Contemporary Engineering Sciences, Vol. 11, 2018, no. 51, 2537 - 2549
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2018.85261

Influence of Vacuum Deep Fat Frying Process on Quality of Potato Variety Primavera Snacks: A Functional Food with Antioxidant Properties

Manuela Gallón Bedoya

Universidad Nacional de Colombia, Facultad de Ciencias Agrarias
Carrera 65 No. 59A - 110, Medellín - Colombia

Misael Cortés Rodríguez

Universidad Nacional de Colombia, Facultad de Ciencias Agrarias
Carrera 65 No. 59A - 110, Medellín - Colombia

José Miguel Cotes Torres

Universidad Nacional de Colombia – sede Medellín – Facultad de Ciencias Agrarias - Carrera 65 No. 59 A - 110, Medellín – Colombia

Abstract

Potatoes with pulp coloration, have a large number of antioxidant compounds, new varieties with agronomic and nutritional properties have been developed, from which the diploid potato cv *Primavera* was selected, a process of vacuum frying was applied. The aim of the present study was to evaluate the effect of the process conditions on the snacks quality of potatoes. Response surface methodology was used by a central composite design, with independent variables: ΔT (T_{oil}-$T_{boiling\ point\ water}$) (°C), vacuum pressure (25-70 kPa), frying time (240-420 s) and dependent variables: antioxidant capacity, peroxides index, moisture, a_w, texture, color, fat content for potato chips and polar compounds inside the frying oil. The results for the optimization process were: vacuum pressure = 59.4 kPa, ΔT = 50.8 °C and t =420 s. The optimization allowed to obtain a diploid potato snack with good quality attributes: high antioxidant compounds, low fat content, crunchy texture, and acceptable color, among others.

Keywords: Phenolic compounds, polar compounds, vacuum pressure, oil, oxidation

1 Introduction

Potatoes are plant species of the genus Solanum, family Solanaceae, with more than 2000 species cultivated in the world [19]. Colombia, is the world´s largest producer of *Solanum phureja*, a native potato which is characterized by being a small round tuber with colors ranging from yellow to purple [2], its clones have the capacity to cross with other potato genotypes, thus they have been widely used in potato breeding programs [13]. Currently, the tuber that is marketed in Colombia, has yellow peel and pulp, but there are other non-commercial materials with different colors [23].

National University of Colombia has developed new varieties of colored diploid potatoes: *Paola, Primavera, Paysandú, Violeta* and *Milagros*, with agronomic improvements and antioxidant compounds. Tuber coloration depends on the anthocyanin, phenolic compounds and carotenoids present [4], phenolic compounds are also found such as coumarins, flavones, tannins, lignin, chlorogenic acid, caffeic acid, Protocatechuic acid, quercetin, kaempferol [8].
The diploid potato cv Primavera shows a variation in its internal and external coloration, being approximately 80-90% of its transverse area of reddish pigmentation, which has been characterized by its high content of antioxidants which can be beneficial to health, preventing diseases such as cancer and cellular DNA damage, because these compounds are able to neutralize the action of free radicals, is considered within the range of functional foods, which are the foods of higher expectations by the modern consumer, contributing to a better quality of life for the population [14].

Vacuum frying (VF) is a process that presents some advantages compared to conventional frying: the process carried out under lower pressure conditions than the local atmospheric pressure (lower partial pressure of O_2), and lower frying temperatures; reducing final product and oil deterioration processes, in addition it diminishes the oil absorbed by the product and the formation of acrylamides and other toxic compounds, improving the nutritional, physical, sensorial properties and the contents of compounds with physiological activity present in the food [18]. VF has been used with positive results in a wide variety of fruits and vegetables such as apples, bananas, kiwifruits, mushrooms, potatoes, sweet potatoes, purple yam, among others [7].
This research was carried out to evaluate the effect of process conditions of VF on the snacks of potatoes variety Primavera, in order to obtain the best quality in the final snacks.

2 Materials and methods

2.1 Materials

Diploid potato (*S. phureja* cv Primavera) cultivated in Santa Elena, Antioquia was used, at an altitude of 2300 meters above sea level, 14.5 ° C temperature and a relative moisture of 89%.

2.2 Vacuum Fry

For the VF process, the potatoes were cut into sheets of 2 mm thickness. The oil used was palm oil, high oleic (Palmali). A fryer (FVJCU001, Colombia) connected to a vacuum pump (Weg W22, Brazil) was used. The equipment has a PLC (Delta Electronics) type control system for oil temperature, vacuum pressure and frying time, as well as a steam trap before the pump in order to condense the water coming from the product. Initially the tank was charged with 16 L of oil under agitation at 60 rpm and heated under atmospheric conditions to the desired frying temperature, then 250 g of samples were placed in the basket and the tank hermetically sealed, applying the vacuum at the required vacuum pressure. The samples were submerged by a pneumatic system in the oil during the programmed time. At the end of this time, a vibration was applied for 30 s and an additional 10 s was left to rest, keeping the vacuum in place. Finally, the equipment was manually depressurized to local barometric pressure (85.3 kpa). The samples were removed and cooled to room temperature. From the initial oil load, every 5 fryings a 50% change was made for new oil.

The diploid potato VF process was optimized using the surface response methodology. A central composite experimental design (Table 1) as a function of three independent variables: ΔT (T_{oil}-$T_{water\ boiling\ point}$) (45-65 ° C), immersion time (t) (4-7 min), vacuum pressure (VP) (25-70 kPa), and the dependent variables: moisture, a_w, peroxides index (PI), fat content (FC), color, texture and antioxidant capacity (AC), was used; the optimization process was carried out for the dependent variables. Analysis of Variance (ANOVA) was developed in the experimental. The level of significance was less than or equal to 5%. Data were statistically analyzed with the software Statgraphics Centurion XVI. A regression analysis was used with a second-order polynomial model according to Equation 1:

$$Y = \beta_0 + \beta_A A + \beta_B B + \beta_C C + \beta_{AB} AB + \beta_{AC} AC + \beta_{BC} BC + \beta_{A^2} A^2 + \beta_{B^2} B^2 + \beta_{C^2} C^2 \quad (1)$$

Where β_0 is the intercept, $\beta_A, \beta_B, \beta_C$ are the factors coefficients, $\beta_{AB}, \beta_{AC}, \beta_{BC}$ are coefficients of the interactions between factors, and $\beta_{A^2}, \beta_{B^2}, \beta_{C^2}$ are the coefficients of double interaction.

Process conditions resulted from the optimization were verified and the experimental results were compared with predicted values from the optimized model.

2.3 Quality Analysis of products

Antioxidant capacity. Extraction of the antioxidant compounds was done by mixing 3.5mL of reagent grade methanol with 3g of previously macerated fried potatoes; the sample was sonicated for 20min and centrifuged for 30 min at 9000 rpm. Measurement of AC was done by indirect methods: DPPH (2,2-diphenyl-1-picryl hydrazyl), as reported by [3] and ABTS (2,2'-Azinobis ethylbenothiazole-6-sulfonic acid), as reported by [24].
Peroxide index. 1g of previously macerated fried potatoes was mixed with 10 mL of a mixture of Hexane: Isopropanol 3: 1), this was taken to evaporation in a convective stove at 70 ° C for 150 min; between 20-30 mg of the extracted oil were taken and mixed with 10mL of a Chloroform: Methanol (7: 3) mixture, to which 20 µL of thiocyanate solution and 20 µL of ferrous chloride were added. After 5 minutes in the dark, the absorbance lecture at 500 nm was read; the result was expressed in meq H_2O_2 kg dry basis^{-1}, as reported by [9].
Moisture content. Determined by weight loss in stove at 105 ° C for 5 hours [1].
Water activity (a_w). A dew point hygrometer at 25 ° C (Aqualab 3TE series, Decagon, Devices, Pullman, WA, USA) was used.
Color. Carried out in an X-Rite spectrophotometer model SP64; the color was determined by using the CIE-L*a*b* coordinates, illuminant D65, observer 10°, specular compound included (SPIN). The color was measured in the internal zone of reddish tonality.
Texture. Fracture tests were performed using a texture analyzer TA-.XT2i (Stable Micro Systems, United Kingdom) and Texture Exceed Software, version 2.64, load cell of 50 kg, with accessories SMS P/0.25s and SMS /35.
Fat content: Performed by solvent extraction [1].

3 Results and discussion

VP-ΔT response surface plot shows that the best values of DPPH (0.49 mg trolox g db^{-1}) are at conditions of PV = 50 kPa and ΔT = 45 ° C (oil temperature = 126°C while the less favorable values (0.24 mg trolox g db^{-1}) were reached at VP = 75 kPa and ΔT = 65°C (oil temperature = 156 ° C) (Table 1, Figure 1). This result is attributed to the fact that antioxidant compounds have a greater degradation by the effect of heat, as reported by [11] or also due to the increase of oxidation in the product since oil undergoes greater fry temperatures and lower vacuum in the system, which causes antioxidants to be involved in various reactions in order to stop radical formation and lipid oxidation [10].
On the other hand, DPPH favors at low and high values of frying time (240 and 420 min respectively) and especially when the system operates at VP = 50 kPa, reaching DPPH values of approximately 0.50 mg trolox g^{-1}. The fact that the antioxidant capacity increase at high temperatures could be due to the formation of antioxidant compounds during Maillard reaction which is favored at high temperatures [15], however this hypothesis needs to be confirmed by a research for this potato variety. The results obtained for antioxidant capacity were similar to the one reported by

[26], who found that the increase in frying times have a significant effect on antioxidant capacity for fried potatoes *(Solanum Tuberosum L.*) even more that an increase in temperature, due to the antioxidant compounds formed by Maillard reaction. From Table 2, DPPH showed significant differences ($p<0.05$) regarding the quadratic interaction of time.
According to the Alimentarius Codex, the maximum PI value for virgin oils and fats, and cold pressed oils is 15 meq O_2 kg^{-1} (7.5 meq H_2O_2 kg^{-1}) and for other fats and oils it is 10 meq O_2 kg^{-1} (5 meq H_2O_2 kg^{-1}) [6].
For diploid potato snacks obtained by VF, the IP did not present significant statistical differences ($p> 0.05$) regarding to independent variables evaluated (table 3). Among the obtained results in VF diploid potato, the majority of IP values were below the Codex's established parameters.

Obtained results showed that VF contributes in IP reduction among fried products, in a previous study, IP was determined for the potato variety Primavera processed by conventional deep-fat frying (180°C, 300 s) and it was evidenced that the amount of peroxides was greater (12,67 ± 1,46 meq H_2O_2 kg^{-1}) than all those obtained in this research, even for the highest temperatures and times., it should be due to the reduction of the frying temperature and minimal contact between oil and oxygen during the process [16]. During the VF process, the pressure of the processing system is low, so, oil and water vapor pressures of food are low too; which produces a fat reduction regarding fats contained in the finished product, as the oil absorption decreases [7].

The ANOVA showed significant differences ($p <0.05$) in the moisture content respecting to the independent variables ΔT and t, as is shown is table 3; in addition, with the interaction ΔT-t and ΔT-PV. It is observed that as t increases, final moisture from diploid potato snack decreases, mainly when the system operates at higher ΔT; while the increase in ΔT also reduces moisture content, but mainly to low frying t. The effect of the interaction between ΔT and time is more evident, when enhancing product's moisture decrease of at high times and ΔT. This situation is attributed to the fact that under these operating conditions a higher rate of evaporation of the water is reached and the product becomes drier. Moisture results obtained in the product varied between 0.37 and 4.23% (bh), being within the established by [20] as acceptable parameters for fried potatoes (1.67% bh).

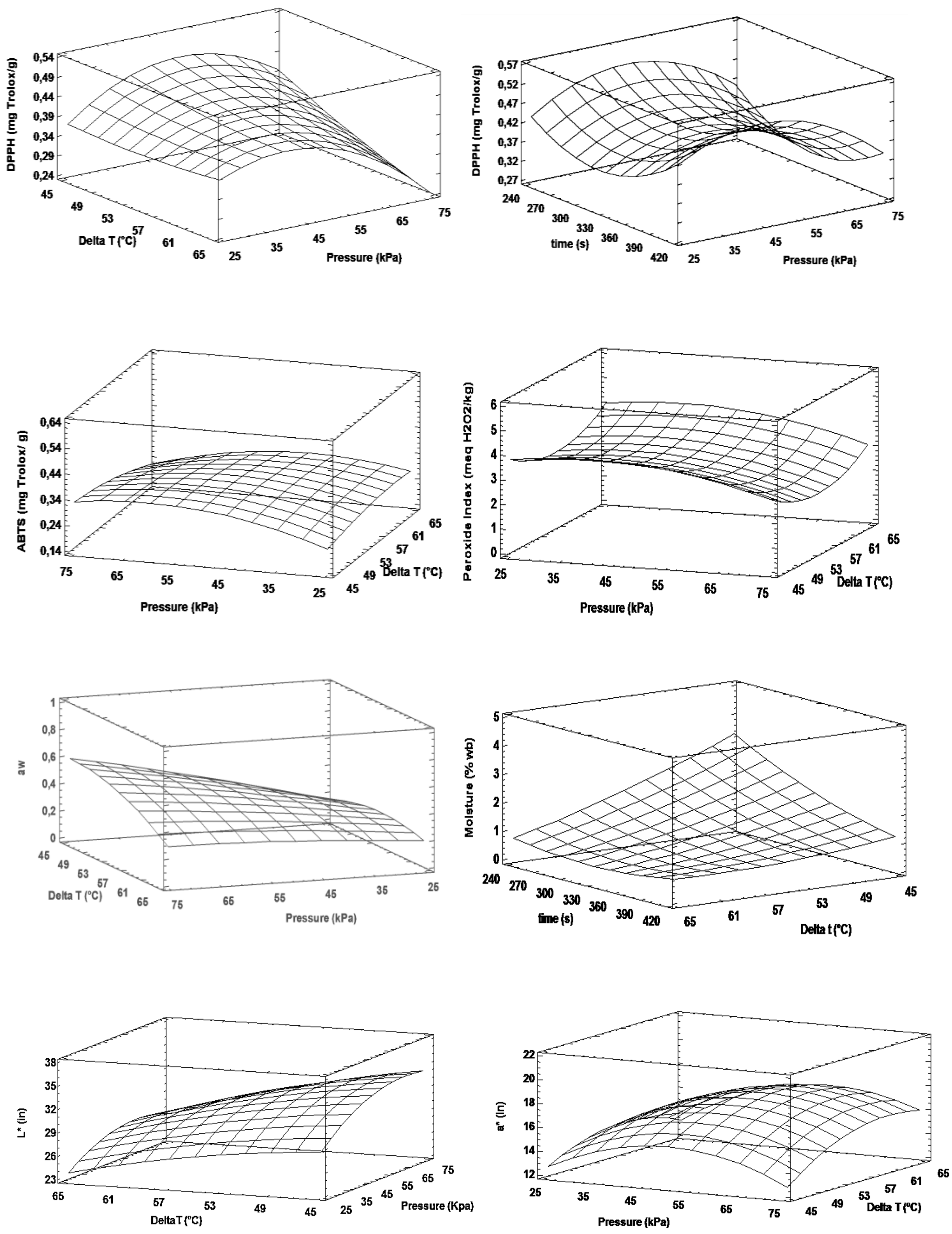
The ANOVA not showed significant differences of a_w ($p <0.05$) respecting to any variable, it was a decrease of a_w when the system operates at higher vacuum levels (PV → 25 kPa), which was consistent with the lowest moisture content found at this pressure condition. This situation is attributed to the fact that at lower pressures, the water vapor pressure is lower and there is a rapid evaporation of free water in the product, causing a decrease in the food's water activity [30].

The a_w of VF diploid potatoes, was very fluctuating, with mean oscillating values range of 0.790 – 0.164, which identifies it as a critical dependent variable since it is directly related to shelf life [5]. It is worth noting that when the system operated at minor t (t → 240 s), lower ΔToil (ΔT → 45 ° C) and lower vacuum levels (PV → 70 kPa), the product reached its highest a_w value (0.790) and moisture (4.230%). Some investigations have reported potato chips a_w values for conventional frying, between 0.185-0.977 for different varieties of potatoes (white, sweet and purple) fried at temperatures between 160 – 200 °C, for 1-5 minutes [31].

The ANOVA showed a significant difference ($p < 0.05$) in the FC regarding the PV, with an observable decrease in the products' absorbed fat when the system operates at higher vacuum levels (PV → 25 kPa). This is due to the fact that when the system operates with lower PV, there is a higher water vapor gradient coming out of the products' surface, which prevents the oil from entering the food [25]. In general, the FC values range between 27.4 and 39.0%, similar to the values obtained by [28] for VF potato chips. Some investigations in diverse matrixes have identified that the greater rate of absorption of oil in the fried foods occurs at the moment of the pressurization and in the products' cooling, reason why there is a dependence of the speed of pressurization and free water of the food, since at the moment of frying, the oil that succeeds to enter the interior of the matrix is very little due to the impediment held by the water vapor gradient, which leaves the food towards the middle; At the time of cooling and pressurizing, the evaporation is reduced and the remaining steam condenses, allowing to create an oil flow gradient from the outside to the interior of food [17]. On the other hand, VF creates a large hydrodynamic gradient, which can affect the microstructure of the product, and therefore modify the physicochemical and transport properties of the product [31].

For the internal zone or reddish color, ANOVA presented significant differences ($p<0.05$) in L_{in}*, a_{in}* and b_{in}* regarding the PV factor; while a_{in}* also had significant influences ($p < 0.05$) respecting to ΔT, t and all quadratic and linear interactions except with ΔT- t.

L_{in}* has a tendency to decrease with high vacuum levels (PV → 25 kPa) to any condition of ΔT, but the major changes take place when ΔT is lower; while ΔT confers a greater darkening in different combinations, ΔT: 60-61 ° C, 70 kPa or ΔT: 55 ° C, 20 kPa [21], founding a minor dimming for potato chips when the system operated at lower t (240 s) and temperatures (ΔT = 45 ° C). Usually in conventional or vacuum frying processes as temperatures rise, various reactions are accelerated: carbohydrate degradation, sugar pyrolysis, ascorbic acid decomposition, oxidation of fatty acids, among others contributing to the reduction of luminosity and browning of the fried product [12].


DPPH (mg Trolox/g)
0,54
0,49
0,44
0,39
0,34
0,29
0,24
45
49
53
57
61
65
Delta T (°C)
25
35
45
55
65
75
Pressure (kPa)
DPPH (mg Trolox/g)
0,57
0,52
0,47
0,42
0,37
0,32
0,27
240
270
300
330
360
390
420
time (s)
Pressure (kPa)
ABTS (mg Trolox/ g)
0,64
0,54
0,44
0,34
0,24
0,14
Pressure (kPa)
Delta T (°C)
Peroxide Index (meq H2O2/kg)
Pressure (kPa)
Delta T (°C)
aw
Delta T (°C)
Pressure (kPa)
Moisture (% wb)
time (s)
Delta t (°C)
L* (in)
Delta T (°C)
Pressure (Kpa)
a* (in)
Pressure (kPa)
Delta T (°C)

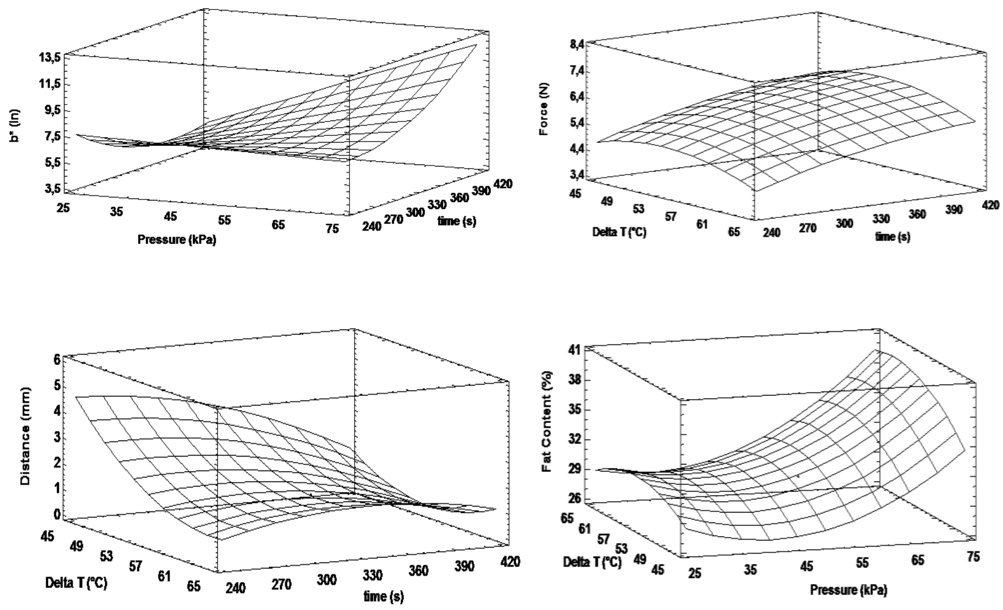


Figure 1. Surface response graphs of dependent variables as functions of independent variables

Texture is a very important parameter of quality in foods, and especially in snacks where consumers expect a crisp texture, which is determined experimentally with a texturometer where the maximum strength is measured and this indicates the hardness of the fried product [29]. In the diploid potato snacks the fracture strength showed significant differences ($p < 0.05$) respecting to t, whereas the distance presented significant differences ($p < 0.05$) respecting to ΔT, time and the interaction ΔT- t. The fracture strength increased with increased t, which is attributable to a possible formation of superficial crust during frying, which is potentiated with the temperature difference between potatoes and oil.
On the other hand, the distance at which the fracture occurs is greater at lower frying t (240 s) and lower ΔT (45 ° C); which is logical since as the food is fried at lower ΔT, the oil temperatures are low, there is a lower porosity and less evaporation of water, so the product presents a more flexible structure, which is reflected in an increase in the distance of rupture [27]. At short frying t and low temperatures, it has been shown that there is no complete gelatinization of potato starch, which makes the food less brittle and crunchy. These results are consistent to the ones reported by [22] where temperature and time of frying directly influence the texture of fried products.

The experimental optimization of the VF process was done using statistical tools, with the objective of determining the conditions of the independent variables of operation, which allowed obtaining a final product with desired quality attributes. The following considerations for the dependent variables or quality attributes were taken as optimization criteria: maximize DPPH, ABTS, moisture, strength, L_{int}*,

a_{int}*, b_{int}*, a_{out}*, b_{out}*, and minimize PI a_w, Strength, L_{out}* and fat. According to the adjustment model for data, the optimum operating conditions were: PV = 59.4 kPa, ΔT = 50.8 ° C (Toil = 136 ° C) and frying time = 420 s (7 min)

Table 1. Regression coefficient table for different response.

Parameter	Intercept	β_A	β_B	β_C	β_{AB}	β_{AC}	β_{BC}	β_A^2	β_B^2	β_C^2	R^2
DPPH	1.00	0.03	-0.002	-0.006	-0.0002	-0.000006	-0.000009	-0.0001	0.00009	-0.00001*	0.60
ABTS	-0.13	0.02	0.03	-0.007	-0.0001	-0.00001	-0.00003	-0.00009	-0.0002	0.00001	0.46
Moisture	21.93	0.08	-0.35*	-0.06*	-0.002*	0.00007	0.0006*	0.0003	0.002	0.00003	0.81
aw	-0,31	0,03	0.08	-0.01	-0.0003	-0.00001	0.00005	-0,00003	-0,0008	0.00001	0.49
PI	23.53	0.07	-0.81	0.004	-0,00002	0.00001	-0.0002	-0.0009	0.008	0.000006	0.21
L^*_{in}	71.20	0.41*	0.28*	-0.3	-0.003	0.0005	0.001	-0.003	-0.008	0.0003	0.70
a^*_{in}	-21.33	0.41*	1.65*	-0.13*	0.002*	-0.0003*	-0,00002	-0.004*	-0.01*	0.0002*	0.93
b^*_{in}	-3.3	-0.18*	1.35	-0.15	-0.0007	0.0009*	0.00006	-0.000007	-0.01	0.0002	0.73
Force	-14.33	-0.04	0.58	0.03*	0.002	-0.000001	-5.55E-07	-0.0007	-0.006	-0.00003	0.61
Distance	51.39	-0.01	-1.47*	-0.004*	-0.0005	0.00008	0.0009*	0.001	0.01	-0.00008	0.81
FC	-23.67	-0.94*	2.60	-0.02	0.004	0.0007	-0.0009	0.007	-0.02	0.00007	0.71

β_A, β_B, and β_C are vacuum pressure, Delta T, and frying time respectively. * values presented significant differences (p-value < 0.05)

Table 2. Quality Attributes Results for VF of potato CV Primavera by multiple response optimization and the comparison between experimental results.

Quality Attribute	Theoretical Optimum	Experimental Optimum
DPPH (mg Trolox/g)	0.51	0.49 ± 0.02
ABTS (mg Trolox/g)	0.48	0.57 ± 0.01
PI (meq H_2O_2/ kg)	3.28	4.42 ± 0.57
a_w	0.500	0.390 ± 0.02
Moisture (%)	2.24	3.41 ± 0.06
Distance (mm)	2.13	1.36 ± 0.35
Force (N)	5.45	5.84 ± 1.15
L_{in}*	34.95	33.98 ± 5.25
a_{in}*	16.11	14.53 ± 2.24
b_{in}*	10.48	7.29 ± 2.75
FC (%)	34.04	26.73± 1.79

4 Conclusions

The potato cv *Primavera*, represents a raw material with a great agro industrialization potential, due to its quality characteristics and its antioxidant activity, ABTS (0.52 ± 0.03 mg Trolox/g) and DPPH (0.45 ± 0,02 mg Trolox/g). The use of statistical tools allowed the optimization of the VF process of the diploid potato, with the most suitable operating conditions PV: 59.4kPa, ΔT: 50.8°C and t: 420s. In general, most of the quality attributes assessed for diploid potato snacks are affected by these dependent variables. The VF allowed to maintain antioxidant properties at the diploid potato snack and to imprint customer-appreciated qualities in texture (crisp) and color.

Acknowledgements. This work was supported by Colciencias and Universidad Nacional de Colombia.

References

[1] AOAC. *Official Methods of Analysis of AOAC International*. *Association of Official Analysis Chemists International*, (2005). Retrieved from http://www.eoma.aoac.org/

[2] C. Bianeth, *Evaluación del contenido nutricional y actividad antioxidante en Solanum tuberosum grupo Phureja*, Universidad Nacional de Colombia, (2015). Retrieved from http://www.bdigital.unal.edu.co/

[3] W. Brand-Williams, M. E. Cuvelier, C. Berset, Use of a free radical method to evaluate antioxidant activity. *LWT - Food Science and Technology*, **28** (1995), no. 1, 25–30. https://doi.org/10.1016/S0023-6438(95)80008-5

[4] A. Burmeister, S. Bondiek, L. Apel, C. Kühne, S. Hillebrand, P. Fleischmann, Comparison of carotenoid and anthocyanin profiles of raw and boiled Solanum tuberosum and Solanum phureja tubers, *Journal of Food Composition and Analysis*, **24** (2011), no. 6, 865–872. https://doi.org/10.1016/j.jfca.2011.03.006

[5] J.-B. Cazier, V. Gekas, Water Activity and Its Prediction: a Review. *International Journal of Food Properties*, **4** (2001), no. 1, 35–43. https://doi.org/10.1081/JFP-100002187

[6] Codex Alimentarius. Norma del codex para aceites vegetales especificados, Pub. L. No. Codex stan 210-1999, 1 (1999). EEUU.

[7] L. M. Diamante, S. Shi, A. Hellmann, J. Busch, Vacuum frying foods: Products, process and optimization, *International Food Research Journal*, **22** (2015), no. 1, 15–22.

[8] N. C. Fuenzalida, *Determinación De La Cantidad De Fenoles Totales Y La Actividad Antioxidante En Papas Nativas Pigmentadas*, Universidad Austral de Chile, 2008. Retrieved from http://cybertesis.uach.cl/tesis/uach/2008/faf954d/doc/faf954d.pdf

[9] D. Hornero-Méndez, A. Pérez-Gálvez, I. Mínguez-Mosquera, A Rapid Spectrophotometric Method for the Determination of Peroxide Value in Food Lipids with High Carotenoid Content, *J. Am. Oil Chem. Soc.*, **78** (2001), no. 11, 1151–1155. https://doi.org/10.1007/s11746-001-0404-y

[10] C. Jin, X. Wu, Y. Zhang, Relationship between antioxidants and acrylamide formation: A review, *Food Research International*, **51** (2013), no. 2, 611–620. https://doi.org/10.1016/j.foodres.2012.12.047

[11] I. Juániz, I. A. Ludwig, E. Huarte, G. Pereira-Caro, J. M. Moreno-Rojas, C. Cid, M.-P. De Peña, Influence of heat treatment on antioxidant capacity and (poly)phenolic compounds of selected vegetables, *Food Chemistry*, **197** (2016), 466–473. https://doi.org/10.1016/j.foodchem.2015.10.139

[12] I. Juániz, C. Zocco, V. Mouro, C. Cid, M. P. De Peña, Effect of frying process on furan content in foods and assessment of furan exposure of Spanish population, *LWT - Food Science and Technology*, **68** (2016), 549–555. https://doi.org/10.1016/j.lwt.2015.12.061

[13] D. K. Juyó, H. N. Gerena, T. Mosquera, Evaluación de marcadores moleculares asociados con resistencia a gota (Phytophthora infestans L.) en papas diploides y tetraploides, *Revista Colombiana de Biotecnología*, **13** (2011), no. 2, 51–62. Retrieved from http://www.revistas.unal.edu.co/index.php/biotecnologia/article/view/27917/38321

[14] N. Kaur, D. P. Singh, Deciphering the consumer behaviour facets of functional foods: A literature review, *Appetite*, **112** (2017), 167–187. https://doi.org/10.1016/j.appet.2017.01.033

[15] L. Manzocco, S. Calligaris, D. Mastrocola, M. C. Nicoli, C. R. Lerici, Review of non-enzymatic browning and antioxidant capacity in processed foods, *Trends in Food Science and Technology*, **11** (2000), no. 9–10, 340–346. https://doi.org/10.1016/S0924-2244(01)00014-0

[16] M. Mariscal, P. Bouchon, Comparison between atmospheric and vacuum frying of apple slices, *Food Chemistry*, **107** (2008), no. 4, 1561–1569. https://doi.org/10.1016/j.foodchem.2007.09.031

[17] J. Mir-Bel, R. Oria, M. L. Salvador, Influence of the vacuum break conditions on oil uptake during potato post-frying cooling. *Journal of Food Engineering*, **95** (2009), no. 3, 416–422. https://doi.org/10.1016/j.jfoodeng.2009.06.001

[18] J. Mir-Bel, R. Oria, M. L. Salvador, Deep-fat frying under moderate vacuum of potato cylinders, *International Journal of Food Science and Technology*,

47 (2012), no. 7, 1369–1377. https://doi.org/10.1111/j.1365-2621.2012.02982.x

[19] Y. Molina, G. Rabe, M. L. Rodríguez, M. del S. Cerón, A. M. Garnica, Contenido De Antioxidantes En Papas Criollas Nativas, *Revista de La Asociación Colombiana de Ciencia y Tecnología de Alimentos*, ***23***(2015). no. 36, 31–41.

[20] F. Pedreschi, Chapter 11 - Fried and Dehydrated Potato Products, *Advances in Potato Chemistry and Technology* (First Edit), Elsevier, 2009. https://doi.org/10.1016/b978-0-12-374349-7.00011-8

[21] F. Pedreschi, J. León, D. Mery, P. Moyano, R. Pedreschi, K. Kaack, K. Granby, Color development and acrylamide content of pre-dried potato chips, *Journal of Food Engineering*, **79** (2007), no. 3, 786–793. https://doi.org/10.1016/j.jfoodeng.2006.03.001

[22] F. Pedreschi, P. Moyano, N. Santis, R. Pedreschi, Physical properties of pre-treated potato chips, *Journal of Food Engineering*, **79** (2007), no. 4, 1474–1482. https://doi.org/10.1016/j.jfoodeng.2006.04.029

[23] C. B. Peña, L. P. Restrepo, Compuestos fenólicos y carotenoides en la papa: revisión, *Actualización En Nutrición*, **14** (2013), 25–32.

[24] R. Re, N. Pellegrini, A. Proteggente, A. Pannala, M. Yang, C. Rice-Evans, Antioxidant activity applying an improved ABTS radical cation decolorization assay, *Free Radical Biology and Medicine*, **26** (1999), no. 9-10, 1231–1237. https://doi.org/10.1016/S0891-5849(98)00315-3

[25] J. Sandhu, H. Bansal, P. S. Takhar, Experimental measurement of physical pressure in foods during frying, *Journal of Food Engineering*, **115** (2013), 272-277. https://doi.org/10.1016/j.jfoodeng.2012.10.016

[26] A. Serpen, V. Gökmen, Evaluation of the Maillard reaction in potato crisps by acrylamide, antioxidant capacity and color, *Journal of Food Composition and Analysis*, **22** (2009), no. 6, 589–595. https://doi.org/10.1016/j.jfca.2008.11.003

[27] K. A. Taiwo, O. D. Baik, Effects of pre-treatments on the shrinkage and textural properties of fried sweet potatoes, *LWT - Food Science and Technology*, **40** (2007), no. 4, 661–668. https://doi.org/10.1016/j.lwt.2006.03.005

[28] E. Troncoso, F. Pedreschi, Modeling water loss and oil uptake during vacuum frying of pre-treated potato slices, *LWT - Food Science and Technology*, **42**

(2009), no. 6, 1164–1173. https://doi.org/10.1016/j.lwt.2009.01.008

[29] K. N. van Koerten, M. A. I. Schutyser, D. Somsen, R. M. Boom, Crust morphology and crispness development during deep-fat frying of potato, *Food Research International*, **78** (2015), 336–342. https://doi.org/10.1016/j.foodres.2015.09.022

[30] C. V. Yagua, R. G. Moreira, Physical and thermal properties of potato chips during vacuum frying. *Journal of Food Engineering*, **104** (2011), no. 2, 272–283. https://doi.org/10.1016/j.jfoodeng.2010.12.018

[31] Y. Yuan, D. Chen, H. Liu, S. Wu, H. Yan, A Comparison Study of Frying Conditions on Furan Formation in 3 Potato Varieties, *Journal of Food Science*, **81** (2016), no. 8, T2114–T2121. https://doi.org/10.1111/1750-3841.13386

Received: June 15, 2018; Published: July 14, 2018