, mechanical properties and organoleptic quality of the products. Despite the high costs...
and time consuming of freeze drying, this process generates minor changes in color, flavor, chemical composition and texture (Nawirska et al., 2009). For a consumer, the color of a product is a primary perceived characteristic that plays an important role on food. Apart from the perceived primary characteristics, texture and flavor play also an important role on the acceptability of foods by the consumers. Texture is the result of complex interactions among food components at a microstructural level and at higher structural levels as, for instance, the structure of the tissue (cellular orientation, porosity) and the different types of tissues or organs that constitute food materials (Aguilera and Stanleym, 1999; Mayor et al., 2007).

Hence, it is crucial to determine and control the color and texture of the processed foods. The changes of color can be related with the degradation of carotenoids during processing that have important antioxidant properties (Gonçalves et al., 2007). In what concerns texture, this implies knowledge about changes in the mechanical properties because they are related with the textural and sensorial characteristics of the food. Several authors have studied the changes of the mechanical properties of food during convective drying and, in general, they found that a soft product (fresh) is transformed into a rigid product (dried). Alternatively it changed from a predominantly plastic behavior to a more elastic behavior (Telis et al., 2005). The fresh pumpkin has values ranging from 0.96 to 2.53 for apparent modulus of elasticity, 250–630 kPa for failure stress, 0.42–0.71 for failure strain and 85–285 kJ/m3 for toughness and their failure mode is fiber debonding (Mayor et al., 2007).

The present work aimed at studying the effect of freeze-drying and air drying at different temperatures on the color and texture of pumpkin and green pepper. Texture attributes (hardness, adhesiveness, springiness, cohesiveness, and chewiness) were estimated after measurements made with a texturometer.

2. Experimental

2.1. Drying procedures

Pumpkin and green bell pepper were purchased in a local market, washed and cut to samples of approximately 2 cm × 2 cm and dried in ventilated oven and freeze drier. For the drying of pumpkin only the pulp was used, whereas the bell pepper was dried with skin.

For the convective drying, an electrical stove WTB Binder with ventilation was used. The stove was operated at constant temperatures of 30–C, 50–C and 70–C, and the air flow was 300 m3/h.

For the freeze drying, the samples were frozen in a conventional kitchen freezer, and then left in the freeze-drier (model Table Top TFD5505) for 38 h at a temperature between −47–C and −50–C, and a pressure of 5 mTorr (0.666 Pa).

Table 1 shows the conditions of each drying trial, for comparison purposes.

2.2. Texture measurements

For determining the textural properties of pumpkin, texture profile analysis was carried out on cylindrical samples removed at 1, 3 and 4 cm of the skin and on axial and radial directions as illustrated in Fig. 1.

Measurements to the fresh green pepper were done on both sides of the pepper tissue, that is to say, from the skin (external) and the flesh (internal) sides.

Texture profile analysis (TPA) to all the samples was performed using a Texture Analyser (model TA.XT.Plus). The texture profile analysis was carried out by two compression cycles between parallel plates performed on cylindrical samples (diameter 10 mm, height 3 mm) using a flat 75 mm diameter plunger, with a 5 s of time between cycles. The parameters that have been used were the following: 5 kg force load cell and 0.5 mm s−1 test speed.

The textural properties: hardness, springiness, cohesiveness, and chewiness were calculated after Eqs. (1)–(4) (see Fig. 2):

\[
\text{Hardness}, H = F_1
\]

\[
\text{Springiness}, S = \frac{\Delta T_2}{\Delta T_1} \times 100
\]

\[
\text{Cohesiveness}, C = \frac{A_2}{A_1}
\]

\[
\text{Chewiness} = H \times S \times C
\]

2.3. Color measurements

The color of the fresh and dried samples was assessed using a handheld tristimulus colorimeter (Chroma Meter – CR-400, Konica Minolta) calibrated with a white standard tile. A CIE standard illuminant D65 was used to determine CIE color space coordinates, \(L^*a^*b^*\) values. This system is suggested by Mendoza et al. (2006) as the best color space for quantification in foods with curved surfaces. These Cartesian coordinates can be used to calculate the polar or cylindrical coordinates: \(L^*H^*C\), with \(H^*\) representing the hue angle and \(C\) the chroma, as defined by Eqs. (5) and (6):

\[
H^* = \arctan(b^*/a^*)
\]

\[
H^* = 180^\circ + \arctan(b^*/a^*)
\]

\[
H^* = 270^\circ + \arctan(b^*/a^*)
\]

\[
H^* = 360^\circ + \arctan(b^*/a^*)
\]

The total color change (\(\Delta E\)), was the parameter considered for the overall color difference evaluation, between a dried sample and the fresh vegetable (designated with an index 0) in Eq. (7):

\[
\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2}
\]

Fresh vegetables were used as the reference and a larger \(\Delta E\) denotes greater color change from the reference material.

3. Results and discussion

3.1. Texture measurements

Table 2 resumes the values of the textural properties for green bell pepper calculated from the compression TPA curves (through Eqs. (1)–(4)). The parameter hardness can be related to the force performed by mastication that takes part during
Table 1 – Experimental conditions of the different dryings tested.

<table>
<thead>
<tr>
<th></th>
<th>Freeze drying</th>
<th>Convective drying</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td>≈−50 °C</td>
<td>≈30 °C</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>0.7 Pa</td>
<td>Atmospheric</td>
</tr>
<tr>
<td><strong>Air velocity</strong></td>
<td>–</td>
<td>≈0.5 m/s</td>
</tr>
<tr>
<td><strong>Drying time</strong></td>
<td>38 h</td>
<td>40 h</td>
</tr>
<tr>
<td><strong>Initial moisture</strong></td>
<td>Pumpkin: 90%</td>
<td>Pumpkin: 90%</td>
</tr>
<tr>
<td></td>
<td>Pepper: 95%</td>
<td>Pepper: 95%</td>
</tr>
<tr>
<td><strong>Final moisture</strong></td>
<td>Pumpkin: 8%</td>
<td>Pumpkin: 7%</td>
</tr>
<tr>
<td></td>
<td>Pepper: 7%</td>
<td>Pepper: 10%</td>
</tr>
</tbody>
</table>

Fig. 1 – Sample preparation in pumpkin.

With respect to the results obtained, it was possible to see that rupture of the skin from the flesh side required a lower force (10.9 N) when compared with the same action from the skin side (13.8 N). In the first bite the fresh green pepper requires a much higher energy than the dried vegetable, which means that drying makes the product softer. For example, comparing the fresh (internal) pepper with the pepper dried at 30 °C, the hardness decreased from 10.9 N to 0.7 N, which was a very extreme change. Moreover, the increase in temperature for the air drying of the bell pepper, also produced a pronounced effect on firmness with a decrease from 0.7 N at 30 °C to 0.3 N at 50 °C, corresponding to 60% reduction over a

Fig. 2 – Illustration of a texture profile analysis, and variable definition.
The fresh pumpkin to that dried at 30°C from 50°C. However, the freeze drying treatment also induced a pronounced softening of the pepper, although not so intense as the air drying does. In fact, the freeze dried pepper shows a hardness of 1.4N, representing a decrease of 90% relative to the fresh product, but higher than the samples dried by convection, either at 30°C or at 50°C.

From the results presented in Table 2, it can be observed that in general, the air convection of green pepper at 30°C and 50°C had a small effect on cohesiveness and springiness as compared with the fresh vegetable. However, springiness, which is a measure of the recovery in height after the compression during the mastication, was higher for the green peppers dried at higher temperatures. As to cohesiveness, it also increased from the fresh state to the dried one as well as increased with drying temperature. Regarding chewiness, it diminished greatly with drying and drying temperature, as a result of the variation observed previously in hardness.

As to the comparison between the two drying methods tested, the results showed a trend for texture of green peppers to be more sensitive to air convective drying, and particularly at the highest temperature, than the freeze drying.

Table 3 shows the textural attributes of fresh pumpkin for samples taken at different distances from the skin (as shown in Fig. 1), and with different orientations (axial or radial). At each position analyzed, 1, 3 and 4 cm from the skin, the results showed small differences between both directions. This means that there is no dependence of hardness on the fiber orientation, that is to say that the maximum force needed for the first bite is approximately the same independently of the orientation of the bite. The medium values of hardness for the fresh pumpkin were 12.4, 20.0 and 32.6 at 4, 3 and 1 cm of the skin, respectively. However the results also showed that hardness was very dependent of the distance from the skin. This can be attributed to the heterogeneous composition of the flesh of the pumpkin from skin to seeds. In fact, the flesh of the pumpkin was considerably harder than the pulp near the centre.

Table 4 illustrates the textural properties of pumpkin in the fresh form and dried with convective and freeze drying. The compression was performed on axial direction and at 3 cm of the skin during all the tests. The results show that the fresh pumpkin had a much higher hardness (19.4N) when compared to the dried samples (varying from 6.6N at 30°C and 0.3N at 70°C). For example, the reduction in hardness from the fresh pumpkin to that dried at 30°C was 66%, which was the same reduction from 30°C to 50°C (2.2N). As to the reduction from 50°C to 70°C it was greater, 86%, thus indication that higher temperatures have a more pronounced effect on the softening of the pumpkin pulp. Furthermore, the freeze drying treatment produced pumpkin with firmness equal to 1.6N, higher than the sample dried at 70°C, but smaller than the sample dried at 50°C. Finally, the freeze drying treatment also induced a pronounced softening of the pumpkin, representing a decrease of over 90% relative to the fresh product.

The results in Table 4 also show that the cohesiveness of pumpkin remained approximately constant after drying, with just a slight increase, which means that fresh and dried pumpkins have similar strengths of internal bonding. Based on the values found for springiness, it is also possible to conclude that drying (convective air drying and freeze drying) did not alter significantly the capacity of the pumpkin to return to its original shape after deformation. An exception was observed for the product dried at 30°C, which showed a lower value for springiness that those to all other cases. Furthermore, the drying of pumpkin reduced significantly the chewiness of the pumpkin, once again due to the intense diminishing in the hardness, as observed earlier. Finally, comparing the freeze dried pumpkin with that dried by convection, it is possible to see that the values encountered for the different texture parameters are situated between those of the samples dried at 30°C and those dried at 70°C.

### 3.2. Color measurements

Table 5 shows the CIELAB color parameters for the green bell pepper, in the fresh form and after drying with different conditions. The values for the L*, a* and b* coordinates of the fresh green pepper were 37.22, −14.11 and 22.52, respectively. In general, the air drying at 30°C produced no remarkable changes in the color parameters of peppers, as compared with the fresh vegetable. However, the increase of temperature from 30°C to 70°C allowed both coordinates L* and a* to rise and b* coordinate to decrease. In particular, the greenness parameter (a*) presents a mean value about 3 times higher than the mean value obtained for the samples of pepper dried at 30°C, indicating that the samples dried at 70°C presented a much lesser intensity of the green color than the fresh product. The dried vegetable at 70°C turns the final product lighter and less green (pale yellow color) with L*a*b* coordinates with values of 40.59, −4.35 and 18.27, respectively. The decrease of a* and b* values may be due to decomposition of chlorophyll and other pigments, and non-enzymatic reactions (Maskan, 2001). Hence, with the high air temperature the rate of color degradation became faster as a result of the high energy transferred to the food material. The freeze drying caused a more pronounced lightening of vegetable surface and a less loss of green color (L* = 44.12, a* = −12.11, b* = 19.59).

The results for chroma and hue angle show color stability for the samples dried at 30°C and a decrease of the color intensity of the vegetable when dried at 70°C, shifting towards the slightly yellow region. These color alterations may be explained by heat carotenoid degradation as stated by Gonzalves et al. (2007). The freeze drying treatment has a small effect on chroma of the product. The hue angle of fresh bell pepper was about 122°, which represents a color in the yellow/green region (hue angle between 90° and 180°).

The total color difference ΔE, which is a combination of the L*, a* and b* values, as given by Eq. (7), is a colorimetric param-
The color difference parameter had extensively used to characterize the variation of color in foods during processing. The color difference parameter had a value of 0.5 to the pepper dried at the lower temperature of 30°C and raised to 11.1 at the highest temperature of 70°C. The freeze drying treatment induced a decrease in the intensity of color between those of the air drying at 30°C and at 70°C (ΔE = 7.8).

The average values of the color parameters for pumpkin in fresh, and after air and freeze-drying are presented in Table 6 for L* (brightness), a* (redness), b* (yellowness), chroma, hue angle and color change. The fresh pumpkin exhibited a light yellow color, with L*, a* and b* equal to 68.97, 18.21 and 49.82, respectively. The results show a decrease of the L coordinate and an increase of a* and b* with the increasing of air temperature. However, the effect of temperature was smaller in L coordinate than in a* and b* parameters, which turned the samples more reddish and yellowish as the temperature raises. Comparing the two methods of drying it is possible to conclude that the lightest dried pumpkin was obtained by freeze drying. From the values of chroma and hue angle for the fresh and dried pumpkin is possible to see that he increase of temperature from 30°C to 70°C increased the color saturation while diminished the hue angle. The increase in temperature from 30°C to 70°C has changed the color difference parameter from 7.6 to 13.5, and the freeze drying made the samples more dully than the fresh pumpkin allowing a color difference of 12.4.

### Table 3 - Textural attributes of fresh pumpkin at different locations and different orientations (in brackets the standard deviation associated to each value).

<table>
<thead>
<tr>
<th>Property</th>
<th>Orientation</th>
<th>Distance from the skin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 cm</td>
</tr>
<tr>
<td>Hardness (N)</td>
<td>Axial</td>
<td>33.088 (4.855)</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td>32.015 (4.992)</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>Axial</td>
<td>0.552 (0.016)</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td>0.477 (0.035)</td>
</tr>
<tr>
<td>Springiness (%)</td>
<td>Axial</td>
<td>71.577 (1.098)</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td>57.469 (3.254)</td>
</tr>
<tr>
<td>Chewiness (N)</td>
<td>Axial</td>
<td>13.077 (2.001)</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td>8.726 (1.145)</td>
</tr>
</tbody>
</table>

### Table 4 - Textural attributes of pumpkin after different drying treatments for axial samples taken at 3 cm (in brackets the standard deviation associated to each value).

<table>
<thead>
<tr>
<th>Property</th>
<th>Orientation</th>
<th>Distance from the skin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 cm</td>
</tr>
<tr>
<td>Hardness (N)</td>
<td>Axial</td>
<td>19.372 (1.437)</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td>6.579 (1.146)</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td>2.195 (0.464)</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td>0.287 (0.135)</td>
</tr>
<tr>
<td></td>
<td>Freeze dried</td>
<td>1.594 (0.581)</td>
</tr>
</tbody>
</table>

### Table 5 - Color of pepper before and after different drying treatments (in brackets the standard deviations).

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Chroma</th>
<th>Hue angle</th>
<th>∆Ε</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>37.224 (3.652)</td>
<td>−14.110 (1.665)</td>
<td>22.523 (4.949)</td>
<td>26.578</td>
<td>122.066</td>
<td>−</td>
</tr>
<tr>
<td>Dried (30°C)</td>
<td>37.176 (1.962)</td>
<td>−14.257 (1.278)</td>
<td>23.013 (2.542)</td>
<td>27.072</td>
<td>121.779</td>
<td>0.514</td>
</tr>
<tr>
<td>Dried (70°C)</td>
<td>40.589 (3.072)</td>
<td>−4.353 (1.940)</td>
<td>18.273 (5.115)</td>
<td>18.784</td>
<td>103.398</td>
<td>11.162</td>
</tr>
<tr>
<td>Freeze dried</td>
<td>44.122 (0.786)</td>
<td>−12.107 (2.083)</td>
<td>19.587 (4.720)</td>
<td>23.027</td>
<td>121.721</td>
<td>7.760</td>
</tr>
</tbody>
</table>

### Table 6 - Color of pumpkin before and after different drying treatments (in brackets the standard deviations).

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Chroma</th>
<th>Hue angle</th>
<th>∆Ε</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>68.972 (1.969)</td>
<td>18.213 (0.714)</td>
<td>49.818 (2.220)</td>
<td>53.043</td>
<td>69.918</td>
<td>−</td>
</tr>
<tr>
<td>Dried (30°C)</td>
<td>65.320 (3.096)</td>
<td>24.290 (2.381)</td>
<td>52.413 (4.728)</td>
<td>57.767</td>
<td>65.135</td>
<td>7.550</td>
</tr>
<tr>
<td>Dried (70°C)</td>
<td>63.385 (3.096)</td>
<td>24.290 (2.381)</td>
<td>52.413 (4.728)</td>
<td>57.767</td>
<td>65.135</td>
<td>7.550</td>
</tr>
<tr>
<td>Freeze dried</td>
<td>77.703 (0.787)</td>
<td>15.249 (1.301)</td>
<td>41.435 (0.974)</td>
<td>44.152</td>
<td>69.795</td>
<td>12.462</td>
</tr>
</tbody>
</table>

4. Conclusions

From the results of the present work it was possible to conclude that drying temperature reduced drastically the hardness of green peppers and the freeze drying had an intermediate effect between vegetables dried at 30°C and 70°C. In addition, the springiness was higher in dried green peppers though an opposite effect was observed on chewiness. With respect to pumpkin, it was not observed dependence between fiber orientation and the hardness of the fresh vegetable. Furthermore, the drying of pumpkin reduces particularly the hardness and the chewiness of dried product but cohesiveness and springiness remain approximately constant.

With respect to color, the results obtained for the green pepper enable us to conclude that the air drying at 30°C produced very small changes in color whereas the air drying at 70°C originated more intense color changes. The values of L* have raised, while values of a* and b* have decreased during hot air drying. The color change of freeze dried peppers was small, as compared with the vegetables dried at high tem-
perature. The increase of temperature on air drying increased the color saturation of dried pumpkin while it decreased linearly the hue angle. Moreover, the chroma of dried pumpkin decreased significantly with the freeze drying while the hue angle was maintained constant when compared with the fresh vegetable.

References


