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Full Length Research Paper

Optical absorption coefficient of different tortillas by photoacoustic spectroscopy

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The color of the tortilla is one of the properties that determine the purchasing decision and acceptance for the consumer. This sensory attribute is altered, when making tortillas with elements to improve digestion and nutrition. Therefore, the objective of this investigation was to determine some information about the color in different types of tortilla found in the commercial market in "Ecatepec, Edo de Mexico". Optical absorption coefficients (β) were obtained from them by photoacoustic spectroscopy technique of closed cell, one of the photothermal techniques. Optical absorption spectra of each tortilla were recorded by means of photoacoustic spectroscopy (PAS) in the 350 to 700 nm range. Thirteen types of tortillas were evaluated, the experimental unit comprised three tortillas, among which one tortilla was selected at random for each repetition. The *β* values were determined from the photoacoustic (PA) signals amplitude and using the Rosencwaig and Gersho model. Data was subjected to variance analysis (ANOVA) using the SAS GLM procedures. The ANOVA revealed significant ($p \leq 0.05$) differences among tortillas. The results were analyzed statistically and correlated with preferences of a group of people in the same area, when a sensory test was applied; the test evaluated the color attribute by using the hedonic scale.

Key words: Tortilla, color, optical absorption coefficient, photoacoustic spectroscopy, sensory evaluation.

INTRODUCTION

Photothermal (PT) techniques are presently used in different areas of science to study thermal and optical properties of a wide range of specimens ranging from semiconductors to biological samples. The applications of PT techniques worth mentioning are the evaluation of agricultural seeds, seedlings and foodstuffs (Cruz et al., 1999; Dóka et al., 2010;Egesel et al., 2003; Favier et al., 1994; Fernandez et al., 2001; Luterotti et al., 2007). Among the photothermal techniques, Photoacoustic spectroscopy (PAS) is well suited for obtaining the optical absorption spectra of highly transparent or opaque and highly light-scattering materials. By using PAS technique and the Rosencwaig and Gersho (R and G) model (1976), which described mathematically the photoacoustic effect in solids, it is possible to get successfully the optical absorption coefficient, as a function of the incident wavelength (Paulet and Chambron, 1979) of biological samples as maize grains. The maize can be used for preparing a wide variety of foodstuffs such as the tortilla. The knowledge about a tortilla's optical parameters is of great relevance in the "mass and tortilla" technology practice. Such parameters provide information about its absorption and reflectance, which in turn is related to its color. The color could be related to its quality, health condition and nutrient content indicating

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the presence of carotenoids, anthocyanins, flavonoids and other pigments (Irani et al., 2003). In "the mass and tortilla" industry, it is important to characterize this attribute of the tortilla because it is one of the attributes that directly affect the quality of food consumed by the population and their purchasing decision. Thus, it is important to have techniques that contribute to the characterization of these foodstuffs because it is one of the attributes which depends on consumer acceptance.

Therefore, the objective of this research suggests the application of the PAS to determine the optical absorption coefficient (variable associated with the color) of “tortillas” by the Rosencwaig and Gersho model, for thermally thick samples. Correlating the results with preferences of a group of people, when applied to them a sensory test to evaluate the preferences based on color by using the hedonic scale. The preferences of people consuming food are of great importance, as well as complex. Some authors report that these preferences are based on numerous factors, including physiological, demographic, education, income, food availability, lifestyle, knowledge of diet and health that they have. It will also depend on the tastes and preferences of people with the physical condition of the product to consume. Consumer preferences that lead to a purchase decision are relevant to the mental and physical health of the population. In developing countries, it is more evident because it causes malnutrition and disease (Birch, 1999), as is the case of obesity which is considered a pandemic affecting most of the Western countries (OECD, 2010; WHO, 2010).

MATERIALS AND METHODS

Tortilla samples

Thirteen types of tortillas that are sold and consumed in some municipalities, such as “Ecatepec, Edo de Mexico”, Mexico, were selected in this study. The sample selection was based on the following criteria: (a) samples were chosen that would have different sensory characteristics, and people could express their tastes and preferences; (b) representative samples were chosen from the wide variety of tortillas in the commercial market, homemade, small, medium or large scale; these are the most sold in markets and tortilla establishments and those sold in malls. The characteristics of the samples used in the study are presented in Table 1, which contains descriptions about each of the 13 samples, numbered from T1, T2, T3 up to T13. Noting the description of each tortilla and characteristics in terms of thickness per tortilla, weight per tortilla, tortilla price per kilo, origin and the last column of Table 1, indicates whether the production of the tortilla is a small scale, medium or large scale. Mitutoyo brand micrometer precision and analytical balances Ohaus were used for determining the thickness and weight of the tortilla’s samples, respectively.

Optical characterization of the “tortilla”

The photoacoustic instrumentation consisted of a Xenon lamp (Oriel), a monochromator (Oriel), a chopper adjusted at a frequency of 17 Hz, and a fiber optic cable was connected to a photoacoustic cell with quartz glass windows hermetically sealed with vacuum grease. A sensor element was used as an electret microphone whose signal was captured by a lock-in (EG and G) which is interfaced to a personal computer that simultaneously displays the wavelength dependent signal amplitude and phase, and monitored by a computer (Figure 1). In order to take into account the xenon lamp emission spectrum, the PA signal was normalized to the signal obtained from charcoal powder. All the optical absorption spectra were obtained during 6 days; the mean time for obtaining each spectrum was 30 min. The spectra were obtained according to the design of randomized complete block. The absorption spectrum of each tortilla was obtained in a range of wavelengths (λ) of 350 to 700 nm. Calibrating the Xenon lamp to a power of 700 W, the amplitude and phase data were recorded by a computer. The data of photoacoustic signal amplitude obtained was used to obtain the optical absorption coefficient (β), using the model of R and G. The necessary condition for thermally thick samples is $a_s l_s >> 1$, this means that the 13 samples of “tortillas” used in this study complied with this necessary condition; that is, varying “l”, the sample thickness, from 0.78 to 1.87 mm. So, the optical absorption coefficient was obtained from equation 1, which corresponds to thermally thick samples (Paulet and Chambron, 1979).

$$\beta = \frac{a_s\{q^2 + q(2-q^2)^{1/2}\}}{(1-q^2)} \tag{1}$$

Where:

$$a_s = \left(\frac{\pi f}{\alpha}\right)^{1/2}, \qquad a_s = \frac{1}{\mu_s} \tag{2}$$

Where, q is the normalized PA intensity; a_s is the thermal diffusion coefficient at the modulation frequency f of 17 Hz, α = 0.00444 cm^2 s^{-1} is thermal diffusivity of the sample (Rodriguez et al., 1995) and l_s refers to the sample thickness. The samples previously homogenized in color and sizes were placed in the photoacoustic cell, ordering the measurement in a complete block design at random with three replications, the thirteen types of tortillas; preparing the sample to the size of 6 × 3 mm of dimension, in order to be allocated in the photoacoustic cell. The “tortilla” used in this study (and consumed in Mexico) has two faces. The criterion selected for homogenization of color refers to use of the same side of the “tortilla” for its analysis and also we selected the part of this face with homogeneous and predominant color. To relate the results of spectroscopic measurements of the “tortilla” with consumer preferences, we proceeded to perform a sensory test with consumers.

Characteristics of consumer

For sensory testing, 64 consumers were selected, considering the following criteria: (1) that inhabit the area “Ecatepec, Edo de Mexico”; (2) Do not use lenses; and (3) that have available time and patience to assess the color of the tortilla; (4) who are over 18 years. Among the consumers who participated in the test, 16 were men between 41 to 65 years (1 overweight and 3 normal weight) and 12, between 25 and 40 years (4 overweight and 8 normal weight) and 48 women: 15 between 25 to 40 years (8 with normal weight, 7 overweight) and 32 women aged 41 to 70 years (24 overweight, 6 obesity, 2 normal weight). Average monthly income of the families of the panelists indicated is 750 to 1250 USD, salary for the middle class in the Mexican population (INEGI, 2010).

Table 1. Description of thirteen samples of tortillas that are sold and consumed in “Ecatepec, Edo de Mexico”, Mexico.

Sample	Description of the tortilla	Thickness/T (mm)	Weight/T (g)	Price/Kg	Calories	Source	Production
T1	Manually processed corn, cooked in skillet	1.87	37.09	14	130	“Ecatepec, mercado Jardines”	Homemade
T2	Produced by a tortilla shop owned by a market. Maize and nopal	1.3	19.26	16	60	“Ecatepec, mercado Jardines”	Homemade
T3	White maize, a traditional shopping	1.674	28.11	8.5	110	“Ecatepec, mercado Jardines”	Homemade
T4	Wheat flour	0.692	25.87	35.57	168	“Walmart, Ecatepec- Edo de Mex”	Large scale
T5	Maize and nopal; taste epazote, free cholesterol	1.175	25.97	44	20	“Walmart, Ecatepec- Edo de Mex”	Medium scale
T6	Wheat flour	0.78	12.51	42.3	196	“Walmart, Ecatepec- Edo de Mex.”	Large scale
T7	Wheat flour and linseed	0.835	22.3	43.13	181	“Walmart, Ecatepec- Edo de Mex”	Large scale
T8	Maize, nopal and linseed.	1.24	20.38	42	23	“Walmart, Ecatepec- Edo de Mex”	Large scale
T9	Whole grains, Integral	0.896	19.42	54.54	133	“Walmart, Ecatepec- Edo de Mex”	Large scale
T10	Maize	1.434	26.82	11.25	105	“Ecatepec, shop”	Medium scale
T11	Traditional, white maize	1.361	27.65	8.5	110	“Ecatepec shop”	Small scale
T12	Blue maize	1.064	14.43	9.5	90	“Walmart, Ecatepec- Edo de Mex”	Medium scale
T13	Maize traditional	1.178	18.86	7.5	100	“Walmart, Ecatepec- Edo de Mex”	Medium scale

T: “Tortilla”

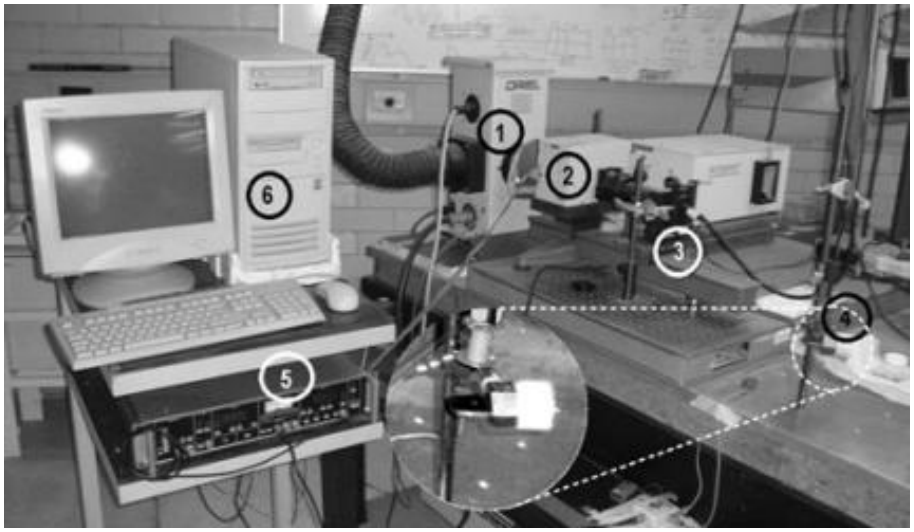

Figure 1. Experimental setup for PA measurements (1: Xenon lamp, 2: monochromator, 3: chopper, 4: photoacoustic cell, 5: lock-in amplifier and 6: PC).

Table 2. Means comparison of β value for different wavelength of 13 types of “tortillas” that are sold and consumed in Ecatepec and the means comparison of the consumer preferences according to the hedonic scale.

Samples tortilla	β value (cm^{-1})								Consumer preferences hedonic scale
	Wavelength (nm)								
	360	400	450	500	550	600	650	700	
T1	7.2^{b}	7.24^{b}	5.63^{b}	4.74^{a}	4.16^{a}	3.81^{a}	3.49^{a}	3.12^{a}	6.46^{a}
T2	4.2^{e}	4.12^{e}	1.89^{g}	1.04^{h}	0.8^{i}	0.83^{k}	0.85^{i}	0.75^{jk}	2.07^{f}
T3	9.12b^{a}	9.28^{a}	6.56^{a}	4.87^{a}	3.92^{b}	3.36^{b}	2.95^{b}	2.67^{b}	6.32^{a}
T4	3.10^{g}	3.28^{g}	2.13^{f}	1.73^{d}	1.47^{f}	1.400^{f}	1.15^{gf}	1.11^{fg}	4.65^{de}
T5	5.06^{c}	5.78^{c}	4.19^{d}	3.07^{c}	2.16^{d}	1.83^{d}	1.67^{d}	1.57^{d}	3.86^{e}
T6	1.2^{i}	1.71^{i}	1.34^{i}	1.16^{h}	1.10^{h}	1.061^{ji}	0.99^{h}	0.94^{hi}	4.80^{bdec}
T7	2.37^{h}	2.57^{h}	1.89^{g}	1.46^{f}	1.20^{hg}	1.11^{hi}	1.10^{g}	1.0^{hg}	5.99^{ba}
T8	7.32^{b}	7.47^{b}	5.33^{c}	4.23^{b}	3.44^{c}	2.8^{c}	2.39^{c}	1.93^{c}	4.73^{dec}
T9	2.3^{h}	2.41^{h}	1.68^{h}	1.33^{g}	1.14^{h}	1.03^{j}	0.94^{h}	0.85^{ji}	4.40^{e}
T10	1.54^{i}	1.64^{i}	1.64^{h}	0.70^{i}	0.70^{i}	0.61^{l}	0.65^{j}	0.65^{k}	5.95^{bac}
T11	5.14^{d}	5.25^{d}	2.27^{f}	1.58^{ef}	1.33^{g}	1.17^{g}	1.16^{f}	1.29^{b}	6.01^{ba}
T12	3.61^{f}	3.63^{f}	2.95^{e}	2.95^{c}	1.85^{e}	1.66^{e}	1.51^{e}	1.254^{fe}	3.98^{e}
T13	3.56^{f}	3.58^{f}	2.29^{f}	1.68^{ed}	1.52^{f}	1.14^{hg}	1.19^{f}	1.12^{fg}	5.85^{bdc}
LSD (0.05)	0.2031	0.2305	0.1831	0.134	0.1341	0.0663	0.066	0.1437	1.22

LSD = Least significant difference. Values with the different letter in columns are statistically different ($p \leq 0.05$).

Sensory test

The tests were conducted in a room located in “Ecatepec de Morelos, Edo de Mexico” at 16:00 h day, influencing natural day light and artificial energy-saving bulbs were used during the sensory test. People were asked to give a brief explanation of what they would do and were given a questionnaire containing: (1) General information and (2) The table to record their evaluation preferences about the color of the tortilla based on hedonic scale. This was explained through their sense of sight, and evaluation using the hedonic scale in the range of 1 to 9 in the following manner; I like to end 9, I really like 8, I like moderately 7, I like slightly 6, I neither like nor dislike 5, I dislike slightly 4, I dislike moderately 3, I hate to 2 and 1 dislike extremely. Using a randomized complete block design, sensory testing was conducted; the “tortillas” were heated before passing them to consumers through a variety of participants who helped support the distribution. The “tortillas” were purchased the same day before carrying out the test and were previously heated, depending on the tortilla between 30 to 60 s. The duration time of each sensory test was 3 h.

Statistical analysis

A randomized complete block experimental design with 3 replications of the thirteen types of “tortillas” was used. Data were subjected to analysis of variance by the software of the Statistical analysis system (SAS, 2008) using the procedure of general linear model (PROC GLM). The least significant difference (LSD) test at the 5% probability level was used for comparing treatments (Steel and Torrie, 1980).

RESULTS

The analysis of variance (ANOVA) presented statistically significant differences ($P \leq 0.05$) in the optical absorption coefficient of the studied tortillas type (T1, T2, T3 …. T13) in the range of 350 to 700 nm for each one of the repetitions. Table 2 shows the mean values of beta for each “tortilla” sample, evaluated at wavelengths of 360, 400, 450, 500, 550, 600, 650 and 700 nm. These values reflect the behavior of the optical absorption coefficient at wavelengths corresponding to flavonoids (360 and 400 nm), carotenoids (400, 450, 500 and 550 nm), chlorophylls (600, 650, 700 nm) and anthocyanins (450, 500, 550, and 600 nm) (Hoppe et al., 1983; Harbone and Mabry, 1976; Su et al., 1996). Statistical analysis performed found its least significant statistical differences, represented in the table with different letters. It is possible to observe in each column, different letters which mean that obtained mean values were statistically different. In the same Table 2, also, it is possible to observe that there were statistical differences between sensory preferences according to the visual attribute, color, evaluated by the group of people, through the sensory test, using the hedonic scale. The colors of “tortilla” sample, preferred by consumers, were T1 and T11, which were samples of maize tortillas. These samples were “tortilla” processed manually and the traditional “tortilla” of white maize, respectively.

In Figure 2, we can see the β value as a function of the wavelength; that is, beta decreases with the increase of λ for all the tortillas that were evaluated. In the wavelength of 360 nm, range of the flavonoids; the tortilla sample with most high β value (9.12 cm^{-1}) was the type T3, and is the type second of “tortilla” most preferred by the consumer.

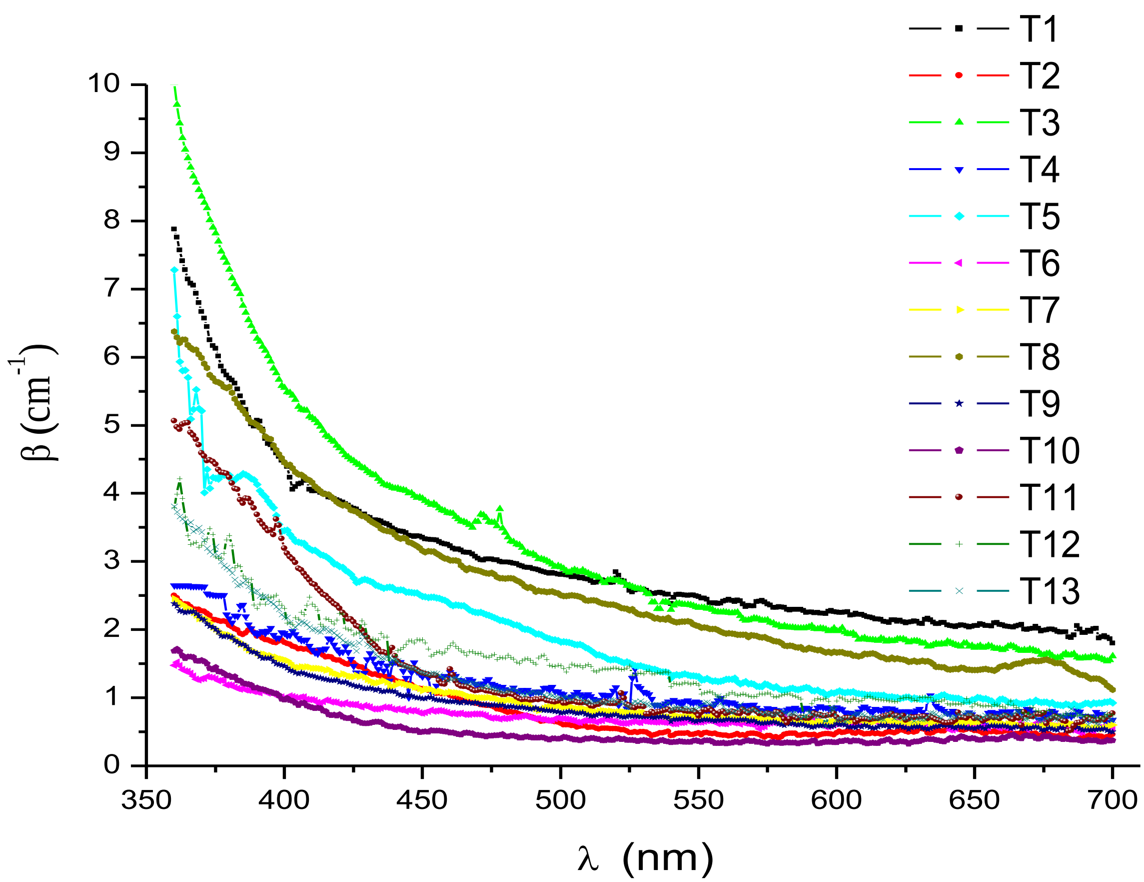

Figure 2. Optical absorption coefficient of thirteen types of “tortillas” that are sold and consumed “in Ecatepec, Edo de Mexico”, Mexico.

In the same manner, the sample T3 had the highest value of β at 400, 450 and 500 nm corresponding to 9.28, 6.56 and 4.87 cm^{-1}, respectively.

In the wavelength of 550 nm; the “tortilla” sample with most high β value were the T1, T3 and T8 (4.16, 3.92 and 3.44 cm^{-1}, respectively) and is the tortilla type T1, the most preferred by the consumer according to the people that evaluated their preference in color. In the wavelength of 600, 650 and 700 nm the highest β values were 3.81, 3.49 and 3.12 cm^{-1}, corresponding to sample of tortilla T1. Tortilla types most preferred by consumers were the T1 and T3. The results show that being preferred are tortillas which have higher β values in the wavelength of flavonoids and carotenoids, this means that consumers prefer tortillas with contents of flavonoids and carotenoids, as they were preferred as corn tortillas, white and quasi yellow. Figure 3 summarizes the visualization of the evaluation of color of the “tortilla” according to consumer preferences using the hedonic scale. Tortilla samples evaluated with the scale values higher were T1, T3 and T11, whose values were 6.46, 6.32 and 6.01, respectively, according to the hedonic scale, being so these are most preferred by the consumers.

DISCUSSION

Color is an important property of food because it is often associated with the quality (Bicanic et al., 2006) and the preferences of the consumer. To satisfy customer needs, food industry is trying to produce products having other natural components. The availability of techniques capable of rapidly and accurately assessing/controlling the color of foods in a simple and inexpensive way is therefore a necessity. In this research, we found optical properties of thirteen tortilla types which are sold and consumed in Ecatepec, with the application of photoacoustic spectroscopy, and using the Rosencwaig and Gersho theory developed for homogeneous samples. Of this way was calculated the β value for each tortilla type studied. The variable β could be an indirect way of measuring color. Herrera et al. (2007) have reported that color of the “tortilla” is one of the most important attributes for consumption and purchase intent by the consumer. In this research, the experimental results show different behaviors of the β value for the “tortillas” evaluated, depending on natural products incorporated. Likewise, the consumer preferences differed depending on the color of

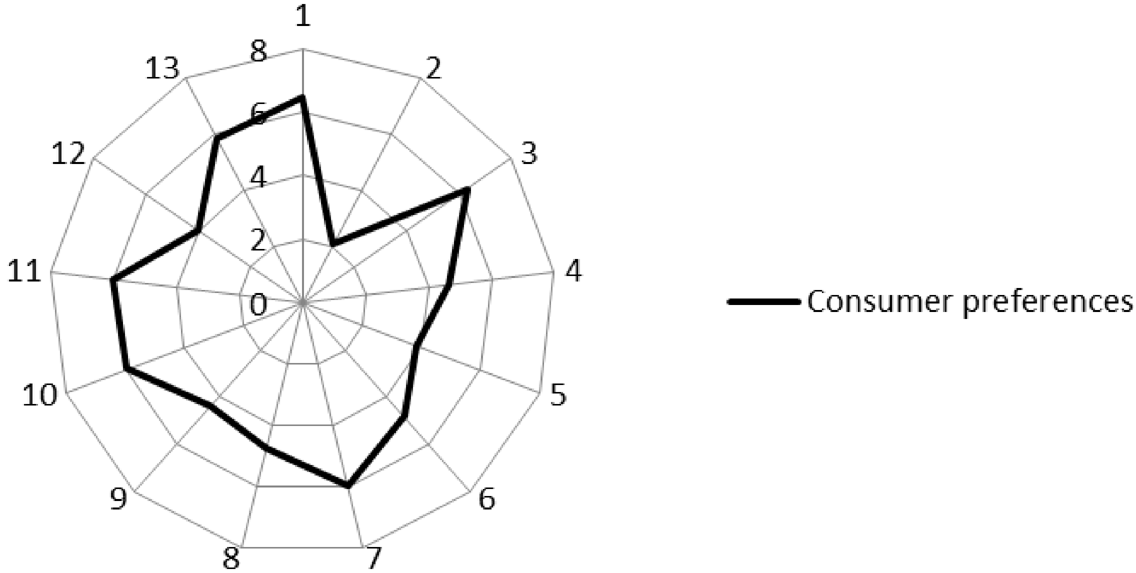

Figure 3. Consumer preferences about of color attributes according to sensory evaluation of tortillas (13 samples evaluated: (1) T1, (2) T2, (3) T3, (4) T4, (5) T5, (6) T6, (7) T7, (8) T8, (9) T9, (10) T10, (11) T11, (12) T12 and (13) T13).

the tortilla. It was found that the tortilla preferred, according to consumers consulted was white corn, which corresponds to the traditional "tortilla". Why consumers do not accept colored tortillas may provide some advantage in terms of digestion and/or nutrients.

Other authors indicated that tortillas elaborated with blue maize grain and others, quality protein maize, and others with resistant starch, produce a color of "tortillas" which are not well liked by the consumer (Salinas-Moreno et al., 2007). On the other hand, Herrera et al. (2007) at evaluating sensorial quality of 10 tortilla types in Texcoco, Mexico, found that consumers prefer tortillas with agreeable smell and taste that do not break at rolling them up and they preferred the white color tortilla. In Mexico, maize tortillas are an important source of energy; in 2007, the per capita consumption was 122.94 kg of maize a year (FAO, 2010) and in addition, are a source of calcium which could reduce problems of osteoporosis (Cortés et al., 2005); but it is important that consumers begin to accept the tortillas that are combined with natural products, which would allow them to improve digestion and increase these protein and antioxidants like anthocyanins; for example, tortillas made with linseed, whole wheat grain, nopal, amaranth, chile and spinach among others, although they do not have attractive colors for the consumer. On the other hand, the food storage period affects the food´s quality, in the case of "tortillas", some authors report changes in nutritional status, digestion, color and consumer preferences according to the storage time (Bejosano et al., 2005; Mora et al., 2009). In our case, the tortillas samples were purchased before carrying out each one of the tests. So, the tortillas were purchased the same day before carrying out the test.

In Mexico, there is a serious problem of obesity, so consumers must re-learn to choose their food and so incline more towards those that provide nutrients and not only for their sensory preference. Thus, industry of the "mass and tortilla" should develop more sensory analysis to generate improved products that captures the attention of the consumer. Also, the consumers should be flexible to new products that are generated to maintain their health, by becoming conscientious and taking the right decisions that impact quality of life for themselves and their families. For the industry of the "mass and tortilla", photoacoustic spectroscopy (PAS) relies on the indirect measurement of color in the sample. PAS is simple to use, requires only a small quantity of sample for analysis, involves a minimum of preparation (samples are studied just as they are). Recent researches indicate that the PAS can be applied in the agricultural sector, for the characterization of seeds samples (Singhal et al., 2002). Optical absorption spectra of maize seed of different production cycles have been reported by Dominguez et al. (2009). On the other hand, the application of the PAS to obtain β by obtaining photoacoustic signal and the use of Rosencwaig and Gersho model in wheat seeds was obtained (Hernandez et al., 2008). Also, in the area of food, it has been used in obtaining the absorption spectra of copaiba oil to determine its quality (Santos et al., 2008). Tomato juice also was reported by obtaining the photoacoustic spectra and lycopene was evaluated (Bicanic et al., 2009). Other authors (Soares et al., 2011) have obtained the thermal diffusivity of periderm from tomatoes of different maturity stages by open photoacoustic cell. In samples of flour, it has also been employed by establishing a direct relationship between the photoacoustic signal and the color of flour (Enrique et al., 1995; Favier et al., 1994; Muñoz et al., 2000). Other applications of the PAS in the food area is in the estimation of carotenoid concentration in dried pastas. According to the results of this research, It could serve for application in the industry of "mass and tortilla".

Conclusion

Photoacoustic spectroscopy is increasingly used in more applications in the food industry, this research has shown that it is possible to be used for characterization of “tortilla”, and could be used in the industry of the “ Mass and Tortilla”, in the case of Mexico. This research work was able to find the optical absorption coefficients (β) of colors of different tortillas from the photoacoustic signals amplitude and using the Rosencwaig and Gersho model. PAS is simple to use, requires only a small quantity of sample for analysis and involves a minimum preparation. In general, the types of tortillas more preferred by consumers, of the thirteen types of tortillas evaluated in this research, were the T1 and T3, which had at 360, 400, 450,500,550, 600, 650 and 700 nm a β of 7.2, 7.24, 5.63, 4.74, 4.16, 3.81, 3.49, 3.12, 6.46 and 9.12, 9.28, 6.56, 4.87, 3.92, 3.36, 2.95, 2.67, and 6.32 cm^{-1}, respectively; having T1 as preference, greater than T3 in the hedonic scale, with 6.46.

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