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# Effect of ultrasound pretreated hydrocolloid batters on quality attributes of fried chicken nuggets during post-fry holding

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A B S T R A C T

In this study, batters formulated with different hydrocolloids (i.e., pectin, locust bean gum, xanthan gum, guar gum, hydroxypropyl methylcellulose and methylcellulose) were treated with ultrasound as edible coatings for fried chicken nuggets. Quality characteristics (i.e., batter pickup, flow behaviours, thermal properties, moisture loss, color and textural properties) in chicken nuggets coated with ultrasound treated batters were evaluated before and after post frying exposure to heat lamp. Ultrasonication significantly reduced batter pickup, flow behavior and gelatinization enthalpy, revealing its tendency to alter functional properties of batter systems. Rheological evaluation of all batter samples revealed a pseudoplastic (shear thinning) flow characteristic when fitted to power law model, with ultrasonicated (US) samples exhibiting a significant reduction in viscosity over non-ultrasonicated (NUS) samples. Compared to the control NUS, fat content of chicken nuggets coated with US-treated batters decreased by 39.0, 60.9, 62.87, 64.1, 65.7, and 65.0 % for pectin, locust bean gum, xanthan gum, guar gum, hydroxypropyl methylcellulose and methylcellulose, respectively. Finally, chicken nuggets coated with US and NUS treated batters exhibited greater cutting force values immediately after frying but declined within the first 10 min of heat lamp exposure and increased subsequently with extended heat lamp holding time. Furthermore, NUS-treated guar gum resulted in chicken nuggets with the most minimal variability in cutting force during post-frying holding, indicating that crispiness was maintained. Overall, application of ultrasound as a batter pretreatment technique can be exploited by the frying food industry as an alternative approach to producing low fat chicken nuggets with appreciable quality attributes.

## 1. Introduction

Fried foods have high consumer acceptability due to their desirable organoleptic qualities such as crispiness, appearance, palatability and flavor [1–3]. However, the high fat content of fried foods has been associated with risks of chronic diseases such as arteriosclerosis, obesity, hypercholesterolemia, diabetes and cardiovascular diseases [4–6]. Thus, for the fried food industry to maintain its market share in the increasingly competitive food world, there is a need to develop alternative processes that will limit fat absorption during processing. However, it should also be highlighted that, while meeting this need, desirable organoleptic qualities such as crispiness must not be sacrificed.

Crispiness, a textural attribute of fried foods, is one of the most important factors responsible for consumer acceptability and purchasing power of fried food [7]. Crispiness is affected by microstructure, moisture, fat content and fat redistribution during frying and post frying periods [8]. To date, the inability to maintain the crispy nature of fried foods during post frying remains a big challenge to the fried food industry. According to Rahimi et al. [9] and Luyten et al. [10], fried foods lose their crispiness and become soggy during post-frying, due to moisture gradient between the core and the crust. Therefore, there's a need to develop alternative ingredients with duo properties, that is, limiting fat and water absorption during frying and post frying holding, respectively. Considering this, the potential of hydrocolloids has been exploited and reported in literature. Previous authors such as Kim et al. [11] and Sothornvit et al. [12] pointed out that, application of hydrocolloids in foods has multifunctional benefits including texture modification, stability maintenance, moisture control, and fat reduction. Furthermore, Amboon et al. [13] mentioned that the water binding capacity of hydrocolloids could help in reducing the loss of crispiness in chicken nuggets during post frying holdings, by reducing permeability of water from the core to the crust. Supporting these literatures is the

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study of Sanz et al. [14] who observed a 54.8 % reduction in fat content and an increase in moisture retention upon coating fried seafood with methylcellulose, with the authors attributing this observation to the film forming ability and thermal gelation properties of methylcellulose.

To reduce fat absorption in fried foods, novel pretreatment methods such as battering, pre-drying, pre-dusting, vacuum treatment, ultrasonication and a combination of these processes have been documented [15,16]. Ultrasonication is a novel non-thermal technology that has been proven to positively impact various food qualities such as color, fat, and moisture loss [17,18]. Additionally, Yao [19] reported ultrasound as an efficient pre-treatment method to enhance food physical properties such as density, moisture, porosity, shrinkage and color. Ultrasonication minimises internal and external resistance to mass transfer in a liquid or osmotic solution by causing cavitation and producing microscopic channels through convection [16]. In one study, Lua et al. [20] investigated the fat absorption capacity of French fries coated with an ultrasound treated methylcellulose batter, with the authors reporting a 31 % reduced fat content. Oladejo et al. [16] also reported a 65–75 % reduced fat content with potato slices immersed in ultrasonic treated distilled water before frying, compared to their control.

Despite these reports, dearth information exists with respect to how ultrasound influence crispiness of fried foods coated with hydrocolloid formulated batter. Taking advantage of the green technology of ultrasound and GRAS status of food hydrocolloids, it will be worth studying their combinative effects on fat absorption and final crispiness of fried foods such as chicken nuggets. Thus, the main objective of this study was to investigate the combinative effect of ultrasound and different hydrocolloids (i.e., pectin, guar gum, locust bean gum, methylcellulose, xanthan gum and hydroxypropyl methylcellulose) pre-treated batters on key quality parameters (i.e., texture, moisture and fat content) of fried chicken nuggets during post frying holding time under heat lamp.

## 2. Materials and methods

### 2.1. Materials

Wheat flour (Five roses white all-purpose flour), corn starch (Fleischmann's corn starch), canola oil (Selection TM/MC, Quebec, Canada), chicken breast, and leavening agent ($Na_2H_2P_2O_7/NaHCO_3$) were purchased from a local grocery store in Montreal, Canada. Hydrocolloids (pectin, guar gum, locust bean gum, xanthan gum, and hydroxypropyl methylcellulose) were procured from Spectrum Chem. Mfg. Corp. New Brunswick, USA, whereas methylcellulose (Viscosity (2 % in Water); 3000–5600 CP) was purchased from Fisher Scientific, Canada.

### 2.2. Batter formulations

Batter formulations contained wet and dry ingredients. The dry ingredient was made up of wheat flour- corn starch blends (i.e., 80 % wheat flour and 20 % corn starch), 1 % hydrocolloid, 2 % salt and 0.5 % leavening agent. The dry ingredient to water ratio was 1:1.3. For complete hydration of hydrocolloids, 1 % (dry ingredient basis) of each investigated hydrocolloid was weighed into water and held in a water bath at 10 °C for about 30 min. Afterwards, the remaining dry ingredients (99 %) were added to the solution and mixed following the procedure of [21].

### 2.3. Ultrasound treatment

Briefly, two-third of a 200 mL beaker was filled with formulated batter and stirred consistently for about 5 min. Afterwards, each formulated batter was subjected to high intensity ultrasonication for 20 min at 40 % amplitude and 20 °C by using an ultrasound probe (Model VCX 500, Sonics and Materials, Inc. CT. USA). To avoid possible heating of batter, ultrasonication was carried out in an ice-cold water bath.

### 2.4. Measurement of rheological properties

Rheological properties were measured using a controlled stress rheometer (Advanced Rheometer 2000, TA Instruments, Delaware, USA). A 40 mm circular plate geometry with a gap of 1000 μm was used to determine the rheological properties of each ultrasound treated batter. Prior to measurement, the batter slurries were kept at room temperature (25 °C) for 10 min. The samples were then subjected to a steady shear viscosity test, with the steady shear estimated within ranges of 0.1–100 /s at 15 °C. The sample temperature was kept constant for 2 min prior to the start of the measurement. Finally, the flow behaviour of treated batters was determined with the power law model shown below:

$$\tau = K(\gamma)^n \quad (1)$$

where $\tau$ is shear stress ($N/m^2$), $\gamma$ is shear rate ($s^{-1}$), $K$ is consistency coefficient ($Pa.s^n$), and $n$ is flow behavior index (dimensionless).

### 2.5. Differential scanning calorimeter

Gelatinization profile for all developed batter sample was measured using a differential scanning calorimeter (DSC250, TA Instruments, New Castle, Delware, USA). The peak temperature (Tpeak) and change in enthalpy ($\Delta H_m$) of the instrument were calibrated to be 156.59 °C and 28.425 J/g, respectively, by using an indium. About 15 ± 2 mg of batter was measured into a DSC 40 μl aluminium pan and sealed hermetically. The gelatinization profile (onset, peak, and conclusion temperatures of gelatinization) was evaluated from the DSC thermogram according to the method of [22], with an empty pan of equal weight used as a reference. Precisely, the pans were heated from 25 °C to 110 °C at a heating rate of 2 °C/min. The gelatinization enthalpy (ΔH) was recorded from the area of the endothermic peak and the average of three replicates of each treatment was used.

### 2.6. Preparation of chicken meat

Chicken breast meat was cleaned and placed on a mesh to drain the water. Excess water on the chicken breast was drained off with a paper towel. Afterwards, chicken breast was cut into 20 ± 2 g. Control sample was pre-dusted with dry ingredients containing no hydrocolloid, while other investigated samples were pre-dusted with dry ingredients containing and their respective hydrocolloids.

### 2.7. Batter pickup

Chicken nuggets were coated separately with each batter formulation. The control batter of NUS was devoid of hydrocolloid, whereas the control sample of US was devoid of hydrocolloid but treated with ultrasound. Before final weighing and determination of batter pickup, excess batter from each battered chicken nugget was allowed to drip off for 20 s. Afterwards, batter pickup was measured as the percentage of battered chicken nugget weight compared to the original weight of the non-battered or pre-dusted chicken nugget.

### 2.8. Frying and post-frying holding

The Frying experiment was carried out using a programmable deep fat fryer (De'Longhi, America Inc., Saddle Brooke, NJ 076663, China). Before frying, the fryer was filled with about 1.5 L of canola oil and preheated to 180 °C for 1 h. Samples were fried for 6 min at 180 °C, and the surface oil from each fried chicken nugget was drained with a paper towel. Afterwards, heat lamp (Model Sw-2430, Merco Inc., Lakewood, N.J. USA) was preheated for 30 min for post-frying exposure. Each fried sample was subsequently exposed to heat lamp for 0, 10, 20, 30, 40, and 50 mins.

### 2.9. Moisture loss and distribution

Moisture contents of fried chicken nuggets were determined following the AOAC standard method [23]. The core and the crust of fried chicken nuggets were separated by using a sharp knife. Samples were oven dried in a dryer at 105 ± 2 °C for 24 h and transferred immediately into a desiccator to allow equilibration for 20 min. Moisture content was calculated in dry basis from the weight of the fried chicken nuggets before and after oven drying.

### 2.10. Fat content determination

Fat contents of the different samples were determined using a Soxhlet extractor (SER 148, Velp Scientifica, Usmate, Italy). The solvent used was petroleum ether. Percentage fat content was determined by dividing weight of the extracted fat over the initial sample weight prior to extraction.

### 2.11. Color

Crust color of fried chicken nuggets was measured using the Konica Minolta spectrophotometer (CM-3500d, Konica Minolta Sensing Americas, Inc., NJ, USA). L*(blackness/whiteness), a* (greenness/redness), b* (blueness/yellowness), and ΔE (color difference) color parameters were obtained. For every formulated batch, six measurements were carried out at the surface of four coated nuggets, and one measurement at different sides of each chicken nugget. The net color difference (ΔE) was determined using Equation (2).

$$\Delta E = \sqrt{\left((L_0 - L_t)^2 + (a_0 - a_t)^2 + (b_0 - b_t)^2\right)} \tag{2}$$

$L_0$, $a_0$, $b_0$ are the L, a, and b values for chicken nugget coated with control batter (i.e., without hydrocolloid).
$L_t$, $a_t$, $b_t$ are the L, a, and b values for chicken nugget coated with the formulated batter.

### 2.12. Texture analysis

Textural properties were determined using a texture analyzer (TA-HD plus, Stable micro systems, Godalming, UK) operating at 500 V-ampere. Hardness of developed chicken nuggets was determined by a compression test (TA-42 knife blade with 45 °C chisel end) after storing the samples under heat lamp for different post-frying durations (0, 10, 20, 30, 40, and 50 min), as described by Mah and Brannan [24] with slight modifications. The pre-test, test, and post-test speeds were set at 10, 1 and 10 mm/s, respectively.

### 2.13. Statistical analysis

Analysis of variance (ANOVA) was performed using the Generalized Linear Model (PROC GLM) procedure of SAS system software (Version 9.2, SAS Institute, Inc., Cary, USA) to assess the effect of ultrasound on quality attributes of battered chicken nuggets during post frying holding time. Tukey multiple comparison was performed on the mean separation and treatment significance was measured at $p < 0.05$. All treatments were performed in triplicate and all data were presented as mean ± sd.

## 3. Results and discussion

### 3.1. Effect of ultrasound treatment on batter pickup

Batter pickup of chicken nuggets coated with formulated batters are shown in Fig. 1. Overall, ultrasound (US) exerted significant reductions ($p < 0.05$) in batter pickup for each treated fried chicken nugget. However, the extent of decrease in batter pickup was dependent on hydrocolloid type with pectin and locust bean gum showing the lowest and highest trend, respectively. Compared to NUS samples, batter pickup of US treated samples decreased by 7.2, 8.2, 27.4, 36.0, 39.1 and 45.9 % for P, XG, GG, MC, HPMC and LB, respectively.

### 3.2. Impact of ultrasound formulated batter on rheological properties

All the batters used in this study exhibited the pseudoplastic (shear thinning) flow behavior. Table 1 shows the combined effect of ultrasound (US) and hydrocolloids on the consistency coefficient (k) and flow index (n) of the different formulated batters.

Consistency index (k) values for all US treated batter samples were lower than observed for NUS samples. Overall, k values for control

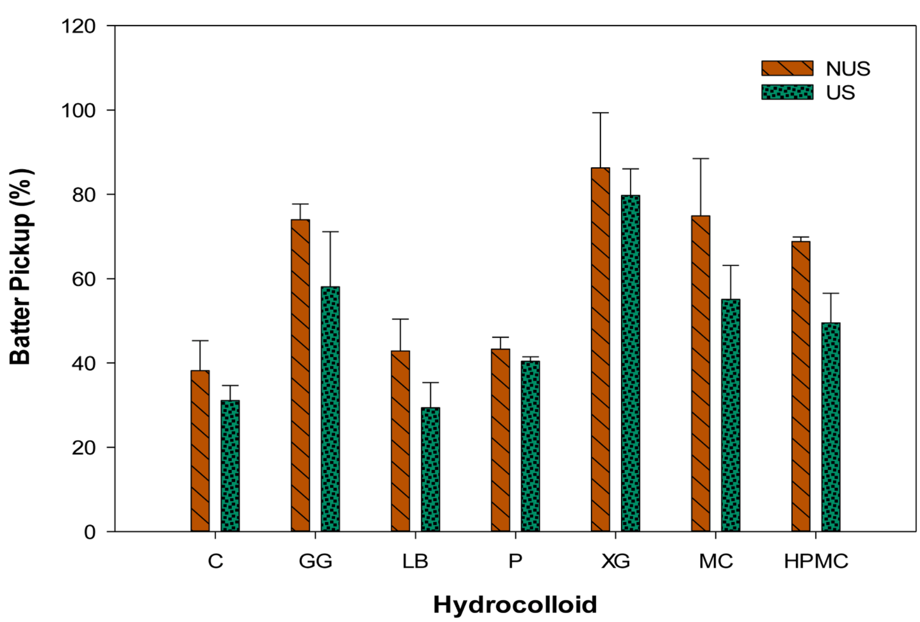


**Fig. 1.** Changes in coating pick up of batters formulated with different ultrasound treated hydrocolloids. NUS – non-ultrasonicated; US – ultrasonicated; C – control; P – pectin; GG – guar gum; LB – locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose. Results are presented as mean ± SD of three independent experiments.

**Table 1**
Effect of ultrasonication on the rheological properties of wheat flour – corn starch-based batter.

| NUS | | | | US | | |
|---|---|---|---|---|---|---|
| Sample | k | n | $R^2$ | k | n | $R^2$ |
| CON | 7.56 ± 0.24[f] | 0.573 ± 0.01[a] | 0.99 | 4.87 ± 0.21[e] | 0.701 ± 0.01[b] | 0.99 |
| GG | 74.69 ± 7.71[b] | 0.391 ± 0.03[b] | 0.99 | 35.05 ± 1.67[b] | 0.537 ± 0.01[d] | 0.99 |
| LB | 17.44 ± 1.35[e] | 0.543 ± 0[a] | 0.99 | 4.86 ± 0.18[e] | 0.710 ± 0b[ab] | 0.99 |
| P | 13.77 ± 0.51[ef] | 0.588 ± 0.02[a] | 0.99 | 6.23 ± 0.14[e] | 0.721 ± 0.01[a] | 0.99 |
| XG | 91.69 ± 0.09[a] | 0.298 ± 0.01[c] | 0.99 | 73.03 ± 0.2[a] | 0.350 ± 0[e] | 0.99 |
| MC | 43.63 ± 3.12[c] | 0.579 ± 3.12[a] | 0.99 | 21.49 ± 0.3[c] | 0.665 ± 0[c] | 0.99 |
| HPMC | 33.84 ± 2.6[d] | 0.55 ± 2.6[a] | 0.99 | 13.45 ± 0.6[d] | 0.721 ± 0.01[a] | 0.99 |

Results are means of triplicate ± standard deviation. Different letters within the same column depicts a significant difference ($p < 0.05$).

batters were the lowest for both NUS and US treatments. Among NUS hydrocolloid treated samples, k values were higher in the order of XG > GG > MC > HPMC > LB > P, with this observation decreasing significantly by 20, 53, 51, 60, 72 and 55 %, respectively, upon ultrasonication. Additionally, the flow index (n) for US treated MC, XG, P, LB, HPMC and GG batters increased by 12.9, 14.8, 18.4, 23.5, 23.7 and 27.2 %, respectively, compared to their NUS counterparts. Variations in consistency and flow indexes of formulated batters could be due to structural modifications of hydrocolloids during ultrasound treatment. Ultrasonic energy is known to drive several chemical reactions leading to changes in functional properties of proteins and carbohydrate in liquid food systems [25,26]. These reactions are generated by acoustic cavitation via the formation and subsequent collapse of ultrasound-induced bubbles leading to the observed changes in flow properties.

Fig. 2 shows the impact of US on apparent viscosities of formulated batters, as a function of shear rate. From the results, ultrasonication significantly ($p < 0.05$) reduced apparent viscosity of all investigated batter samples. This could be attributed to structure modification of hydrocolloids upon ultrasonication. According to Chan et al. [27] and Munoz-Almagro et al. [28], decreased viscosities among polysaccharides exposed to ultrasonication can be attributed to the breaking down of their complex molecular structures into simpler forms due to cavitation effects. Furthermore, ultrasound has been shown to break down complex polysaccharides such as pectin into their smaller molecular components [29]. Rheological data reported from this study are in synchrony with previous studies reported on starches from mung bean, potato, rice, and green banana [30,31].

### 3.3. Effect of ultrasonication on thermal properties of hydrocolloid formulated batters

From the results, onset temperature of US slightly increased for LB, P, XG and HPMC but decreased for MC and GG (Table 2). Likewise, peak temperature for US treatments showed a decreasing and increasing trend for GG, LB, XG and P, MC, HPMC, respectively. However, there was no significant difference in peak temperature of gelatinization for both US and NUS samples.

Furthermore, the conclusion temperature of gelatinization showed an increasing trend for GG and P, whereas that of LB, MC, HPMC and XG showed an opposite trend. Additionally, US decreased the gelatinization enthalpy (ΔH) for all investigated batter samples. This observation is in synchrony with the work of Zhu and Li [32], who reported a decrease in gelatinization enthalpy of quinoa flour upon US treatment. Accordingly, hydrocolloid-based batter samples treated with US showed the lowest values for gelatinization enthalpy compared to their NUS counterparts. The lower gelatinization enthalpy observed with US treated batter could be attributed to the internal structure of the batter being broken down during ultrasound exposure, thus, resulting in a lower energy required for gelatinization. According to Xue and Ngadi [33] various factors such as distribution of water between starch and gluten, hydration rate, starch granule size, and interactions between their biochemical components could contribute to changes in gelatinization enthalpy.

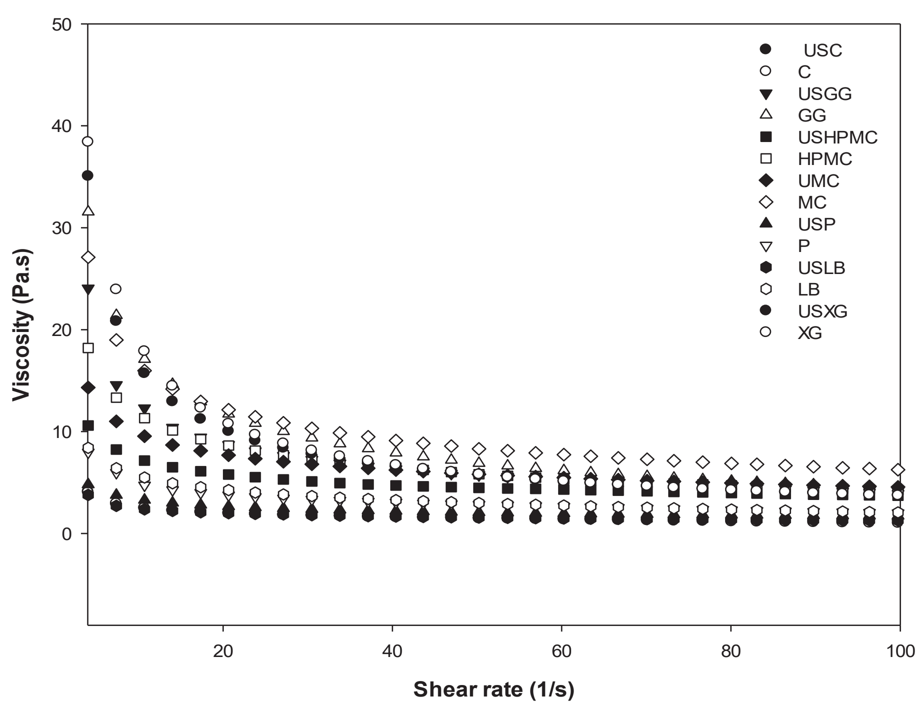


**Fig. 2.** Changes in apparent viscosity of batters formulated with different ultrasonic treated hydrocolloids. US – Ultrasonicated; C – Control; P – pectin; GG – guar gum; LB – Locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

**Table 2**
Effect of hydrocolloids type and ultrasonication on thermal properties of wheat flour and corn starch batter blends.

| | NUS | | | | US | | | |
|---|---|---|---|---|---|---|---|---|
| | $T_o$ | $T_p$ | $T_c$ | ΔH | $T_o$ | $T_p$ | $T_c$ | ΔH |
| C | 60.23 ± 0.14$^{d}$ | 66.53 ± 0.21$^{bc}$ | 73.42 ± 0.66$^{ab}$ | 3.15 ± 0.72$^{a}$ | 61.25 ± 0.35$^{bc}$ | 66.53 ± 0.2$^{b}$ | 70.06 ± 0.16$^{ab}$ | 1.46 ± 0.17$^{b}$ |
| GG | 61.84 ± 0.02$^{ab}$ | 66.51 ± 0.06$^{bc}$ | 69.93 ± 0.56$^{d}$ | 1.61 ± 0.06$^{bc}$ | 61.40 ± 1$^{bc}$ | 66.43 ± 0.$^{28b}$ | 71.46 ± 1.91$^{ab}$ | 0.93 ± 0.01$^{c}$ |
| LB | 61.43 ± 0.21$^{bc}$ | 66.99 ± 0.02$^{a}$ | 74.57 ± 0.24$^{a}$ | 2.18 ± 0.21$^{abc}$ | 62.13 ± 0.41$^{abc}$ | 66.34 ± 0.12$^{b}$ | 71.12 ± 0.6$^{ab}$ | 1.01 ± 0.06$^{c}$ |
| P | 62.40 ± 0.04$^{a}$ | 67.23 ± 0.13$^{a}$ | 71.85 ± 0.16$^{bc}$ | 1.731 ± 0.11$^{bc}$ | 63.31 ± 0.15$^{a}$ | 67.36 ± 0.23$^{a}$ | 72.46 ± 0.14$^{a}$ | 0.78 ± 0.07$^{c}$ |
| XG | 62.05 ± 0.56$^{ab}$ | 66.94 ± 0.03$^{ab}$ | 71.45 ± 0.68$^{cd}$ | 1.82 ± 0.97$^{abc}$ | 62.50 ± 0.29$^{ab}$ | 66.62 ± 0.05$^{b}$ | 71.29 ± 1.25$^{ab}$ | 0.78 ± 0.17$^{c}$ |
| MC | 61.61 ± 0.33$^{b}$ | 66.04 ± 0.02$^{d}$ | 71.75 ± 0.38$^{bc}$ | 1.27 ± 0.33$^{c}$ | 60.99 ± 0.21$^{c}$ | 66.44 ± 0.08$^{b}$ | 69.54 ± 0.28$^{b}$ | 1.85 ± 0.06$^{a}$ |
| HPMC | 60.75 ± 0.14$^{cd}$ | 66.31 ± 0.35$^{cd}$ | 72.07 ± 0.96$^{bc}$ | 2.61 ± 0.33$^{ab}$ | 62.18 ± 0.38$^{abc}$ | 66.66 ± 0.06$^{b}$ | 71.13 ± 0.33$^{ab}$ | 0.73 ± 0.13$^{c}$ |

NUS: non-ultrasonicated; US: Ultrasonicated; C: Control; P: Pectin; GG: guar gum; LB: Locust bean gum; MC: methylcellulose XG: xanthan gum; HPMC: hydroxypropyl methyl cellulose). Note: Results are means of triplicate ± standard deviation. Different letters within the same column depicts a significant difference ($p < 0.05$).

### 3.4. Impact of ultrasound pretreated batters on color attributes of chicken nuggets

Xanthan gum formulation presented the highest lightness (L*) value, irrespective of treatment. However, lightness for US treated coated batter nuggets were lower than their NUS forms. This observation agrees with the work of Zhu and Li [32] who also reported a decrease in the lightness of US treated quinoa flour. The authors attributed this observation to possible stimulation of Maillard reaction in the presence of polyphenols along ultrasonication, leading to browning and reduction of lightness. Compared to NUS samples, a* values of US treated samples decreased significantly for LB and GG, and increased for XG, MC, HPMC, and XG. Overall, US treated pectin formulation recorded the highest a* value of 6.56 compared to the control which showed 4.30 (Table 3). For yellowness b*, a significant difference ($p < 0.05$) was found in US treated samples but not in NUS. Also, values for total color difference (ΔE) were significantly higher for all US treated samples except with xanthan gum. Some of the color variations occurring in chicken nuggets after frying may be linked to browning due to the presence of reducing sugars in the crust portions of chicken nuggets.

### 3.5. Moisture content

Post-frying holding time under heat lamp caused a significant decrease in moisture content of the core, crust and whole fractions of fried chicken nuggets coated with formulated batters. Fig. 3 shows the effect of heat lamp exposure on the overall moisture content of fried chicken nuggets.

Generally, the rate of moisture reduction was very pronounced in NUS samples relative to US treated nuggets. This could be due to the lower moisture content reported for US treated samples which ranged between 1.15 and 0.69 g/g. Similarly, Mohammadalinejhad and Dehghannya [34] observed low moisture content with potato strip pretreated with ultrasound. The authors attributed this observation to the capacity of ultrasound to create micro-channels at early stages of frying, resulting into larger pores that connected neighboring cells together as frying continued.

Fig. 4 shows crust moisture content of deep-fried chicken nuggets coated with NUS and US treated batters under heat lamp. Overall, crusts of fried chicken nuggets coated with NUS batters showed higher moisture content at all post frying holding times, compared to their US counterparts. Chicken nuggets coated with NUS xanthan gum displayed the highest moisture content among all investigated samples at all post frying holding times. This trend could be linked with the high batter pickup and viscosity results observed with xanthan gum coated chicken nuggets, which may have decreased the rate of moisture migration to the crust and evaporation from the crust. This observation is in accordance with the discussion of Xue and Ngadi [33] that the migration of moisture in fried foods depends on the batter composition and crust microstructure. A similar decreasing pattern was observed by Antonova et al. [35] where moisture content of chicken nugget crusts kept under heat lamp decreased by 39.67 %.

For the core portion, moisture content decreased at a lesser rate compared to the crust during post-frying holding time under heat lamp (Fig. 5). This trend could be due to the provision of core covering by hydrocolloid coating. Also, mean moisture content of chicken nuggets core portion were lower for US compared to NUS after exposure to post-heat lamp holding by 23.81 %. Results of the current study suggests a linear decrease in moisture content of fried samples held under heat lamp, especially at the holding time of 30 min.

### 3.6. Impact of ultrasound pretreated batters on fat redistribution during post-frying holding

Fat content is the amount of oil absorbed by a fried food during the frying process. Literature has reported that fried foods absorb most oil during post frying holding time, that is the period immediately after frying [9]. Results of this study showed that, combination of ultrasound with hydrocolloids can help reduce fat content in fried chicken nuggets. Ultrasonication reduced fat content by 7.3, 16.4, 26.6, 33.8, 44.3 and 45.6 % for XG, P, MC, GG, HPMC and LB, respectively, compared to their NUS forms. Similar result was reported by Lua et al. [20] where a 31.03 % reduced fat content was reflected in French fries coated with 1 % MC ultrasound treated batter (Fig. 6).

**Table 3**
Effect of ultrasound pretreated batters on color attributes and ΔE of fried chicken nuggets.

| | NUS | | | | US | | | |
|---|---|---|---|---|---|---|---|---|
| | L* | a* | b* | ΔE | L* | a* | b* | ΔE |
| C | 55.23 ± 2.02$^{b}$ | 4.16 ± 0.6$^{a}$ | 21.20 ± 1.23$^{a}$ | 3.86 ± 2.15$^{b}$ | 52.75 ± 1.11$^{bc}$ | 4.30 ± 0.86$^{b}$ | 17.37 ± 1.85$^{abc}$ | 4.00 ± 2.01$^{ab}$ |
| LB | 52.29 ± 2.15$^{b}$ | 3.61 ± 1.56$^{a}$ | 18.62 ± 3.6$^{a}$ | 3.65 ± 2.83$^{ab}$ | 51.06 ± 0.44$^{c}$ | 3.33 ± 0.61$^{bcd}$ | 15.29 ± 1.57$^{bc}$ | 6.73 ± 1.52$^{ab}$ |
| GG | 54.10 ± 0.17$^{b}$ | 3.97 ± 0.36$^{a}$ | 19.34 ± 0.12$^{a}$ | 1.70 ± 0.13$^{b}$ | 51.62 ± 0.39$^{bc}$ | 2.48 ± 0.36$^{d}$ | 14.19 ± 0.22$^{c}$ | 7.43 ± 0.06$^{a}$ |
| XG | 63.02 ± 2.56$^{a}$ | 2.15 ± 0.18$^{a}$ | 20.26 ± 1.82$^{a}$ | 7.82 ± 2.43$^{a}$ | 55.27 ± 0.1$^{a}$ | 2.79 ± 0.09 $^{cd}$ | 17.15 ± 0.26$^{abc}$ | 3.45 ± 0.19$^{b}$ |
| MC | 57.00 ± 0.52$^{b}$ | 2.72 ± 0.22$^{a}$ | 18.32 ± 0.1$^{a}$ | 2.91 ± 0.46$^{b}$ | 53.37 ± 1.07$^{ab}$ | 3.18 ± 0.14$^{bcd}$ | 16.91 ± 1.51$^{abc}$ | 4.11 ± 1.81$^{ab}$ |
| P | 55.70 ± 1.82$^{b}$ | 3.71 ± 1.17$^{a}$ | 19.80 ± 0.47$^{a}$ | 0.74 ± 1.04$^{b}$ | 51.47 ± 0.18$^{bc}$ | 6.56 ± 0.51$^{a}$ | 19.47 ± 0.49$^{a}$ | 4.71 ± 0.32$^{ab}$ |
| HPMC | 57.13 ± 2.78$^{b}$ | 3.04 ± 0.19$^{a}$ | 18.88 ± 1.45$^{a}$ | 2.47 ± 1.04$^{b}$ | 51.54 ± 1.02$^{bc}$ | 3.90 ± 0.4$^{bc}$ | 17.62 ± 1.13$^{ab}$ | 4.77 ± 1.49$^{ab}$ |

NUS: Non-ultrasonicated; US: Ultrasonicated; C: Control; P: Pectin; GG: guar gum; LB: Locust bean gum; MC: methylcellulose XG: xanthan gum; HPMC: hydroxypropyl methyl cellulose). Results are means of triplicate ± standard deviation. Different letters within the same column depicts a significant difference ($p < 0.05$).

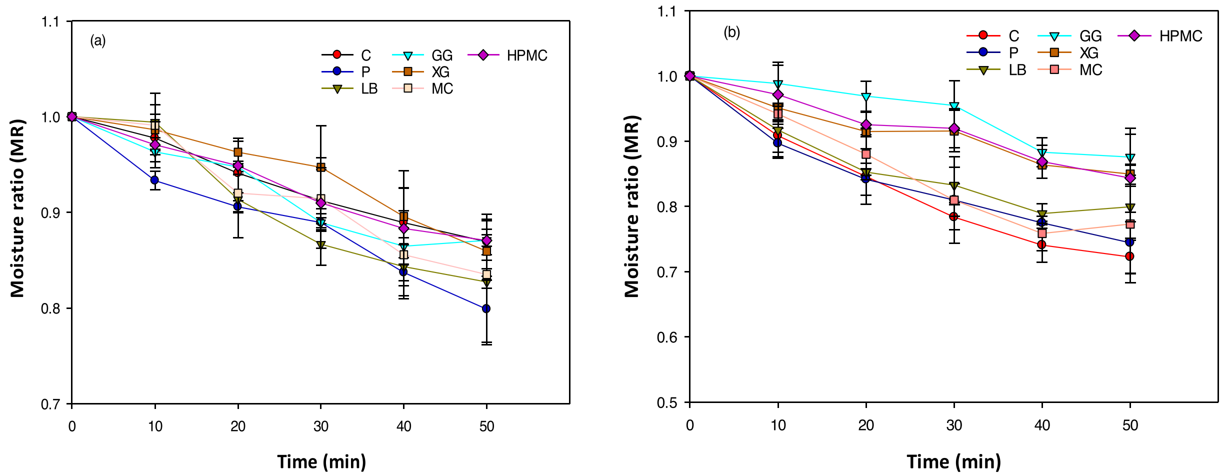


**Fig. 3.** Effect of post-frying holding time on the overall moisture content of chicken nuggets under heat lamp: (a) non-ultrasonicated; (b) Ultrasonicated; C – control; P – pectin; GG – guar gum; LB – locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

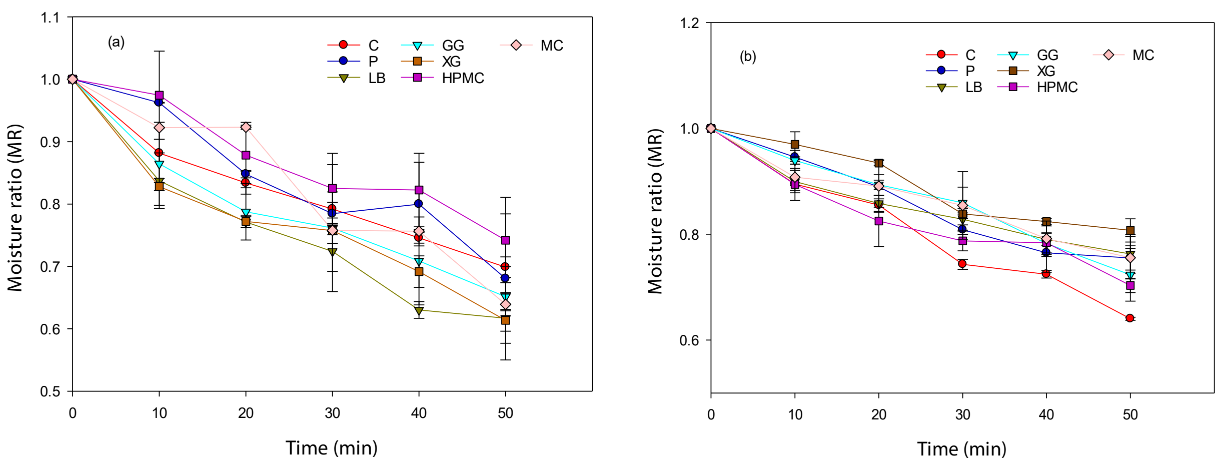


**Fig. 4.** Effect of hydrocolloid and ultrasonic treatment on the crust moisture content of chicken nuggets (a) US crust, (b) NUS crust, C – Control; P – pectin; GG – guar gum; LB – Locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

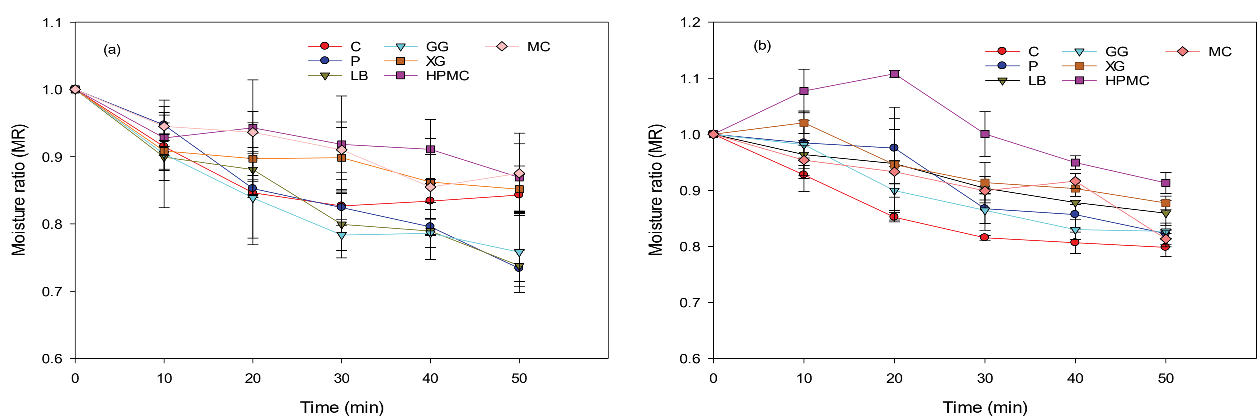


**Fig. 5.** Effect of hydrocolloid type and ultrasonic treatment on the core moisture content of chicken nuggets (a) US core; (b) NUS core; C – Control; P – pectin; GG – guar gum; LB – Locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

Also, fat content of the crust portion of fried chicken nuggets decreased under heat lamp holding times (Fig. 7). Significant reduction was observed in crust fractions of all investigated chicken nuggets after 10 min holding period, with 50 min holding time reporting the lowest crust fat content. In aggregate, crusts of fried chicken nuggets coated with US treated MC, XG and GG batters showed reduced fat contents than other investigated batter formulations.

Similarly, the combinative effect of hydrocolloid and ultrasound resulted in a lower core fat content compared to their NUS samples at 50 min (Fig. 8). Specifically, the fat content of core fractions of chicken

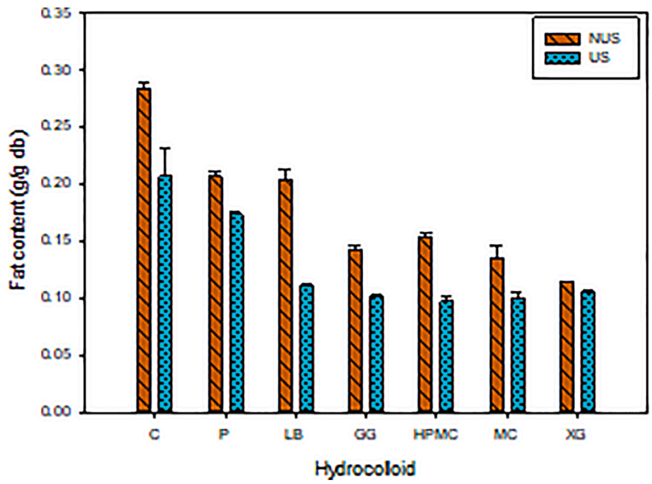


**Fig. 6.** Mean overall fat content of chicken nuggets at 10 min holding time. NUS: Non-ultrasonicated; US: Ultrasonicated; C – Control; P – pectin; GG – guar gum; LB – Locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

nuggets coated with ultrasound treated hydrocolloids ranged between 0.04 and 0.07 g/g at 50 min, with XG effecting the lowest core fat content.

### *3.7. Effect of ultrasound pretreated batters on the crispiness of chicken nuggets during post frying holding*

Fig. 9 shows the textural attributes of chicken nuggets coated with different hydrocolloids and stored for different times under heat lamp. Significant differences ($p < 0.05$) were obtained for the samples with different coatings. Overall, US resulted in higher cutting force for all investigated fried chicken nuggets coated with treated hydrocolloid batters, with this observation increasing with the prolongment of heat lamp exposure. The increased cutting force observed with US could be attributed to the low moisture and reduced fat content of the crusts of its respective fried chicken nugget. This is due to the process of cavitation which occurred in the water within or outside the product cells along ultrasonication, resulting in tissue destruction and subsequent development of cavities and micro channels. Formation of micro channels is assumed to be the key effect of ultrasonication, with respect to the enhancement of mass transfer during food processing [36]. From this study, NUS-treated guar gum and control were able to retain the crispiness of fried chicken nuggets held under heat lamp due to minimal differences in cutting force throughout heat lamp exposure periods. Interestingly, although US-treated LB, HPMC, MC and GG presented higher cutting forces immediately after frying, post-frying exposures caused a fluctuation in their respective cutting force values compared to their NUS counterpart.

## 4. Conclusion

This research examined how ultrasound (US) impacted different properties of batter formulated with 1 % of different hydrocolloids and final quality attributes of fried chicken nuggets. According to the obtained results, US had a significant impact on batter pickup, gelatinization profile, and rheological properties of the different formulated batters. Furthermore, US treated HPMC and MC batters significantly reduced the overall fat content of fried chicken nuggets by 65.68 and 64.99 %, respectively when compared with untreated control NUS sample. Additionally, storage of fried chicken nuggets coated with US treated hydrocolloid batters showed reduced fat and moisture contents under heat lamp exposure. In comparison to NUS, US treated chicken nuggets (LB, HPMC, GG, and MC) had the maximum level of crispiness following frying, although this showed an opposite trend during post-frying holding. Thus, US and hydrocolloids can be exploited by the frying food industry as a combinative technique to meet the growing health-conscious populace. Also, for the food industry to fully embrace this approach, there is the need to develop appropriate formulation levels for different hydrocolloid concentrations and ultrasound conditions to optimize sensory quality parameters for diversified fried food products.

## CRediT authorship contribution statement

**Dare Oloruntoba:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **Josephine Ampofo:** Conceptualization, Supervision, Writing – review & editing. **Michael Ngadi:** Conceptualization, Supervision, Funding acquisition, Methodology, Validation, Writing – review & editing.

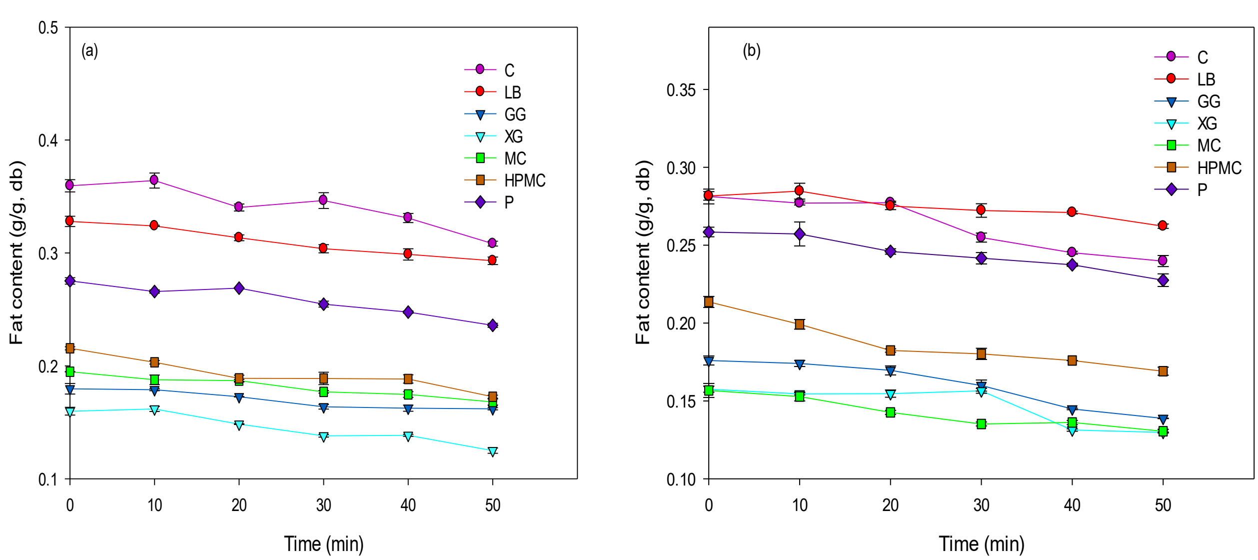


**Fig. 7.** Mean fat content of the crust portion of chicken nuggets a) NUS crust, b) US crust, during post-frying holding time under heat lamp. C – Control; P – pectin; GG – guar gum; LB – Locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

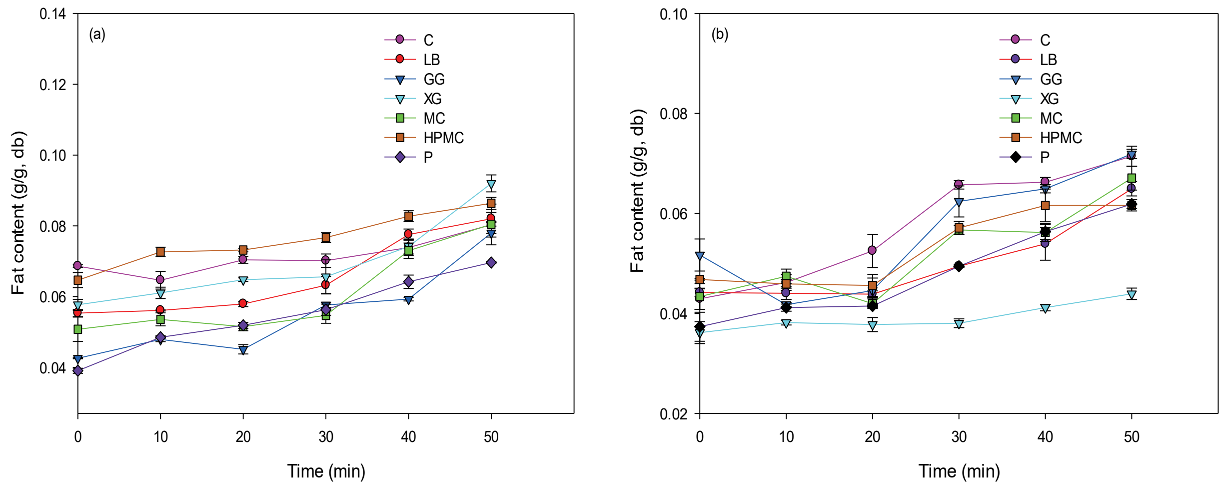


**Fig. 8.** Mean fat content of the core region of chicken nuggets a) NUS core; b) US core, during post-frying holding time under heat lamp. C – Control; P – pectin; GG – guar gum; LB – Locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

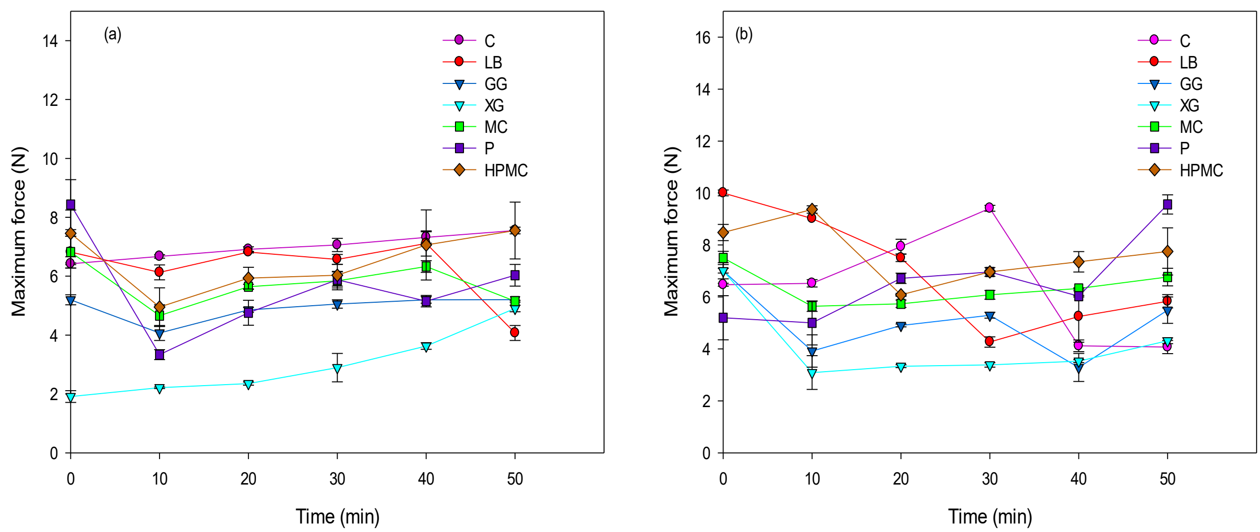


**Fig. 9.** Variation in the breaking force of chicken nuggets during post-frying holding under heat lamp (a) non-ultrasound treated (b) ultrasound treated; C – Control; P – pectin; GG – guar gum; LB – Locust bean gum; MC – methylcellulose XG – xanthan gum; HPMC – hydroxypropyl methyl cellulose.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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