Vacuum frying of peas: effect of coating and pre-drying

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Abstract The objective of the research was to compare the effect of coating with sodium carboxymethyl cellulose, hot-air and vacuum microwave pre-drying on the physicochemical properties and sensory scores of vacuum-fried peas. The three pre-treatments prior to frying were shown to obviously reduce oil absorption in vacuum-fried peas. Among the three pre-treatments, coating with sodium carboxymethyl cellulose for peas produced the lowest oil content products (24.53 %), and the chlorophyll retention was 77.08 %. Vitamin C and breaking force for fried products with vacuum microwave pre-drying were 46.56 $\mu\text{g}/100\text{ g}$ (db) and 8.64 N, which were significantly ($P \leq 0.05$) better than those of other treatments. However, fried peas treated by hot air pre-drying showed the highest breaking force and lowest chlorophyll retention. All the fried peas had water activity (A_w) values of less than 0.35, indicating that the products have a long shelf life. Sensory scores showed vacuum-fried peas treated by vacuum microwave pre-drying had the highest acceptability.

Keywords Coating · Hot-air · Vacuum microwave · Pre-drying · Vacuum frying · Peas · Oil absorption

Introduction

Pea is a kind of leguminous plants, abundant in protein and carbohydrate that makes a useful contribution to the nutritional requirement. Dried peas are easily transported and don't require specialized storage, which allows them to be used in off-season when demand is high, and the ability to produce a wide variety of snack food also adds value to the peas.

Vacuum frying under negative pressure reduces the oil penetrating into the material and the deterioration and oxidation of the frying oil, resulting in good fried food products (Da Silva and Moreira 2008), which may be a promising technology for production of vegetables with low oil content, desired texture and flavor characteristics. Additionally, vacuum frying can preserve natural color and reduce the generation of toxic molecules in the foodstuff, such as acrylamide (Granda et al. 2004) due to low temperature and oxygen conditions. Some vegetables contain pigments, such as chlorophyll, which is instable during frying (Niu et al. 2011). Therefore, some pre-treatments are needed before frying to protect the color. Excessive consumption of oil, especially, saturated fat, is related to health problems associated with obesity, coronary heart disease, hypertension and so on (Dueik et al. 2010). Appreciative consumer's preference for low-fat products has been the driving force of the food industry to produce lower oil uptake products while maintaining the desirable organoleptic qualities (Pedreschi and Moyano 2005).

Several factors, such as oil quality, samples' shape, initial moisture content, initial porosity, pre- and post-treatments, frying time and temperature have strongly affected oil absorption (Bouchon and Aguilera 2001). Furthermore, Fan et al. (2005) showed that with the increasing frying oil temperature and vacuum degree, the rate of fat absorption of vacuum fried products increased. It indicated that oil absorption occurs when water evaporates from the samples (Moreira et al. 2009). Before frying, drying for potatoes using microwave,

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hot-air treatment and baking resulted in a significant reduction in oil content of different products (Moyano et al. 2002). Food hydrocolloids, such as gums, methyl cellulose, have been widely used as multifunctional additives in food processing to improve stability, modify the surface and control the moisture content (Chaisawang and Supphantharika 2005). It was showed that coating with 1 % (m/v) pectin solution for bananas chips decreased the oil content in fried bananas chips by approximately 23 % (Singthong and Thongkaew 2009). Sothornvit (2011) showed that banana chips coated with guar gum and using the higher speed during the oil centrifuge step in vacuum frying maintained a good quality with low oil content.

Vacuum frying technology has been extensively investigated for fruit and vegetables, for example, vacuum frying of potato chips (Pedreschi et al. 2007), apple chips (Mariscal and Bounchon 2008), carrot chips (Fan et al. 2005), mango chips (Nunes and Moreira 2009) and green beans (Da Silva and Moreira 2008). Previous researches emphasized on frying chips, however, there was no literature concerning the vacuum frying of peas, especially when the raw material was dried peas. Considering of the shape of samples, comparing the effect of the three pre-treatments for peas, coating with sodium carboxymethyl cellulose, pre-dried by hot-air and vacuum microwave on the changes of moisture and oil content during the vacuum frying process would be a breakthrough. Furthermore, the physicochemical properties of final vacuum-fried peas, such as Vitamin C content, chlorophyll retention, texture, color, water activity and sensory evaluation were also reported in this paper.

Materials and methods

Materials Dried peas and palm oil were offered by Wenzhou Chanmao Food Ltd. Co., and dried peas were stored in dry place at room temperature.

Pre-treatments Dried peas were dipped in water for 8 h at 25 °C until they were fully bibulous, afterwards, rehydrated peas were immersed in 2 % Na₂CO₃ solution for 30 min, blanched in hot water at 95 °C for 2 min and cooled by flowing cold tap water for 3 min. The treatments were divided into groups: (1) blanched samples were considered as the control; (2) coating with sodium carboxymethyl cellulose (CMC): blanched peas were immersed in a dilute CMC solution (0.5 % m/v) at 25 °C for 2 h; (3) hot-air pre-drying (HAD): blanched peas were placed in convection oven at 100 °C for 30 min; (4) vacuum microwave pre-drying (VMD): blanched peas were arranged in one single layer on a tray, and dried in a vacuum microwave dryer, which power output at 343±2.2 W and vacuum degree was set at 60 kPa for 8 min. Before frying, pre-treated peas were frozen under -18 °C for 12 h. Freezing before frying could fix the shape

of peas, and ice crystals could be formed. During Frying, when oil temperature rose high enough to the boiling point of water, ice crystals were sublimated rapidly, so lots of pores were left, which increased the crispness of peas.

Frying experiments The experiments were performed using a vacuum fryer (Fig. 1, Nanfeng Light Machinery Company, Wuxi, Jiangsu, China), which has a capacity of 15 L and a maximum temperature and vacuum degree of 150 °C and 95 kPa respectively. The frying process consists of loading 100 g peas each time. Once the oil temperature reached 105 °C, the peas were placed into the basket, the lid closed, the vacuum pump opened until the vacuum degree reached 80 kPa. At this moment, the basket was immersed into the oil (5 L). Once the products were fried, the basket was raised and the vessel pressurized up to atmospheric pressure (Garayo and Moreira 2002). A centrifuging step (450 rpm for 8 min) before pressurizing the vessel after frying was added and its aim is to remove the excess surface oil. Afterwards, the peas were removed from the basket, allowed to cool to room temperature, and stored in polyethylene bags inside of desiccators for analysis. The moisture and oil content of the peas were measured at 0, 2, 4, 8, 12, 16 and 20 min of frying. On the other hand, color, chlorophyll retention, Vitamin C content, texture, water activity and sensory evaluation were measured at 20 min of frying.

Product quality attributes

Moisture ratio Samples (approximately 3 g, weighed by a digital balance) were dehydrated to constant weight for 4–5 h at 105 °C in the drying oven. The moisture ratio was calculated by following equation. Triple tests were carried out.

$$\text{Moisture ratio} = \frac{M_t - M_e}{M_0 - M_e} = \frac{M_t}{M_0} \quad (M_e \rightarrow 0) \quad (1)$$

Where t (min) was frying time; M_t (g/g) was the moisture content at time t; M₀ (g/g) was the initial moisture content and M_e (g/g) was the equilibrium moisture content.

Oil content The vacuum-fried peas were ground and oven dried. Oil content of peas was determined by Soxhlet extraction with petroleum ether. The test was performed in triplicate.

Color The color was measured using a Minolta spectrophotometer (CM-3600D, Minolta, Co. Ltd. Japan). The measuring aperture diameter was 10 mm, and the colorimeter was calibrated by a standard white board. Color was reported as lightness-darkness (L*), redness-greenness (a*), yellowness-blueness (b*). The overall color differences (ΔE*) were

Fig. 1 Schematic diagram of the vacuum frying system. 1. Frying basket, 2. Vacuum fryer, 3. Oil storage reservoir, 4. Condenser, 5. Segregator, 6. Vacuum pump, 7. Electric motor

estimated from the coordinates of the color by applying the following Eq. (1). Fifteen random samples were evaluated, and the mean values of L^* , a^* and b^* were recorded.

$$\Delta E^* = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (2)$$

Chlorophyll retention Ground peas were immersed in organic solvent acetone until the extraction of chlorophyll from the disrupted cells into it. The extract was then analyzed by spectrophotometric method, and visible ultraviolet spectrophotometer (Day Beauty science instrument Co., LTD, Shanghai, China) measured the absorbance of light by chlorophyll at 663 nm and 645 nm. The chlorophyll content and retention were obtained using the following equations.

$$\text{Chlorophyll content (mg/100g)} = \frac{(20.2 \times \text{Abs}_{645} + 8.02 \times \text{Abs}_{663}) \times V \times n}{m} \quad (3)$$

$$\text{Chlorophyll retention} = \frac{W_t}{W_0} \times 100\% \quad (4)$$

Where V = the volume of extract (L); n = dilution coefficient; m = the dry weight of samples (g); W_0 = the initial chlorophyll content of peas (mg/100 g) and W_t = at time t the chlorophyll content of samples (mg/100 g).

Vitamin C content Vitamin C content of fried peas, which were oil-free, was measured by 2, 4-dinitrophenyl hydrazine colorimetry (Fan et al. 2005).

Texture The crispness in texture of vacuum-fried products was measured by a Texture Analyzer (TA-XT2i, Stable Micro Systems Ltd., Surrey, United Kingdom) fitted with a cylindrical stainless probe (P/5). The pre-speed, test-speed and post-speed were 1.5, 1.0 and 5.0 mm/s, respectively. The force (N) at the broken point (high value in the plot) was used as the resistance to the breakage. Ten replications were used in this experiment.

Water activity (A_w) The A_w of vacuum-fried peas was measured using a Novasina ms-1 (NOVASINA Company,

Switzerland) with a measurement range of 0.03–0.098 A_w . Novasina ms-1 has a sensitive component that is a resistance, and the resistance value of sensor changes with the saturated vapor pressure of samples. Finally, sensor changes the A_w into electrical signal and outputs the data. The test was performed in triplicate.

Sensory evaluation Fifty panelists were selected to evaluate the quality of vacuum-fried peas based on appearance, color, flavor, texture, oiliness and overall acceptability. The scores were assessed using a 9-point hedonic scale. Each sample was presented to the panelists for identification. Spring water was provided between samples for mouth rinsing by each panelist.

Statistical analyses

Data were analyzed using SPSS 11.5, and analysis of variance (ANOVA) was conducted. Mean values were considered significantly different when $p \leq 0.05$.

Results and discussion

Changes in moisture ratio (M_t/M_0) during frying process of peas

The changes in moisture ratio during frying process of peas in four conditions were shown in Fig. 2. The loss of moisture during frying exhibited a classical drying profile. In vacuum frying operation, the wet solid samples were heated under reduced pressure (80 kPa) in a closed system that lowered the boiling points of water (about 61 °C) in the food. From the figure, at the beginning of 4 min, the free water evaporated from the peas rapidly. The drying rate of the control was the highest for its high initial moisture content, while coating with CMC could decrease the rate of moisture loss. This could be attributed to the fact that CMC coatings provided effective moisture retention of the peas due to a strong interaction of hydrogen bonds between water molecules (Akdeniz et al. 2006). With the increasing frying time, the loss of surface and unbound inner water increased. After 20 min, the moisture level in the products was so low that the drying rate decreased entering the falling rate period. The moisture ratio of fried peas coated with CMC reached the balance of 0.032, which was highest among all. Peas pretreated by HAD and

VMD kept lower initial moisture content than the control, beside that, when frying was finished, the moisture ratio were 0.026, 0.003 and 0.029 respectively.

Changes in oil content during frying process of peas

Figure 3 showed the changes in oil content during frying processing of peas. It can be observed that within the first 4 min, the oil absorption of peas increased as frying time is increasing. This coincided with the period of time at which water evaporated from the peas at the fastest rate (Fig. 2). The oil adhered on the food surface first, and then sucked into the voids of the food. Therefore, the oil absorption is a surface phenomenon, which is related to the equilibrium between the adhesion and drainage of oil after that the food has been removed from the oil bath. Comparing to the control, peas coated with the CMC exhibited a reduction in oil absorption with content of 24.53 %. This result correlated with previous studies for CMC having the ability to form edible coatings to barrier lipids into peas (Albert and Mittal 2002). On the other hand, coating altered the water holding capacity by trapping moisture inside and prevented the replacement of water by oil (Varela and Fiszman 2011), which gave its potential to reduce oil uptake in fried products. Peas treated with HAD and VMD also could reduce the oil uptake compared to untreated products, and the oil content was 28.98 %, 26.34 % and 36.45 % respectively. It might suggest that the initial water content of samples affected the oil absorption of products, where high initial free moisture content resulted in high final oil content (Moreira et al. 1997). We could come to the conclusion that the three pre-treatments could decrease the oil content of fried peas.

A_w of fried peas

Water activity affects the stability of dehydrated products, because it determines both chemical reaction rates and microbial activity. The limiting value of A_w for the growth of any microorganism is around 0.6. In the present work, all the fried peas had A_w values of less than 0.35, which is a good indicator of the potential of vacuum frying to maintain quality and prolong the shelf life of the product (Fig. 4).

Color and chlorophyll retention of fried peas

In general, color provides an important measurement for determining changes for acceptability by consumers. Chlorophyll of peas is fragile and easily altered or destroyed during process (Koca et al. 2006). Table 1 showed the color changes of fried peas after different treatments. The degradation of chlorophyll had a big impact on a^* and b^* values. From the table, we could know that a^* value of hot-air pre-dried peas was -6.89 and the chlorophyll retention (Fig. 5)

Fig. 2 Changes in moisture ratio (M_t/M_0) during vacuum frying of peas in four experimental conditions

was the minimum due to damage of chlorophyll at high temperature. Besides, a^* value was -10.34 in fried peas, treated by VMD. The chlorophyll retention of fried peas treated with CMC coating, HAD, VMD were 77.08 %, 62.50 %, and 72.91 %, respectively. Vacuum microwave technology did not only keep the color of products, but also decreased the activity of enzyme to prevent browning. CMC formed coatings, which could avoid the contact of oxygen with the surface of peas, resulting in retention of good color. It was also found the ΔE^* values after different treatments and the control treatment different ($p \leq 0.05$). Considering the color, both coating and VMD had an advantage over HAD.

Vitamin C content of fried peas

Vitamin C is an important composition of green peas, which is useful to people's health. Vitamin C is water soluble and is easily oxidized to unstable dehydroascorbic acid (Darias et al.

Fig. 3 Changes in oil content during vacuum frying of peas in four experimental conditions

Fig. 4 A_w and breaking force of vacuum-fried peas in four experimental conditions after frying 20 min

2011). The content of Vitamin C of fried peas was shown in Fig. 5. Vitamin C contents in the fried peas by different pre-treatments (coating with CMC, HAD and VMD) were 43.83 µg/100 g (db), 34.78 µg/100 g (db) and 46.56 µg/100 g (db), respectively, and they were lower than that of the control (53.23 µg/100 g (db)). Vitamin C entered into water, when peas were dipped into CMC solution, and was oxidized during HAD, resulting in the reduction of content, while the samples pre-dried under vacuum conditions without oxygen retained more the content of Vitamin C.

Texture of fried peas

During frying, moisture is removed from the peas resulting in textural changes, and crispness is another important quality factor of most fried food products (Sothornvit 2011). The breaking force or hardness is an indicator of the extent of crispness, and the texture of fried peas by different treatments was shown in Fig. 4. Peas coated with CMC showed a higher breaking force than the control, the reason might be that the coated samples formed a rigid, resistant film on the surface of the peas that protected the structure during frying, so CMC could provide protection against mechanical damage. Conversely, the peas treated by VMD were the crispiest, because during the process, the more irregular pores formed result in good crispness of the products. Peas treated by HAD

Fig. 5 Chlorophyll retention and Vitamin C content of vacuum-fried peas in four experimental conditions after frying 20 min

were the hardest, because the microstructure of peas was characterized by tight packing and strong connection between cells, which decreased the amount of pores during vacuum frying. The break force of fried peas as control was less than treated products except for vacuum microwave pre-treated due to the highest free water contained in the control, and more pores came into being when water evaporated during frying.

Sensory evaluation of fried peas

A sensory analysis was performed to determine the consumer preference of vacuum-fried peas. The panelists overwhelmingly preferred the vacuum-fried peas for color, texture, flavor and overall quality. Results showed that the panelists liked the products as indicated by overall acceptability scores (Fig. 6). All groups received scores of over 5 on a 1–9 point hedonic scale. No significant differences were found in flavor, appearance or color detected by the judges, since vacuum frying can preserve the natural color and flavor of peas. In addition, vacuum-fried peas treated by the VMD had the lowest hardness value among all. All panelists considered that the untreated peas tasted oily after vacuum frying compared to others, which indicated that coating and pre-frying could reduce the oil absorption. Still, a conclusion could be made based on sensory evaluation that the vacuum-fried peas

Table 1 Color changes of peas in four experimental conditions after frying 20 min

Sample	Color coordinate			
	L*	a*	b*	ΔE*
Control	49.25±0.60 ^a	−7.26±0.18 ^a	15.70±0.26 ^a	48.75±0.60 ^a
Coating with CMC	46.69±1.59 ^b	−7.96±0.11 ^b	12.63±0.69 ^b	52.08±1.26 ^b
HAD	45.12±1.29 ^b	−6.89±0.55 ^a	17.26±4.0 ^{bc}	53.51±1.04 ^c
VMD	48.92±1.59 ^a	−10.34±0.66 ^c	19.57±1.27 ^c	50.44±1.19 ^d

Samples in same column with different letter differ significantly at $p \leq 0.05$

Fig. 6 Sensory evaluation on the quality of vacuum-fried peas in four experimental conditions after frying 20 min

pretreated by VMD were the best in appearance, texture, oiliness, color and flavor.

Conclusions

The results of the present investigation revealed that using CMC as edible coatings, HAD and VMD helped in reducing the oil absorption of vacuum-fried peas. Due to the different initial free moisture of peas treated by different methods, the rates of water loss were different. As coating with CMC, HAD and VMD decreased the rate of water loss, resulting lower oil absorption, therefore, the oil absorption had a reciprocal relationship with the moisture content retained in the vacuum-fried peas. HAD not only affected the color and decreased the Vitamin C content, but also increased the breaking force of products. On the contrary, coating and vacuum microwave pre-treatments had an ability to maintain the color and chlorophyll content. Furthermore, vacuum microwave treated peas after frying tasted crispiest. All the fried peas had A_w values of less than 0.35, indicative of products with a long shelf life. The group of VMD was preferred to others according to sensory analysis results. Reduction of oil absorption in fried products would be good for both food industries and consumers, adding value to the snack market as a healthy food product.

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