Vacuum frying of high-quality fruit and vegetable-based snacks

Paulo F. Da Silva, Rosana G. Moreira*

Department of Biological and Agricultural Engineering, Texas A&M University, College Station, TX 77843-2117, USA

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Abstract

Sweet potato, green beans, Tommy Atkins mango, and blue potato were fried in a vacuum frying process at a temperature of 120–130 °C. Before frying, green beans and mango slices were soaked in a 50% maltodextrine 0.15% citric acid solution. The products were also fried in a traditional (atmospheric pressure) fryer at 160–165 °C for 4 min. A 30-member consumer panel rated the sensory quality of both types of fried snacks using a 1–9 hedonic scale. Compared with traditional frying, oil content of vacuum-fried sweet-potato chips and green beans was 24% and 16% lower, respectively. Blue potato and mango chips had 6% and 5% more oil, respectively, than the traditional-fried samples. Anthocyanin (mg/100 g d.b.) of vacuum-fried blue potato chips was 60% higher. Final total carotenoids (mg/g d.b.) were higher by 18% for green beans, 19% for mango chips, and by 51% for sweet-potato chips. Sensory panelists overwhelmingly preferred (p < 0.05) the vacuum-fried products for color, texture, taste, and overall quality. Most of the products retained or accentuated their original colors when fried under vacuum. The traditional-fried products showed excessive darkening and scorching. These results support the applicability of vacuum frying technology to provide high-quality fruit and vegetable snacks.

Keywords: Vacuum frying; Fruit and vegetables; Oil content; Vitamin; Sensory

1. Introduction

For decades, consumers have desired deep-fat fried products because of their unique flavor—texture combination, ranging from potato chips, French fries, doughnuts, extruded snacks, fish sticks, and the traditional-fried chicken products. In 2000, Americans spent $110 billion on fast foods, with fried foods playing an important role. Americans consume about three hamburgers and four servings of French fries per week (Schlosser, 2001). However, the increased awareness of consumers to the relationship between food, nutrition, and health has emphasized the need to limit oil consumption, calories originating from fat, and cholesterol among others.

Today, consumers are more interested in healthy products that taste good. Fried products are produced today using non-hydrogenated oil, and contain no saturated fat and no trans-fats. Some of these products (sweet-potato chips, apple chips, potato chips-blue) are fried under vacuum yielding less oil absorption (taste less greasy) with higher retention of their natural color and flavors.

Vacuum frying is an efficient method of reducing the oil content in fried snacks, maintaining product nutritional quality, and reducing oil deterioration. It is a technology that can be used to produce fruits and vegetables with the necessary degree of dehydration without excessive darkening or scorching of the product. In vacuum frying operations, food is heated under reduced pressure [<60 Torr ~ 8 kPa] causing a reduction in the boiling points of the oil and the moisture in the foods (Shyu, Hau, & Hwang, 1998).

French fries processed in a vacuum fryer can achieve the necessary degree of dehydration without excessive darkening or scorching of the product. Garayo and Moreira (2002) showed that vacuum fryers could produce potato chips with lower oil content (30% less) and the same texture and color characteristics of those fried in conventional (atmospheric) fryers. Ophithakorn and Yamsaengsung (2003) proved that
vacuum frying produces lighter color tofu products with lower oil contents. The frying oil showed lower amounts of free fatty acid (FFA) and a slightly lighter color after 30 batches of frying. Yamsaengsung and Rungsee (2003) found that vacuum-fried potato chips and guava slices had lower oil content and more natural colorations than those fried in conventional fryers.

Granda, Moreira, and Tichy (2004) demonstrated that vacuum frying could also produce potato chips with 97% less acrylamide content, a potential carcinogenic found in fried snacks, than the traditionally fried chips. Preliminary kinetic studies (Granda & Moreira, 2005) of acrylamide formation during frying indicate that the rate of acrylamide formation during frying behaves differently under vacuum and conventional frying. Granda, Moreira, and Castell-Perez (2005) showed that both glucose and asparagine are responsible for the formation of acrylamide in fried products. However, medium to high glucose content resulted in higher acrylamide content compared with medium to high asparagine content.

Fruits and vegetables are source of many vitamins and antioxidants. However, the average American consumer eats only about three servings of fruits and vegetables a day, according to the US National Cancer Institute (http://progressreport.cancer.gov/) (2007 trends — fruits and vegetables consumption). Consumers often find it difficult to eat more fruits and vegetables because they believe they are too expensive, spoil too quickly, or take too long to prepare. There are many high nutritious vegetables and fruits that could be vacuum fried: fava beans, broccoli, cauliflower, carrots, pineapple, mango, etc. Many countries in Asia (Japan, Thailand, Taiwan) are using this technology to produce high nutritious snacks. This technology is expected to improve the Nation’s nutrition and health by producing products that taste good, keep most of their nutrition values, have lower fat content than the conventionally fried snacks, are safer with little or no acrylamide formation, and keep longer.

Carotenoids make corn yellow, carrots orange, and tomatoes red. More than 600 carotenoids have been found in plants. About half of the roughly 50 carotenoids in the human diet are absorbed into the blood stream. Lycopene and beta-carotene each constitutes about 30% of plasma carotenoids. Only alpha, beta, and a few other carotenes (not lycopene or lutein) can be converted to Vitamin A. Both alpha-carotene and beta-carotene are protective against liver cancer and lung cancer in cell culture and animal studies. Heating frees-up carotenoids, especially beta-carotene and lycopene. Carotenoids are nearly insoluble in water and are best absorbed when associated with oils.

Anthocyanins (flavonoids polyphenolics) are water-soluble glycosides and acyl-glycosides of anthocyanidins, making them susceptible to losses during the frying process. Anthocyanins make cherries and strawberries red and blueberries blue. Anthocyanins have anti-inflammatory effects.

The length of time and the method of frying are important factors that affect phytochemical/nutraceuticals stability (Shirsat & Thomas, 1998).

Therefore, the objective of this study was to compare the changes in product quality attributes (PQA) such as color, texture, phytochemicals, and oil content, and sensory characteristics for different fruits and vegetables (sweet potato, blue potato, mango, and green beans) fried in vacuum and traditional fryers.

2. Materials and methods

2.1. Raw material

Tommy Atkins mangoes (Mangifera indica), green beans (Phaseolus vulgaris), and sweet potatoes (Ipomoea batatas) were all acquired from local stores in College Station, Texas. The blue potatoes (Solanum tuberosum) were provided by the Texas A&M University Potato Variety Development Program.

2.2. Sample preparation

All products (with exception of green beans) were peeled and then sliced to 1.5 mm thickness (Mitutoyo Thickness Gage, Japan) using a Mandolin Slicer (Matfer model 2000, France).

2.3. Osmotic dehydration

Based on preliminary results, green beans and mangoes were soaked in a 50% maltodextrin (Cargill Dry MD 01913, Cargill, Minneapolis, MN)—0.15% citric acid solution for about 1 h before frying. These compositions provided products with better color and texture. Maltodextrin was used to increase the solid content of the products and improve texture and the acid citric to decrease discoloration (Lombard, Oliveira, Fito, & Andres, 2008). The parameters of the osmotic dehydrate paper measured were water activity, pH, and degree-Brix. Water activity determinations were done using a Novasina Thermostanometer (model TH2/RTD-33/BKS, Novasina CO). Soluble solid content (Brix) was measured in a refractometer (ABBE ATAGO model 3T, Bellevue).

2.4. Frying experiments

2.4.1. Vacuum frying

A detailed description of the process is described elsewhere (Garayo & Moreira, 2002). Fig. 1 illustrates a schematic of the vacuum system. The vacuum vessel was set to the target temperature and allowed to operate for 1 h before frying started. Fresh canola oil was used in all experiments. The volume of oil used was 7.5 L.

The process (operating at $P < 10$ Torr $= 1.33$ kPa) consisted of loading the products into the fryer basket (about 50 g per batch), closing the lid, and then depressurizing the vessel. When the pressure in the vessel achieved vacuum, the basket was submerged into the hot oil. Once the products were fried, the basket was raised, the vessel pressurized up to atmospheric pressure, the samples blotted dry with paper towels to remove excess oil, and stored in polyethylene bags inside of a desiccator for further analysis. Three replications (three batches of 50 g) were used in this study.
2.4.2. Atmospheric frying

A bench type electric fryer (Hobart model HK3-2, Hobart Corp., Troy, Ohio) with a frying oil capacity of 7.5 L was used in this study. About 50 g of products per batch were loaded into the fryer baskets and then immersed into the hot oil for a specified time. The vegetables were then blotted dry with paper towels to remove excess oil. Three replications (three batches of 50 g) were used in this study.

Table 1 shows the experimental conditions for the vacuum and traditional frying. Frying time and temperatures were chosen based on preliminary trials. Note that for the traditional-frying procedure, the temperature used is based on commercially procedures for frying potato chips \( (165 \, ^\circ C) \) \cite{Garayo2002}. In addition, frying at atmospheric pressure requires higher temperature to produce products with the same cooking and crispness characteristics than vacuum frying. These conditions were selected based on product characteristics in terms of low oil content, color, and desired crispness (crunchier). Fig. 2 shows pictures of sweet-potato preparation (top pictures) and fried chips in vacuum and traditional fryers (bottom pictures).

2.5. Product quality attributes

2.5.1. Oil content

The Soxtec System HT extraction unit (FOSS, Eden Prairie MN) was used to determine the oil content of the samples using petroleum ether as solvent \cite{AACC1986}. Measurements were made at least in triplicate.

2.5.2. Moisture content

Moisture content of fried samples was measured using a vacuum oven (Squared Lab Line Instruments, Melrose Park, IL, USA), according to \textit{AOAC} (1990) method 930.04. Measurements were made at least in triplicate.

2.5.3. Color

A Labscan XE colorimeter (Hunter Lab, Inc., Reston, VA, USA) with the Universal v. 3.73 software was used to evaluate the fried products color using the CIELAB system. The measuring aperture diameter was 36 mm, the illuminant was the D65, and 10° for the observer. The colorimeter was calibrated using standard white and black tiles. Five randomly samples were evaluated and five readings were recorded as an average reading. Mean values of the coordinates \( L^{*} \) (lightness—darkness), \( a^{*} \) (redness—greenness), and \( b^{*} \) (yellowness—blueness) were used to determine the color of the produce through reflectance mode.

2.5.4. Texture

A three-point bending rig (support span of 16 mm), mounted in a TA XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) was used to determine the force required to break the fried snacks. A steel blade of 3 mm thickness with flat edge was used to fracture (snap) the samples at a constant speed rate of 10 mm/s. The force (N) at the fracture point (highest value in the plot) was used as the resistance to breakage. About 10 replications were used in this experiment.

2.5.5. Total content of monomeric anthocyanins

In this study, total anthocyanin content was used as a nutrition index for blue potato. The pH-differential method \cite{Wrolstad2002} was used to measure the total content of anthocyanins.
Fig. 2. Sample preparation to make sweet-potato chips. Top: (a) raw material; (b) cross section cut of raw sweet potato; (c) slice cut to precise diameter and thickness; and (d) thickness determination. Bottom: (a) slices are placed in the basket of vacuum fryer; (b) vacuum-fried sweet-potato chips; (c) slices immersed in the oil of a traditional fryer; and (d) traditional-fried sweet-potato chips.
monomeric anthocyanins in fried blue potatoes. This method permits accurate and rapid measurement of the total anthocyanins even in the presence of polymerized degraded pigments and other interfering compounds.

Appropriate dilutions of the methanolic extract were made in potassium chloride buffer pH 1.0, and sodium acetate buffer pH 4.5 and allowed to rest for at least 15 min. The absorbance of each dilution was measured at the λ_{vis-max} and at 700 nm (to correct for haze) against a blank cell filled with distilled water (using a UV-1601 Spectrophotometer (Shimadzu Corp., MD)).

The absorbance of the diluted sample (A) was calculated by

$$A = (A_{\lambda\text{vis-max}} - A_{700})_{\text{pH}=1} - (A_{\lambda\text{vis-max}} - A_{700})_{\text{pH}=4.5}$$  

(1)

The monomeric anthocyanin pigment concentration in the original samples was obtained by using Eq. (2) assuming a path length of 1 cm:

$$\text{MAC (mg/L)} = \left(\frac{A \times M_w \times D_f \times 1000}{\epsilon \times 1}\right)$$  

(2)

where $M_w$ is the molecular weight, $D_f$ is the dilution factor, and $\epsilon$ is the molar absorptivity. Cyanidin-3-glucoside was chosen as the reference pigment: $M_w = 449.2$ g/mol and $\epsilon = 26,900 (10^5 \text{ L/mol cm})$.

2.5.6. Total carotenoid content

In this study, total carotenoid content was chosen as a nutrition index for green bean, mango, and sweet potato. Total carotenoid content was determined by spectrophotometric measurements using a UV-1601 Spectrophotometer (Shimadzu Corp., MD) at 450 nm following the methodology cited by Rodríguez-Amaya (1989) with slight modifications. Fifty milliliters of acetone were added to about 1 g of fried samples previously ground in Erlenmeyer flasks. The flasks were closed and allowed to rest in a dark place at 22 °C for 24 h. The solution was then filtered using a Whatman® filter paper #4. The extract solution was then placed in decantation flasks and 50 mL of petroleum ether was added to it. The residue was washed with approximately 5–7 washes of 100 mL distilled water. At the end, a small amount of sodium sulfate was added to the decantation flask to bind any remaining water. The carotene extract was recovered by concentration of the previous extract in a Rota-vapor-R110 (Brinkman Instruments, Westbury, NY) at 32 °C for 10 min to evaporate all the petroleum ether and any remaining acetone. The spectrophotometric determination of the samples was made by diluting the previous concentrate with hexane (EM Science, Gibbstown, NJ). The tests were conducted in triplicate at 22 °C.

The total carotenoid content was determined by a standard curve where beta-carotene was used as standard.

3. Sensory analysis

A 30-member consumer panel, consisted of faculty, students, and staff of Texas A&M University, rated the sensory quality of the fried vegetables (snacks) on the following attributes: color, odor, texture, flavor, and overall quality.

The samples from each produce were placed in capped glass containers and presented to each panelist at once. They were presented in containers labeled with a random three-digit number and randomly displayed. Between samples, the panelists were asked to drink some water.

A nine-point hedonic scale was used to evaluate the samples as described by Carr, Meilgaard, and Civille (1999). A score of 1 represented attributes most disliked and a score of 9 represented attributes most liked. Scores higher or equal to 5 were considered acceptable.

4. Statistical analysis

Data analysis was performed using SPSS software for Windows, v. 11.5.1 (SPSS 2002). The effect of the treatment (traditional frying or under vacuum) was evaluated. Differences among product quality attributes and sensory attributes were tested for significance ($p < 0.05$) by one-way analysis of variance (ANOVA).

5. Results and discussion

5.1. Oil content

Fig. 3 shows the effect of frying technique on the amount of oil absorbed. Sweet potatoes and green beans fried under vacuum showed less oil (24% and 16% less, respectively) content than those fried in the traditional fryer. In the case of blue potatoes and mangoes, the traditional-frying method resulted in lower oil content, around 5–6% less, but these values were not significantly different ($p < 0.05$). The mechanism of oil absorption under vacuum is still not clear (Garayo & Moreira, 2002). The amount of moisture removed during both processes was similar for all products (Table 1), indicating that the product structure and composition are more important than the moisture removed during the process. Visual inspection (Fig. 4) showed that the vacuum-fried blue potato chips had

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**Fig. 3.** Comparison between oil content of product fried in vacuum and traditional fryers (white-bar: traditional fryer; and black-bar: vacuum fryer).
Fig. 4. Color differences between products fried under vacuum and traditional fryers. Top: (a) blue potato fried in the vacuum fryer; (b) blue potato fried in the traditional fryer; (c) sweet potato fried in the vacuum fryer; and (d) sweet potato fried in the traditional fryer. Bottom: (a) mango fried in the vacuum fryer; (b) mango fried in the traditional fryer; (c) green bean fried in the vacuum fryer; and (d) green bean fried in the traditional fryer.
large numbers of small pockets (filled with oil) at the surface compared to the traditional-fried samples. On the other hand, the traditional-fried sweet-potato chips had large pockets formed at the surface compared to the ones fried at vacuum. In the case of mango chips, more investigation is needed to understand the composition and structure of raw materials on the oil absorption during vacuum frying.

In general, the traditional-frying process for manufacturing chips (for example potato and tortilla chips) uses temperatures as high as 195 °C (Moreira, Castell-Perez, & Barrufet, 1999). The higher temperature is used to provide the fastest cooking and dehydration rates that would ultimately result in the correct microstructure (porosity), color, lower oil content, and crispness. Frying at lower temperature in traditional fryers is not possible because it would negatively affect all these quality product attributes (Moreira et al., 1999).

When frying under vacuum, a much lower temperature can be used (Garayo & Moreira, 2002) without affecting the product qualities. This is possible because as the water boiling point in vacuum frying is reduced, the water vapor in the product leaves earlier but at the same rate than in the traditional fryers thus resulting in a high-quality final product.

That is the reason why the temperature and frying time differ when frying these products in the different frying methods. Sweet potato, for example, requires higher temperature and shorter time to produce the best quality attributes than the other products when fried under vacuum. Blue potatoes, on the other hand, needed 400 s at 120 °C to produce good chips. Green beans were fried for longer time than mangoes at the same temperature.

In the case of the traditional-frying process, we selected a lower oil temperature that would not burn the products. The blue potato was fried at the shortest and the green beans at the longest time. Mangoes and sweet potatoes were fried for the same time, but the final moisture content was higher for sweet potato (lower moisture would result in much higher oil content). Compared to the vacuum frying process, the blue potatoes fried faster in the traditional fryer probably due to the higher oil temperature. The other products required longer times to produce acceptable final products and all the sensory attributes were worst for all products fried in the traditional fryer.

In conclusion, raw material characteristics (composition, shape, etc.) affect the selection of the right frying time and oil temperature when operating any frying process.

Tables 2 and 3 show the results obtained for the mango and green bean samples’ pre-treatment. After osmotic dehydration, the mango slices lost about 28% of water and gained 6.75% of maltodextrin. The green beans lost around 7% of water, but absorbed 9.65% of sugar during the process. The effect of osmotic dehydration on the final product quality needs further investigation.

5.2. Color

There were significant differences (p < 0.05) for lightness ($L^*$), green—red chromaticity ($a^*$), and blue—yellow chromaticity ($b^*$) for most products, with exception of sweet-potato chips. The mango chips and green beans fried under vacuum had $L^*$ values that were significantly higher (p < 0.05) than the values corresponding to the potato chips fried under the atmospheric condition (Fig. 5). A higher $L^*$ value indicates a lighter color, which is desirable in these products.

The $a^*$ values were significantly higher (p < 0.05) for mango chips and green beans fried at atmospheric pressure than for those fried at the vacuum conditions, indicating more Maillard reaction occurred at the atmospheric frying conditions (Fig. 5).

The blue—yellow chromatically ($b^*$) values were also significantly (p < 0.05) higher (more yellow than blue) for the mango chips and green beans fried at vacuum pressure than for those fried at atmospheric conditions (Fig. 5).

In the case of sweet-potato chips, the vacuum-fried product was lighter and more yellow than the products fried in the traditional fryer, but no significant differences (p < 0.05) in $a^*$ (redness) values were obtained with the Labscan XE colorimeter. For the blue potato chips, the significant differences (p < 0.05) were observed in the blue—yellow chromatically ($b^*$) and in the $a^*$ (redness) values. The blue potatoes fried under vacuum showed higher $b^*$ values (more blue) and lower $a^*$ values (less red) compared to those fried at atmospheric pressure (Fig. 5).

To better interpret color in terms of sensory properties, we also calculated the psychophysical magnitudes of the hue angle $h_{ab} \left[^\circ \right]$ ($h_{ab} = \arctan \left( b^*/a^* \right)$), a value of 0° indicating pure red, and a value of 90° indicating pure yellow, and the chroma $C_\ast ^\ast \left[\%\right]$ ($C_\ast ^\ast = \left( a^{\ast 2} + b^{\ast 2} \right)^{0.5}$, increasing values indicating increasing saturation). Results shown in Table 4 indicate that the mangoes and green beans fried in the vacuum fryer were more yellow (mango) and closer to green-hue (green bean) than the ones fried in the vacuum fryer. The chroma values indicated that the mangoes and the green beans were more saturated when fried in the vacuum fryer. The values for hue and chroma for the vacuum-fried sweet potatoes indicated more yellow and more saturated than those fried in the atmospheric fryer. The vacuum-fried blue potato chips showed a blue hue.

<table>
<thead>
<tr>
<th>Products</th>
<th>pH</th>
<th>$a^*$</th>
<th>Degree-Brix [g/g]</th>
<th>MC [g/100 g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before OD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mango</td>
<td>3.48 ± 0.01</td>
<td>0.98 ± 0.01</td>
<td>12.77 ± 0.01</td>
<td>85.87 ± 0.28</td>
</tr>
<tr>
<td>Green beans</td>
<td>6.15 ± 0.01</td>
<td>0.98 ± 0.01</td>
<td>5.00 ± 0.01</td>
<td>88.90 ± 0.78</td>
</tr>
<tr>
<td>After OD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mango</td>
<td>3.46 ± 0.01</td>
<td>0.97 ± 0.01</td>
<td>20.33 ± 1.04</td>
<td>77.67 ± 0.43</td>
</tr>
<tr>
<td>Green beans</td>
<td>5.43 ± 0.01</td>
<td>0.99 ± 0.01</td>
<td>14.67 ± 0.29</td>
<td>79.84 ± 0.40</td>
</tr>
</tbody>
</table>

Table 2

Product quality attributes of mango and green beans before and after osmotic dehydration (OD)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mango</th>
<th>Green bean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar gained [g/100 g initial product]</td>
<td>2.52</td>
<td>9.65</td>
</tr>
<tr>
<td>Water lost [g/100 g initial product]</td>
<td>27.96</td>
<td>6.75</td>
</tr>
</tbody>
</table>

Osmotic dehydration process: maltodextrin solution 50% (w/w); time = 1 h; $T = 25.0 ± 0.1\ ^\circ$C; 1:10 product/sugar solution ratio.
and slightly less saturated chroma than the ones fried in the traditional fryer.

Visual observations (Fig. 4) confirmed the results obtained with the colorimeter. The products fried under atmospheric conditions were darker and more red in color than the products fried under vacuum. Most of the products retained or accentuated their original colors when fried under vacuum. The traditional-fried product showed excessive darkening or scorching, especially for the mangoes and green beans. The vacuum frying method clearly reduced color degradation due to the absence of oxidation during the process.

5.3. Texture

During frying, most of the water is removed from the products resulting in textural changes. Fig. 6 shows the effect of frying method on the texture characteristics of mango, green bean, sweet potato, and blue potato at the end of frying. The frying method did not cause significant differences on the force required to break the products ($p < 0.05$) for the products fried at vacuum and atmospheric conditions.

5.4. Total carotenoid and monomeric anthocyanins content

Table 5 shows the effect of frying methods on carotenoids and anthocyanins content or the selected products by the end of frying.

Both frying methods caused a decrease in carotenoids and anthocyanins content. However, the products fried under vacuum had higher content of these phytochemicals. The retention of total carotenoids (Fig. 7) in fried mango, green beans, and sweet potato was 20–50% higher when these products were vacuum fried than processed in the traditional fryer. Caixeta, Moreira, and Castell-Perez (2001) showed that Vitamin C degradation in dried potato slices was the result of not only the high processing temperature but also the oxidative...

Table 5

<table>
<thead>
<tr>
<th>Produce</th>
<th>Total carotenoids [µg/g d.b.]</th>
<th>Total anthocyanins [mg/100 g d.b.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum fryer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue potato</td>
<td>37.71 ± 0.16$^a$</td>
<td>57.28 ± 0.23</td>
</tr>
<tr>
<td>Green bean</td>
<td>66.61 ± 0.38$^a$</td>
<td>340.06 ± 2.35</td>
</tr>
<tr>
<td>Mango</td>
<td>14.67 ± 0.52$^a$</td>
<td>51.29 ± 0.73</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>189.99 ± 1.66$^a$</td>
<td>440.50 ± 2.35</td>
</tr>
<tr>
<td>Traditional fryer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue potato</td>
<td>15.00 ± 0.09$^b$</td>
<td>57.28 ± 0.23</td>
</tr>
<tr>
<td>Green bean</td>
<td>54.63 ± 0.42$^b$</td>
<td>340.06 ± 2.35</td>
</tr>
<tr>
<td>Mango</td>
<td>11.85 ± 0.05$^b$</td>
<td>51.29 ± 0.73</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>92.67 ± 0.58$^b$</td>
<td>440.50 ± 2.35</td>
</tr>
</tbody>
</table>

Means within a column which are not followed by a common superscript letter are significantly different ($p < 0.05$).
effect of the drying air. Similarly, in this study the higher temperature and the presence of oxygen in the traditional fryer contribute to the degradation of carotenoids in mango, green bean, and sweet potato as compared to the vacuum process. Carotenoids’ degradation between vacuum and tradition frying was clearly observed in sweet-potato chips (Fig. 7), with ~45% carotenoids retention under vacuum compared to 20% under atmospheric pressure.

The total monomeric anthocyanins retention (Fig. 7) for fried blue potato was 60% higher for the samples fried at vacuum than those fried at atmospheric pressure. Anthocyanins have been shown to be destroyed in the presence of oxygen and often result in loss of color (Fig. 4), functional properties, and nutritional quality (Garcia-Viguera & Bridle, 1999).

5.5. Sensory evaluation

Panelists’ scores (Fig. 8) indicated a stronger preference for the vacuum-fried products over the traditional ones. The panelist showed greater preference for the mango and green beans fried under vacuum than the traditional fryer. In the case of blue potato chips, the most important characteristics were the color and flavor of the product fried under the two methods. For the sweet-potato chips, color was also the most important parameter for quality. In general, the overall acceptability of the vacuum-fried products was strongly correlated to the color of the final products. As seen in Fig. 4, the traditional-fried products showed poor color (appearance) quality in comparison to the vacuum-fried ones.

6. Conclusions

In general, vacuum-fried snacks retain more of their natural colors and flavors due to the less oxidation and lower frying temperature.

Oil content of vacuum-fried sweet-potato chips was significantly ($p < 0.05$) lower than traditional-fried products. Blue potato and mango chips showed no significant ($p < 0.05$) differences in oil content for each frying method. Anthocyanin and total carotenoids content were significantly ($p < 0.05$) high for the products fried in the vacuum fryer than those in the traditional fryer. The texture characteristics of the products for both frying methods were not significantly different. There were significant differences ($p < 0.05$) for lightness ($L^*$), green-red chromaticity ($a^*$), and blue-yellow chromaticity ($b^*$) for most products.

Sensory panelists overwhelmingly preferred ($p < 0.05$) the vacuum-fried products for color, texture, taste, and overall quality. No color degradation was observed on the vacuum-fried products. The traditional-fried products showed excessive darkening or scorching.

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References


