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Effect of hydrocolloids type and concentration to the physical properties of plant-based nugget

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Abstract

This study investigated the effect of adding hydrocolloids to the cooking and moisture loss, water holding capacity and texture of plant-based nuggets. Methylcellulose, carrageenan, and xanthan gum were incorporated at concentration of 1 and 2% during plant-based nugget formulation. The results found that addition of hydrocolloids at higher concentrations significantly altered the physical properties of plant-based nuggets. Methylcellulose was able to reduce the cooking and moisture loss, while carrageenan improved the water holding capacity and texture of plant-based nuggets. On the other hand, although xanthan gum was able to alter several properties of the plant-based nuggets, utilization with other hydrocolloids may improve the properties of plant-based nuggets. Overall, the study highlights the potential of specific hydrocolloid to enhance physical properties of plant-based meat alternatives, contributing to the development of product.

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1. Introduction

Ultra-processed foods (UPF) are processed foods that are formulated with refined natural ingredients such as sugars, oils, and fats and often combined with additives such as colors, flavors, and emulsifiers to increase palatability and shelf life. The ingredients used then undergo chemical modifications and a series of industrial processes such as extrusion, molding, and/or pre-frying. UPF is known to be convenient and highly palatable, owned by large corporations and are marketed in a multinational scale. The marketing strategies instigates the move to consume ultra-processed foods, where the sales have increased by 1% of sales yearly in developed countries and 10% in middle-income countries (1–3). One of the common examples of UPF is processed meat such as chicken nugget.

At the same time, there is an increasing demand for non-animal food options due to increasing concerns from the production of meat products which have negative impacts towards the environment and human health (4). The number of consumers who are shifting towards healthier and more sustainable diets results in the growth of the plant-based meat alternatives market globally, where the number of sales has been shown to reach $10 billion and is projected to go over $30 billion by 2026 (5). Consumers believe that plant-based diets which are found to be healthier and more sustainable. Plant-based diet also provides benefits such as reduced obesity while providing high nutritional content, as well as positively affecting

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animal welfare (6). By reducing or substituting meat consumption, plant-based meat (PBM) products offer better solution to address environmental damage, health risks, and ethical concerns (5). The market for PBM products is expected to continue growing, owing to the prospects for innovation and development (7).

PBMs are generally developed with plant proteins, such as gluten, soybeans, cereals, legumes and algae. These protein sources can be processed to produce fibrous textures through methods such as spinning, extrusion, and steam texturization. The processes will produce PBM products that mimic the sensorial properties of animal-based proteins, while also providing the protein requirements of the consumers. However, physical properties, such as the texture of plant-based meat products may reduce the acceptance and consumption of PBM products. The sensory attributes and taste that do not satisfy consumers when compared to meat products affects the consumers' drive in purchasing plant-based meat goods. As a means to increase its acceptability, it is necessary to improve PBM's sensory properties as the success of PBM relies on the flavor, sensory appeal, and nutritional characteristics. When PBM does not satiate the sensory characteristics of animal-based products including its texture, PBM products can be rejected by consumers (7).

To stimulate meat consumption through plant-based meat alternatives, the texture could be improved through the utilization of various ingredients, including hydrocolloids. Hydrocolloids have been added in PBM products to provide structure due to its gelling, thickening, and stabilizing properties that allows for consistency and interaction with other components such as water, protein and starch (8,9). Addition of hydrocolloids provide binding properties and shape retention especially since soy or plant-based proteins do not have good binding properties (8). Hydrocolloids added in plant-based meats include carrageenan, xanthan gum, methylcellulose, and guar gum to name a few. In general, only a small amount of hydrocolloids is added to the formulation of food products, where the amount depends upon the type of hydrocolloids used. In particular, a study found that only 1% of xanthan gum is enough to give hardness and gumminess to soy-protein isolate (10), while addition of only 0.3 - 0.6% of kappa carrageenan result in high consumer acceptability of plant-based sausage (9).

The effects of various hydrocolloids on the physical properties of plant-based nuggets (PBN) were investigated in this research. Hydrocolloids used include methylcellulose (MC), k-carrageenan (CG), and xanthan gum (XG) at concentrations 1% and 2%, while properties such as moisture loss, cooking loss, water holding capacity, hardness, and springiness were observed.

2. Materials and Methods

2.1. Sample preparation

Ingredients prepared for PBN can be found in Table 1. PBN samples were made by first boiling TVP (Textured Vegetable Protein) chunks and mushrooms in vegetable broth for 20 minutes, followed by grinding for 30 seconds. Ground TVP, on the other hand, was soaked in vegetable broth until it was moist. Water found in extra firm tofu was drained by pressing with heavy weight. Potato starch was dissolved in warm water. Ingredients were then combined with a stand mixer for five minutes, where palm oil and dry ingredients such as SPI (Soy Protein Isolate), vital wheat gluten, corn flour, seasonings, as well as nutritional yeast were subsequently added. Seasonings utilized for the PBN consist of pepper, garlic powder, and onion powder. Finally, the sample mixture was weighed to determine the amount of hydrocolloid required to be added (Table 2).

Table 1. Ingredients required for PBN preparation.

Materials	Amount (g)
Textured vegetable protein chunks	20
King oyster mushrooms	24
Vegetable broth	224
Ground TVP	24
Extra firm tofu	40
Potato starch	10
Soy protein isolate	16
Vital wheat gluten	12
Corn flour	6
Seasonings	4
Nutritional yeast	6
Palm oil	16

Hydrocolloids had different preparation methods. Methylcellulose and xanthan gum were added to 30 g of cold drinking water respectively, while kappa carrageenan was added to the hot drinking water. Each mixture was combined with the rest of ingredients until they were completely cooperated. A 25 g of the mixture was formed into nuggets with a 3.5x4.5x1.5cm mold. The nugget samples were steamed until the internal temperature reached 68°C, for around 20 minutes for starch gelatinization. The wet batter was made with 25 g of all-purpose flour mixed with 50 g of water until they were well-mixed. Then, PBN was dipped in the wet batter until the nugget was completely covered, before they were covered with bread crumbs on all sides of the nugget. Subsequently, the nuggets were placed in the freezer at -18°C for 30 minutes before the deep-frying process.

Table 2. Hydrocolloid concentrations added based on the final weight of the samples.

Formulation	Methylcellulose	Kappa carrageenan	Xanthan gum
Control	-	-	-
MC1	1%	-	-
MC2	2%	-	-
CG1	-	1%	-
CG2	-	2%	-
XG1	-	-	1%
XG2	-	-	2%

Nuggets were deep fried at the temperature of 160°C until they were golden brown (± three minutes). The nuggets were then placed on tissue papers to absorb oil, and then cooled to room temperature before the tests. Commercial chicken nuggets were utilized as reference sample for comparison with the plant-based nuggets. According to the product label, the ingredients consisted of chicken meat, water, wheat flour, breadcrumbs, soy protein isolate, vegetable oil, sugar, seasoning, salt, acidity regulator, flavor enhancer and stabilizer. All samples were prepared in 3 batches.

2.2 Physical analysis

2.2.1. Cooking loss

Weight of the sample before and after cooking was measured. Excess oil on the surface was bloated prior to weighing. Cooking loss indicates the percentage of the weight that was lost during cooking, where it is quantified with the equation as follows (11):

$$\text{Cooking loss (\%)} = \frac{(\text{Wb - Wa})}{\text{Wb}} \text{ x } 100 \tag{1}$$

Wb is the sample weight before cooking (g), and Wa is the sample weight after cooking (g)

2.2.2 Moisture loss

Moisture content of samples were measured ahead of and later after the cooking process with the rapid moisture analyzer. 2 g of samples were first crushed then placed on the aluminum plate. Samples were then dried at the temperature of 110°C with Step drying as the drying profile, and the time was set automatically. The moisture loss is calculated with the formula as follows (12):

$$\text{Moisture loss (\%)= (MCb - MCa) x} \frac{(100\text{-CL})}{100} \tag{2}$$

Where MCb is the moisture content before cooking (%), MCa is the moisture content after cooking (%), and CL is the cooking loss (%).

2.2.3 Water holding capacity

Measurement of water holding capacity (WHC) was done based on studies by Wi et al (11) and Serdaroğlu et al (13). Samples that were raw and fried were placed in a water bath at 90°C for 10 minutes. 10 g of the samples then enclosed in cheesecloth, and then placed in a 15mL centrifuge tube to be centrifuged for 15 minutes with 1400 rpm at 25°C. Samples were weighed again and water holding capacity was determined with equation (3):

$$\text{Water Holding Capacity (\%)= } \frac{\text{Wa}}{\text{Wb}} \text{]x100} \tag{3}$$

Where Wb is the sample weight before centrifugation (g), and Wa is the sample weight after centrifugation (g).

2.2.4 Texture profile analysis

Fried samples were observed for its texture profile analysis with a texture analyzer. Samples were cut into size of 2x2x1cm and the breadcrumbs were removed. For the analysis, a 10mm cylindrical probe was utilized, where results were observed with the TexCalc software to determine the hardness and springiness of the samples. Parameters applied for the analysis were as follows: multiple or double cycle with 35% compression of initial thickness, 1 mm/s initial and retract speed, and trigger force of 5 g. Hardness (N) indicates the maximum force required for the first compression, while springiness is calculated by dividing the distance to reach the second compression peak by the distance of the initial compression's peak (14).

2.3 Data analysis

Measurements for each parameter were done in triplicates. Statistical analysis was performed through IBM SPSS Statistics 26 with the significance level of 0.05. Data obtained were analyzed with one-way ANOVA, followed by Tukey HSD for the post-hoc test to determine the significant differences.

3. Results and Discussion

3.1 Cooking and moisture loss of plant-based nugget

Cooking loss indicates the shrinkage of a meat product after the cooking process, which determines its juiciness and cooking yield. It measures the ability of protein in terms of binding water and fat after denaturation and aggregation (15). Table 3 displays the cooking and moisture loss in samples. It can be observed that in terms of cooking loss, all the samples with added hydro colloids were significantly lower in comparison to the commercial and control samples. Hydrocolloids form gels through the cross-linking of polymers with hydrogen bonds, forming three-dimensional networks that bind to water molecules (16). The matrix formed due to the gelling promotes trapping of water, improving the cooking loss (17,18). Lower cooking loss indicates better quality in soy protein products due to their ability to retain water, which were observed through the addition of hydrocolloids (19).

Table 3. Cooking and moisture loss observed on plant-based nugget samples.

Formulation	Cooking Loss (%)	Moisture Loss (%)
Commercial	9.013 ± 0.588^{f}	13.009 ± 0.723^{e}
Control	7.639 ± 0.4690^{e}	9.109 ± 0.424^{d}
MC1	5.355 ± 0.303^{b}	5.686 ± 0.344^{b}
MC2	3.990 ± 0.154^{a}	3.711 ± 0.436^{a}
CG1	6.186 ± 0.223^{c}	6.787 ± 0.286^{c}
CG2	5.288 ± 0.215^{b}	4.893 ± 0.393^{b}
XG1	5.694 ± 0.385^{bc}	5.449 ± 0.402^{b}
XG2	6.833 ± 0.278^{d}	6.636 ± 0.496^{c}

$^{a\text{–}f}$ Superscript letters within the same row indicate significant difference between the treatments ($p < 0.05$)

The addition of methylcellulose at 2% had the lowest cooking loss, while the commercial sample resulted in the highest cooking loss with over 9%. This indicates that PBN formulations particularly containing methylcellulose were more efficient in retaining moisture during cooking process compared to commercial. This finding is in agreement with Bakhsh (2021) (20), where higher concentration of methylcellulose in PBN resulted in lower cooking losses due to the ability of binding the moisture which gels upon heating. Although the moisture content of PBM is not increased, the addition of cellulose aids in reducing cooking loss (20). The reduced cooking loss may be related to the increase in WHC, as methylcellulose is said to have the ability to retain water due to its hydrophilic nature (21,22). Increased concentration of carrageenan also resulted in reduced cooking loss, which is in agreement with the finding by Pietrasik and Jarmoluk (2003) (23), where higher addition of kappa carrageenan yielded in lower cooking loss and improved thermal stability in pork gels. In particular, kappa carrageenan has displayed excellent firmness in gel structures, resulting in improved water-binding properties (17). During the cooking process, which involves heat, carrageenan increases the viscosity in the matrix which also increases its water retention. Then, upon cooling, gel formation occurs by the carrageenan, leading to reduced cooking loss as observed in the PBN samples.

Except for XG, samples with higher concentration of hydrocolloids are found to have lower cooking loss %. A similar result is obtained by Majzoobi (2017) (24), where decreased cooking loss in meat-free sausages was observed with increased concentrations of k-carrageenan, while higher concentrations of xanthan gum resulted in higher cooking loss, possibly due to the lower water holding capacity found in xanthan gum. Similarly, moisture loss was found to decrease with higher concentration of hydrocolloids except for XG where the moisture loss increased in samples with higher concentration. 2% methylcellulose also resulted in lowest moisture loss and highest is found in the commercial sample. Cooking loss in the nugget product is mainly caused by moisture loss or the evaporation of water during the cooking process (24).

3.2 Water holding capacity of plant-based nugget

Water holding capacity describes the highest amount of water that can be absorbed and held by the protein matrix (25). WHC is related to the juiciness and springiness of the protein, determining the quality and yield of the product (11,25).

Table 4. Water holding capacity of raw and cooked plant-based nugget.

Formulation	WHC Raw (%)	WHC Cooked (%)
Commercial	95.479 ± 0.348^{c}	95.813 ± 0.560^{c}
Control	93.437 ± 0.569^{a}	92.553 ± 0.536^{a}
MC1	94.348 ± 0.299^{b}	94.300 ± 0.279^{b}
MC2	95.762 ± 0.288^{cd}	95.473 ± 0.471^{c}
CG1	97.342 ± 0.302^{d}	97.296 ± 0.287^{d}
CG2	98.602 ± 0.442^{f}	98.222 ± 0.287^{d}
XG1	96.554 ± 0.186^{de}	95.751 ± 0.429^{c}
XG2	95.217 ± 0.594^{bc}	95.356 ± 0.566^{bc}

$^{a–f}$ Superscript letters within the same row indicate significant difference between the treatments ($p < 0.05$)

The addition of hydrocolloids influenced the WHC of the plant-based nuggets, where significantly higher WHC ($p<0.05$) can be observed compared to the control in both the raw and cooked product, especially with higher concentrations of hydrocolloids (Table 4). Except for the addition of xanthan gum, samples with hydrocolloids MC and CG improved the water holding capacity of the PBN. Methylcellulose has been widely applied in meat analogues, as their ability to retain high moisture has been found to improve eating qualities (26). MC exhibits a thermo-reversible gelation behavior, whereby heating induces network formation which can trap water within the matrix (27).

Carrageenan has high affinity and binding ability with water due to its structural 'memory', in which the addition of water results in swelling back of the particles (26). Higher WHC found in samples with CG is contributed by the ability of holding water between the matrices of the food product (28). Kappa-carrageenan is ionic polymer in which the formation gels is affected by the presence of salts and cations. During preparation process, mineral water which rich in ions was used, allowing cations and carrageenan interaction to form helical and aggregated gel networks via ionic cross linking which contributing to water retention (29). This phenomenon helps improve the water holding capacity, improving the eating quality.

Xanthan gum, on the other hand, has the ability to bind water in a protein-polysaccharide matrix, but not with higher concentrations, which was reflected in the results (28). This is postulated to be caused by the interruption of the gelling process due to steric hindrance, especially with the high molecular weight found in XG. Xiong and Blanchard (30) also noted that higher concentrations of XG (1-2%) did not improve the water binding when applied in meat processing. Although XG has the ability to produce intermolecular associations, their ability to gel is weaker compared to other hydrocolloids, in which gel formation is usually improved with the addition of other hydrocolloids (31).

Wi et al. (11) found that in TVP, increase of WHC after cooking occurred due to the increased gel network formation during heating, as the protein structures unfold and induce hydrophobic interactions in the protein. However, this is not observed in the plant-based nuggets, most likely due to the lesser amount of protein found in the samples.

3.3. Texture of plant-based nugget

The texture analysis of plant-based nuggets was done with two parameters, which are hardness and springiness. Textural properties of food products are commonly measured based on their scale of resistance when applied with compressive forces (32). Textural properties of PBMs are important factors when mimicking the organoleptic properties of animal-based protein (11).

Table 5. Texture properties of plant-based nuggets.

Formulation	Hardness (N)	Springiness
Commercial	1.697 ± 0.176^{d}	0.928 ± 0.022^{e}
Control	1.083 ± 0.277^{ab}	0.789 ± 0.032^{b}
MC1	1.540 ± 0.078^{cd}	0.828 ± 0.015^{bc}
MC2	2.074 ± 0.121^{e}	0.865 ± 0.023^{cd}
CG1	1.820 ± 0.120^{de}	0.812 ± 0.012^{bc}
CG2	3.012 ± 0.164^{f}	0.905 ± 0.017^{de}
XG1	1.233 ± 0.143^{bc}	0.770 ± 0.034^{ab}
XG2	0.839 ± 0.154^{a}	0.719 ± 0.032^{a}

$^{a–f}$ Superscript letters within the same row indicate significant difference between the treatments ($p < 0.05$)

Hardness refers to the highest load (N) applied to the sample on the first compression (33). Table 5 displayed that there were significant differences between the hardness of the control and all of the samples, where generally higher concentrations of hydrocolloids resulted in higher hardness except for XG 2%. Out of all the samples, highest hardness was found in samples with addition of kappa-carrageenan, where addition of kappa-carrageenan has been found to effectively increase hardness in meat batters (34). Addition of CG also improved the hardness of PBN, as application of CG in meat analogues with heat allows for ingredients to bind and gel, contributing to firm textures mimicking meat (26).

Meanwhile, the sample with XG 2% has the lowest hardness value. Incorporation of xanthan gum in soy protein at higher concentration has been found to cause competition between the xanthan gum and soy protein in water absorption, which leads to the weakening of both the emulsion and texture (24), thus resulting in lower hardness. In addition, Foegeding and Ramsey (1987) (34) stated that addition of XG in meat batters decreases the protein gel strength, which would result in decreased hardness. Higher concentration of XG in soy protein was also found to increase the interactions with water, causing the emulsion to be weak with softer texture (10). Increased hardness can be obtained with XG if used collectively with other hydrocolloids, namely locust bean gum (26).

On the other hand, springiness refers to the product's ability to recover to its initial form after the first compression (33,35). Addition of methylcellulose and carrageenan improved the springiness of the product, where higher springiness is observed with higher concentration of hydrocolloids. On the contrary, XG addition reduced the springiness of PBN at both concentrations. Similar result is found by Nanta et al. (10), where plant-based meat samples with XG, especially at higher %, resulted in lower springiness, compared to the springiness found in samples with CG. Xanthan gum's ability to hold water may affect the decreased springiness due to the interstitial space in the protein matrix that was filled with water, resulting in lower springiness (35). In comparison, the commercial and control samples both have higher springiness value. This result conforms with the finding of Majzoobi (2017) (24), where meat-free sausages decreased in springiness with the addition of higher concentrations of hydrocolloids. Additionally, springiness was also found to be higher in meat patties compared to plant-based patties in a study by Bakhsh (2021) (20).

4. Conclusions

Plant-based meat consumption has increased in recent years, which is contributed by the increased awareness and demand from the consumers. A particular concern in PBM consumption lies in the lack of sensory satisfaction when compared to meat products, which could be enhanced by adding hydrocolloids such as methylcellulose, carrageenan, and xanthan gum. Physical properties of the plant-based nuggets were observed in this study, such as moisture and cooking loss, water holding capacity, as well as textural properties. Addition of MC at 2% provided the least cooking and moisture loss in plant-based nuggets, while WHC is best with the addition of CG 2%. Meanwhile, CG 2% also provided the most ideal textural properties in plant-based nuggets. Overall, improved physical properties of plant-based nuggets were observed with higher concentrations of hydrocolloids, except for XG. Future scope may explore the combination of gelling agent (e.g. methylcellulose) and thickening agent (e.g. xanthan gum) to further investigate the synegestic effect. Xanthan gum may contribute to the pre-cook hydration and dispersion of ingredients, while methylcellulose can strengthen the gel network during cooking.

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Author Contributions

D.P.A.P.D conceptualized the research topic and study design, data analysis and interpretation, validated the methodology, draft validation, review, and editing, administered as well as supervised the project; E.L analyzed the data, visualization, writing original draft, review and editing of the manuscript; M.N.S. carried out the analysis, data collection, investigation, validation; W.I. and R.M.S.I validated the methodology.

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Conflicts of Interest

Authors may declare no conflict of interest.

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