Optimization of guacamole formulation made with avocado powder and fresh avocado

Misael Cortés-Rodríguez, Francy Stephanie Orrego-Vargas & Eduardo Rodríguez-Sandoval

Facultad de Ciencias Agrarias, Universidad Nacional de Colombia. Medellín. Colombia. mcortesro@unal.edu.co, stephanieorregovargas@gmail.com, edrodriguezs@unal.edu.co

Abstract

Guacamole is a very desired product in the world market. This research aims to develop a formulation of guacamole prepared with avocado powder (AP), fresh avocado (FA) and spices as main ingredients, using response surface methodology. The independent variables were: dry solids of guacamole (DS_G) (20.2 - 30.3%), dry solids contributed by FA in the guacamole (DS_{FA}) (0 - 50%), and lime color (0 -0.03%). Dependent variables were: moisture (Xw), pH, acidity, peroxide index (PI), viscosity (η), zeta potential (ζ) and color (CIE-L*a*b*). The best formulation was obtained by multiple optimization: DS_G (20.9%), DS_{FA} (28.9%) and lime color (0.029%), and its properties were: Xw (78.3%), pH (5.1), acidity (0.4%), PI (0.787 meq H_2O_2/kg), η (2952.2 cP), ζ (27.0 mV) and color (L*: 51.0, a*: -5.8, b*: 31.2). The AP is a raw material with industrial potential, which facilitates the production system of guacamole and its control.

Keywords: emulsion; colloidal stability; lipid oxidation; dressing.

Optimización de una formulación de guacamole elaborada con polvo de aguacate y aguacate fresco

Resumen

El guacamole es un producto muy apetecido en el mercado mundial. El objetivo fue desarrollar una formulación de guacamole preparado con polvo de aguacate (PA), aguacate fresco (AF) y especias como ingredientes principales, aplicando la metodología de superficie de respuesta. Las variables independientes fueron: sólidos secos del guacamole (SS_G) (20,2-30,3%), sólidos secos del AF en el guacamole (SS_{AF}) (0-50%) y color lima (0 -0,03%). Las variables dependientes fueron: humedad (Xw), pH, acidez, índice de peróxidos (IP), viscosidad (η), potencial zeta (ζ) y color (CIE-L*a*b*). La mejor formulación fue obtenida por optimización múltiple: SS_G (20,9%), SS_{AF} (28,9%) y color lima (0,029%), y sus propiedades fueron: Xw (78,3%), pH (5,1), acidez (0,4%), IP (0,787 meq H_2O_2/kg), η (2952,2 cP), ζ (27,0 mV) y color (L*: 51,0, a*: -5,8, b*: 31,2). El PA es una materia prima con potencial industrial, el cual facilita el sistema productivo del guacamole y su control.

Palabras clave: emulsión; estabilidad coloidal; oxidación lipídica; aderezo.

1. Introduction

Guacamole dressing is a food product made with fresh avocado (FA), lemon, vegetables, spices, antioxidants, preservatives, condiments, among others, stored at refrigeration temperatures [1]. It is known by being oil-in-water (O/W) emulsion that behaves like a thermodynamically unstable colloidal system, requiring additives for adequate emulsification and stability which can cause loss of flavor, aroma, color, and appearance [2]. Guacamole-making process is performed with FA using different chemical and natural additives in order to increase its shelf-life. The most commonly used additives are: antioxidants with lipid and/or enzymatic effect (sodium erythorbate, butylhydroxytoluene (BHT), sulfur dioxide, ascorbic acid, citric acid and α tocopherol) [3], preservatives (Sodium benzoate and potassium sorbate) [4], and spices like garlic and onion, which have been associated with antibrowning properties [5].

FA is the basic raw material for guacamole making process and is also very susceptible to deterioration problems due to lipid degradation and browning because of its oxidative and enzymatic reactions [6]. One of the alternatives to counteract this problem is to dry the pulp, however, loss of avocado flavor has been reported when applying this conservation technique [7]. Guzmán-Gerónimo et al. (2008) [8] treated avocado pulp by microwaves, finding a decrease in volatile compounds responsible for its flavor: estragole, terpenoids, hexanol and 2-hexenal. Grajales et al. (1999) [9] reported bitter tastes by sensory analysis of avocado powder (AP) obtained by emulsified spray drying using mono acyl glyceride and antioxidants: Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tertiary butyl hydroquinone (TBHQ). On the other hand, avocado pulp freeze drying, an expensive technology due to processing times and energy costs, has been one of the methods with best results in terms of sensory characteristics [10]. In the Mexican market, freeze dried pulp is used in the preparation of various products: sauces, guacamole, dressings, snacks and chip flavoring, among others [11].

Currently, the design and formulation of new foods implies the use of adequate raw materials that facilitate and guarantee their quality. Therefore, AP represents an industrial interest for food, cosmetic and pharmaceutical sectors. In the case of food industry, it is necessary to have raw materials of smaller volume and weight than fresh products, stackable, that do not darken during storage or by simple exposure to air, in addition to retaining their quality and sensory properties. These conditions are adequately met by AP for the elaboration of different foods, among which guacamole stands out. Additionally, lime color is a natural colorant that can contribute to improve this quality characteristic of guacamole made with PA since, as mentioned, it may have deficiencies in this sensory property.

On the other hand, support of statistical tools allows an analysis of multiple intrinsic factors in food quality, and the use of the response surface methodology (RSM) represents an effective way to innovate and create products with special traits. This methodology has been applied in different food products like a sauce prepared with olive oil, isolate protein, whey and xanthan gum [12]; a drink based on walnut oil and gum arabic [13]; and an orange drink with xanthan and gum arabic [14]. The aim of this research was to develop a formulation of guacamole prepared with FA and AP that had quality characteristics similar to a commercial guacamole, using RSM.

2. Materials and methods

2.1. Raw material

Hass avocado (*Persea americana* Mill) from Abejorral, Antioquia, Colombia, was used, with a ripening time between 11 and 15 days. Red onions (*Alliumcepa* L.), sweet pepper (*Capsicum annuum*), coriander (*Coriandrum sativum*), garlic (*Allium sativum*) (0.508% db), and salt (1.421% db) were purchased at the local market. Potassium sorbate, butylhydroxytoluene (BHT), sodium benzoate, citric acid, sodium erythorbate (0.621% db), and lime color (Ecoflora

S.A.S.) were used as guacamole additives. Additionally, AP obtained by spray drying according to the methodology described by Marulanda, (2014) was used [15], it is composed of avocado pulp, maltodextrin, gum arabic, salt, and lemon juice.

2.2. Characterization methodologies

Dressing formulations, FA and AP were characterized in terms of moisture content (Xw) (AOAC 930.15 /1997), water activity (a_w) by dew point hygrometer (Aqualab 3TE series, Decagon, Devices, USA) (AOAC 978.18 / 1997), pH using a potentiometer by electrode immersion in the sample, and previous calibration with buffer solutions of pH 4 and 7 (method AOAC 981.12 / 1997), acidity was determined by titration with NaOH 0.1N using 1% phenolphthalein as indicator and expressed as citric acid (%), peroxide index (PI) by FOX method, performing spectrophotometric readings at 500 nm wavelength and expressing the eq. (1) as meqH$_2$O$_2$/sample kg [16].

$$\frac{meq\ H_2O_2}{Sample\ kg} = \frac{(A_m - A_b) * \frac{1}{m}}{W * 2 * 55.84} * V_t \qquad (1)$$

Where, A_m and A_b are sample absorbance and blank, respectively, m is the slope of calibration curve (μg/mL), W is the sample weight (g), Vt is the final volume (mL) of reaction mixture; 2 is the conversion factor to express meq H$_2$O$_2$, and 55.84 is the molecular weight of iron (μg/μmol).

Color coordinates (Luminosity: L*, green-red chromaticity: a*, blue-yellow chromaticity: b*) were determined using a X-Rite model SP64 spectrophotometer, D65 illuminant and 10° observer [3]; apparent viscosity (η) was determined with DV-III Ultra rheometer (Brookfield Engineering Laboratories, Inc., USA) coupled with thermostatic bath at 25°C (Brookfield model TC-502) using the RV6 spindle and a speed range of 0.01 to 100 rpm (η was reported at 100 rpm) [17]; zeta potential (ζ) was determined in samples diluted in distilled water in a 1:100 ratio, using Zeta Sizer Nano (ZS90, Malvern Instruments Ltd., Worcester, UK) and DTS 1060 capillary cells [16, 18]. In addition, wettability (W) and solubility (S) were determined for AP. For W, 1 g of the powder sample was weighed and spread on the surface of 400 mL of distilled water at 25°C without agitation. The time until the last particle of dust was submerged was recorded [19]. S was determined by dispersing 1 g of AP in 50 mL of water using vortex for 60s. The obtained mixture was centrifuged at 3000 rpm/5min at 25 °C. Subsequently, an aliquot of 25 mL of the supernatant was taken, transferred to previously weighed Petri dishes, which were immediately dried in an oven at 105 °C for 5 h. S (%) was calculated as the difference of weights divided by initial weight [20].

2.3. Formulations development

For developing guacamole formulations, RSM was used with a face-centered central composite design of 6 repetitions in the central point, for a total of 20 experiments. Independent

variables were: dry solids of guacamole (DS_G) (20.2 - 30.3%), dry solids contributed by FA in the guacamole (DS_{FA}) (0 - 50%), and lime color (0 - 0.03%).

The total water of the formulation was incorporated in three moments. Initially, AP was reconstituted with 50% of the formulation water using a mixer (Kitchenaid Artisan, mod. KSM150PSER, St. Joseph, MI) at 194 rpm (position 6) for 4 min. Then, a premix of vegetables, spices, condiments, preservatives, antioxidants (constant in all the experimental runs) and 25% of the formulation water were added, which was previously prepared in a blender (Oster® 4655 Sunbeam Products, Inc, Miami, FL) (position 2). Finally, FA was mashed and mixed with the remaining 25% of water, and added to the product in the blender maintaining the agitation for additional 2 min. Xw, acidity, pH, a_w, PI, ζ, η, L*, a* and b* were determined. For experimental optimization, the properties of commercial guacamole were considered as a reference and a quadratic model was used for analysis, eq. (2), where Y_i is the predicted response β_0 is the model constant; β_A, β_B, and β_C are regression coefficients for linear effects; β_{AA}, β_{BB}, β_{CC} quadratic effect coefficients; and β_{AB}, β_{AC}, and β_{CB} are interaction coefficients. Adequacy of the models was determined using lack of fit test and regression coefficient (R^2). In addition, analysis of variance (ANOVA) was performed with a significance level of 5%. The analysis of results and optimization were performed using Statgraphics Centurion XVI.II software.

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

3. Results and discussion

3.1. Characterization of raw material

Table 1 shows mean values plus standard deviation of AP and FA physicochemical properties. There were significant differences ($p<0.05$) in Xw, a_w, acidity, pH, PI, L*, a* and b*. Spray drying process produces a reduction of Xw and a_w of AP, resulting in a microbiologically stable product, with Xw values close to monomolecular layer of water [21]. Acidity values for AP were higher than FA due, on the one hand, to acidic components concentration coming from FA [7], contained in AP, and to the acidic contribution of lemon juice present in AP [15]; this is consistent with pH values found for each raw material. AP presented the highest IP values, which could be due to: the oxidizing effect of lipoxygenase at the moment of feeding preparation for the dryer, and to drying during its making process which involves an air inlet temperature of 160 °C that can cause hydrolysis of triglycerides, releasing organic acids then oxidized to form hydroperoxides, and this in turn is related to acidity increase and pH decrease [22].

Regarding color, L*, a* and b* values in FA, they are similar to those reported in the literature [23]. Raw materials have similar values of L* and a* chromaticity (red-green); while b* chromaticity was different, probably because of the water contained in FA that enhances a greater absorption of light and highlights the yellow tone.

Table 1.
Physicochemical and physical properties of raw materials: FA and AP.

Properties	Fresh Avocado	Avocado Powder
Xw (%)	70.2 ± 2.2	1.65 ± 0.18
a_w	0.971 ± 0.012	0.257 ± 0.010
Acidity (%)	0.4 ± 0.0	1.1 ± 0.0
pH	6.6 ± 0.0	5.0 ± 0.0
PI ($meqH_2O_2/kg$)	0.9 ± 0.1	5.7 ± 0.1
L*	75.5 ± 0.3	74.8 ± 0.20
a*	-5.9 ± 0.3	-5.0 ± 0.1
b*	42.0 ± 1.5	27.6 ± 0.3
S (%)	--------	71.2 ± 1.2
W (s)	--------	83.3

Source: The Authors.

L* of AP is the result of various reactions like enzymatic and non-enzymatic browning given the high temperatures experienced by the matrix during spray drying [24]; besides the addition of maltodextrin and gum arabic. Whereas, a* chromaticity is a consequence of the partial degradation of FA alpha and beta chlorophylls and lemon juice, up to pheophytins and pyropheophytins during spray drying process [25]. In a*b* chromatic plane, FA and AP are in the second quadrant, denoting a similarity in the presence of chlorophyll component (a* <0) and the presence of carotenoid components (b*> 0), b* chromaticity of AP was lower than that of FA, probably due to compounds degradation during spray drying process [26].

S and W are important to establish powdered products reconstitution mechanism, since they predict their rehydration rate [24]. Results of these properties in Table 1 are considered acceptable values, despite being a structure rich in lipid component with no affinity with water and with gum Arabic presence, which delays its wetting. The values found for S and W are higher than those reported in other food matrices like pomegranate and apple powder [27]

3.2. Quality properties of guacamole formulations

Table 2 presents mean values with standard deviations of the dependent variables as a function of independent variables, and Fig. 1 shows response surfaces of each dependent variable. Xw is a fundamental attribute in dressing development because it is directly related to nutritional, mechanical, optical, microbiological, and sensory properties. As DS_G and DS_{FA} increased in the guacamole formulations, Xw decreased.

With respect to microbiological stability of guacamole, a_w values fluctuated between 0.963 and 0.971, being established in an area for products prone to the development of pathogenic microorganisms for any formulation [28], so it is necessary to use industrial chemical preservatives like potassium sorbate and sodium benzoate.

Table 2.
Experimental design of guacamole dressing formulations based on AP and FA.

Run	Formula	DS_G (%)*	DS_{FA} (%)*	Lime color (%)	Moisture (%)	Water activity	Viscosity (cP)	pH	Acidity (%)	Luminosity L *	Chromaticity a*	Chromaticity b *	Zeta potential (mV)	Peroxide Index (meqH$_2$0$_2$/kg)
1	F_1	30.30	50	0.000	65.9±0.2	0.967 ± 0.001	9257 ± 110	5.6 ± 0.0	0.47 ± 0.01	50.9 ± 0.1	-6.9 ± 0.2	33.5 ± 1.6	-22.4 ± 0.3	1.79 ± 0.11
2	F_2	25.25	25	0.015	73.6±0.0	0.971 ± 0.002	5200 ± 98	5.2 ± 0.0	0.5 ± 0.02	51.8 ± 0.3	-5.8 ± 0.1	34.9 ± 0.3	-21.5 ± 0.4	0.95 ± 0.05
3	F_3	30.30	25	0.015	67.3±0.2	0.968 ± 0.001	6283 ± 212	5.1 ± 0.1	0.66 ± 0.04	50.8 ± 1	-6.1 ± 0.2	32.8 ± 0.6	-22.3 ± 1	1.23 ± 0.32
4	F_4	30.30	0	0.030	68.6±0.2	0.968 ± 0.002	4867 ± 142	5.0 ± 0.1	0.57 ± 0.02	47.8 ± 0.3	-4.6 ± 0.1	32.5 ± 1.4	-20.8 ± 0.6	0.94 ± 0.03
5	F_5	30.30	0	0.000	68.2±0.3	0.964 ± 0.002	5358 ± 89	4.8 ± 0.0	0.7 ± 0.02	48.1 ± 0.7	-6.5 ± 0.1	32.5 ± 1.3	-21.6 ± 0.1	0.86 ± 0.04
6	F_6	25.25	0	0.015	74.1±0.1	0.969 ± 0.001	3203 ± 78	4.9 ± 0.0	0.47 ± 0.02	50.9 ± 0.3	-5.5 ± 0.0	33.7 ± 0.4	-21.6 ± 0.5	0.98 ± 0.01
7	F_2	25.25	25	0.015	73.9±0.2	0.968 ± 0.003	4017 ± 162	5.2 ± 0.1	0.46 ± 0.01	51.6 ± 0.7	-5.8 ± 0.5	32.5 ± 0.4	-22.1 ± 0.2	0.95 ± 0.02
8	F_7	25.25	25	0.000	72.2±0.1	0.964 ± 0.002	5263 ±71	5.2 ± 0.0	0.46 ± 0.01	53.3 ± 0.2	-5.9 ± 0.0	34.1 ± 0.1	-22.5 ± 0.6	0.95 ± 0.01
9	F_8	20.20	50	0.030	78.6±0.1	0.970 ± 0.001	2968 ± 105	5.3 ± 0.0	0.42 ± 0.01	54.6 ± 0.2	-7.3 ± 0.1	33.8 ± 0.7	-22.9 ± 0.4	0.93 ± 0.03
10	F_9	20.20	0	0.000	79.6±0.0	0.969 ± 0.003	1773 ±143	4.8 ± 0.0	0.49 ± 0.01	52.9 ± 0.6	-4.9 ± 0.1	31.7 ± 0.7	-24.0 ± 0.2	0.96 ± 0.02
11	F_2	25.25	25	0.015	72.9±0.1	0.971 ± 0.001	4337 ±232	5.1 ± 0.0	0.52 ± 0.02	52 ± 0.6	-5.9 ± 0.0	34 ± 0.2	-24.3 ± 0.3	0.95 ± 0.02
12	F_2	25.25	25	0.015	72.8±0.1	0.965 ± 0.002	4470 ±105	5.0 ± 0.1	0.6 ± 0.01	49.9 ± 0.2	-5.6 ± 0.0	34.9 ± 0.3	-23.2 ± 0.9	0.96 ± 0.02
13	F_{10}	20.20	25	0.015	77.9±0.0	0.971 ± 0.002	2560 ± 87	5.1 ± 0.0	0.47 ± 0.01	52.9 ± 0.7	-5.2 ± 0.1	32.6 ± 0.2	-22.7 ± 0.6	1.17 ± 0.02
14	F_{11}	20.20	50	0,000	77.1±0.1	0.97 ± 0.002	3570 ±225	5.4 ± 0.0	0.42 ± 0.01	52.8 ± 0.2	-5.9 ± 0.1	35.1 ± 0.9	-25.9 ± 0.7	1.17 ± 0.02
15	F_2	25.25	25	0.015	73.4±0.1	0.97 ± 0.001	4557 ± 205	5.1 ± 0.0	0.53 ± 0.03	52.5 ± 0.1	-5.3 ± 0.0	35.3 ± 0.2	-24.7 ± 0.2	0.96 ± 0.05
16	F_{12}	30.3	50	0.030	65.3±1.3	0.963 ± 0.002	10777 ±248	5.3 ± 0.0	0,52 ± 0,01	47.3 ± 0.2	-6.1 ± 0.1	33.1 ± 0.7	-23.8 ± 0.4	1.06 ± 0.03
17	F_{13}	25.25	25	0.030	71.8±0.1	0.963 ± 0.004	6547 ±575	5.0 ± 0.0	0.52 ± 0.00	53.6 ± 0.0	-5.7 ± 0.1	31.6 ± 0.2	-24.0 ± 0.4	0.97 ± 0.01
18	F_{14}	20.2	0	0.030	79.0±0.3	0.971 ± 0.002	2527 ±183	4.8 ± 0.0	0.5 ± 0.01	51.8 ± 0.2	-6.1 ± 0.1	31.1 ± 0.9	-23.4 ± 0.6	0.95 ± 0.02
19	F_{15}	25.25	50	0.015	71.4 ± 0.0	0.966 ± 0.001	7517 ± 527	5.3 ± 0.0	0.44 ± 0.01	54.4 ± 0.4	-5.7 ± 0.1	32.6 ± 0.6	-24.4 ± 0.4	1.11 ± 0.14
20	F_2	25.25	25	0.015	72.6 ± 0.0	0.964 ± 0.004	6373 ± 387	5.0 ± 0.0	0.5 ± 0.01	52.3 ± 0.4	-5.4 ± 0.1	36.1 ± 1.0	-24.1 ± 0.1	0.94 ± 0.02

*DS_G: Dry solids of guacamole and DS_{FA}: Dry solids contributed by FA.
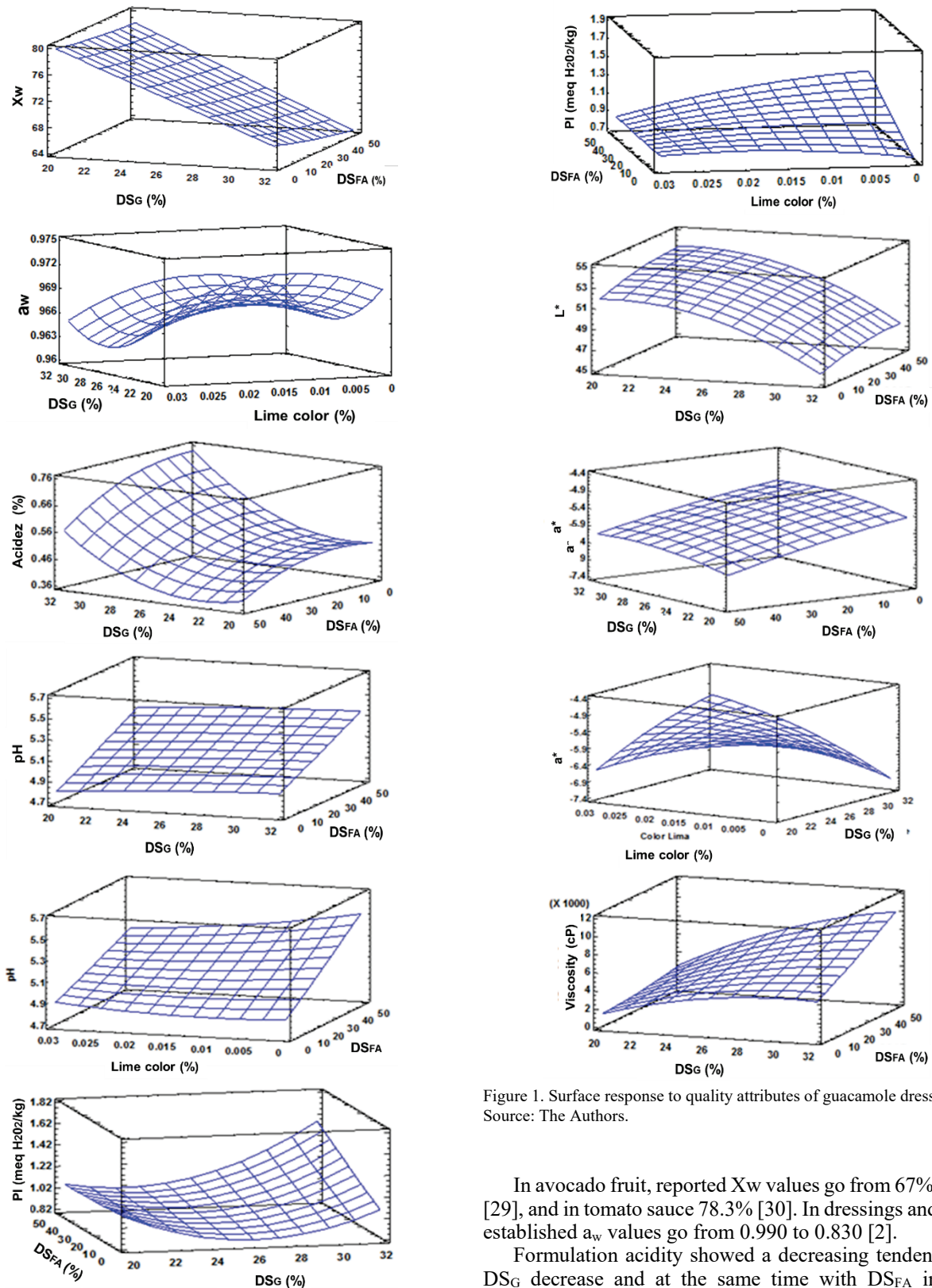Source: The Authors.

Figure 1. Surface response to quality attributes of guacamole dressing.
Source: The Authors.

In avocado fruit, reported Xw values go from 67% to 78% [29], and in tomato sauce 78.3% [30]. In dressings and sauces established a_w values go from 0.990 to 0.830 [2].

Formulation acidity showed a decreasing tendency with DS_G decrease and at the same time with DS_{FA} increase, reaching highest values of acidity when DS_{FA} contribution was zero (100% AP) and DS_G was higher. pH values were consistent with acidity, being lower when DS_{FA} contribution was zero (100% AP) and pH was higher when DS_{FA} contribution was 50%. The differences of pH and acidity are

mainly related to AP and FA acidity, and pH described in Table 1. On the other hand, Hass FA contains acids typical of this fruit, even in higher concentration compared to other varieties like Creole avocado. It is noteworthy that pH values were higher than 4.6, a value suggested as safe pH in sauces and dressings [31]. However, microorganism inhibition capacity in sauces and salad dressings stored at temperatures of 5°C and a pH of 6.5 is reporte [2].

Lipid oxidation is one of the most serious causes of quality deterioration in many foods. Compounds responsible for unpleasant odors and tastes are produced in parallel with lipid peroxidation [32]. PI is related to hydroperoxides formation; a first product formed by lipid oxidation, and is used to determine the initial degradation rate [32]. The maximum oxidation value obtained in guacamole formulations was 1.79 ± 0.11 meq H_2O_2/kg, which is favorable when compared to the limits allowed for avocado oil according to the Mexican norm NMX-F-052-SCFI-2008, and with those reported by Ariza et al. [33] in Hass avocado subjected to electric field (2.46 meq O_2/kg). This result could be attributed to the effect of dilution of AP solids in the elaboration of guacamole.

The most important increase in PI (1.79 meq H_2O_2/kg) occurs at high values of DS_G and DS_{FA}, which is consistent with higher fat content of the formulations and therefore, greater number of hydroperoxides. This oxidative phenomenon starts from the avocado fruit processing: pulp cutting and mashing with exposure to O_2 and light.
Mashing promotes the action of lipolytic enzymes on triglycerides causing hydrolysis and fatty acids release [24]. Also, the action of light causes an activation of the chlorophyll (photo-oxygenation) contained in FA, which in this state is a potential catalyst for lipid oxidation reactions, responding directly with the substrate to form free radicals that continue lipid oxidation reactions [34]. The same behavior was reported for a guacamole emulsion for spray drying purposes [16].

On the other hand, the increase of lime color in the formulations inhibited the oxidative process, mainly when the formulation had higher contributions of DS_{FA}. This influence is partly due to natural lime-colored dye characteristics, which is obtained from jagua blue (*Genipa americana*) and curcumin, a natural ingredient obtained from *Curcuma longa L.*, that can confer antioxidant activity involving radicals and peroxides uptake [34].

L* fluctuated between values of 47.3 and 54.6, observing darker tones (<L*) when the formulation contained a higher amount of DS_G. This behavior is related to PI results and to light absorption increase (less translucent) with higher content of DS_G, which produces a decrease in reflectance, causing a decrease in L* and getting darker. The a* and b* chromaticities fluctuated between values (-7.0 and -5.5) and (31.1 and 36.5) respectively, defining the product in the chromatic plane a*b* with a light green tone. As lime color increased in the formulations a* chromaticity (greenish chromaticity) decreased, mainly when the formulation had a low content of DS_G. While in formulations with a high content of DS_G, the effect was opposite, decreasing the greenish hue. Similar values were found in other studies with smashed avocado [8].

Viscosity has a direct effect on consumer acceptance, since it is an indicator of food quality [2]. Furthermore, this rheological property affects the release of flavors such as garlic, pepper and acid in products like dressings [35]. The viscosity of formulations fluctuated between 1773.3 and 10776.7 cP, showing a deformation in colloidal structure when shear rate increases, causing viscosity decrease. This behavior is a non-Newtonian pseudoplastic fluid and was also reported in salad dressing based on plantain and egg powder [35], in tomato sauce [36], and in mayonnaise and golf sauce [37]. The viscosity of guacamole was higher when the DS_G and DS_{FA} increased, maximizing with 30.3% DS_G and 50% DS_{FA}. Some of the viscosity results presented values similar to those reported for traditional mayonnaise, using a methodology that took into account agitation effort and a fixed temperature not reported by the author (4000 cP) [38], and low-fat mayonnaises among 856 and 2002 cP.

Although ζ did not present significant statistical differences (p> 0.05), its values ranged between -20.8 and -25.9 mV which denoted a partial contribution to colloidal system stability due to the predominant negative electrostatic forces in co-ions layer formed at the oily particles interface. In literature, stability studies are reported in different matrices with different ζ values: egg yolk-based dressing, rapeseed oil and dextran (ζ between -20 and -50 mV) [39], emulsion based on olive oil and hydrolyzed coconut protein (ζ between -13.7 and -17.7 mV) [23] and emulsions based on orange oil, gum arabic and xanthate gum (ζ between -26.8 and -29.3mV) [17]. In colloidal systems, like dressings, stability can be improved by increasing repulsive forces or electrical potential at the interface to $|\zeta| > 30$ mV [18], or with the use of hydrocolloids, such as xantha gum (stabilizer-thickener), which increases viscosity without depending on pH, it is also soluble in cold and hot water, and increases repulsion forces [40].

ANOVA (Table 3) identified that the DS_G variable had influence on Xw, a_w, acidity, L*, a*, η dependent variables; whereas DS_{FA} also had an effect on Xw, acidity, pH and η. Additionally, η and PI variables presented significant differences (p<0.05) with respect to DS_G-DS_{FA} interaction, and also PI with respect to lime color and DS_G quadratic interaction.

The analysis of formulations in this study was carried out according to the properties of a commercial guacamole (Xw: 80.1%, DSG: 19.9%, a_w: 0.971, acidity: 0.45%, pH: 5.6, PI: 0.219 meq H_2O_2/kg, ζ: -35.2 mV, L*: 55.9, a*: -5.6, b*: 30.0, and η: 3310.0 cP). It should be noted that the country does not have a specific regulation for avocado-based dressings.

The values of R^2 (Table 4) for the response surface models of b* and ζ were very low, which is not important taking into account that these variables did not show significant differences. However, a_w also presented a low R^2 value (0.605) due to low variability (0.963 - 0.971). For the other variables, response surface models could explain more than 75% of the variation found in each of them. The lack of adjustment that measures models capacity, was not significant (p>0.05), indicating that models were adequate to describe data behavior. Normally, experimental optimization processes are performed from significant dependent variables [13].

Table 3.
ANOVA of response surface models for the obtaining process of guacamole dressings.

Variables Response	Main effects			Quadratic effects			Effects of the interaction		
	A	B	C	AA	BB	CC	AB	AC	BC
Moisture (%)	0.0000*	0.0010*	0.4096	0.9099	0.5864	0.2483	0.1988	0.6222	0.6269
Water activity	0.0183*	0.3246	0.1078	0.0858	0.782	0.0471	0.8852	0.7367	0.2120
Luminosity L*	0.0016*	0.1190	0.9847	0.1766	0.6434	0.6566	0.9373	0.2674	0.9206
Chromaticity a*	0.0183*	0.3246	0.1078	0.0858	0.7820	0.0471	0.8852	0.7367	0.212
Chromaticity b*	0.7659	0.1721	0.2449	0.4255	0.8283	0.5212	0.2655	0.7083	0.7941
Viscosity (cP)	0.0000*	0.0002*	0.1130	0.1775	0.6888	0.1660	0.0094*	0.7180	0.7870
Zeta potential (mV)	0.2026	0.0888	0.9758	0.5056	0.9454	0.6890	0.5336	0.249	0.9565
Acidity (%)	0.0100*	0.0359*	0.7173	0.0743	0.1445	0.6558	0.3772	0.5114	0.2537
pH	0.1253	0.0000*	0.5779	0.8704	0.9013	0.4276	0.9025	0.9756	0.020*
Peroxide Index (meqH₂O₂/kg)	0.3208	0.0268*	0.0326*	0.0205*	0.8729	0.3006	0.0138*	0.2083	0.0047*

* $P < 0.05$. A: % dry solids of guacamole (DS$_G$), B: % dry solids contributed by FA (DS$_{FA}$), C: lime color
Source: the authors.

Table 4.
Regression coefficients of response variables mathematical models.

Regression coefficients	Moisture (%)	Water activity	Luminosity L*	Chromaticity a*	Chromaticity b *	Viscosity (cP)	Zeta potential (mV)	Acidity (%)	pH	Peroxide Index (meqH₂0₂/kg)
β_0	101.353	1.040	27,455	1.040	14,196	-20441.2	-18,180	1.529	4,448	4,911
β_A	-1.132	-0.006	2.189	-0.006	1.417	1696.0	-0.689	-0.098	0.024	-0.332
β_B	-0.002	0.000	0.076	0.000	0.160	-143.7	0.027	0.004	0.013	-0.012
β_C	101,947	0.607	127,113	0.607	-12.805	-125966.0	225,387	4.238	-3.512	27,960
β_{AB}	-0.003	0.000	0.000	0.000	-0.004	7.5	-0.002	0.000	0.000	0.001
β_{AC}	-1,617	-0.004	-7.772	-0.004	2.426	1448.3	-6.975	-0.154	0.011	-0.639
β_{BC}	0.322	-0.003	-0.137	-0.003	-0.341	218.6	0.064	0.055	-0.196	-0.347
$\beta_A{}^2$	0.002	0.000	-0.049	0.000	-0.027	-28.6	0.020	0.002	0.000	0.007
$\beta_B{}^2$	0.000	0.000	-0.001	0.000	0.000	0.3	0.000	0.000	0.000	0.000
$\beta_C{}^2$	-2239.730	14,478	1741,410	14,478	-2405.390	3345250.0	1348.140	-59,663	166,330	-297,743
R^2	0.986	0.605	0.747	0.862	0.489	0.929	0.527	0.771	0.927	0.865
Lack of adjustment (P-Value)	0.1483	0.5881	0.0931	0.1631	0.3628	0.5338	0.5609	0.4359	0.3647	0.5239

Source: The Authors.

Table 5.
Experimental optimization of guacamole formulation made from FA, PA, vegetables, spices, condiments and others.

Trait	Lower limit	Upper limit	Individual optimization						Multiple optimization DS$_G$*: 20.9 % DS$_{FA}$*: 28.9% Lime Color: 0.029%	
			Criterion	DS$_G$ (%)	DS$_{FA}$ (%)	Lime Color (%)	Predicted value	Impact	Predicted Value	Real value
Xw (%)	65.3	79.6	Max.	20.2	0.0	0.014	79.6	3	77.4	78.3±0.3
a$_w$	0.963	0.971	Min.	27.4	50	0.030	0.962	1	0.968	0.970±0.001
Acidity (%)	0.4	0.7	Max.	30.3	2.3	0.000	0.7	4	0.5	0.4±0.0
pH	4.8	5.6	Min.	20.2	□	0.010	4.8	2	5.1	5.1±0.0
PI (meqH₂O₂/kg)	0.9	1.8	Min.	25.1	0	0.000	0.7	5	0.9	0.8±0.0
L *	47.3	54.6	Max.	20.2	50.0	0.030	54.1	2	53.7	51.0±0.5
a*	-7.3	-4.6	Min.	24.4	27.3	0.020	-5,7	4	-6.5	-5.8±0.4
b *	31.7	36.1	Ma.	22.8	50	0.005	34.9	-----	-----	31.2±0.4
η (cP)	1773.3	10777	3310 cP	21.9	22.6	0.024	3310	5	3420.7	2952±117
ζ (mV)	-25.9	-20.8	Min.	20.2	50	0	-25.1	-----	-----	27.0±0.7

*DS$_G$: Dry solids of guacamole and DS$_{FA}$: Dry solids contributed by FA.
Source: The Authors.

3.3. Experimental optimization of guacamole formulations

Table 5 summarizes the experimental optimization of guacamole formulations considering dependent variables criterion individually and multiple optimization. Individual criteria were set considering some characteristics similar to a commercial guacamole ($\eta = 3310.0$ cP) and its best thermodynamic stability condition measured in terms of

repulsive forces. On the other hand, the impact was considered for effects of multiple optimization, which can be established from 1 to 5 based on the importance of each response variable. Impact values were established according to ANOVA results and variation between the lower and upper limit of response variables. The highest coefficients of variation were found for η and PI, for which an impact factor of 5 was assigned.

Results of the multiple optimization defined independent variable values. Therefore, the product with DS$_G$ of 20.9%, DS$_{FA}$ of 28.9% and lime color of 0.029% was within the overall optimum region for all the dependent variables studied. Statistical tool application for optimization resulted in the previous formulation of guacamole made with PA, FA, vegetables, spices and preservatives. The comparison of response variables predicted values obtained by response surface model of multiple optimization, they were acceptable which denoted a partial contribution to colloidal system stability due to the predominant negative electrostatic forces in co-ions layer formed at the oily particles interface. The variation of guacamole dressing properties as a function of the independent variables considered in the formulation development.

4. Conclusions

This research allowed standardizing the making process of a guacamole dressing from FA, AP, vegetables, spices and preservatives. By applying statistical tools for experimental optimization in the preparation of a guacamole dressing, an optimal formulation with DS$_G$ of 20.9%, DS$_{FA}$ of 28.9% and lime color of 0.029% could be established. AP can be used as raw material for guacamole making process, partially replacing fresh avocado, facilitating its process and obtaining a stable product with quality characteristics similar to a commercial guacamole. AP represents an effective alternative as raw material in the food sector and even with a potential use in cosmetic and pharmaceutical industries.

References

[1] Coello, V.N., Efecto de la adición de ácido ascórbico y butil hidroxitolueno (BHT) en la oxidación enzimática y rancidez oxidativa de pasta de aguacate (*Persea americana*) variedades Hass y Bacon, Food Engineering Thesis, Universidad Técnica de Ambato, Ecuador, 2015.

[2] Pourkomailian, B., Sauces and dressings, in: Kilcast, D., Ed., The stability and shelf-life of food, India, Woodhead Publishing Series in Food Science, Technology and Nutrition, 2000, pp. 311-331. DOI: 10.1533/9781855736580.2.311

[3] Daiuto, É., Tremocoldi, M. and Vileigas, D., Estabilidade físico-química de um produto de abacate acondicionado em diferentes embalagens e conservado pelo frio. Alimentos y Nutrición. [Online]. 21(1), 99-107, 2010. [date of reference February 8th of 2019]. Available at: http://serv-bib.fcfar.unesp.br/seer/index.php/alimentos/article/viewFile/1395/917

[4] Sandoval, A., Forero, F. y García, J., Postcosecha y transformación de aguacate: agroindustria rural innovadora, Colombia, Corpoica, 2010.

[5] Orozco, M.L., Prieto, R.E. y Díaz, L.E., Efecto de la adición de cebolla, ajo y la aplicación de ultrasonido de alta intensidad sobre la actividad de la polifenoloxidasa en guacamole. Vitae, [Online]. 19(1), pp. S132-S134, 2012. [date of reference February 8th of 2019].

Available at: http://www.redalyc.org/articulo.oa?id=169823914036

[6] Castorena, J., Rojas, M. y Robles, R., Análisis de pulpa y aceite de aguacate con espectroscopia infrarroja. Conciencia Tecnológica [Online]. (42), pp. 5-10. 2011. [date of reference February 8th of 2019]. Available at: http://www.redalyc.org/pdf/944/94421442002.pdf

[7] Jacobo, D., Castellanos, G., Caballero, P. y Hernández, C., Cambios bioquímicos durante el almacenamiento de puré de aguacate adicionado con antioxidantes naturales y procesado con alta presión hidrostática. CyTA-Journal of Food, 11(4), pp. 379-391, 2013. DOI: 10.1080/19476337.2013.775185

[8] Guzmán-Gerónimo, R., López, M.G. and Dorantes-Alvarez, L., Microwave processing of avocado: volatile flavor profiling and olfactometry. Innovative Food Science and Emerging Technologies, 9(4), pp. 501-506, 2008. DOI: 10.1016/j.ifset.2008.05.003

[9] Grajales, A., Garcia, H., Angulo, O. and Monroy, J., Stability and sensory quality of spray dried avocado paste. Drying Technology, 17(1-2), pp. 318-326, 1999. DOI: 10.1080/07373939908917532

[10] Castañeda, C., Valdés, E., Campos, E. y Alvarado, A., Efecto del liofilizado y del proceso de producción en la composición química y el perfil de ácidos grasos de la pulpa de aguacate. Revista Chilena de Nutrición, 41(6), pp. 404-411, 2014. DOI: 10.4067/S0717-75182014000400009

[11] Souza, D., Pimentel, J., Prado, M., Marques, L. and Narain, N., Rehydration characteristics of freeze-dried avocado (*Persea americana*). Chemical Engineering [Online], 2011. [date of reference February 8th of 2019]. Available at: http://www.icef11.org/content/papers/aft/AFT1155.pdf

[12] Caporaso, N., Genovese, A., Burke, R., Barry-Ryan, C. and Sacchi, R., Effect of olive mill wastewater phenolic extract, whey protein isolate and xanthan gum on the behaviour of olive O/W emulsions using response surface methodology. Food Hydrocolloids, 61, pp. 66-76, 2016. DOI: 10.1016/j.foodhyd.2016.04.040

[13] Gharibzahedi, S.M.T., Mousavi, S.M., Hamedi, M. and Ghasemlou, M., Response surface modeling for optimization of formulation variables and physical stability assessment of walnut oil-in-water beverage emulsions. Food Hydrocolloids, 26(1), pp. 293-301. 2012 DOI: 10.1016/j.foodhyd.2011.06.006

[14] Mirhosseini, H., Tan, C.P., Hamid, N. and Yusof, S., Effect of arabic gum, xanthan gum and orange oil contents on ζ-potential, conductivity, stability, size index and pH of orange beverage emulsion. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 315(1-3), pp. 47-56, 2008. DOI: 10.1016/j.colsurfa.2007.07.007

[15] Marulanda, A.M., Desarrollo de un producto en polvo a partir de aguacate (*Persea Americana* Mill), variedad Hass, mediante el proceso de secado por aspersión, MSc. Thesis, Universidad Nacional de Colombia, Medellín, Colombia, 2013.

[16] Estrada, E., Optimización experimental del proceso de secado por aspersión para la obtención de guacamole en polvo. MSc. Thesis, Universidad Nacional de Colombia, Medellín, Colombia, 2016.

[17] Drakos, A. and Kiosseoglou, V., Depletion flocculation effects in egg-based model salad dressing emulsions. Food Hydrocolloids, 22(2), pp. 218-224, 2008. DOI: 10.1016/j.foodhyd.2006.11.003

[18] Thaiphanit, S., Schleining, G. and Anprung, P., Food hydrocolloids effects of coconut (*Cocos nucifera* L.) protein hydrolysates obtained from enzymatic hydrolysis on the stability and rheological properties of oil-in-water emulsions. Food Hydrocolloids, 60, pp. 252-26, 2016. DOI: 10.1016/j.foodhyd.2016.03.035

[19] Santana, A., Oliveira, R. De Pinedo, A., Kurozawa, L. and Park, K.J., Microencapsulation of babassu coconut milk. Food Science and Technology (Campinas), 33(4), pp. 737-744, 2013. DOI: 10.1590/S0101-20612013000400020

[20] Ji, J., Fitzpatrick, J., Cronin, K., Crean, A. and Miao, S., Food hydrocolloids assessment of measurement characteristics for rehydration of milk protein based powders. Food Hydrocolloids, 54, pp. 151-161, 2016. DOI: 10.1016/j.foodhyd.2015.09.027

[21] Cortes, M., Rodríguez, E., Ciro, H.J. y Largo, E. Secado por aspersión de concentrado de caña panelera: una tecnología apropiada para mejorar la competitividad de la cadena. Vitae, [Online], 19, pp. 51-52, 2012. [date of reference February 8th of 2019]. Available at: http://www.redalyc.org/articulo.oa?id=169823914009

[22] Santillán, T., Yahumaca, J. y Martínez, E., Evaluación de la calidad oxidativa de tres aceites comerciales en condiciones de almacenamiento acelerado. Proceedings of XII Congreso Nacional de Ciencia y Tecnología de Alimentos, 2010. pp. 1-8.

[23] Duque, A., Londoño-Londoño, J., Álvarez, D.G., Paz, Y. y Salazar, B., Comparación del aceite de aguacate variedad hass cultivado en Colombia, obtenido por fluidos supercríticos y métodos convencionales: una perspectiva desde la calidad. Revista Lasallista de Investigación [Online]. 9(2), pp. 151-161, 2012. [date of reference February 8th of 2019]. Available at: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S1794-44492012000200016

[24] Chávez, S., Efecto de la potencia y el tiempo de escaldado en horno microondas sobre la actividad de la polifenoloxidasa, características fisicoquímicas y sensoriales del puré refrigerado de palta (*Persea americana* Millar) variedad fuerte, Agroengineering Thesis, Universidad Nacional de Trujillo, Trujillo, Perú, 2010.

[25] NGo, T. and ZHA, Y., Formation of zinc-chlorophyll-derivative complexes in thermally processed green pears (*Pyrus communis* L.). Food Chemistry and Toxicology, 72(7), pp. 397-404, 2007. DOI: 10.1111/j.1750-3841.2007.00465.x

[26] Lu, Q.Y., Zhang, Y., Wang, Y., Wang, D. and Lee, R.P., California hass avocado: profiling of carotenoids, tocopherol, fatty acid, and fat content during maturation and from different growing areas. Journal of Agricultural and Food Chemistry, 57(21), pp. 10408-10413, 2009. DOI: 10.1021/jf901839h

[27] Gonzales, S.M., Ochoa, L.A., Morales, J., Rocha, N., Trancoso, N. y Urbina, M., Propiedades de rehidratación y funcionales de un producto en polvo a base de jugo de granada y manzana. Ciencia@UAQ [Online], 4(2), pp. 19-25, 2011. [date of reference February 8th of 2019]. Available at: http://www.uaq.mx/investigacion/revista_ciencia@uaq/ArchivosPDF/v4-n2/propiedades.pdf

[28] Borda, M., Formulación de un aderezo de ensaladas con características de alimento funcional, MSc. Thesis, Universidad Tecnológica Nacional de Buenos Aires, Buenos Aires, Argentina, 2011.

[29] Duarte, P.F., Chaves, M.A., Borges, C.D. and Mendonça, C.R.B., Avocado: characteristics, health benefits and uses. Ciênc. Rural, 46(4), pp. 747-754, 2016. DOI: 10.1590/0103-8478cr20141516

[30] Torbica, A., Belović, M., Mastilović, J., Kevrešan, Ž., Pestorić, M., Škrobot, D. and Dapčević-Hadnadev, T., Nutritional, rheological, and sensory evaluation of tomato ketchup with increased content of natural fibres made from fresh tomato pomace. Food and Bioproducts Processing, 98, pp. 299-309, 2016. DOI: 10.1016/j.fbp.2016.02.007

[31] Fernandez, V.E., Palazolo, G.G., Bosisio, N.A. and Martínez, L.M., Rheological properties and stability of low-in-fat dressings prepared with high-pressure homogenized yeast. Journal of Food Engineering, 111(1), pp. 57-65, 2012. DOI: 10.1016/j.jfoodeng.2012.01.029

[32] Kishk, Y. and Elsheshetawy, H.E., Effect of ginger powder on the mayonnaise oxidative stability, rheological measurements, and sensory characteristics. Annals of Agricultural Sciences, 58(2), pp. 213-220, 2013. DOI: 10.1016/j.aoas.2013.07.016

[33] Ariza, J.A., Delgado, R.J., López, F., Coyotl, J., Ramos, M.E. y Soriano, A., Efecto del campo eléctrico sobre el aceite de aguacate almacenado a varios tiempos. Ingeniería Agrícola y Biosistemas, 3(2), pp. 67-73. 2011. DOI: 10.5154/r.inagbi.2011.11.005

[34] Kirschweng, B., Tátraaljai, D., Földes, E. and Pukánszky, B., Efficiency of curcumin, a natural antioxidant, in the processing stabilization of PE: concentration effects. Polymer Degradation and Stability, 118, pp. 17-23 2015. DOI: 10.1016/j.polymdegradstab.2015.04.006

[35] Bortnowska, G., Balejko, J., Schube, V., Tokarczyk, G., Krzemińska, N. and Mojka, K., Stability and physicochemical properties of model salad dressings prepared with pregelatinized potato starch. Carbohydrate Polymers, 111, pp. 624-32, 2014. DOI: 10.1016/j.carbpol.2014.05.015

[36] Li, J.-M. and Nie, S.-P., The functional and nutritional aspects of hydrocolloids in foods. Food Hydrocolloids, 53, pp. 46-61, 2016. DOI: 10.1016/j.foodhyd.2015.01.035

[37] Gallego, H., Álvarez, C., Vélez, C. y Fernández, A., Caracterización reológica de dos salsas. Vitae, [Online], 19, pp. 1-4, 2012. [date of reference February 8th of 2019]. Available at: http://www.redalyc.org/articulo.oa?id=169823914136

[38] Cornelia, M., Siratantri, T. and Prawita, R., The utilization of extract durian (Durio zibethinus L.) Seed gum as an emulsifier in vegan mayonnaise. Procedia Food Science, 3, pp. 1-18, 2015. DOI: 10.1016/j.profoo.2015.01.001

[39] Chen, H. et al. Improved the emulsion stability of phosvitin from hen egg yolk against different pH by the covalent attachment with dextran. Food Hydrocolloids, 39, pp. 104-112, 2014. DOI: 10.1016/j.foodhyd.2013.12.031

[40] Mirhosseini, H. and Tan, C.P., Response surface methodology and multivariate analysis of equilibrium headspace concentration of orange beverage emulsion as function of emulsion composition and structure. Food Chemistry, 115(1), pp. 324-333, 2009. DOI: 10.1016/j.foodchem.2008.11.090

M. Cortés-Rodríguez, received the BSc. Eng in Chemical Engineering in 1989 and the PhD. in Food Engineering in 2004. His research interests include: food engineering, science and technology, functional foods. Currently, he is a titular professor in the Agricultural and Food Engineering Department, Faculty of Agricultural Sciences, Universidad Nacional de Colombia. Author of 3 patents, 93 articles published in scientific journals and 3 book chapters. Participation in 39 research projects; director of 5 extension projects; director of 4 Doctoral Thesis and 33 Master Thesis; director of 7 Doctoral Thesis and 5 Master Thesis in development. Speaker in 95 national and international events, national industry consultant, evaluator of research projects, scientific articles of national and international scientific journals; member of editorial and scientific committees of national and international scientific journals.
ORCID: 0000-0003-3407-1635

F.S. Orrego-Vargas, received the BSc. Eng. in Agricultural Engineering in 2014, and MSc. Food Science and Technology in 2017. His research interests include: agricultural engineering, food engineering and functional foods. Member of the research group on functional foods Colciencias, co-author of 1 patent, author of several scientific articles in the area. For 4 years she has worked in the food industry with emphasis on quality and safety, development of food matrices and control of production processes. She is currently director of a food company recognized in the sector.
ORCID: 0000-0001-8270-6039

E. Rodríguez-Sandoval, received the BSc. Eng. in Chemical Engineering in 2001, and the PhD. degree in Engineering with emphasis on food engineering in 2006. His research interests include: carbohydrate science, food engineering, food texture and rheology. Currently, he is a full professor in the Agricultural and Food Engineering Department, Faculty of Agricultural Sciences, Universidad Nacional de Colombia. He has published in different international and national journals of great impact and has more than 50 peer reviewed journal articles. He has also served as a reviewer of research projects, scientific manuscripts of national and international scientific journals.
ORCID: 0000-0001-9146-2419