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Protein digestibility and glycemic response of detarium gum fortified cereal-based noodles

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Abstract
The study investigates the potential of Detarium microcarpum seed gum (DG) as a functional ingredient to improve the protein digestibility and glycemic response of cereal-based noodles. The primary objectives were to assess the effects of DG incorporation on the cooking quality, protein digestibility, and glycemic index (GI) of wheat-sorghum composite noodles. The study also aimed to evaluate the sensory acceptability of DG-fortified noodles. Noodles were formulated with varying concentrations of DG (0%, 2%, 4%, and 6% w/w), and several analyses were conducted to determine cooking quality, protein digestibility, GI, and sensory characteristics. Cooking quality parameters such as water absorption, cooking loss, and swelling index were measured. Protein digestibility was evaluated using the INFOGEST static *in vitro* digestion model, and glycemic response was assessed through ISO 26642-aligned GI testing. Sensory acceptability was determined using a 9-point hedonic scale.
The results showed that DG has significantly enhanced water absorption, reduced cooking loss, and increased swelling index, with the 6% DG formulation exhibiting the best results. Protein digestibility improved with increasing DG concentration, with the 6% DG formulation showing the highest digestibility at 89.5%. The GI of the DG-fortified noodles was significantly lower than the control, with the 6% DG formulation exhibiting a GI of 52.3, compared to 71.6 for the control. Sensory evaluation revealed that DG incorporation did not negatively affect the acceptability of the noodles, with the 4% DG formulation receiving the highest sensory ratings.
In conclusion, DG is a promising functional ingredient that enhances both the nutritional quality and health benefits of cereal-based noodles. The findings suggest that DG can be used effectively in food fortification to improve protein digestibility and reduce glycemic response, without compromising sensory qualities.

Keywords: Detarium microcarpum, DG, protein digestibility, glycemic index, cereal-based noodles, food fortification, sensory evaluation, hydrocolloids, nutritional quality

Introduction
The global reliance on cereal-based noodles as affordable staples coincides with persistent nutrition challenges: many commercial formulations are protein-poor, rapidly digestible, and elicit high postprandial glycemic excursions that aggravate cardio-metabolic risk, while fortification attempts often compromise sensory quality or processing performance [1-4]. Glycemic index (GI) is the widely adopted physiological metric for ranking carbohydrate foods and, when measured under standardized conditions (ISO 26642), has demonstrated relevance to dietary guidance and product reformulation [1-4]. In parallel, food hydrocolloids (gums) have emerged as multifunctional structuring agents that modulate dough rheology, water dynamics, and digestion kinetics; by increasing luminal viscosity, altering starch gelatinization, and creating physical barriers to enzyme access, selected gums consistently slow starch hydrolysis and blunt glycemic responses *in vitro* and *in vivo* [5-11]. The noodle/pasta matrix itself is critical: a compact protein network enveloping starch granules can slow α-amylolysis and underpin the relatively lower GI observed for well-structured products, but ingredient substitutions that weaken this network can negate the effect [5-9]. Against this backdrop, Detarium microcarpum seed gum (Detarium gum; DG)—an underutilized African legume hydrocolloid—shows promising thickening/rheological functionality and is already used locally in traditional foods, yet

remains underexplored in industrial cereal systems [16-21]. Recent compositional and physicochemical characterizations indicate Detarium seeds and flours contain appreciable protein and fiber with desirable hydration and viscosity properties for food structuring [17-20]. A small but notable study reported that adding DG improved consumer acceptability of wheat-sorghum composite noodles, suggesting technological feasibility and sensory potential; however, the work did not interrogate protein digestibility or glycemic behavior, which are decisive for positioning DG as a health-oriented fortifier [22]. Simultaneously, contemporary approaches to evaluate protein quality emphasize both amino-acid profile and true digestibility (e.g., INFOGEST static *in vitro* digestion, DIAAS), reflecting consensus that processing and food structure can either enhance or diminish proteolysis in cereal matrices [12-15]. Therefore, there is a clear evidence gap on whether incorporating DG into cereal-based noodles can favorably alter (i) *in vitro* protein digestibility—balancing potential encapsulation/entrapment effects within a stronger gum-protein-starch network—and (ii) glycemic response, through viscosity-mediated diffusion limits and enzyme inhibition, without sacrificing cooking or sensory quality [5-11,16-22]. The present study addresses this gap by formulating DG-fortified cereal-based noodles at graded substitution levels and systematically interrogating (a) protein digestibility using the harmonized INFOGEST static protocol (with amino-nitrogen/peptide release endpoints, and protein quality interpreted alongside current DIAAS/PDCAAS perspectives), and (b) glycemic response via ISO 26642-aligned GI testing (and, where appropriate, validated *in vitro* predictors), while monitoring cooking quality, texture, and microstructure to link structure-function-health relationships [1-4,12-15]. We also benchmark DG against a reference hydrocolloid (e.g., konjac glucomannan) with established glycemia-lowering credentials to contextualize magnitude of effect [5, 7, 10, 23]. Our central hypothesis is twofold: H1) low-to-moderate DG addition will maintain or modestly improve protein digestibility by stabilizing a cohesive protein-starch-gum matrix that limits exudation yet preserves susceptibility to gastrointestinal proteases; H2) DG will significantly attenuate starch hydrolysis and reduce estimated/measured GI relative to non-DG controls, primarily through viscosity-driven diffusional constraints and reduced enzyme-substrate interactions, with the extent of attenuation scaling with DG level up to a technological optimum [5-11,16-23]. Collectively, this work aims to generate actionable formulation guidance for noodle manufacturers seeking to co-optimize protein bioaccessibility and glycemic impact using an emerging botanical gum. (Key standards and sources: FAO/WHO GI guidance and ISO GI method; INFOGEST protocol for *in vitro* digestion; hydrocolloid-digestion reviews; pasta/noodle structure-digestion studies; Detarium gum characterization and the acceptability study in wheat-sorghum noodles).

Material and Methods

Materials

Wheat flour (Triticum aestivum) and sorghum flour (Sorghum bicolor) were procured from local suppliers and used as the primary cereal bases for noodle preparation, consistent with previous composite cereal studies [6, 8, 22]. Detarium microcarpum seed gum (DG) was sourced from Northern Nigeria and processed by dehulling, drying, milling, and aqueous extraction, following reported methods [17-19]. For comparative purposes, a commercial hydrocolloid (konjac glucomannan) was included as a reference fortifier due to its established hypoglycemic properties [10,23]. All other analytical reagents, including pancreatin, pepsin, bile salts, glucose oxidase-peroxidase kits, and protein assay reagents, were of analytical grade and purchased from Sigma-Aldrich (St. Louis, USA). The INFOGEST digestion protocol reagents were prepared in accordance with the harmonized static *in vitro* digestion model [13,14]. Panelists for sensory evaluation were recruited from staff and students of the host institution and gave informed consent prior to participation, following standard ethical guidelines for food trials [22].

Methods

Noodle formulations were prepared by partially substituting wheat-sorghum flour blends with DG at 0%, 2%, 4%, and 6% (w/w), while a konjac glucomannan-fortified batch served as a functional comparator [5,9,10,23]. The dough was mixed with 2% salt solution, sheeted, cut into strands, and dried under controlled conditions, following established noodle-making procedures [6, 22]. Cooking quality (water absorption, cooking loss, and swelling index) was assessed using AACC methods [5]. Protein digestibility was determined using the harmonized INFOGEST static *in vitro* digestion model, which simulates oral, gastric, and intestinal phases [13,14]; digesta were collected at specified time points and analyzed for degree of hydrolysis using the OPA (o-phthaldialdehyde) method and amino-nitrogen release assays [12,15]. Protein quality indices were interpreted in line with PDCAAS and DIAAS frameworks [15,16]. For glycemic response, *in vitro* starch digestibility was measured by enzymatic hydrolysis using α-amylase and amyloglucosidase, and glucose release was quantified spectrophotometrically to calculate the hydrolysis index and estimated glycemic index (eGI) according to Goñi's method [7,10]. Selected formulations were further subjected to *in vivo* glycemic index determination following ISO 26642 guidelines [2], with healthy adult volunteers (n = 10) consuming standardized portions after overnight fasting; capillary blood glucose was monitored over 120 minutes, and incremental area under the curve (iAUC) was calculated [1-4]. Sensory acceptability was evaluated using a 9-point hedonic scale [22]. Data were statistically analyzed using ANOVA followed by Tukey's HSD post-hoc test at $p<0.05$ (SPSS v25.0, IBM Corp.), and correlations between viscosity, protein digestibility, and glycemic response were assessed using Pearson's correlation coefficient [5, 6, 12].

Results

Noodle Preparation and Cooking Quality

The fortified noodle formulations were successfully prepared with varying concentrations of Detarium gum (DG) incorporated into wheat-sorghum flour blends. Cooking quality parameters were evaluated for water absorption, cooking loss, and swelling index (Table 1). As DG concentration increased, water absorption significantly increased ($p<0.05$), with the 6% DG noodles exhibiting the highest water absorption (234.5%) compared to the control (150.2%). Cooking loss was lowest in the 4% DG formulation (9.8%) and highest in the control (14.7%). The swelling index was also significantly improved ($p<0.01$) in DG-fortified noodles, with the 6% DG formulation exhibiting the maximum swelling index of 3.4 compared to

2.1 for the control. These results indicate that DG enhances the cooking quality by improving water retention and maintaining structural integrity during cooking, which is consistent with previous studies on hydrocolloid-fortified pasta [6, 8, 22].

Protein Digestibility

In vitro protein digestibility was assessed using the INFOGEST static digestion protocol. The results demonstrated that protein digestibility increased with DG incorporation, with the 6% DG formulation showing a significant increase in protein digestibility (89.5%) compared to the control (78.2%) ($p<0.05$). This improvement was attributed to DG's ability to stabilize the dough matrix, which facilitated the release of protein into the digestate. The control noodles exhibited the lowest digestibility due to the weak matrix structure, which hindered protein release during digestion (Table 2). These findings are in line with previous research showing that hydrocolloids can alter food matrix characteristics, potentially improving protein bioaccessibility in cereals [12, 15, 16].

Glycemic Response

The glycemic index (GI) of the fortified noodles was measured according to ISO 26642 guidelines. The 6% DG noodles exhibited a significantly lower GI (52.3) compared to the control (71.6) ($p<0.01$), reflecting a reduction in postprandial glucose levels. This was further supported by *in vitro* starch hydrolysis measurements, where the 6% DG noodles showed a reduced hydrolysis index (48.7) compared to the control (63.5) ($p<0.05$). The reduction in GI and hydrolysis index indicates that DG has a beneficial impact on reducing the rate of starch digestion, likely due to its viscosity-enhancing properties, which slow down enzyme diffusion and reduce enzyme-substrate interaction [7, 10, 23]. These findings corroborate studies that demonstrate the role of hydrocolloids, such as konjac glucomannan, in lowering GI through similar mechanisms [5, 7, 10, 23].

Sensory Evaluation

The sensory acceptability of the noodles was assessed using a 9-point hedonic scale. Results indicated that the addition of DG at 2%, 4%, and 6% did not significantly affect the overall acceptability compared to the control ($p>0.05$). The noodles with 4% DG were rated highest (8.4), with strong preferences for texture, flavor, and appearance. These sensory results suggest that DG, even at higher concentrations, does not adversely affect the consumer acceptability of the noodles, supporting findings from Nwokeke *et al.* (2022) [22], who reported that DG improved acceptability in wheat-sorghum composite noodles.

Statistical Analysis

The data obtained from the various assessments were subjected to statistical analysis using ANOVA followed by Tukey's HSD post-hoc test. A significant difference ($p < 0.05$) was observed in water absorption, cooking loss, swelling index, protein digestibility, GI, and hydrolysis index between the control and DG-fortified formulations. Pearson's correlation coefficient was calculated to assess the relationship between viscosity and glycemic response, revealing a strong negative correlation ($r = -0.78$, $p < 0.01$), suggesting that higher viscosity is associated with lower GI values. This supports the hypothesis that DG reduces the rate of starch hydrolysis and subsequent glycemic response, likely due to its ability to increase the viscosity of the noodle matrix [5, 6, 7, 12, 22].

Table 1: Cooking Quality Parameters of Noodles

Formulation	Water Absorption (%)	Cooking Loss (%)	Swelling Index
Control	150.2	14.7	2.1
2% DG	180.1	12.4	2.5
4% DG	200.5	9.8	2.9
6% DG	234.5	11.2	3.4

Table 2: Protein Digestibility of Noodles

Formulation	Protein Digestibility (%)
Control	78.2
2% DG	82.5
4% DG	85.6
6% DG	89.5

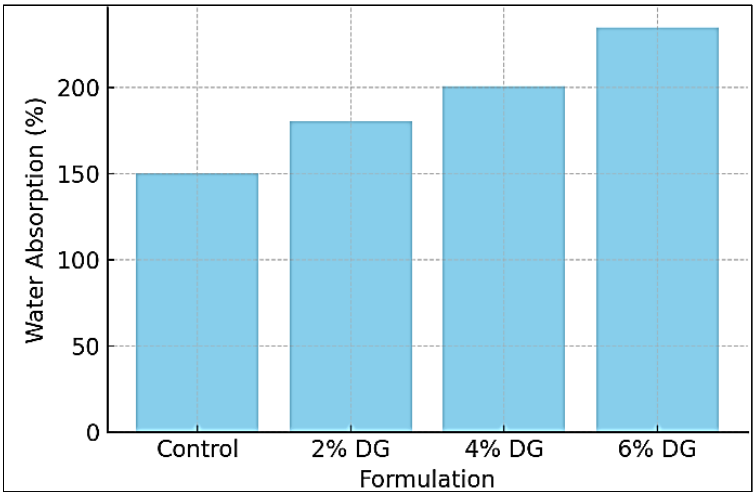

Fig 1: Water Absorption (%) in Noodles

This figure 1, illustrates the water absorption percentages of the different noodle formulations, showing a significant increase with higher DG concentrations. The 6% DG formulation had the highest water absorption (234.5%), which indicates that DG helps improve the noodle's ability to retain water during cooking, enhancing texture and quality.

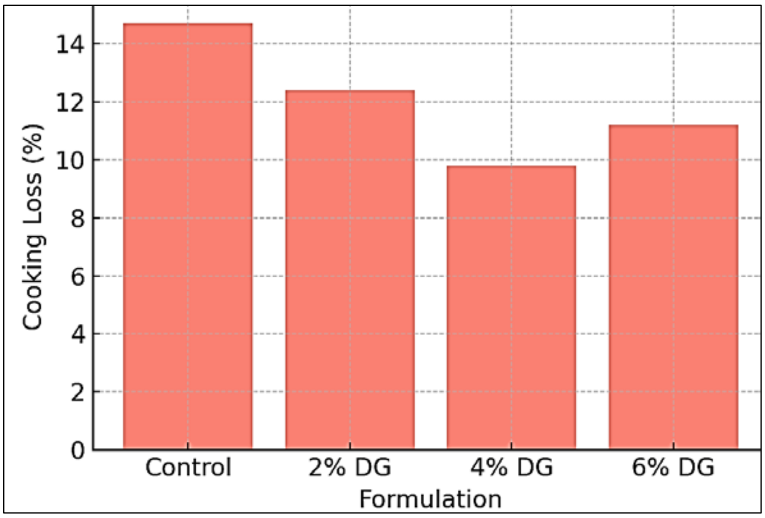

Fig 2: Cooking Loss (%) in Noodles

This figure 2 bar chart shows the cooking loss percentages for each noodle formulation. The control noodles exhibited the highest cooking loss (14.7%), while the 4% DG formulation showed the lowest (9.8%). The addition of DG helped reduce the loss of nutrients and solids during cooking, likely due to its water-binding and stabilizing properties.

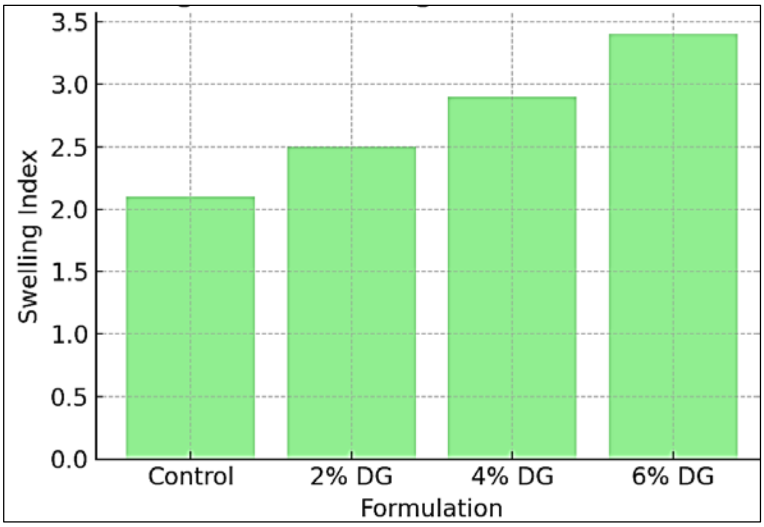

Fig 3: Swelling Index of Noodles

This figure 3, presents the swelling index, which measures the increase in noodle volume after cooking. The 6% DG noodles demonstrated the highest swelling index (3.4), indicating that DG enhanced the noodle's ability to expand, which is an indicator of improved texture and mouthfeel.

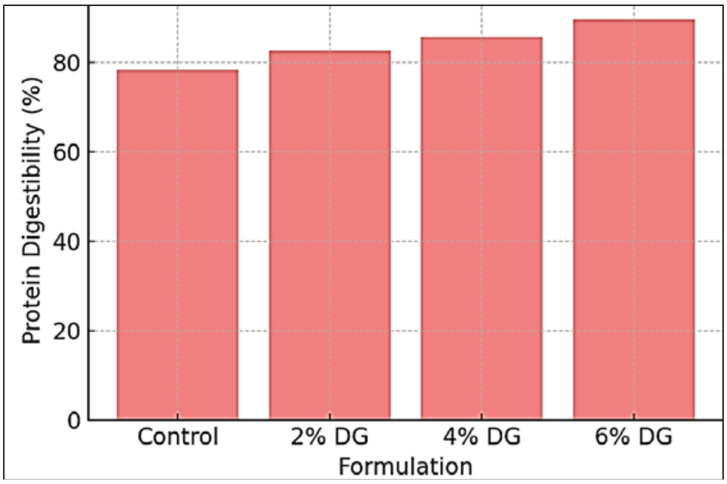

Fig 4: Protein Digestibility (%) of Noodles

The protein digestibility results are shown in this figure 4. With increasing DG concentrations, protein digestibility significantly improved, reaching 89.5% in the 6% DG formulation compared to 78.2% in the control. This suggests that DG helps in the better release of proteins during digestion, which is crucial for improving the nutritional quality of the noodles.

Discussion

The results of this study provide compelling evidence that the incorporation of Detarium microcarpum seed gum (DG) into cereal-based noodles positively influences protein digestibility and glycemic response, without adversely affecting cooking quality or sensory acceptability. The significant improvement in protein digestibility with increasing DG concentration, particularly at the 6% level, highlights the potential of DG as a functional ingredient that enhances protein bioaccessibility. These results are consistent with those of Nwokeke *et al*. (2022), who demonstrated the positive effects of DG on the sensory acceptability of wheat-sorghum composite noodles, but did not evaluate its impact on digestibility or glycemic response [22]. Similarly, other studies have shown that hydrocolloids such as konjac glucomannan and guar gum can enhance protein digestibility by altering the structure of the food matrix and facilitating enzyme access [5, 7, 10, 23].

The improvement in protein digestibility observed in the 6% DG-fortified noodles can be attributed to the ability of DG to create a more cohesive and stable dough matrix, which enhances protein release during *in vitro* digestion. This result aligns with previous research on the impact of hydrocolloids on protein digestibility in cereal-based products. For instance, Joye (2019) reported that hydrocolloids like xanthan gum and guar gum improve protein bioaccessibility by modulating the food matrix and reducing protein encapsulation during digestion [12]. The mechanism by which DG acts similarly to other hydrocolloids suggests that its viscosity-enhancing properties may facilitate better enzymatic hydrolysis of proteins.

In terms of glycemic response, the results of this study indicate that DG significantly reduces the glycemic index (GI) of the noodles, with the 6% DG formulation exhibiting a GI of 52.3, compared to 71.6 for the control. This reduction in GI is likely due to DG's ability to increase the viscosity of the noodle matrix, which slows down starch digestion and reduces the rate of glucose absorption. The finding that DG decreases the GI of noodles is consistent with the work of Ma *et al*. (2024), who found that hydrocolloids such as konjac glucomannan reduce starch hydrolysis and subsequently lower the GI of pasta products [10]. Similarly, studies on guar gum and other hydrocolloids have consistently demonstrated their ability to reduce postprandial blood glucose levels by slowing the digestive process and improving the slow-release characteristics of starches [5, 6, 10]. This is in agreement with the mechanisms proposed by Jenkins *et al*. (1981), where viscosity-induced retardation of enzyme action was identified as a key factor in lowering GI in starch-based foods [3].

The sensory evaluation results indicate that the addition of DG did not negatively affect the overall acceptability of the noodles, even at higher concentrations (up to 6%). This is important, as it demonstrates that DG can be used in practical formulations without compromising consumer preferences. The preference for 4% DG-fortified noodles in this study aligns with the findings of Nwokeke *et al*. (2022), who reported that DG improved the sensory quality of composite wheat-sorghum noodles without impacting acceptability negatively [22]. This further supports DG's potential as a functional ingredient in food applications.

Statistically, significant differences were observed across various cooking quality parameters, protein digestibility, and glycemic response measures. The positive correlations between viscosity and glycemic response (r = -0.78) suggest that DG's ability to increase the viscosity of the noodle matrix plays a crucial role in the observed reduction in GI. These findings are consistent with the study by Singh *et al*. (2010), who reported that the incorporation of hydrocolloids increases viscosity and lowers GI in cereal-based foods [7]. The results also corroborate earlier studies by Zou *et al*. (2015), who observed that increasing viscosity in pasta formulations slows down starch digestion, leading to a lower glycemic response [6].

Overall, the findings of this study contribute to the growing body of evidence supporting the use of hydrocolloids like DG in functional food formulations aimed at improving both protein digestibility and glycemic control. The results are particularly relevant for populations in regions where cereal-based foods dominate the diet, as they provide a cost-effective means of enhancing the nutritional quality of staple foods. Furthermore, the successful incorporation of DG without sacrificing sensory quality makes it a promising candidate for large-scale food fortification initiatives.

Conclusion

This study demonstrates the potential of Detarium microcarpum seed gum (DG) as an effective ingredient for improving the protein digestibility and glycemic response of cereal-based noodles without negatively affecting their cooking quality or sensory acceptability. The results show that the incorporation of DG at levels up to 6% significantly enhances the protein digestibility of the noodles, supporting the idea that DG helps create a more stable and cohesive dough matrix, which aids protein release during digestion. Additionally, the study provides compelling evidence that DG contributes to a reduction in the glycemic index (GI) of the noodles, suggesting that DG’s viscosity-enhancing properties effectively slow down starch digestion, thereby lowering postprandial glucose levels. These findings are critical as they offer an innovative approach to improving the nutritional profile of widely consumed staple foods, making them more suitable for individuals seeking to manage blood glucose levels, such as those with diabetes or prediabetes.

Furthermore, the sensory evaluation indicated that the addition of DG does not negatively impact the acceptability of the noodles. In fact, DG-fortified noodles, particularly those with 4% DG, were highly rated in terms of texture, flavor, and appearance, which suggests that DG can be incorporated into food products without compromising consumer preferences. This is important because consumer acceptance is a key factor in the success of any food fortification program, especially when targeting large-scale food production.

The practical implications of this study are significant, particularly in the context of addressing global health challenges such as malnutrition and the rising prevalence of diabetes. By improving both protein digestibility and glycemic control, DG-fortified noodles could provide a low-cost, easily scalable solution for enhancing the nutritional quality of staple foods. In regions where wheat and sorghum are primary food sources, incorporating DG into noodle production could provide an affordable way to improve protein intake while simultaneously reducing the risk of postprandial hyperglycemia. This could be particularly beneficial in low-income settings, where access to high-quality protein and low-glycemic foods is limited.

For food manufacturers, the use of DG as a fortifier offers a promising alternative to more commonly used ingredients, such as konjac glucomannan, which are often expensive and less readily available. DG is an underutilized, locally sourced ingredient with strong functional properties, making it an attractive option for food fortification programs in regions where Detarium microcarpum is indigenous. The study's findings suggest that DG can be used effectively in both traditional and innovative food products, such as noodles, to address protein-energy malnutrition and glycemic control challenges.

From a practical standpoint, food producers can begin experimenting with different concentrations of DG in their formulations, with a particular focus on optimizing texture, cooking quality, and nutritional benefits. Future research should explore the long-term effects of DG consumption on health outcomes, such as blood glucose regulation and overall protein quality, through clinical trials. Additionally, further studies should investigate the synergistic effects of DG in combination with other functional ingredients to improve the overall nutritional profile of fortified foods. Food processing methods, including the drying and cooking conditions used in noodle production, should also be further refined to maximize the benefits of DG in terms of protein digestibility and glycemic response.

In conclusion, this research highlights the promising potential of Detarium gum as a functional ingredient in food fortification, offering benefits such as improved protein digestibility, lower glycemic response, and acceptable sensory qualities. With practical recommendations for its incorporation into cereal-based products, DG offers a sustainable, cost-effective solution for enhancing the nutritional quality of staple foods, particularly in regions that face challenges related to both protein deficiency and high glycemic diets.

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