ADDITION OF ENCAPSULATED EVOO IN THE BREADCRUMBS IMPROVES FOOD SAFETY AND SHELF LIFE OF REFRIGERATED MAP PACKAGED CHICKEN NUGGETS

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Abstract: *Consumer's health awareness increasement towards convenience foods is compromising refrigerated pre-fried breaded products demand. Thus, this study aimed to obtain chicken nuggets incorporating encapsulated extra-virgin olive oil (EVOO) (as α-cyclodextrin complex) during the breading phase (mixing breadcrumbs and complex in a ratio of 2:1 w/w) to obtain a product by infrared baking (new technology, NT) with similar, or even higher, quality than deep pre-fried ones (CTRL). Evaluation of the obtained products (MAP packaged under 30 % CO_2 / 70 % /N_2) stored at 4 ºC was conducted for up to 14 days. NT samples maintained their fresh appearance throughout conservation and showed ($p > 0.05$) similar color values of pre-fried nuggets. Fat levels were reduced by 84.5 %, and sensory scores showed similar results as CTRL samples. Furthermore, NT nuggets reduced microbial growth, extending refrigerated shelf life from 2 to 4 weeks. In conclusion, encapsulated EVOO in the breading phase combined with infrared baking allowed to obtain healthier, higher quality nuggets with longer shelf life.*

Keywords: Low fat-content, quality, microbiology, infrared baking, α-cyclodextrin complex.

1. INTRODUCTION

Healthy and sustainable food is a consumption trend. This "social boom" has generated market pressure towards a greater demand for more varied, healthier, higher quality and safer food products, which in turn use more efficient and sustainable food processing and packaging systems that are compatible with environmental conservation. Parallel to this, ready to cook meals (in boom marked by the lack of time and the ease in which they can be prepared) are negatively valued by consumers with healthier habits. This is due to the high fat content, or because they do not meet the typical sensory expectations of these products caused by changes in formulation and/or processing technology [1].

Frozen or refrigerated pre-fried breaded products are ready-to-cook meals manufactured by a common pre- cooking procedure known as deep-fat frying. It is rapid process (approx. 30 s) in which raw breaded product is immersed in a boiling heating medium (edible fat or oil) typically set at 180 ºC. This processing operation is a dehydration involving a simultaneous transfer of heat and mass, and it is responsible for providing fried foods with their unique and desirable sensory characteristics [2]. However, this cooking procedure presents a series of disadvantages, both for consumers and for the industry itself: (i) high oil absorption,

resulting in final products with high fat content, (ii) acrylamide formation, given the high cooking temperatures, (iii) and high oil waste [3]. For this reasons, research has been done to modify or develop new formulations and technologies for manufacturing healthier breaded products. However, up to this date, their unique organoleptic characteristics haven´t been matched [2], [4].

Cyclodextrins (CDs) are natural cyclic oligosaccharides, starch derivates and obtained by enzymatic degradation, and lacking of taste, odor, and calories. They can be used in a wide spectrum of applications within the food industry, due to their ability to form inclusion complexes by hosting, in their hydrophobic and lipophilic internal cavity, a variety of food compounds. In this manner, the encapsulated substances as olive oil became water soluble [5]. Generally, lipid microencapsulation purposes include retarding oil oxidation, masking undesirable tastes, aromas, and/or colors, and providing protection to the sensitive ingredients enclosed in the protected food matrix, against environmental factors [6], [7].

The aim of the current study was to deal with a substantial improvement of the healthy and nutritional character of chicken nuggets (a ready-to-cook breaded meat product), by replacing the deep-fat "pre-frying" operation with infrared baking and incorporating extra virgin olive oil (EVOO) encapsulated in α-cyclodextrin in the breadcrumbs used in breading phase. This study investigates the effect of encapsulated EVOO use on quality and shelf life changes of chicken nuggets. In this way, it will be validated the NT as a procedure for preparing a healthier chicken nugget version suitable for health-conscious consumers, and with the expected and desirable mild oily nuances and crunchiness of traditional chicken nuggets. Furthermore, the incorporation of a natural preservative encapsulated in α-cyclodextrin aims to extend shelf life of chicken nuggets by reducing the spoilage microbiology.

2. MATERIAL AND METHODS

2.1. Materials

Frozen chicken discs (37.23 × 47.97 × 9.02 cm; weight = 13.5±0.11 g) were supplied by the company Fripozo S.A. (Las Torres de Cotillas, Murcia). Xanthan gum was supplied by Doscadesa S.L. (Molina de Segura, Murcia). Wheat breadcrumbs were obtained from a local supermarket (Cartagena, España). The EVOO-αCD- maltodextrin complex, in powder format, was produced and supplied by the company Bio-iPack (Bioencapsulation and iPackaging S.L., Fuente Álamo, Murcia).

2.2. Preparation of chicken nuggets

Batter formulation was composed of 0.25 % xanthan gum. Two treatments of breading were studied: (1) wheat breadcrumbs (control, CTRL), and (2) wheat breadcrumbs with EVOO microencapsulated in α-CD and maltodextrin, ratio 2:1 (w/w) (new technology, NT). Nuggets were thawed at room temperature for 15 min and, then, immersed into the batter and breaded accordingly to the treatment. Deep pre-frying with sunflower oil was made at 180 ºC for 30 s (2-L volume, model Professional 2; Taurus, Oliana, Spain), and then, baking was made in a domestic hot-air oven at 150 ºC for 3.5 min (35-L capacity, model HBC36P753; Bosch, Germany) for CTRL nuggets. Medium-long wavelength infrared baking for 8 min at 182 ºC (with oven belt speed of 3.75 m/h) (model CT3000B; Roller Grill International, Bonneval, France) was made for NT nuggets as pre-cooking method. Batches of 100 nugget units were then frozen and stored at -20 ºC for 2 days, then MAP packaged in frozen state under modified atmosphere (70 % N_2, 30 % CO_2). Then, the packaged product was thawed and stored in cold room at 4 ºC for 13 days. Final baking for consumption consisted in deep-fat frying in sunflower oil for CTRL samples, at 180 ºC for 1.5 min, and by hot air baking in a domestic oven at 180 ºC for 10 min for NT nugget samples.

2.3. Physicochemical evaluation

Color and pH were the physicochemical parameters evaluated in the nuggets. A portable colorimeter (Konica Minolta chromameter CR-400, Osaka, Japan) was applied to measure color values in the CIELab color space (illuminant D65, 2º observer and viewing aperture of 8 mm), of the breaded surface of the chicken nuggets during the storage period. pH values were determined using a pH−meter (Basic 20, Crison; Alella, Cataluña, Spain) by analyzing 5 g of sample in 20 mL of distilled water. Physicochemical evaluations were carried out in triplicate.

2.4. Fat content determination

Total fat content was determined by Soxhlet fat extraction method according to the ISO 17059 standard [8]. Briefly, a weighted nugget was placed into a porous cellulose thimble (Whatman 10350240) covered with cotton (for sample transfer avoidance). The sample was then placed into the Soxhlet extraction chamber equipped with a condenser, and a distillation flask containing 200 mL of n-hexane. Nugget fat was extracted for 4 h at 69 ºC. N-hexane was later removed by a vacuum rotary evaporator at 40 ºC for 30 min at a rate of 40 rpm. Determinations were performed in triplicate during storage and after final cooking (frying or baking) for consumption (sensory analysis).

2.5. Microbial analysis

Samples of the two different nugget treatments (CTRL, and NT) were taken out of storage at predefined times for microbiological evaluation (yeast, molds, *Pseudomonas*, *Enterobacteriaceae spp*, mesophilic psychotropic, and lactic acid bacteria). Three replicates of 2 nuggets per treatment were homogeneously mixed in a stomacher (Maxicator Colwort Stomacher 400 Lab, Seward Medical, London, United Kingdom) with 160 mL of buffered peptone water and decimal dilutions were prepared. Aliquots of 0,1 mL of the appropriate microbial dilutions were spread-plated for yeast and molds in Rose Bengal Agar, and incubation conditions were 25 ºC for 7 days. Aliquots of 1 mL were pour-plated on Cetrimide Agar, Violet Red Bile Glucose Agar, Plate Count Agar, and MRS Agar, for *Pseudomonas, Enterobacteriaceae spp.,* mesophilic and psychotropic bacteria, and lactic acid bacteria, respectively. Incubation conditions were 37 ºC for 48 h for *Pseudomonas* and *Enterobacteriaceae spp.,* and 31 ºC for 48 h for mesophilic, psychotropic, and lactic acid bacteria. Viable bacteria was expressed as log values of colony-forming units per gram (CFU/g).

2.6. Sensory analysis

The sensory evaluation was carried out according to the work of Jiménez-Martín *et al. (*2016) using 5-point hedonic scale [9]. Shortly after the final baking of the samples, when an ideally eatable temperature was achieved, the following sensory attributes were evaluated by a group of 6 trained panelists: appearance, color, flavor, texture, and aroma.

2.7. Statistical analysis

Data was analyzed with a unidirectional analysis of variance (ANOVA) computed in R studio. Tukey HSD test at a 95% confidence level was assessed (statistical significance $p = 0.05$). Results were expressed as mean ± standard deviation.

3. RESULTS AND DISCUSSION

3.1. Color and pH

Table 1 shows the evolution of the crust color during storage at 4 °C. All samples (CTRL and NT) lacked visual deterioration and color remained without appreciable changes throughout

storage. No significant differences ($p > 0.05$) were detected between NT and CTRL nuggets at any time during storage. Thus, NT samples (without deep-fat pre-frying) achieved the visual appearance ($p > 0.05$) of a deep-fat pre-fried nugget in all the color parameters evaluated (L^*, a^* and b^*). Therefore, infrared cooking combined with the introduction of EVOO inclusion complex in the breadcrumbs achieve the same color perception of deep-fat pre-fried nuggets. The visual similarity would result in a success for its commercialization since no different color perception would be perceived as refrigerated at sale point.

Table 1. Crust color of control and new technology nuggets stored at 4 ºC for up to 14 days (mean (n=3) ± standard deviation).

	Treatment	Storage time at 4 ºC (days)				
		1	3	5	8	13
L^*	CTRL	65.2±1.67^{a,A}	64.1±1.25^{a,A}	66.3±1.84^{a,A}	67.2±1.77^{a,A}	68.0±1.75^{a,A}
	NT	69.1±2.59^{a,A}	67.4±1.81^{a,A}	69.4±6.76^{a,A}	70.3±2.88^{a,A}	71.2±1.37^{a,A}
a^*	CTRL	2.24±0.29^{a,A}	1.71±0.51^{a,A}	2.56±0.65^{a,A}	1.77±0.33^{a,A}	0.97±0.05^{a,A}
	NT	0.87±0.34^{a,A}	1.02±0.66^{a,A}	2.65±2.08^{a,A}	1.59±0.93^{a,A}	0.84±0.53^{a,A}
b^*	CTRL	21.4±1.83^{a,A}	21.3±1.16^{a,A}	21.9±1.58^{a,A}	20.2±1.37^{a,A}	18.6±1.25^{a,A}
	NT	21.4±2.31^{a,A}	21.8±1.18^{a,A}	21.9±1.51^{a,A}	19.9±0.74^{a,A}	17.9±1.97^{a,A}

$^{a-c}$ Different lowercase letters (superscripts) within each column indicate significant differences ($p < 0.05$).
$^{A-C}$ Different capital letters (superscripts) within each row indicate significant differences ($p < 0.05$).
CTRL = control treatment, corn breadcrumbed nuggets deep-fried in sunflower oil at 180 ºC for 30 s and baked at150 ºC for 3.5 min, NT = new technology treatment, corn breadcrumbed nuggets with encapsulated EVOO in the breading phase (2:1, w/w) and baked in an infrared oven for 8 min at 182±1 ºC.

pH values of samples (both CTRL and NT) ranged with a slightly decreasing trend between 6.4 and 6.2. These results are analogous to the study carried out by [10], where pH values of raw nuggets (without precooking) ranged downwards between 6.32 and 6.15, and nuggets fried in soybean oil at 190±2 ºC for 5 min were between 6.55 and 6.44.

pH fluctuation throughout meat-based products shelf life can be directly associated with the proliferation of Gram positive or negative bacteria. The presence of Gram-positive bacteria –such as lactic acid bacteria– acidifies the product by producing organic acids, while Gram-negative bacteria alkalinize it by accumulating alkaline compounds, such as ammonia and triethylamine [10], [11]. Our results showed a slight downward trend in the first 5 days of shelf life, while they remained stable during the last 8 days of storage. Likewise Hwang *et al.,* 2013, detected a reduction in the first 7 days for fried nuggets and a continuous pH reduction for raw nuggets [10]. For the control samples, there are three sections throughout the useful life where the pH values change significantly ($p < 0.05$); being the ranges of 0-1, 3-5, 8-13 days. For NT, two phases were detected: 0-1 day and 3-13 days. The third phase of change in pH values for the control samples (8-13 days) may be related to the growth of lactic acid bacteria. However, NT did not reach a third phase of changes in pH, possibly due to a low microbiological growth of lactic acid bacteria.

3.2. Fat content

Fat content along refrigerated storage and after cooking for consumption is shown in Table 2. During storage CTRL nuggets (wheat breadcrumbs, deep-fat fried at 180 ºC for 30 s and baked at 150 º C for 3.5 min) had a fat percentage of 6.92 ± 0, 68. However, in NT nuggets (wheat breadcrumbs with encapsulated EVOO, baked in IR oven at 182 ºC for 8 min) fat content dropped to 1.07 ± 0.81 % ($p < 0.05$), with a reduction of 84.54 ± 1.06 % (6.47 times less). This

reduction in fat content is due to the reformulation of the product (changing the breadcrumbs) and the deep-fat frying operation removal in the nuggets manufacturing process. Many researchers have studied different formulas and/or methods to reduce the fat content in this product; nevertheless, no evidence have been found to reduce more than 50%. El-Anany and Ali (2020) [12] studied the incorporation of cauliflower (20, 15, 10 and 5 %) in chicken nuggets as a fat substitute. In raw nuggets (without precooking) they reduced fat by 4.3, 4, 2 and 1.3 times compared to control samples containing 20 % chicken skin as fat source, for 20, 15, 10 and 5 % of cauliflower content, respectively. The precooking carried out was by deep-fat frying at 175 ºC in sunflower oil for 59 s. The fat content of the precooked nuggets ranged from 6.9 to 20.3 %. Although the addition of 20 % cauliflower in the formulation gave the best nutritional results, they did not obtain a good sensory evaluation.

Table 2. Fat content (g/100 g) of control and new technology nuggets, during storage and cooked for final consumption (mean (n=3) ±standard deviation).

		After cooking for consumption	
	During storage	**Deep frying 180 ºC/1.5min**	**Hot-air baked 150 ºC/10 min**
CTRL	6.92 ± 0.68^{aA}	10.47 ± 1.18^{aB}	6.79 ± 1.49^{aA}
NT	1.07 ± 0.81^{bA}	9.50 ± 2.02^{aB}	2.58 ± 0.31^{bA}

$^{a-c}$ Different lowercase letters (superscripts) within each column indicate significant differences ($p < 0.05$).
$^{A-C}$ Different capital letters (superscripts) within each row indicate significant differences ($p < 0.05$).
CTRL = control treatment, wheat breadcrumbs nuggets deep-fried in sunflower oil at 180 ºC for 30 s and baked at 150 ºC for 3.5 min, NT = new technology treatment, wheat breadcrumbs nuggets with encapsulatedEVOO in the breading phase (2:1, w/w) and baked in an infrared oven for 8 min at 182 ºC.

3.3. Microbiological quality

Microbiological analyses of chicken nuggets were performed at predefined times throughout 13 days of storage at 4 ºC. Mesophilic, *Enterobacteriaceae*, yeast and lactic acid bacteria counts are presented in Figure 1. The use of encapsulated EVOO (NT nuggets) in the breadcrumbs formulation resulted in lower microbiological counts at the end of the storage period. However, there was no significant difference in microbial loads throughout the initial days of storage (to 6 days). The CTRL nuggets had a higher heat treatment than that usually carried out by these industries (pre-frying + pre-baking). Despite this, the count of mesophilic microorganisms reached 5 logarithmic units after 13 days of storage at 4 ºC, limiting their commercial life to 2 weeks. However, for the same period of time, and under the same storage conditions, NT nuggets did not exceed 2 logarithmic units, being lower than maximum limit of 6 log CFU g^{-1}. In this way, the use of encapsulated EVOO in the breadcrumbs seems to be associated to a bacteriostatic effect (likely due to the phenolic compounds of extra virgin olive oil) increasing shelf life of chicken nuggets.

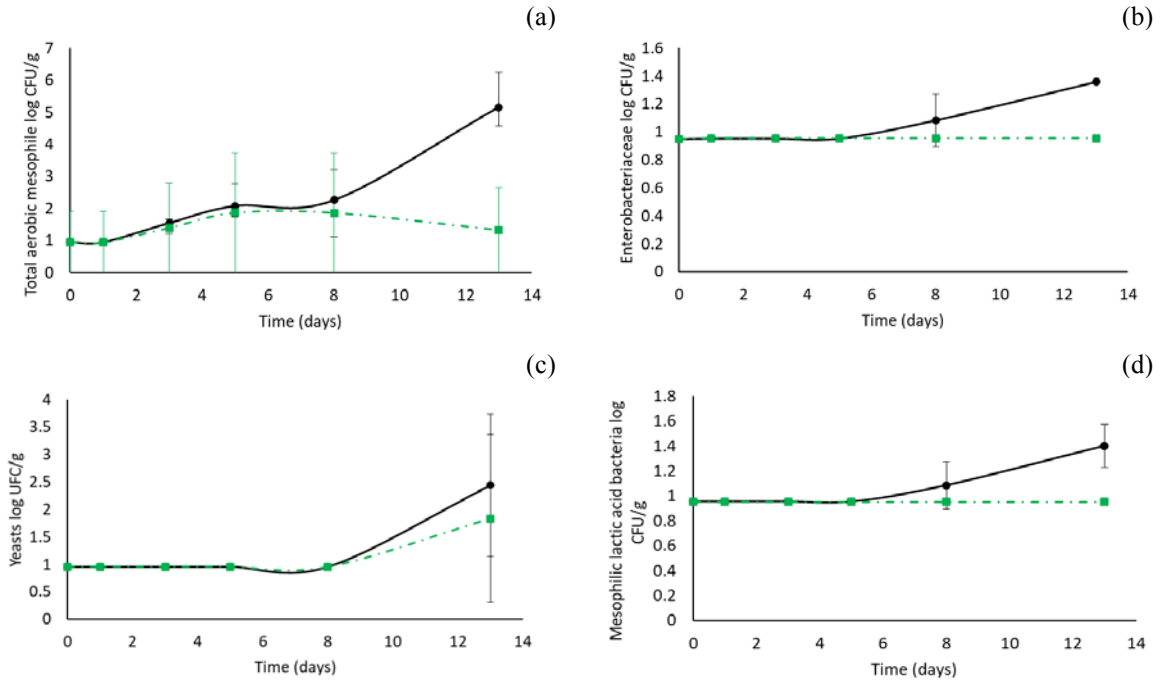

Figure 1. Microbiological counts throughout 13 days of refrigerated storage at 4 °C for (●) control and, (■) new technology nuggets (mean (n=3), error bars represented standard deviations of the mean value) for (a) total mesophilic aerobes, (b) *Enterobacteriaceae*, (c) yeasts, and (d) lactic acid bacteria.

3.4. Sensory properties

During refrigerated storage, samples appearance did not differ between treatments, being both equally scored. Once hot air baked (NT nuggets) or deep-fat fried (CTRL nuggets) panelists scored NT nuggets lower in appearance, and color. These lower values may be due to the pale-colored appearance of the encapsulated EVOO breadcrumbs, which could be improved by the addition of food colorants. On the other hand, NT nuggets were found to be "less sticky and oily". In addition, according to panelists, the flavor of the core of the fried nuggets (CTRL nuggets) was masked by the absorbed oil, whilst NT nuggets accentuated the pleasant flavor of the chicken.

4. CONCLUSIONS

Results obtained from the study showed that reduced-fat, high-fiber, frying-free chicken nuggets can be processed by infrared baking and with incorporation of encapsulated EVOO in the breadcrumbs (ratio 1:2, w/w). Sensory preference was not affected by the breadcrumbs reformulation, while microbiological analysis depicted significant impact of this new technology, improving refrigerated shelf life.

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