Effect of repeated frying on the physical characteristics, the formation of acrylamide and oil uptake of tortilla chips subjected to pre-drying treatment

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Abstract Even though snacks such as tortilla chips are gaining popularity, the high intake of these products may cause problems related to their fat and acrylamide content. In consequence, this study is aimed at evaluating the effect of pre-fry drying on the absorption of oil, physicochemical characteristics and formation of acrylamide in corn tortilla chips fried in ten batches. Pre-drying was carried out at 40 °C, 50 °C and 60 °C and two air velocities (1.0 m/s² year 1.5 m/s²). Frying conditions were selected from pre-tests where the physicochemical variables of frying oils (palm olein and avocado oil) were measured. Acrylamide content was measured by GC–MS analyses. The results revealed that the type of oil did not

show a significant effect on the physicochemical variables studied. Pre-dried chips showed a decrease in the final oil content of 41–58% (depending on the type of oil used) when compared to two brands of commercial chips. All the detected acrylamide concentrations on the samples were below the detection limit (20 µg/kg). According to our results, avocado oil may also be an option for producing corn tortilla chips.

Keywords Frying · Convective drying · Avocado oil · Palm olein

Introduction

Tortilla chips consumption has augmented in many countries around the globe (Chen and Moreira 1997; Global Industry Analysts 2014). The need for healthy products has prompted the food industry to develop low-fat foods without losing its original sensorial characteristics and texture (Kawas and Moreira 2001; Pedreschi and Moyano 2005). The food industry tends to use frying oil repeatedly because its reuse reduce the expenses (Chen and Moreira 1997; Nayak et al. 2016). However, scientific evidence suggests that oils used in batch frying are highly deteriorated with compounds such as acrylamide and polar compounds (Totani et al. 2006). In this sense, it has been observed that drying of foods before frying process can reduce fat absorption (Gamble and Rice 1987; Moreira et al. 1997; Mellema 2003; Pedreschi and Moyano 2005).

In general, palm olein is commonly used for industrial frying of foods due to its low cost and its high availability. However, it has been associated with some health problems in humans. On the other hand, avocado oil brings health benefits such as the prevention of coronary heart disease,

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diabetes and possibly prostate issues (Eyres et al. 2001; Birkbeck 2002). Thusly, this work is aimed at studying oil absorption during repeated frying of the tortilla chips that were subject to air drying before frying them in two different oils (palm olein and avocado oil). The acrylamide content produced during food frying was also investigated.

Materials and methods

Materials

Traditionally, tortilla chips are made with pieces of tortillas manufactured at local mills, which are subsequently deep-fried. The fabrication of tortillas is not standardized and the variability of their physicochemical properties has not been studied yet. Thusly, pre-tests of the physicochemical properties of two different commercial and handmade corn tortillas from different mills located in Veracruz City were carried out by randomly selected tortilla mills. Four samples of commercial tortillas were purchased from various randomly selected local markets.

For the frying tests, the oil used was Type 1 frying oil (100% palm olein) from Proteins and Oils (Proteins and Oils, Mexico) and Type 2 oil (100% avocado oil) from Diricom (Diricom, Mexico).

Pre-drying treatment

The tortillas were cut in a triangular shape ($6.0 \times 6.0 \times 4.8$ cm) and pre-drying was performed in a tray dryer (Apex 28-BE). Pre-drying was carried out at 40 °C, 50 °C and 60 °C and two air velocities (1.0 m/s^2 year 1.5 m/s^2). The chip thickness was 0.75 mm and all tests were repeated twice.

Deep-fat frying experiments

Frying conditions were selected from pre-tests where the frying oil was preheated to a selected temperature then the samples were immersed in the oil and covered carefully with a stainless steel mesh. The tortilla chips were fried at two different temperatures (160, 180 °C) for 60 and 90 s. according to Morales-Pérez and Vélez-Ruiz (2011) and in a ratio of oil and product of 40:1 mL/g according to Pérez-Tinoco et al. (2007).

Once the process conditions were chosen, the deep-fat frying procedure was established according to Martínez-Avila (2012). In this protocol, 100 chips were fried under the conditions mentioned above (160 °C for 60 s., 40:1 mL/g of oil: product ratio) ten times with twenty minutes between each procedure. This was repeated three times with each type of oil (palm olein and avocado oil).

Samples for the determination of all the physicochemical and analytical variables described were subsequently taken from the first, third, sixth and tenth frying steps.

Two sets of single deep-fat frying experiments were also carried out to compare their fat content with those of commercial brands. The tortilla chips in one set of trials were pre-dried and the tortilla chips in another were not pre-dried. The same frying procedure was used on repeated tests. Both experiments represent control treatments.

Determination of analytical and physicochemical variables

The moisture content was determined according to the AOAC 32.1.03 method (1995). The moisture content was expressed as the dimensionless moisture content (X^*) to select the drying condition where the tortilla chips attained 48% (wet basis) in the shortest time. X^* was calculated by means of Eq. 1:

$$X^* = \frac{X - X_e}{X_0 - X_e} \quad (1)$$

where X corresponds to the moisture content at any time in g water/g of wet solid, X_0 is the initial moisture content in g water/g of wet solid, and X_e is the equilibrium moisture content in g water/g of wet solid. Tests were performed twice on four repeated deep-frying cycles.

The water activity of the fried tortilla samples was conducted on AquaLab equipment (series 3, AquaLab, USA). The texture of the samples was measured regarding the fracturability and the modulus of deformation. Both variables were evaluated with a texture meter analyzer (PSB0010, ComTen Industries, USA).

For the color determination of tortilla chips, samples were ground and placed on white trays and subsequently read using a reflectance colorimeter (D/8-L, Hunter Lab, USA). The colorimeter displayed the L^* , a^* , b^* coordinates directly. The color was expressed regarding the polar coordinates L^* , C^* , h° . C^* and h° were calculated according to Eqs. (2) and (3):

$$C^* = (a^* + b^*)^{1/2} \quad (2)$$

$$h^\circ = \arctg(b^*/a^*) \quad (3)$$

Acrylamide and total oil content

The total oil content in the tortilla chips was determined in duplicate by the Soxhlet method according to the Mexican Standard NMX-F-089-S-1978. Acrylamide content was determined following the methodology proposed by Salazar et al. (2014) for tortilla chips with slight modifications.

One mathematical model was used to analyze the effect of the number of cycles and the use of palm and avocado oil on eight physicochemical characteristics (water activity, moisture content, fat content, °Hue parameter, Chroma parameter, luminosity, fracturability, and modulus of deformation) during deep-frying of the samples. The statistical model used for the analysis corresponds to:

$$y_n = (\beta_0 + \gamma_0 X_{i2}) + (\beta_1 + \gamma_1 X_{i2}) X_{i1} \quad (4)$$

where y_n represents the obtained values of tested physicochemical and analytical variables, X_{i1} represents the number of deep-frying cycles, X_{i2} the code for each type of oil used in tests (0 for palm olein and 1 for avocado oil), and β_0 , β_1 and γ_0 , γ_1 are intercept terms.

The statistical analysis of physicochemical parameter data was performed using SAS statistical package (SAS Software Inc.), and regression models were adjusted with a confidence interval of 95% using a source code compiled in C ++.

Results and discussion

Pre-drying of tortilla chips

Figure 1 shows the kinetics of tortilla chips dried at two different air velocities and temperatures. As expected, higher drying rates were observed when higher air velocities were used. Gamble and Rice (1987) found that the highest oil reduction in potato chips dried with hot air was found in samples with 48% moisture content (wet basis). Data revealed that this moisture value for tortilla chips (48% moisture content, 0.1 dimensionless moisture content) was achieved at 60 °C and 1.5 m/s in lesser time.

Fig. 1 Drying kinetics of tortilla chips at different temperatures and air velocity of 1.5 m/s

The effect of repeated deep-frying on the physicochemical characteristics of tortilla chips subjected to a pre-drying treatment

Pre-frying tests revealed that there were no significant differences between treatment temperatures and the duration and the use of palm or avocado oil regarding the color change, the texture, the total fat content and the water activity ($p > 0.05$) (Table 1). Accordingly, the treatment which represented the lowest energy consumption, duration (i.e., the treatment with less exposure to thermal degradation product) was selected (160 °C for 60 s). Table 2 shows a summary of the analytical and some physicochemical variables of pre-dried tortilla chips after different deep-frying cycles.

In general, no significant differences in the color measurement, texture variables, water activity, moisture content and fat content between repeated deep-fat frying of avocado and palm olein were found. Tortilla chips values of moisture content, texture variables and color did not show a significant difference either due to repeated frying cycles nor to the oil type ($p < 0.05$).

Results obtained for the fracturability coincide with those reported by Morales-Perez and Vélez-Ruiz (2011) and Moreira et al. (1997) which indicated that the fracturability of tortilla chips ranges between 5 and 8 N and 6 N, respectively. No significant difference between the fracturability values of samples of tortillas chips subjected to repeated frying steps in both oils and commercial trademark 1 chips were observed ($p > 0.05$). At the same time, the commercial brand which showed a lower water activity value (commercial trademark 2) showed a significant difference ($p < 0.05$) between the same variables. Moreover, no significant difference between the values of

Table 1 Physicochemical parameters of tortilla chip samples from pre-frying tests

Physicochemical parameter	Treatments with palm olein				Treatments with avocado oil			
	160 °C/60 s	160 °C/90 s	180 °C/60 s	180 °C/90 s	160 °C/60 s	160 °C/90 s	180 °C/60 s	180 °C/90 s
a_w	0.22 ± 0.02ae	0.19 ± 0.04ae	0.14 ± 0.03de	0.12 ± 0.02de	0.19 ± 0.01ae	0.20 ± 0.06ae	0.13 ± 0.04de	0.09 ± 0.05e
% Fat content (w/w)	10.32 ± 0.59d	11.92 ± 0.76ad	12.63 ± 0.14ad	12.72 ± 1.27ad	10.29 ± 0.66d	11.72 ± 2.64ad	13.39 ± 0.96ad	11.29 ± 0.22ad
Texture								
PR (N)	7.82 ± 1.22d	5.15 ± 0.95d	5.92 ± 2.49d	8.62 ± 1.67ad	8.62 ± 1.67ad	7.68 ± 1.93d	7.42 ± 2.94d	8.73 ± 3.37ad
Slope (N/mm)	8.36 ± 2.60d	8.96 ± 2.74d	7.81 ± 3.86d	15.70 ± 5.78a	15.70 ± 5.78a	10.81 ± 2.98d	12.67 ± 6.13d	13.29 ± 6.43ad
Color								
L*	63.17 ± 1.62ab	62.99 ± 0.18ab	61.00 ± 0.19b	58.46 ± 2.33b	64.76 ± 2.95ab	62.83 ± 2.60ab	59.10 ± 2.37b	56.14 ± 0.02b
C*	31.76 ± 0.98c	32.46 ± 5.23c	37.45 ± 1.2ac	41.05 ± 1.04ac	31.18 ± 1.84c	32.80 ± 3.44c	36.06 ± 2.55c	39.46 ± 1.93ac
H(°)	78.63 ± 2.03ab	75.89 ± 1.04ab	75.89 ± 1.04ab	72.91 ± 0.57b	75.28 ± 7.46ab	77.44 ± 1.91ab	76.14 ± 0.09b	74.97 ± 0.48b

Different letters represent significant difference between columns with Tukey $p < 0.05$. Treatment mean ± standard deviation. The media with the greatest value are assigned with “a” letter

Table 2 Summary table of analytical and physicochemical parameters after different frying cycles to obtain tortilla chips

Type of oil	Number of frying cycle	Color			H(°)		% Moisture content at the end of frying		a_w	Texture		Acrylamide content (µg/kg)
		L*	C*	H(°)						Fracturability (N)	Modulus of deformation (N/mm)	
Palm olein	1	64.24 ± 2.77	32.14 ± 1.67	79.79 ± 1.49	1.950 ± 0.860				0.275 ± 0.027	5.51 ± 0.19	5.54 ± 3.01	< LOQ
	3	63.33 ± 1.03	33.76 ± 0.39	77.90 ± 1.19	1.953 ± 0.855				0.276 ± 0.030	7.98 ± 0.58	10.74 ± 3.16	< LOQ
	6	62.97 ± 0.35	32.38 ± 0.45	79.15 ± 0.05	1.957 ± 0.845				0.274 ± 0.029	6.35 ± 0.89	9.95 ± 2.40	< LOQ
	10	63.79 ± 2.89	32.20 ± 1.45	80.05 ± 0.71	1.961 ± 0.848				0.276 ± 0.035	6.22 ± 0.64	8.91 ± 2.53	< LOQ
Avocado oil	1	63.58 ± 2.13	30.80 ± 0.26	80.82 ± 0.99	1.950 ± 0.861				0.274 ± 0.034	6.52 ± 1.46	7.17 ± 3.62	< LOQ
	3	63.66 ± 0.29	31.38 ± 1.59	80.52 ± 0.78	1.949 ± 0.858				0.274 ± 0.033	6.82 ± 1.63	9.56 ± 8.26	< LOQ
	6	63.82 ± 0.61	31.76 ± 0.82	80.58 ± 0.42	1.950 ± 0.859				0.275 ± 0.020	7.88 ± 1.32	13.19 ± 3.77	< LOQ
	10	64.48 ± 1.36	31.89 ± 2.20	82.07 ± 2.02	1.952 ± 0.860				0.274 ± 0.053	7.90 ± 1.16	11.52 ± 5.07	< LOQ
Commercial trademark 1	–	67.76 ± 0.52	41.91 ± 0.55	81.225 ± 1.27					0.192 ± 0.001	6.14 ± 0.60	7.21 ± 0.619	
Commercial trademark 2	–	68.65 ± 2.76	29.47 ± 0.891	80.09 ± 0.65					0.145 ± 0.011	12.21 ± 2.64	7.57 ± 0.20	

LOQ = 20 µg/kg

the modulus of deformation of samples of tortillas chips from repeated frying and the oil type were observed ($p > 0.05$). The values of the modulus of deformation for the different frying steps showed high standard deviations even though a good number of repetitions were carried out (ten repetitions). This behavior was also observed by Enriquez-Fernandez et al. (2011). Despite the high standard deviations of the modulus of deformation, the obtained values are of the same order of those observed on the commercial brands investigated (Table 2).

Katz and Labuza (1991) observed a loss in the crispness of snack foods at a_w ranging from 0.35 to 0.5 for chips. It is interesting to note that the average water activity of tortilla chips obtained in the present study was below this critical water activity range. We also observed an inverse relation between fracturability and moisture content values, whereas the opposite behavior regarding the relationship between the modulus of deformation and moisture content was obtained. Both observations may be explained by the mechanical behavior of water in cereal-based foods at certain values of moisture content. In the case of cereal-based foods, fracturability may increase or decrease at different values of moisture content while slight changes of the modulus of deformation can traduce on sharp changes of the fracturability at the same values of moisture content (Roudaut et al. 1998).

As observed with the other variables analyzed, no significant differences in the color variables between samples of tortilla chips from different frying steps (for palm and avocado oil) and the commercial brands were observed ($p > 0.05$). The lack of statistical significance observed in the case of color variables may be attributed to the fact that the heat transfer coefficient may decrease insignificantly during repeated deep-frying of foods at similar

temperatures (1–6 steps at 173 °C) (Debnath et al. 2012). Thus, small differences between the first and the last frying steps might be expected.

Effect of successive deep-fat frying on the fat content of tortilla chips subjected to a pre-drying treatment

A summary of the fat content values obtained from successive deep-fat frying, control tests (frying tests with and without pre-drying treatment) and two commercial brands is given in Table 3.

Data showed that fat content was not affected significantly by the succession of deep-frying steps ($p > 0.05$) and the type of oil ($p > 0.05$). It can be seen from Table 3 that the final oil content values of the samples of tortilla chips subjected to a pre-drying treatment (both in the case of the repeated and control test 1) are lower than the observed on the commercial brands and the samples that were not subjected to a pre-drying treatment. Obtained values reveal that the pre-drying of tortilla chips can reduce the fat content of tortilla chips between 51% and 58% and 41% and 50% when palm olein and avocado oil are used, respectively. In this sense, Lujan-Acosta and Moreira (Luján-Acosta and Moreira 1997) obtained a reduction of the fat content of tortilla chips of 34–46% using pre-drying treatments such as sun drying and impingement drying. The differences between the fat content values may be explained by the differences in the raw materials used and the initial moisture content of tortilla samples before frying. On the study of Lujan-Acosta and Moreira (1997), tortilla chips were prepared from nixtamalized masa (mix of cornmeal and water), and the thickness of tortilla chips was set to 1.5 mm which is twice of that of the samples used in this study. The initial moisture content registered

Table 3 Fat content on fried pre-dried tortilla chips, fried tortilla chips without pre drying treatment and two brands of commercial chips

Type of sample	Number of frying batch	Type of frying oil	Fat content (g/100 g)
Tortilla chips subjected to repeated deep-fat frying	1	Palm olein	12.92 ± 0.93
	3		17.04 ± 0.03
	6		15.37 ± 0.78
	10		15.96 ± 0.85
Tortilla chips subjected to repeated deep-fat frying	1	Avocado oil	16.78 ± 1.81
	3		18.61 ± 3.05
	6		15.66 ± 2.38
	10		18.48 ± 2.54
Pre-dried tortilla chips (control 1)	1	Palm olein	11.79 ± 1.38
Tortilla chips without pre-drying treatment (control 2)	1	Palm olein	23.50 ± 0.71
<i>Brands of commercial chips</i>			
Commercial trademark 1			28.53 ± 2.02
Commercial trademark 2			24.10 ± 0.79

Fig. 2 Acrylamide detection chromatogram for a tortilla chip sample fried in palm olein

before frying also showed a significant difference (14% vs. 48%).

Effect of batch frying on the acrylamide concentration during repeated deep-frying of tortilla chips

Figure 2 shows an example of a chromatogram for acrylamide detection. No sample presented acrylamide levels above the limit of quantification of the method ($< 20 \mu\text{g/kg}$, Table 2). It is interesting to note that in another work on tortilla chips using the same technique for the detection of acrylamide values close to $1000 \mu\text{g/kg}$ of acrylamide were detected (Salazar et al. 2014). The lower concentration of acrylamide observed on the tortilla chips samples obtained in this study seems to be the consequence of the interaction of three factors associated both with the acrylamide formation and the processing of tortilla chips: the frying temperature, the moisture content and the pH of the samples (Pedreschi et al. 2007; Claus et al. 2008). In effect, both the frying temperature and the moisture content used were below or close to the maximum values reported for the formation of acrylamide in both cases ($175\text{--}180^\circ\text{C}$ and $0.15\text{--}0.45$ (wet basis), respectively). Also, the tortilla samples used contained benzoic acid (Fig. 2) which has been reported to reduce up to 57% of acrylamide content when it is employed as a preservative (Park et al. 2005). Benzoic acid was not added intentionally; its presence was due to its use as preservative for the masa (mix of cornmeal and water) employed for the preparation of tortilla chips.

Conclusion

No significant differences between palm olein and avocado oil were found on the physical variables evaluated in tortilla chips during repeated frying. Additionally, it was found that pre-drying tortilla chips until 48% of the moisture content in wet basis reduces the content of fried chips in 41–58% with respect to two commercial trademarks and non-pre-dried chips. It is important to note that the acrylamide content was $< \text{LOQ}$ ($20 \mu\text{g/kg}$) in the essays for palm olein. Avocado oil may be also an option to produce not only low fat chips but also enriched tortilla chips and even though it may be more expensive than palm olein the benefits to human health are far superior.

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