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EFFECT OF MICROENCAPSULATION OF GARLIC EXTRACT ANTIOXIDANTS (ALLIUM SATIVUM) IN CORN TORTILLAS

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Abstract: The corn tortilla is a food in high demand in Mexico, because it is versatile as it can be combined with legumes, fruits and even animal derivatives, which makes it an excellent means for incorporating essential nutrients for the human body. Being that, a blue corn tortilla was made to which emulsions were incorporated with extracts of dried encapsulated garlic (T_{ASE}), fresh encapsulated garlic (T_{AFE}), dried unencapsulated garlic (T_{AS}) and fresh garlic (T_{AF}), as well as, a control tortilla was prepared to evaluate the effect on nutritional intake (through chemical-proximal analysis), texture analysis (texturometer) and antioxidant capacity (ABTS and DPPH). According to the results, the tortillas added with T_{ASE} and T_{AFE} had a higher protein content compared to the control and the other treatments, the same trend was observed in the fiber and lipid content, due to the fact that in the encapsulated It incorporates whey protein, oil and gums, providing nutrients from these sources to the food. In the case of ash and humidity, there were no significant differences between the treatments, only these when compared with the control in terms of humidity since this had up to 50% less. Regarding texture, the encapsulated tortillas presented lower tensile strength, meaning that they were softer and required less force to cause rupture, compared to the other treatments and the control tortilla. In the determination of ABTS and DPPH, it was shown that the treatments added with extracts encapsulated with the $W1/O/W_{GA\ 70\%\ -WPC\ 30\%}$ emulsion, presented a greater inhibition of the ABTS and DPPH radicals, with the protection against temperature being effective during the preparation of tortillas. Therefore, the incorporation of encapsulated bioactive garlic compounds allows the generation of a highly consumed functional food with the security of their protection during the processing stages.
Keywords: Functional food, antioxidant compounds, encapsulation, *Allium sativum*, tortillas.

INTRODUCTION

The nixtamalization of corn is a traditional process applied for thousands of years, which has been considered a key point for the development of Mesoamerican cultures, because the resulting foods had better sensory and nutritional characteristics compared to products made from of raw corn. This can be defined as a cooking process under alkaline conditions, used for the production of tortillas (Chuck *et al.,* 2019), developing two important stages, cooking and resting. During these, the physicochemical and structural properties of the grain are directly affected, promoting various characteristics in the tortilla produced.

The corn tortilla is considered one of the basic foods in the Mexican diet, due to its protein, calcium, dietary fiber and energy content. The nutritional value of tortillas has been a topic of study in the field of research, due to the versatility to be consumed in a complementary way with legumes or animal products, as alternatives to increase the protein intake of the population to mitigate malnutrition. Likewise, tortillas are the ideal vehicle for incorporating micronutrients into the diet, in addition to the advantage of not containing gluten, which represents a nutritious option for people with celiac disease (Serna, 2015).

In recent years, there has been an increase in the use of the term "functional foods." A food can be classified as functional if it is demonstrated that it goes beyond its basic nutritional value, contributing to improving health or reducing the risk of diseases (Estrada-Fernández *et al.,* 2020; Gutiérrez-Uribe *et al.,* 2017). Although strawberries and onions, natural foods in themselves, have been considered functional, the term is mainly applied to processed foods. Therefore, the food industry uses various methods, such as the addition or elimination of components, to develop new products with added value in the market (Estrada-Fernández *et al.,* 2020; Ozen *et al.,* 2012).

Garlic (*Allium sativum*) is a species that belongs to the *Liliaceae* family, native to Central Asia, and has been used since historical times for a wide variety of therapeutic uses, due to its bioactive components, highlighting sulfur compounds. In recent years, research has been directed towards the techno-functional properties of garlic, highlighting its antioxidant capacity (Furdak *et al.,* 2024; Order Akullo *et al.,* 2023; Lu *et al.,* 2017; Teixeira *et al.,* 2014). Antioxidants are natural compounds that, when ingested in foods, have a protective effect on the human body by reducing free radicals, thus preventing or delaying cell damage or death; they are molecules sensitive to processing parameters (Bozin *et al.,* 2008). Encapsulation is a method used to protect biomolecules with food and pharmaceutical importance. This process establishes a barrier against environmental conditions such as temperature, light and humidity, thus ensuring stability.

They also preserve flavor and aroma, mask unpleasant flavors and odors, improve the stability and bioavailability of sensitive compounds. Various encapsulation techniques in use include spray drying, freeze-drying, and multiple emulsions (Herman-Lara *et al.,* 2024). Multiple emulsions are dispersions of larger droplets containing smaller dispersed droplets of a different phase, with more susceptibility to destabilization compared to single emulsions. There are two types of microstructures of multiple emulsions include water-in-oil-in-water ($W_1/O/W_2$) and oil-in-water-in-oil ($O_1/W/O_2$) emulsions. Their intricate compartmentalized microstructure gives multiple emulsions promising application in various industries, serving as a basis for encapsulation and delivery of sensitive ingredients, masking flavor, improving sensory attributes and reducing fat content to reduce calorie intake in food products (Tenorio-Garcia *et al.,* 2024; Havva *et al.,* 2024). It has been shown that these protection systems are feasible for the incorporation of antioxidant agents, dyes and even bacteria (Rodríguez-Huezo *et al.,* 2014). The objective of this research was to prepare a functional tortilla added with an external source of antioxidant compounds from garlic, applying a microencapsulation system to protect it against food production processes and at the same time a way to control the smell and flavor of the garlic so as not to limit the acceptance of the final product.

METHODOLOGY

EXTRACTION OF ANTIOXIDANT COMPOUNDS FROM GARLIC

A total of 50 g of garlic powder were weighed, mixed with 250 mL of solvent (distilled water), each sample was incubated at 25° C with shaking at 250 rpm/24 h. The final extract was filtered and stored at refrigeration temperature (4° C) until use (Jang *et al.,* 2018).

DOUBLE MULTIPLE EMULSION PREPARATION

Multiple emulsions were prepared at room temperature (22 ± 2°C) by the two-step method. In the first stage, a water-in-oil emulsion (W_1/O) was prepared by incorporating an aqueous phase (W_1) (70g) that consisted of garlic extract, in an oil phase (O) (30g), with garlic oil. canola (Capullo®, Unilever de México, SA de CV, Tultitlán Edo. de México, México), in addition to a total concentration of emulsifiers of 8% w/w. The hydrophilic emulsifier used was Panodam SDK (esters of monoglycerides and diglycerides of diacetyl tartaric acid) and the hydrophobic emulsifier Grindsted PGRR 90 (esters of polyglycerol and polyricinoleate fatty acids), both distributed by Danisco México, SA de CV. The emulsification process was carried out with a Virtis 220 homogenizer (Virtis Company, Gardiner, NY, USA) at 9,000 rpm/5 min.

In the second stage, 30 mL of the primary emulsion W_1/O were used, emulsified in 70 mL of aqueous medium, using 30% whey protein concentrate (WPC) and 70% gum arabic (GA), forming the aqueous phase. external (W_2), using a Virtis homogenizer at 4500 rpm/5 min, to generate double emulsions ($W_1/O/W_{GA70\%\text{-}WPC30\%}$), (Rodríguez-Hueso *et al.,* 2014).

TORTILLAS ADDED WITH ENCAPSULATED GARLIC EXTRACT

When preparing the tortillas, 5 mL of emulsion was added to 30 grams of dough. Performance tests were carried out on the tortilla, as well as thickness and diameter, with the results shown in Table 1. The raw tortillas were cooked on a metal plate at 280 ± 10° C for 30 seconds, on one hand, 25 seconds on the other and 15 seconds again on the first side, for the formation of the thin layer, thick layer and inflation, respectively (Sánchez *et al.,* 2004).

Characteristics	Measurement
Mass weight	35.0 ± 0.8 g
Diameter	12.0 ± 1.1 cm
Tortilla	23.1 ± 1.6 g
Thickness	1.80 ± 0.6 mm

Table 1: Parameters of tortillas added with encapsulated garlic extract

BROMATOLOGICAL ANALYSIS

The determination of humidity, ash, fat, protein and fiber was carried out on the tortilla samples made, using the following methods:

HUMIDITY DETERMINATION

It was carried out by the method of the "Association of Official Analytical Chemist (AOAC) (method 925.09; AOAC 2005). The samples were dried at a temperature of 100 ± 3° C for a period of 24 hours. The weight of the crucible with the dry samples was taken and the corresponding calculations were made.

DETERMINATION OF ASHES

This analysis was carried out using the dry method (AOAC, 930.05, 2005) and the dry sample was used, pre-incinerated until it stopped emitting smoke, then placed in the muffle for a period of 3 hours at a temperature of 500° C. The data obtained were recorded and the corresponding calculations were carried out.

DETERMINATION OF ETHER EXTRACT OR CRUDE FAT SOXHLET METHOD

It was carried out in accordance with AOAC 983.23, (2005). 4g of dry sample was used on a filter paper on an analytical balance and subsequently placed in cellulose cartridges. Hexane, coupled with the coolant of the Soxhlet device, was added to the flasks, with extraction for 8 hours, counting the time since the boiling began.

DETERMINATION OF CRUDE FIBER

The AOAC 962.09 method (2000) was used, where the sample was previously defatted for the determination obtained from the ether extract. 2 g of the sample was weighed and placed in Berzelius glasses; 100 mL of 0.225N sulfuric acid was added to each glass. It was placed in the digester for 30 min. Subsequently, in the digester, 100 mL of 0.313N sodium hydroxide was added, boiling for 30 minutes. Subsequently, the samples were filtered on filter paper at constant weight and washed with three portions of 100 mL of hot distilled water. The sample was dried at a temperature of 100 ± 3° C for a period of 12 hours, recording the weight of the residue. Finally, the samples in the crucibles were pre-incinerated and placed in the muffle for 3 hours at a temperature of 500° C.

CRUDE PROTEIN BY THE KJELDAHL METHOD

It was carried out in accordance with the AOAC technique 950.48, (2005) and NMX-F-608-(2011). Digestion; 1g of sample was weighed, the catalyst and 30 mL of concentrated sulfuric acid were placed, finally, the flask was placed in the Kjeldahl apparatus in the digestion section, connecting the fume extractor. This was done for each of the sample replicates.

Distillation; The digestion result was diluted with 300 mL of distilled water and cooled. Separately, 50 mL of 4% boric acid and five drops of the mixed indicator (methyl red and bromocresol green) were added to an Erlenmeyer flask. Subsequently, 110 mL of 40% sodium hydroxide and three zinc granules are added to the Kjeldahl flask without stirring.

Assessment: The 250 mL of distillate were titrated with 0.1 N sulfuric acid until a blue to pale pink color was obtained and with the reading obtained from the spent mL of sulfuric acid, the corresponding calculations were carried out using the following formula:

$$\%N = \frac{(spent\ mL\ of\ acid - mL\ of\ blank)\ (N\ of\ acid)\ (0.014)}{g\ of\ sample\ used} X100$$

%PC = (%N) (Conversion factor)

Conversion factor for tortilla 6.25

TEXTURE IN TORTILLAS

The tension test is a very important sensory and quality indicator; it is desired that this food be soft, elastic and that it can be handled without breaking (Román *et al.,* 2007). Tensile force is related to elasticity and hardness in tortillas; it represents the force necessary to tear a tortilla when stretching it, simulating the tearing of the hands by the consumer (Reyes *et al.,* 1998).

TENSILE STRENGTH

To determine the tensile strength, a rectangular piece was cut from the central part of the tortilla, avoiding the edges. The dimensions of the piece were 2 cm wide by 10 cm long. The tensile test was obtained using the Brookfield Texture Analyzer (CT3 25), with the TA25/1000 probe. This accessory consists of retaining tongs in which the piece of tortilla was placed, taking 2.5 cm from each end, and was subjected to tension until breaking. From the resulting curve, the maximum breaking force, the total area under the curve, and the area under the curve up to the breaking point of the tortilla were determined. The test conditions were: speed 2 mm/s and ten tortillas of each treatment were evaluated, taken at random, from each of the 4 lots.

ANTIOXIDANT ACTIVITY IN TORTILLAS

The antioxidant activity of bioactive compounds from garlic encapsulated in multiple emulsions and without encapsulation was evaluated by testing the content of ABTS and DPPH in a storage period of 15 days.

EXTRACTION OF ANTIOXIDANT COMPOUNDS FROM MICROENCAPSULATES

Once the storage time of 15 days had elapsed, an extraction process was carried out, which consisted of placing the tortilla samples with the encapsulated extracts with 20% ethanol to obtain a first extraction of compounds, centrifuged and stored the supernatant. As a second extraction, the encapsulates were mixed again with 70% acetone to obtain a second extract. The two extracts were mixed and antioxidant tests were determined by the ABTS and DPPH methods (Jang *et al.,* 2018).

ABTS FREE RADICAL SCAVENGING ACTIVITY

This method is based on the study of the decolorization of ABTS free radicals by antioxidants. The 7 mM ABTS (Sigma-Aldrich, USA) was combined with potassium persulfate to generate the ABTS + radical (2.45 mM). 980 µL of ABTS were mixed with 20 µL of the supernatant obtained in the extraction of the tortilla samples with the encapsulated and free extracts. In total, 2 readings were performed per sample; the first measurement was performed at 1 min, and the second measurement was performed at 6 min, both at a wavelength of 740 nm in a spectrophotometer (Jenway 6715 UV-Vis USA). The results were calculated as mg ascorbic acid equivalents of EAA/100 g of encapsulated garlic extract (Kuskoski *et al.,* 2004).

DPPH FREE RADICAL SCAVENGING ACTIVITY

This method is based on the study of the decolorization of DPPH by antioxidants. In total, 2.7 mL of DPPH (Sigma-Aldrich, USA), prepared in 80% methanol, was added. To 0.3 mL of the supernatant obtained in the extraction of the tortilla samples with the encapsulated and free extracts. Two readings per sample (1 min and 1 h) were taken using a spectrophotometer (Jenway 6715 UV-Vis USA) at a wavelength of 515 nm. The results were calculated as mg ascorbic acid equivalents AAE/100 g of encapsulated garlic extract (Kuskoski *et al.,* 2004).

STATISTIC ANALYSIS

A completely randomized design was used. All measurements were performed in triplicate and reported as mean ± SD. A simple rank analysis of variance was applied, and when appropriate, Tukey tests were used to determine differences between the means. ($p \leq 0.05$). Statistical analyzes were performed with NCSS 2000 software (Kaysville, Utah, USA).

RESULTS

BROMATOLOGICAL ANALYSIS OF TORTILLAS ADDED WITH ENCAPSULATED EXTRACT

During the tortilla making process, different significant chemical and nutritional changes occur when corn kernels are processed, mainly due to the partial loss of pericarp and germ during the alkaline cooking process (nixtamalization) (Chuck *et al.,* 2019). Table 2 shows the chemical composition of the corn tortilla (Control) and the corn tortilla added with emulsions containing extracts of dried encapsulated garlic (T_{ASE}), fresh encapsulated garlic (T_{AFE}), and unencapsulated dried garlic (T_{AS}) and fresh garlic (T_{AF}).

Treatment	Moisture (%)	Ashes	Proteins	Fiber	Lipids
T_{AS}	60.46 ± 0.9^{b}	$0.73 \pm$ 0. 40a	1.99 ± 0.06^{b}	19.30 ± 0.03^{b}	3.33 ± 0.03^{b}
T_{AF}	59.12 ± 0.60^{b}	0.80 ± 0.06^{a}	1.73 ± 0.04^{b}	20.70 ± 0.07^{b}	3.73 ± 0.06^{b}
T_{ASE}	60.58 ± 0.70^{b}	0.72 ± 0.04^{a}	2.78 ± 0.03^{c}	28.00 ± 0.04^{c}	6.90 ± 0.04^{c}
T_{AFE}	59.34 ± 0.60^{b}	0.74 ± 0.05^{a}	2.92 ± 0.03^{c}	27.30 ± 0.02^{c}	6.33 ± 0.08^{c}
Control	$33.33 \pm$ 0.70a	0.70 ± 0.09^{a}	1.83 ± 0.08^{a}	16.90 ± 0.06^{a}	1.20 ± 0.04^{a}

Table 2: Physicochemical composition of the functional tortilla

Superscripts with different lowercase letters in the same column indicate significant differences ($p \leq 0.05$).

The moisture content in the added treatments increased compared to the control (33.33 ± 0.70%), with significant differences ($P < 0.05$) to the values presented in added tortillas T_{AS}, T_{AF}, T_{ASE} and T_{AFE} (60.46 ± 0.9, 59.12 ± 0.60, 60.58 ± 0.70 and 59.34 ± 0.60%, respectively). Moo et al. (2022), report a humidity of 38.1% and 39.2% in corn tortillas added with B alicastrum flour at different levels, which is why the values obtained are higher than those reported in the literature.

According to the ash results, it can be seen that there are no significant differences between the treatments and the control. Gomez et al. (1999) report values of 1.43% in tortillas obtained by the traditional nixtamalization process and 1.5% for tortillas made with extruded flours added with 2.5 g of lime/kg of corn.

The protein content shown by the tortilla treatments added with the encapsulated extracts (T_{ASE} and T_{AFE}) is higher with values of 2.78 ± 0.03 and 2.92 ± 0.03%, compared to the control (1.83 ± 0.08%). In the case of the tortillas that present the encapsulated extracts, the protein content derived from the addition of the materials used to prepare the emulsions, such as whey protein concentrate (WPC), increased. This increase in the tortillas added with the encapsulated extracts is important, because during the process of making the tortillas, a decrease in digestibility occurs in the proteins, its content being considered marginal due to the low quantities that are presented. lysine and tryptophan, making the biological value, net protein utilization, protein efficiency index and amino acid score corrected for protein digestibility correspond to half compared to that reported by authors, for products of animal origin such as It's milk (Chuck *et al.,* 2019)

The total dietary fiber is the fraction of food resistant to human gastrointestinal digestion and is mainly made up of lignin, cellulose, hemicellulose and resistant starch. Corn is mainly composed of hemicellulose, with arabinoglucuran and xylans being the main components of hemicellulose in the pericarp, xylans and beta-glucans in the cell walls of the endosperm (Chuck *et al.,* 2019). The addition of the encapsulated ones in the corn tortillas indicates that they have a higher fiber content in the T_{ASE} and T_{AFE} treatments (28.00 ± 0.04 and 27.30 ± 0.02%, respectively). This increase is attributed to the fiber content in the gums used to prepare emulsions for the encapsulation of garlic extracts.

During the nixtamalization process of corn, it releases most of the pericarp and the insoluble fiber in the residual water of the mash, commonly known as nejayote. Raw corn contains 14.1% of total dietary fiber based on dry weight and its dough processing reduces insoluble fiber to 6.3% and increases soluble fiber to 1.75%, leaving 7% dietary fiber in the final composition of the tortilla. total (Chuck *et al.,* 2019). Sánchez et al. (1994) reported values of 6.5%, 5.3% and 1.1%, while Palacios et al. (2009) reported values of 9.03% and 7.74%; demonstrating that there is a decrease in fiber with respect to rest time during nixtamalization.

Regarding the lipid content, table 2 shows a significant increase from 1.20 ± 0.04% of the control to 6.90 ± 0.04% in the tortillas added with the encapsulates (T_{ASE}). Therefore, Treviño et al. (2016) in an analysis of corn tortillas fortified with common bean (*Phaseolus vulgaris* L.), contained between 2.85% and 6.45% lipids, indicating that tortillas added with encapsulated garlic extracts (T_{ASE} y T_{AFE}) they presented values similar to those found in literature.

TEXTURE IN TORTILLAS

Some aspects of tortilla quality are important, such as flavor, hardness, and appearance. Good quality tortillas have been defined as tortillas that are symmetrical, uniform, opaque, with toast marks, puffed, soft, flexible, without cracking and with a long shelf life (Brooker, 2015). The tension test is a very important sensory and quality indicator, since this food must be soft, elastic and allow it to be handled without breaking (Román *et al.,* 2007). Tensile force is related to elasticity and hardness in tortillas; it represents the force necessary to tear a tortilla when stretching it, simulating the tearing of the hands by the consumer (Reyes *et al.,* 1998).

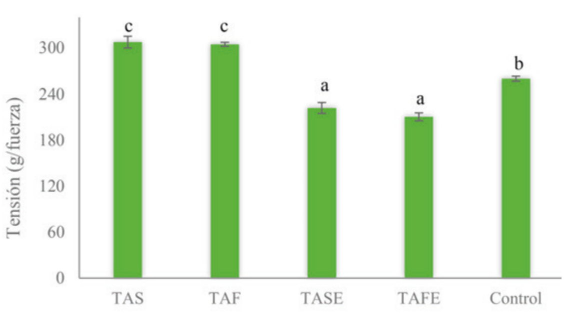

Figure 1: Texture in tortillas with the different treatments (T_{AS}, T_{AF}, T_{ASE} and T_{AFE}) and control. Superscripts with different lowercase letters in the same column indicate significant differences (p≤0.05).

In Figure 1 you can see the tension results of the tortillas with the different treatments (T_{AS}, T_{AF}, T_{ASE} and T_{AFE}) and the control. The tension values decreased compared to the control in the tortillas made with the encapsulated extracts, this indicated that softer tortillas were obtained and with less force to promote the fracture of the product in relation to the control, however, in the treatments added only to the extract, it increases the tension compared to the control. In corn doughs, a range of adhesiveness is required so that the material can be die-cut. A material without adhesiveness does not have consistency to form the tortilla and, therefore, a dough that is too adhesive (chewy) does not allow the tortilla to be formed, because it adheres more strongly to the die cutter and does not allow it to be transported to the comal for cooking. Arámbula et al. (2002) carried out a study in which they added 6% insoluble fiber and found that the tortillas turned out to be softer than the control tortilla. Rivelino Flores (2004) conducted a study in which he added fiber from different sources to corn tortillas, in which he concluded that the added tortillas were softer compared to the control tortilla. A good correlation has been reported between the characteristics of the tortillas and their moisture content; the higher the humidity, the better the texture characteristics.

In Figure 2, you can see the tortillas made with the treatments of encapsulated or unencapsulated garlic extracts. It can be seen that there was a precise addition of water and an adequate mixture to obtain an adequate dough, with the objective of rehydrating solids without causing stickiness due to excessive mechanical work and obtaining a fresh tortilla dough (Serna and Rooney, 2015).

Figure 2. Tortillas with a) T_{ASE}, b) T_{AFE}, c) T_{AS}, d) T_{AF} and e) Control.

ANTIOXIDANT ACTIVITY

Corn and its tortillas are an important source of nutraceuticals such as phenols, carotenoids/xanthophylls, phytosterols and polar and non-polar lipids, known to improve health and prevent oxidative stress, chronic diseases and cancer (Chuck *et al.,* 2019).

During the nixtamalization process, calcium oxide hydrolyzes the bonds that hold hemicelluloses together in the cell walls, allowing the pericarp to be easily removed from the corn kernel. The degraded pericarp, rich in arabinoxylans, act as hydrocolloids and provides desirable texture properties to tortillas. However, lime alters fiber components during cooking, producing products with less dietary fiber and antioxidant compounds. This weak alkali also provides relevant amounts of bioavailable calcium and improves the bioavailability of niacin, but negatively affects the nutraceutical value because cooking enhances the leaching of phenolics, various acids and other important antioxidants in the mash liquid, known as nejayote (Serna and Rooney, 2015; Chuck *et al.,* 2019). Figure 3 shows the results for the antioxidant activity of the tortilla treatments with the encapsulated and unencapsulated extracts, applied to tortillas. The DPPH radical scavenging activity was significantly higher in the tortillas that had the encapsulated extracts 38.27 ± 0.33 % and 39.14 ± 0.01% (T_{ASE} and T_{AFE}, respectively) compared to the T_{AS}, T_{AF} and Control treatments (23.54 ± 0.24, 24.01 ± 0.17 and 20.12 ± 0.28% inhibition, respectively). Likewise, the radical cation uptake results of ABTS were similar to the radical cation results of DPPH. The radical cation capture activity is preserved due to the encapsulation of the extracts, this is because it was significantly higher than the control and the tortilla added with the free extracts. It has been shown in previous research that garlic contains a significant amount of flavonoids, phenols, and sulfur compounds such as S-ally-(L)-cysteine (hydrophilic SAC) and disulfide (hydrophobic). In addition, SAC has high radical scavenging activity. The number of phenolic and flavonoid compounds has a positive correlation with the DPPH and ABTS radical scavenging activities, due to the donation of hydrogen and electrons from the hydroxyl groups of these compounds. The ABTS method is considered potentially more efficient than the DPPH method, as ABTS can measure both hydrophilic and hydrophobic substances (Jang *et al.,* 2018).

The content of antioxidant compounds present in tortillas with encapsulated garlic extracts is attributed to this, and only blue corn tortillas are unique, because they contain significant amounts of anthocyanins, which can significantly reduce the incidence of chronic diseases and improve health (Chuck *et al.*, 2019). Cooking with lime and boiling tortillas have a negative effect on antioxidant compounds; some studies carried out on five types of corn processed into masa, tortillas and toast indicate that masa and tortillas contained significantly lower levels of these components in compared to raw grains (Chuck *et al.*, 2019).

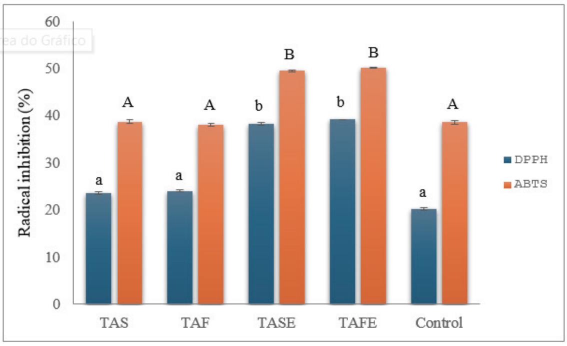

Figure 3: Antioxidant activity of tortillas. Superscripts with different lowercase letters indicate significant differences (p>0.05) in DPPH and superscripts with different uppercase letters in ABTS.

CONCLUSION

Garlic is a food with nutritional and functional properties as added value. These functional properties such as antioxidant activity are due to its Allicin content, which is the compound to which a large part of all the benefits of this super food are attributed. The physicochemical results carried out on all treatments of the tortillas demonstrated significant changes in increased humidity, ash, protein, fiber and lipids, attributed to the addition of the emulsions with the encapsulated garlic extracts, as well as in the determination of ABTS. and DPPH, where it was demonstrated that the treatments added with extracts encapsulated with the W1/O/$W_{GA70\%-WPC30\%}$ emulsion, presented the greatest inhibition of ABTS and DPPH radicals, being effective their protection against the temperature of the production process. of the tortillas. Regarding texture, due to the increase in fiber from the treatments added with emulsions, softer and easier to cut tortillas were obtained, while the tortillas added only with extracts showed an increase in hardness.

REFERENCES

AOAC. (2000). Official Methods of Analysis of AOAC International. (17th Ed). Gaithersburg, E.U.U.

AOAC. (2005). Official Methods of Analysis of AOAC International. (18th Ed). Gaithersburg, E.U.U.

Arámbula Villa, G., Barrón Ávila, L., González Hernández, J., Moreno Martínez, E., & Luna Bárcenas, G. (2001). Efecto del tiempo de cocimiento y reposo del grano de maíz (*Zea mayz L.)* nixtamalizado, sobre las características fisicoquímicas, reológicas, estructurales y texturales del grano, masa y tortillas de maíz. *Archivos latinoamericanos de Nutrición.* 51 (2), ISSN 2309-5806.

Bozin, B., Mimica-Dukic, N., Samojlik, I., Goran, A., & Igic, R. (2008). Phenolics as antioxidants in garlic (*Allium sativum L., Alliaceae*). *Food chemistry*, 111(4), 925-929.

Brooker, Daniel J. (2015). Chapter 4 - Quality Assurance for Corn and Wheat Flour Tortilla Manufacturing, Editor(s): L.W. Rooney, S.O. Serna-Saldivar, Tortillas, AACC International Press, 97-123, ISBN 9781891127885, doi.org/10.1016/B978-1-891127-88-5.50004-9.

Chuck Hernández Cristina Elizabeth, Sergio O. Serna-Saldivar. (2019). Chapter 25 - Soybean-Fortified Nixtamalized Corn Tortillas and Related Products, Editor(s): Victor R. Preedy, Ronald Ross Watson, Flour and Breads and their Fortification in Health and Disease Prevention (Second Edition), Academic Press, Pages 319-332, ISBN 9780128146392.

Estrada-Fernández Ana Guadalupe, Mendoza-Mendoza Bethsua. (2020). Functional Foods in Times of Pandemic: Mini review. *American Journal of Biomedical Science & Research,* 10(6). AJBSR.MS.ID.001580. DOI: 10.34297/AJBSR.2020.10.001580.

Furdak Paulina, Grzegorz Bartosz, Izabela Sadowska-Bartosz. (2024). Antioxidant and cytotoxic properties of garlic and selected garlic constituents, *Free Radical Biology and Medicine,* 218(1), 47, ISSN 0891- 5849, doi.org/10.1016/j.freeradbiomed.2024.04.169.

Gómez-Aldapa, C.A., Martínez-Bustos, F., Figueroa, C.J.D., Ordorica, F.C.A. (1999). A comparison of the quality of corn tortillas made from instant corn flours by traditional or extrusion process. *International Journal of Food Science and Technology*, 34(4):391 - 399.

Gutiérrez-Uribe J.A., Figueroa L.M., Martín del Campo S.T., Escalante A. (2017). Pulque. In: Frias J, Martinez-Villanueva C (Eds.), *Fermented Foods in Health and Disease Prevention*. Academic Press, USA, pp. 543- 556.

Havva Aktaş, Alicja Napiórkowska, Arkadiusz Szpicer, Jorge A. Custodio-Mendoza, Adamantini Paraskevopoulou, Eleni Pavlidou, Marcin A. Kurek. (2024). Microencapsulation of green tea polyphenols: Utilizing oat oil and starch-based double emulsions for improved delivery. *International Journal of Biological Macromolecules,* 274(1), 133295, ISSN 0141-8130, doi.org/10.1016/j.ijbiomac.2024.133295.

Herman-Lara Erasmo, Iván Rivera-Abascal, Ivet Gallegos-Marín, Cecilia E. Martínez-Sánchez. (2024). Encapsulation of hydroalcoholic extracts of Moringa oleifera seed through ionic gelation. *LWT, Food Science and Technology*, 203, 116368, ISSN 0023-6438, doi.org/10.1016/j.lwt.2024.116368.

Jang, H. J., Lee, H. J., Yoon, D. K., Ji, D. S., Kim, J. H., & Lee, C. H. (2018). Antioxidant and antimicrobial activities of fresh garlic and aged garlic by-products extracted with different solvents. *Food science and biotechnology*, 27, 219-225.

Kuskoski, E. M., Asuero, A. G., Troncoso, A. M., Mancini-Filho, J., & Fett, R. (2005). Aplicación de diversos métodos químicos para determinar actividad antioxidante en pulpa de frutos. *Food Science and Technology*, 25(4): 726-732.

Lu Xiaoming, Ningyang Li, Xuguang Qiao, Zhichang Qiu, Pengli Liu. (2017). Composition analysis and antioxidant properties of black garlic extract, *Journal of Food and Drug Analysis*, 25(2), 340-349, ISSN 1021-9498, doi.org/10.1016/j.jfda.2016.05.011.

Moo-Huchin Víctor Manuel, Góngora-Chi Guadalupe Johanna, Sauri-Duch Enrique, Canto-Pinto Jorge Carlos, Betancur-Ancona David, Ramón-Canul Lorena Guadalupe. (2022). Tortilla de maíz adicionada con harina de *Brosimum alicastrum*: propiedades fisicoquímicas y actividad antioxidante. CIENCIA ergo-sum, 28 (3). doi.org/10.30878/ces.v28n3a1.

NMX-F-608-2011. (2011). NMX-F-608-2011. Alimentos. Determinación de proteínas. Norma Oficial Mexicana, 3–6.

Oder Akullo Jolly, Beatrice N. Kiage-Mokua, Dorothy Nakimbugwe, Jeremiah Ng'ang'a, John Kinyuru. (2023). Phytochemical profile and antioxidant activity of various solvent extracts of two varieties of ginger and garlic, *Heliyon*, 9(8), 18806, ISSN 2405-8440, doi.org/10.1016/j.heliyon.2023.e18806.

Ozen Asli E., Pons A., Tur A.J. (2012). Worldwide consumption of functional foods: a systematic review. *Nutrition Reviews* 70(8): 472-481.

Palacios-Fonseca, A.J., Vázquez-Ramos, C., & Rodríguez-García, M.E. (2009). Physicochemical characterizing of industrial and traditional nixtamalized corn flours, *Journal of Food Engineering*, 93, 45-51.

Reyes Vega M. de la L. (1998). Efecto del empacado con películas plásticas sobre la calidad microbiológica, bioquímica y sensorial de la tortilla de maíz. Tesis de Doctorado en ciencias. Departamento de biotecnología y bioingeniería. Centro de Investigación y estudios avanzados del Instituto Politécnico Nacional, M.F

Reyes Vega M. de la L.1998. Efecto del empacado con películas plásticas sobre la calidad microbiológica, bioquímica y sensorial de la tortilla de maíz. Tesis de Doctorado en ciencias. Departamento de biotecnología y bioingeniería. Centro de Investigación y estudios avanzados del Instituto Politécnico Nacional, M.F.

Rivelino Flores Farías. 2004. Efecto de la incorporación de fibra dietética de diferentes fuentes sobre propiedades de textura y sensoriales en tortillas de maíz (Zea mays L). [Tesis de maestría, Instituto Politécnico Nacional].

Rodríguez-Huezo M.E., A.G. Estrada-Fernández, B.E. García-Almendarez, F. Ludena-Urquizo, R.G. Campos-Montiel, D.J. Pimentel-González. (2014). Viability of Lactobacillus plantarum entrapped in double emulsion during Oaxaca cheese manufacture, melting and simulated intestinal conditions. LWT - Food Science and Technology 59, 768-773. dx.doi.org/10.1016/j.lwt.2014.07.004.

Román-Brito, J. A., Agama-Acevedo, E., Méndez-Montealvo, G., & Bello-Pérez, L. A. (2007). Textural Studies of Stored Corn Tortillas with Added Xanthan Gum. *Cereal Chemistry Journal*, 84(5), 502-505.

Román-Brito, J. A., Agama-Acevedo, E., Méndez-Montealvo, G., & Bello-Pérez, L. A. (2007). Textural Studies of Stored Corn Tortillas with Added Xanthan Gum. *Cereal Chemistry Journal*, 84(5), 502-505.

Sánchez, R. A. M., Cárdenas, J. D. D. F., Taba, S., Vega, M. D. L. L. R., Sánchez, F. R., & Galván, A. M. (2004). Caracterización de accesiones de maíz por calidad de grano y tortilla. Revista Fitotecnia Mexicana, 27 (3):213 - 222.

Sánchez-Castillo, C.P., Dewey, P.J.S., Solano, M.L., Tucker, M., & James, W.P.T. (1994). The non-starch polysaccharides in Mexican pulses and cereal products. *Journal of Food Composition and Analysis*, 7(4), 260-281.

Serna-Saldivar Sergio O., Lloyd W. Rooney. (2015). Chapter 13 - Industrial Production of Maize Tortillas and Snacks, Editor(s): L.W. Rooney, S.O. Serna-Saldivar, Tortillas, AACC International Press, Pages 247-281, ISBN 9781891127885, https://doi.org/10.1016/B978-1-891127-88-5.50013-X.

Serna-Saldivar, Sergio O. (2015). Chapter 2 - Nutrition and Fortification of Corn and Wheat Tortillas, Editor(s): L.W. Rooney, S.O. Serna-Saldivar, Tortillas, AACC International Press, Pages 29-63, ISBN 9781891127885, https://doi.org/10.1016/B978-1-891127-88-5.50002-5.

Teixeira Bárbara, António Marques, Carla Pires, Cristina Ramos, Irineu Batista, Jorge Alexandre Saraiva, Maria Leonor Nunes. (2014). Characterization of fish protein films incorporated with essential oils of clove, garlic and origanum: Physical, antioxidant and antibacterial properties, *LWT - Food Science and Technology*, 59(1), 533-539, ISSN 0023-6438, doi.org/10.1016/j.lwt.2014.04.024.

Tenorio-García Elizabeth, Michael Rappolt, Amin Sadeghpour, Elena Simone, Anwesha Sarkar. (2024). Fabrication and stability of dual Pickering double emulsions stabilized with food-grade particles, *Food Hydrocolloids*, 156,110327, ISSN 0268-005X, doi.org/10.1016/j.foodhyd.2024.110327.

Treviño-Mejía D, Luna-Vital DA, Gaytán-Martínez M, Mendoza S, Loarca-Piña G. (2016). Fortification of commercial nixtamalized maize (Zea mays L) with common bean (*Phaseolus vulgaris L*) increased the nutritional and nutraceutical content of tortillas without modifying sensory properties. *Journal of Food Quality*, 39, 569–579.