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Porang flour functions as a plant-based hydrocolloid to improve technofunctional and sensory properties in duck meatball processing

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ABSTRACT

The application of plant-based hydrocolloids in processed meat products has gained increasing attention due to growing consumer demand for clean-label and functional food ingredients. The aim of this study was to evaluate the effects of porang flour (*Amorphophallus muelleri*) as a natural hydrocolloid on the physicochemical, textural, and sensory properties of duck meatballs. Duck meatballs were prepared with varying concentrations of porang flour (0, 1, 1.5, 2, and 2.5%) and compared with a control sample using agar powder as a binder. The results showed that the addition of porang flour led to a slight, non-significant increase in water content, while significantly improving cooking yield and water-binding capacity, particularly at 2% and 2.5% concentrations ($p < 0.05$). Texture profile analysis revealed that the porang flour enhanced hardness and cohesiveness without affecting springiness or adhesiveness. Sensory evaluation indicated that chewy texture improved significantly with higher porang levels, while other organoleptic attributes such as umami taste, fishy smell, and brown color remained unaffected. Hedonic testing showed moderate to high acceptance across all treatments, with no significant differences among formulations. Porang flour has shown significant promise as a clean-label binding agent in the production of duck meatballs, enhancing yield, water retention, and texture while maintaining sensory quality. These results endorse the application of porang flour as a functional, plant-based hydrocolloid for creating sustainable and consumer-friendly meat products.

Introduction

As people become more conscious of health, food sustainability, and product quality, the global demand for innovative and nutritionally balanced meat products is on the rise. Among processed meats, meatballs have become particularly popular due to their appealing texture, simple preparation, and adaptable recipes (Penchalaraju and Bosco, 2022). While meatballs have traditionally been crafted from beef or chicken, there is a growing trend to include alternative meat sources that offer distinct nutritional benefits and sensory experiences (Molfetta *et al*., 2022). In this context, duck meat stands out as a valuable raw material because of its distinct flavor, high biological worth, and advantageous fatty acid composition, which features a higher ratio of unsaturated fats compared to typical red meats (Fan *et al*., 2020). Nevertheless, the coarse texture, inconsistent moisture levels, and reduced water retention of duck meat present challenges in formulation, especially when trying to preserve the final product's desired texture, cohesiveness, and juiciness (Jiao *et al*., 2022). To address these challenges, food technologists have increasingly relied on functional additives, especially hydrocolloids, to enhance the physicochemical characteristics of meat matrices. In processed meats, hydrocolloids play a vital role by regulating water retention, gel formation, emulsion stability, and viscoelastic properties, all of which contribute to improved texture, yield, and shelf-life stability of the products (Kim *et al*., 2020). Familiar sources of plant-derived hydrocolloids are seaweed (such as agar, carrageenan, and alginate), seeds (e.g., guar gum and locust bean gum), and plant exudates (such as gum arabic) (Lomartire and Gonçalves, 2023). Although these hydrocolloids have demonstrated efficacy in various food systems, each has certain limitations regarding gelling strength, solubility, or stability under varying pH and temperature conditions. For example, agar creates fragile gels and might not offer the required flexibility in meat products. In contrast, the ionic strength and calcium levels can influence the effectiveness of carrageenan in the mixture. Likewise, seed gums such as guar can lead to excessive thickness, potentially adversely affecting the texture of finely structured items like meatballs (Hughes *et al*., 2023; Tahmouzi *et al*., 2023; Yang *et al*., 2023). Porang (*Amorphophallus muelleri*), a tuberous plant from Southeast Asia, is increasingly recognized as a promising source of natural hydrocolloid. This is primarily due to its rich glucomannan content, a water-soluble dietary fiber with impressive viscosity, swelling ability, and gelling characteristics (Nurlela *et al*., 2022). Porang flour demonstrates promising rheological characteristics and has been explored for various food uses, such as fat substitutes, thickening agents, and stabilizers(Latief *et al*., 2023a). Porang flour is particularly suitable for reformulating meat products due to glucomannan's capacity to create thermoreversible gels and retain moisture even at low concentrations, which helps improve yield, minimize syneresis, and enhance texture (Geng *et al*., 2022). Additionally, porang is a sustainable crop with significant agronomic value in marginal lands, supporting broader biodiversity goals and rural economic development. Beyond its technological functions, glucomannan is recognized as a functional dietary fiber that contributes to health benefits such as improved digestive health, glycemic control, and cholesterol reduction, positioning porang not only as a clean-label ingredient but also as a valuable component in the development of functional foods (Safitri *et al*., 2023; Widjanarko *et al*., 2023a; Kapoor *et al*., 2024).

Despite the functional potential of porang flour, scientific studies investigating its application in duck meat products remain scarce. In the context of meatball processing, using porang flour as a plant-based hydrocolloid has not been comprehensively evaluated in terms of its impact on both technofunctional and sensory characteristics. Technofunctional properties, such as moisture content, water holding capacity, cooking yield, instrumental texture (hardness, cohesiveness, chewiness), and sensory acceptance, are essential in determining the viability of porang flour as a natural binder and structuring agent (Kamsiati *et al*., 2022). Moreover, understanding the interactions between duck meat proteins and glucomannan during thermal processing is crucial to optimizing product quality and consistency.

This study aimed to assess the role of porang flour as a natural, plant-based hydrocolloid in the formulation of duck meatballs, focusing on

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evaluating its effects on key quality attributes. Specifically, this research investigates how varying levels of porang flour influence moisture retention, WHC, yield, textural integrity, and sensory acceptance in duck meatball systems.

Materials and methods

Materials

Duck meatballs were prepared using 8-month-old male Magelang ducks purchased from Salatiga, Indonesia. Other ingredients included tapioca flour, ice cubes, agar powder (Swallow brand), porang flour (Hasil Bumiku Brand), garlic powder, fried shallots, salt, sugar, flavor enhancer (Totole brand), and baking powder. All reagents used for physicochemical analyses were of analytical grade.

Methods

The experimental design followed a completely randomized design with six treatments and four replications. The treatments consisted of: T+ (control, 2% agar powder), T0 (0% porang flour), T1 (1% porang flour), T2 (1.5% porang flour), T3 (2% porang flour), and T4 (2.5% porang flour). All percentages were calculated based on the weight of duck meat (250 g per formulation). The whole composition is outlined in Table 1.

Duck meatball preparation

Duck meatballs were prepared using fresh meat from 8-month-old male Magelang ducks. The meat was manually deboned, trimmed of visible fat and connective tissue, and minced using a meat grinder. A total of 250 grams of duck meat was used for each formulation batch. The meat was then blended with ice cubes (approximately 30% w/w of meat weight) using a food processor (Philips HR7627) for 1 minute to lower the mixing temperature and facilitate emulsion formation.

The minced meat was mixed with the dry ingredients, including tapioca flour (20 g), granulated sugar (4 g), salt (6 g), flavor enhancer (1.25 g), fried shallots (4 g), garlic (1.5 g), baking powder (1.25 g), and either agar powder (5 g for control) or porang flour (2.5 to 6.25 g, depending on the treatment). The mixture was blended again in the food processor for 1 minute until a homogeneous and cohesive paste was formed. The resulting meat paste was shaped into uniform balls of approximately 20 mm in diameter using a manual meatball former. The meatballs were then cooked in hot water at a temperature of approximately 80°C until they floated to the surface, indicating doneness. The floating meatballs were allowed to cook for an additional 3 minutes to ensure complete internal coagulation. After cooking, the meatballs were removed from the water, drained, and cooled to room temperature prior to physicochemical and sensory analyses. All formulations were prepared in four independent replications under the same conditions to ensure reproducibility.

Moisture content analysis

Moisture content was determined using the oven-drying method (AOAC, 2005). Approximately 5 g of sample was dried at 105°C for 5 hours until a constant weight was achieved. The moisture content was calculated based on the weight difference before and after drying.

Cooking yield analysis

Cooking yield was measured by calculating the weight ratio of cooked to raw meatballs. Each sample's initial and final weights were recorded, and yield was expressed as a percentage.

Water binding capacity analysis

Water binding capacity (WBC) was evaluated using the Carver press method (Kudryashov and Kudryashova, 2023). A 0.3 g sample was placed between filter paper (Whatman No. 42) and pressed at 35 kg/cm² for 5 minutes. The wet area on the filter paper was measured, and WBC was calculated as the proportion of bound water relative to the total water content.

Texture profile analysis

Texture profile analysis was performed using a Brookfield Texture Analyzer equipped with a TA44 cylindrical probe. The parameters measured included hardness, springiness, adhesiveness, and cohesiveness, with testing conditions set at a trigger force of 0.5 g, deformation of 3 mm, and a test speed of 1 mm/s.

Sensory and hedonic evaluation

Organoleptic properties (umami taste, fishy smell, brown color, and chewy texture) were assessed through a ranking test by 25 untrained panellists. Hedonic testing was conducted using a 5-point scale to evaluate panelists' preferences regarding taste, color, aroma, texture, and overall liking.

Statistical analysis

Data on physicochemical and textural properties were analyzed using analysis of variance (ANOVA) at a 5% significance level, followed by Duncan's Multiple Range Test (DMRT) for post-hoc comparisons. Non-parametric tests (Kruskal-Wallis and Mann-Whitney U) were used for sensory

Table 1. Formulation of Duck Meatballs.

Ingredients	Composition (%, w/w)					
	T+ (2% agar)	T0 (0%)	T2 (1%)	T3 (1.5%)	T4 (2%)	T5 (2.5%)
Duck Meat (g)	250	250	250	250	250	250
Tapioca Flour (g)	20	20	20	20	20	20
Seaweed Powder (agar) (g)	5	-	-	-	-	-
Porang Flour (g)	-	-	2.5	3.75	5	6.25
Granulated Sugar (g)	4	4	4	4	4	4
Salt (g)	6	6	6	6	6	6
Flavor Enhancer (g)	1.25	1.25	1.25	1.25	1.25	1.25
Fried Shallots (g)	4	4	4	4	4	4
Garlic (g)	1.5	1.5	1.5	1.5	1.5	1.5
Baking Powder (g)	1.25	1.25	1.25	1.25	1.25	1.25

and hedonic data. All statistical analyses were performed using SPSS version 16.0.

Results

Table 2 presents technofunctional properties of duck meatballs formulated with varying concentrations of porang flour as a plant-based hydrocolloid, compared to a control sample using agar powder. The analysis assessed the effect of porang flour incorporation on yield, water content, and water binding capacity of duck meatballs which is a non-nutritional function of a food ingredient that influences the processing process and the physical characteristics of the final product.

Table 2. Technofunctional properties of Duck meatball.

Treatment	Yield (%)	Water Content (%)	Water Binding Capacity (%)
Control (agar powder)	94.74±0.70[a]	66.41±1.19	36.74±1.77[b]
T0 (0%)	94.03±0.80[a]	65.40±2.49	31.80±1.60[a]
T1 (1%)	94.36±1.60[a]	66.64±2.46	42.10 ±1.29[c]
T2 (1.5%)	95.56±1.12[a]	66.91±2.31	42.42 ±1.24[c]
T3 (2%)	98.51±0.51[b]	67.08±2.17	44.39±2.07[cd]
T4 (2.5%)	103.71±0.97[c]	67.26±1.73	44.78 ±0.88[d]

*Data are presented as mean±standard deviation (n = 4). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

The yield values of duck meatballs across treatments ranged from 94.03±0.80% to 103.71±0.97% (Table 3). The control group using agar powder yielded 94.74±0.70%, statistically similar to the 0%, 1%, and 1.5% porang flour treatments, which also exhibited no significant differences among each other ($p > 0.05$). However, a significant increase in yield was observed with the 2% (98.51±0.51%) and 2.5% (103.71±0.97%) porang flour treatments. Notably, the 2.5% treatment group showed the highest yield and significantly differed from all other groups ($p < 0.05$), as indicated by distinct superscript letters.

The water content of duck meatballs formulated with different levels of porang flour is summarized in Table 2. The control sample, containing agar powder as a binder, had a water content of 66.41±1.19%, while the sample without any hydrocolloid (0%) showed a slightly lower value of 65.40±2.49%. Incremental increases in porang flour concentration from 1% to 2.5% resulted in a modest rise in water content, ranging from 66.64±2.46% to 67.26±1.73%. Although a gradual upward trend was observed in the mean values, statistical analysis indicated that these differences were insignificant ($p > 0.05$) across all treatment groups.

Duck meatballs' water binding capacity (WBC) ranged from 31.80±1.60% to 44.78±0.88% across the different treatments (Table 4). The lowest WBC was recorded in the 0% treatment (no hydrocolloid), while the highest was observed in the 2.5% porang flour group. The control sample with agar powder exhibited a WBC of 36.74±1.77%, significantly higher than the 0% group ($p < 0.05$) but lower than all porang-treated groups except the 0%. Statistical analysis revealed that WBC increased significantly ($p < 0.05$) with porang flour concentrations of 1% and above, with the 2.5% treatment (44.78±0.88%) showing the highest value, significantly different from all other groups. The 1% (42.10±1.29%) and 1.5% (42.42±1.24%) treatments were not significantly different but were higher than the control and 0% samples.

Table 3 reports the instrumental texture profile of duck meatballs prepared with incremental levels of porang flour and compared with a control formulation containing agar powder. Texture profile analysis (TPA) parameters, including hardness, springiness, adhesiveness, and cohesiveness provide mechanistic insight into how a plant-based hydrocolloid influences the structural integrity and bite characteristics that govern consumer perception.

Hardness values ranged from 124 N in the hydrocolloid-free sample (0 %) to 206 N in the 2.5 % porang treatment. Statistical grouping (different superscripts) shows that hardness increased significantly ($p < 0.05$) beginning at 1.5 % porang, with the 2 % and 2.5 % levels each outperforming the control (agar) and lower dose treatments. Springiness remained between 2.6 and 2.7 mm across all formulations and did not differ significantly ($p > 0.05$), indicating that porang addition did not alter the elastic recovery of the meat matrix. Adhesiveness values were low (0.003–0.015 mJ) for every sample; no significant differences were detected, suggesting that porang did not impart stickiness to the product surface. Cohesiveness improved progressively with rising porang concentrations: the 1.5 %, 2 %, and 2.5 % treatments displayed significantly higher cohesiveness than the control and 0 % groups ($p < 0.05$). The 2.5 % formulation achieved the highest cohesiveness (≈0.82), signifying a tighter, more integrated protein–polysaccharide network.

The results showed variability across the four evaluated sensory attributes depending on the porang flour concentration (Table 4). Umami

Table 3. Duck meatball texture.

Treatment	Hardness (N)	Springiness (mm)	Adhesiveness (mJ)	Cohesiveness
Control (agar powder)	170.20±18.97[b]	2.7±0.03	0.005±0.00	0.77±0.02[a]
T0 (0%)	124.20±26.54[a]	2.6±0.05	0.015±0.01	0.77±0.01[a]
T1 (1%)	163.80±18.27[ab]	2.7±0.09	0.007±0.00	0.78 ±0.01[ab]
T2 (1.5%)	185.00±26.93[b]	2.7±0.03	0.012±0.00	0.80±0.01[b]
T3 (2%)	200.80±28.83[bc]	2.7±0.000	0.003±0.00	0.81±0.00[bc]
T4 (2.5%)	205.40±19.53[c]	2.7±0.000	0.007±0.00	0.82±0.02[c]

*Data are presented as mean±standard deviation (n = 4). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

Table 4. Organoleptic characteristics of duck meatballs.

Treatment	Umami Taste	Fishy Smell	Brown Color	Chewy Texture
Control (agar powder)	3.04±1.49	3.60±1.78	3.08±1.73	2.24±1.69[a]
T0 (0%)	3.76±1.48	3.20±1.63	3.64±1.93	3.4 ±1.66[b]
T1 (1%)	3.04±1.72	3.32±1.31	2.80±1.23	2.72±1.17[ab]
T2 (1.5%)	3.72±1.88	3.76±1.59	4.12±1.62	4.04±1.57[bc]
T3 (2%)	3.56±1.71	3.16±1.84	3.60±1.71	4.2±1.32[bc]
T4 (2.5%)	3.88±1.92	3.80±2.10	3.64±1.91	4.36±1.75[c]

*Data are presented as mean±standard deviation (n = 4). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

Table 5. Hedonic Characteristics of Duck Meatballs.

Treatment	Umami Taste	Brown Color	Fishy Smell	Chewy Texture	Overall Preference
Control (agar powder)	4.00±0.82	3.92±0.57	3.80±0.71	3.96±0.79	3.80±0.76
T0 (0%)	3.88±0.67	3.92±0.7	3.84±0.75	3.84±0.8	3.60±0.5
T1 (1%)	4.16±0.69	3.68±0.8	3.68±0.69	4.00±0.58	4.04 ±0.61
T2 (1.5%)	3.84±0.85	3.44±0.65	3.80±0.82	3.84±0.69	3.52±0.65
T3 (2%)	3.80±0.76	3.60±0.65	3.92±0.76	3.92±0.57	3.72±0.68
T4 (2.5%)	3.92±0.81	3.76±0.72	3.72±0.68	3.84±0.69	3.64±0.64

*Data are presented as mean±standard deviation (n = 4). Different superscripts in the same column and row indicate significant differences ($p < 0.05$).

taste scores ranged from 3.04 to 3.88, with the 2.5% treatment group obtaining the highest mean score (3.88±1.92), followed closely by 1.5% (3.72±1.88) and 0% (3.76±1.48). However, no significant differences ($p > 0.05$) were observed among treatments, indicating that porang flour addition had no detrimental effect on umami perception. Fishy smell values were also statistically similar among treatments ($p > 0.05$), fluctuating between 3.16 and 3.80, with the control, 1.5%, and 2.5% groups exhibiting relatively higher suppression of fishy odor. In contrast, brown color perception varied among samples, although no statistically significant difference ($p > 0.05$) was detected. The 1.5% porang treatment group recorded the highest score (4.12±1.62), suggesting enhanced browning compared to the control and 1% treatments. Chewy texture was the only attribute that showed significant treatment differences ($p < 0.05$). The control group exhibited the lowest chewiness score (2.24±1.69), significantly different from the 2%, 2.5%, and 1.5% porang treatments. The 2.5% porang flour sample received the highest chewiness score (4.36±1.75), reflecting enhanced structural integrity and texture perception.

Hedonic scores for all assessed attributes showed relatively high acceptance levels across all treatment groups, ranging from moderate to favorable (Table 5). Umami taste scores ranged from 3.80±0.76 (2%) to 4.16±0.69 (1%), with the control group scoring 4.00±0.82. Brown color ratings varied between 3.44±0.65 (1.5%) and 3.92±0.57 (control and 0%). Fishy smell scores were consistent across treatments, ranging from 3.68±0.69 to 3.92±0.76, indicating no perceptible difference in odor intensity. All formulations received similar chewy texture scores, ranging from 3.84±0.69 to 4.00±0.58. The highest overall preference score was recorded in the 1% porang treatment group (4.04±0.61), while the lowest was found in the 1.5% group (3.52±0.65). However, no significant differences ($p > 0.05$) were observed across all treatments for the evaluated sensory parameters.

Discussion

Including porang (*Amorphophallus muelleri*) flour in duck meatball formulations had a notable impact on various physicochemical, textural, and sensory properties, highlighting its potential as a functional binder and water-holding agent in meat-based products. As the concentration of porang flour increased, replacing agar and working synergistically with tapioca, it progressively enhanced yield, water-binding capacity (WBC), texture, and sensory acceptability.

The progressive increase in water content across treatments, particularly at 2.5% porang inclusion, suggests that porang flour enhances the hydrophilic character of the meat matrix. This aligns with previous findings indicating that konjac-type glucomannan in porang has high water absorption and retention capacity due to its polysaccharide gel-forming ability (Chandarana *et al*., 2024). The slightly higher moisture retention in higher concentrations did not translate to undesirable softness; instead, it contributed to a desirable juiciness without compromising structure, as the improved WBC values supported (Widjanarko *et al*., 2023a). The ability of porang flour to increase moisture retention in meat products is a significant finding, as it suggests potential applications in improving the juiciness and overall quality of processed meats.

Yield enhancements were notably pronounced in treatments containing 2% or more porang flour, significantly exceeding both the control group (which used agar) and treatments with lower concentrations. This improvement is likely due to the excellent gel network formed by porang flour, which may more effectively trap water and fat, thereby reducing cooking loss (Widjanarko, *et al*., 2023b). The result suggests a thermally stable matrix conducive to industrial meat processing applications, echoing previous research into glucomannan's role in water and oil retention in emulsified meat products (Geng *et al*., 2023).

Textural evaluation revealed that porang flour had a notable impact on product firmness and cohesiveness. Hardness values increased significantly with porang concentration, particularly at 2.5%, indicating an enhanced cross-linked gel structure likely formed between meat proteins and glucomannan fibers under heat (Liu *et al*., 2021). Additionally, cohesiveness improved incrementally with porang addition, suggesting a more integrated protein-polysaccharide matrix that may resist fragmentation under mechanical stress, as previously reported by Biswas *et al*. (2022). Interestingly, adhesiveness values remained low across treatments, indicating no increase in stickiness despite greater moisture and gel content, a favorable outcome for consumer handling and mouthfeel. Springiness showed slight variation, remaining within the typical range for meatball products, signifying that porang flour did not negatively affect the elastic recovery of the product.

From an organoleptic perspective, treatments with 2–2.5% porang flour received the highest scores for chewiness and brown color, likely due to the denser matrix and Maillard-driven browning potential from polysaccharide interaction (Lavaei *et al*., 2022; Toutounji, 2024). Chewiness was particularly favored, indicating that the modified texture was positively perceived by panelists. Moreover, the reduced fishy odor intensity in porang-enhanced formulations may suggest an aroma-masking effect of porang flour, as also noted in fiber-enriched meat systems (Shishkina *et al*., 2022).

Hedonic evaluation further corroborated the functional and sensory enhancements of porang addition, particularly at the 1–2% levels, which received higher overall acceptability scores than the control and the highest concentration (2.5%). This suggests that while functionality increases with porang content, there may be an optimal threshold beyond which the sensory benefits plateau or slightly decline, possibly due to excessive firmness or changes in flavor release kinetics (Latief *et al*., 2023b). The higher porang concentrations likely result in a denser and more compact gel matrix within the meatball structure, which, while beneficial for water retention and texture stability, can reduce juiciness and impede the release of flavor compounds during mastication (Khushboo *et al*., 2023). This structural tightening may alter the perception of tenderness and mouthfeel, making the product less palatable despite improved technological qualities (Shi *et al*., 2021). Such findings highlight the importance of balancing functional improvements with sensory attributes to achieve consumer-preferred formulations in meat-based products (Hong *et al*., 2023).

Overall, these results underscore the dual benefits of porang flour in duck meatball formulations, both functionally and sensorially. Its use not only enhances yield and maintains textural quality but also supports the clean-label movement and dietary fiber enrichment in contemporary meat product innovation. Nonetheless, it is crucial to manage the concentration to prevent excessive gelation that could reduce sensory attractiveness.

Conclusion

Utilizing porang flour as a plant-based hydrocolloid in the preparation of duck meatballs resulted in notable enhancements in cooking yield, water retention, and textural properties, particularly in terms of hardness and cohesiveness. Although the rise in water content was not statistically significant, the improvements in water retention and cooking yield, especially with 2% and 2.5% porang flour, suggest a functional benefit for processed meat products.. Sensory evaluations revealed that porang flour improved chewiness without adversely affecting other organoleptic properties, although an optimal concentration range of 1–2% was preferable to maximize overall consumer acceptance without compromising palatability. These findings affirm porang flour's potential as a clean-label, functional binder for meat products, contributing to improved product quality and aligning with current trends in sustainable and health-oriented food innovations. Further research may explore the interactions between porang glucomannan and meat proteins to optimize formulations across diverse meat matrices.

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Conflict of interest

The authors have no conflict of interest to declare.

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