Development and Carbohydrate Profiling of Low-Starch Edamame-Seaweed Instant Analog Rice for Type 2 Diabetes Management

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Abstract. Managing dietary carbohydrate intake, particularly glycemic starch, is essential for regulating blood glucose in Type 2 Diabetes Mellitus (T2DM). This study evaluated the starch and amylose profiles of a newly developed instant analog rice formulated from a composite of edamame and seaweed flours. Using a completely randomized design, we tested three formulations with varying edamame-to-seaweed ratios: P1 (40:60, w/w), P2 (50:50), and P3 (60:40), alongside a commercial instant rice control (P0). Multi-criteria optimization via the Zeleny method was applied to determine the best formulation. The results showed that changing the ingredient ratios significantly altered total starch content ($p < 0.05$) but had no statistical effect on amylose levels ($p > 0.05$). No significant correlation was found between total starch and amylose, suggesting that processing and matrix interactions disrupted their typical linear relationship. The Zeleny method identified P3 as the optimal product; it contained 14.84 g/100 g of starch and 2.16 g/100 g of amylose, dropping the glycemic starch load to nearly half that of the commercial control P0 (30.07 g/100 g starch and 7.06 g/100 g amylose). These findings indicate that substituting traditional rice grains with a legume-seaweed blend successfully limits digestible starch density. The optimized P3 formulation shows strong potential as a functional, low-glycemic alternative staple for diabetic dietary management.

Keywords: Amylose, edamame flour, instant analog rice, seaweed flour, starch.

1 Introduction

Diabetes Mellitus (DM) is a condition characterized by elevated blood glucose levels due to impaired insulin production. This condition occurs as a result of damage to pancreatic β-cells, which are responsible for producing insulin, leading to a deficiency of this hormone in the body [1]. In addition, another cause of DM is insulin resistance, which refers to an impaired insulin response in target tissues, including muscles, liver, and adipose tissue, thereby disrupting glucose metabolism in the body [2].

According to the International Diabetes Federation (IDF) Diabetes Atlas 11th Edition (2025), approximately 589 million adults aged 20–79 years were living with diabetes worldwide in 2024, and this number is projected to increase to 853 million by 2050 [3].

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The World Health Organization also reported that the number of individuals with DM in Indonesia increased from 8.4 million in 2000 to 21.3 million in 2030 [4]. Furthermore, according to the Indonesian Health Survey (SKI) 2023, the prevalence of diabetes among individuals aged ≥15 years was 2.2% based on physician diagnosis and 11.7% based on blood glucose measurements, indicating a substantial burden of diabetes in the Indonesian population [5].

DM may cause complications in both small and large blood vessels. Microvascular complications include retinopathy, neuropathy, and nephropathy, while macrovascular complications include hypertension, heart disease, and stroke [6], [7]. DM is classified into two types, namely Type 1 Diabetes Mellitus (T1DM) and T2DM. T1DM occurs due to pancreatic dysfunction, resulting in impaired insulin production. In contrast, T2DM is caused by elevated blood glucose levels (hyperglycemia) and insulin resistance [8].

T2DM is closely associated with unbalanced dietary habits, particularly excessive carbohydrate consumption. In Indonesia, rice is the most commonly consumed carbohydrate source among the population. Rice is derived from white rice grains, which contain carbohydrates as their primary component [9]. One of the carbohydrate components present in rice is starch or amylose-containing starch [10]. The type of rice consumed may influence blood glucose levels. Elevated blood glucose levels are associated with rice containing high starch and low amylose content [11].

Starch is a carbohydrate that serves as a primary energy source for the body. The average starch content in white rice (Oryza sativa L.) is reported to be 24.47% [12]. Consumption of foods high in starch may trigger disturbances in glucose metabolism because starch is broken down into glucose during digestion. Excessive glucose release from starch digestion may potentially increase blood glucose levels when consumed in large amounts [10], [13]. Starch consists of two major components, namely amylose and amylopectin [14]. Amylose is a polysaccharide composed of linear chains of glucose molecules. The amylose content in milled IR64 rice has been reported to be 28.64% [15]. Foods with high amylose content are digested more slowly, thereby contributing to lower blood glucose levels [16]. Therefore, individuals with T2DM are encouraged to consume rice with low starch and high amylose content [17].

One alternative food product for individuals with T2DM is instant analog rice made from edamame flour and seaweed [18]. The study reported that 100 g of analog rice contained 83.71 g carbohydrates, 2.76 g protein, 0.23 g fat, 7.29 g total fiber, 0.18 g sugar, and provided 346.92 kcal of energy, while also demonstrating a high level of panelist acceptance. However, the study did not examine the starch and amylose contents, both of which play important roles in glucose metabolism. In addition, the available product was still in the form of conventional analog rice, making it less practical for urban communities, disaster victims, and regions with limited access to rice [19]. Therefore, this study focused on the analysis of starch and amylose contents in instant analog rice made from edamame flour and seaweed as an alternative food for individuals with T2DM.

Edamame soybeans are recognized as a healthy food source because they contain various essential nutrients, including antioxidants, isoflavones, beta-carotene, and dietary fiber [20]. The starch content of edamame ranges from 11.9–16.58%, while its amylose

content is approximately 19–22% [21], [22]. In addition, edamame flour contains dietary fiber at a level of 33.16% [23]. Another ingredient used is seaweed, which is rich in dietary fiber, reaching 65.5%, consisting of 26.03% water-soluble fiber (carrageenan) and 39.47% water-insoluble fiber [24]. Seaweed flour has even been reported to contain dietary fiber up to 73.95% and carrageenan at 54.56% [25]. The primary carbohydrate component in seaweed is non-starch polysaccharides; therefore, its starch content is relatively low [26]. The addition of seaweed to analog rice has been shown to influence starch digestibility and increase the fiber content of the product [27].
Based on previous studies, analog rice was further developed into instant analog rice made from edamame flour and seaweed flour, which is considered beneficial for individuals with T2DM. However, studies investigating the starch and amylose contents, which play important roles in glucose metabolism, are still limited. Therefore, this study aimed to analyze the starch and amylose contents of the instant analog rice product.

2 Methods

2.1 Tools and Materials

The primary raw materials used for the production of instant analog rice consisted of edamame flour (Glycine max (L.) Merrill) purchased from Omah Tepung Organik (Hasil Bumiku brand, Indonesia) and seaweed flour (Eucheuma cottonii) obtained from PT. Kappa Carrageenan Nusantara (Indonesia).
To ensure consistency in our analog rice formulations, we set specific quality standards for the edamame flour (Glycine max (L.) Merrill). We strictly used fine-textured flour that was completely free of any visible impurities. The accepted batches had to show a natural greenish-white color and retain the distinct, fresh aroma typical of edamame soybeans.
Similarly, the seaweed flour (Eucheuma cottonii) had to pass our baseline quality checks before processing. We only utilized batches that were finely milled, purely white, and free from physical contaminants, while still carrying the characteristic, mild scent of marine seaweed.
For the control sample, we used a commercially available instant white rice (CJ Hetbahn Cooked White Rice). To properly represent the standard commercial quality and account for minor manufacturing variations, we intentionally sourced the rice from different production batches. Only packages containing clean, pure white grains with no signs of defect were used for the comparative analysis.
Additional ingredients included food-grade carboxymethyl cellulose (CMC, 0.5%), cornstarch (5%), tapioca flour (5%), pandan leaf extract, and water. The major equipment utilized in the processing included an analytical balance (I-2000 Digital Platform Scale, ±0.01 g precision), a food dehydrator (ST-32, Getra, Indonesia), a manual pasta press maker, a steamer, and a vacuum sealer with vacuum plastic packaging.

2.2 Experimental Design

A completely randomized design (CRD) was employed to evaluate the different formulations of edamame and seaweed flour, adapted from a previous study [18]. The experimental setup comprised three treatments with varying proportions of edamame to seaweed flour on a dry weight basis: P1 (40%:60%, w/w), P2 (50%:50%, w/w), and P3 (60%:40%, w/w). Each formulation, along with a commercial instant rice control (P0), was prepared and analyzed in triplicate, yielding a total of 12 experimental units. The total starch content was determined quantitatively following the acid hydrolysis method according to AOAC 920.44 [28]–[30]. Briefly, the starch in the analog rice samples was hydrolyzed using hydrochloric acid (HCl) to yield reducing sugars, which were subsequently quantified. Meanwhile, the amylose content was evaluated using the iodine-binding spectrophotometric method [31]. The intensity of the resulting blue amylose–iodine complex was measured at a wavelength of 625 nm using a UV–Vis spectrophotometer. A standard curve prepared with pure amylose was used for quantification, and the results for both parameters were expressed as percentages (g/100 g) on a dry weight basis.

3 Results

3.1 Characteristics of Instant Analog Rice

Figure 1 presents the visual appearance of the developed instant analog rice. All three formulations, P1, P2, and P3, formed elongated, grain-like structures resembling conventional rice grains following the manual extrusion process. The grains exhibited yellowish-brown to slightly greenish colors. As the proportion of edamame flour increased from P1 to P3, the dried grains appeared progressively more compact.

(a) (b) (c)

Fig. 1. Visual appearance of the formulated instant analog rice: (a) P1 (40% edamame flour and 60% seaweed flour, w/w), (b) P2 (50% edamame flour and 50% seaweed flour, w/w), and (c) P3 (60% edamame flour and 40% seaweed flour, w/w)

The physical characteristics of the three instant analog rice formulations varied according to the proportions of edamame and seaweed flour. Increasing the proportion of edamame flour resulted in a darker color, softer and stickier texture, more dominant edamame aroma, and stronger edamame taste. In contrast, increasing the proportion of seaweed flour produced a firmer and less sticky texture, accompanied by more dominant characteristic seaweed aroma and flavor.

3.2 Starch and Amylose Contents

The total starch content differed significantly among the formulations ($p < 0.05$). The starch content of the instant analog rice formulations ranged from 14.84 to 19.76 g/100 g. P1, containing 40% edamame flour and 60% seaweed flour, had the highest starch content among the analog rice formulations at 19.76 g/100 g. Meanwhile, P3, containing 60% edamame flour and 40% seaweed flour, had the lowest starch content at 14.84 g/100 g.

The commercial instant rice control, P0, had a starch content of 30.19 g/100 g. The starch contents of P1, P2, and P3 were 19.76, 16.27, and 14.84 g/100 g, respectively. Thus, all three instant analog rice formulations had lower starch contents than the commercial control.

The amylose content of the instant analog rice formulations ranged from 2.16% to 2.40%. P2 had the highest median amylose content at 2.40%, followed by P1 at 2.36% and P3 at 2.16%. The Kruskal–Wallis analysis indicated no significant differences in amylose content among the three modified edamame–seaweed formulations ($p > 0.05$). The commercial control, P0, had an amylose content of 7.06 g/100 g. In comparison, P1, P2, and P3 contained 2.36, 2.40, and 2.16 g/100 g of amylose, respectively. Therefore, the amylose contents of the instant analog rice formulations were approximately three times lower than that of the commercial control.

Table 1. Starch and Amylose Content in Instant Analog Rice

Formulation	Starch Content (Mean ± SD) (%) $p = 0.000$	Amylose Content Median (Min-Max) (%) $p = 0.047$
P0	30.19 ± 0.23^{c}	$7.06\ (6.98\text{-}7.09)^{b}$
P1	19.76 ± 2.36^{b}	$2.36\ (2.34\text{-}2.39)^{a}$
P2	16.27 ± 0.93^{a}	$2.40\ (2.37\text{-}2.42)^{a}$
P3	14.84 ± 1.22^{a}	$2.16\ (2.12\text{-}2.40)^{a}$

Notes:
Starch content data are presented as mean ± standard deviation and were analyzed using One-Way ANOVA followed by the Post-hoc LSD test.
Amylose content data are presented as median (min;max) and were analyzed using the Kruskal–Wallis test.
P0 = Commercial instant rice (control).
P1 = 40% edamame flour + 60% seaweed flour.
P2 = 50% edamame flour + 50% seaweed flour.
P3 = 60% edamame flour + 40% seaweed flour.

Different superscript letters within the same column indicate significant differences among formulations ($p < 0.05$) based on the Post-hoc LSD test for starch content and pairwise Mann–Whitney U tests for amylose content.

3.3 Correlation between Starch and Amylose Contents

Spearman's rank correlation analysis showed no statistically significant correlation between the total starch and amylose contents of the edamame–seaweed instant analog rice ($r = 0.000$, $p = 1.000$). Therefore, variations in total starch content were not accompanied by proportional variations in the measurable amylose content of the formulations.

3.4 Selection of the Best Formulation and Comparison with the Commercial Control

The optimal formulation was determined using the Multiple Attribute Zeleny Method based on the evaluated carbohydrate characteristics. The calculation showed that P3, containing 60% edamame flour and 40% seaweed flour, obtained the highest overall score, followed by P2 and P1. Therefore, P3 was selected as the best instant analog rice formulation for further comparison with the commercial instant rice control, P0.
The independent t-test showed significant differences in total starch and amylose contents between P0 and P3 ($p < 0.05$). The commercial control contained 30.07 g/100 g of starch and 7.06 g/100 g of amylose. In contrast, P3 contained 14.84 g/100 g of starch and 2.16 g/100 g of amylose.

3.5 Nutritional Characteristics of the Selected Formulation

The P3 formulation, consisting of 60% edamame flour and 40% seaweed flour, had the lowest starch content at 14.84 g/100 g. A 50 g serving of P3 provides approximately 173.46 kcal, 41.85 g of carbohydrates, 1.38 g of protein, 0.11 g of fat, 7.42 g of starch, and 1.08 g of amylose.

4 Discussion

4.1 Physical Characteristics of Instant Analog Rice

All formulations successfully formed elongated, grain-like structures resembling conventional rice because of the manual extrusion process. The yellowish-brown to slightly greenish color of the grains was derived naturally from the combination of the two principal raw materials, particularly the green chlorophyll in edamame and the natural matrix of seaweed.
The increasingly compact appearance observed from P1 to P3 may be associated with the higher proportion of edamame flour. The greater protein and starch density contributed by edamame may have produced a denser dough matrix after extrusion and drying.

Differences in the sensory and physical characteristics of the formulations also reflected the proportions of the two ingredients. A higher proportion of edamame flour produced a darker, softer, and stickier product with more dominant edamame aroma and taste. Conversely, a higher proportion of seaweed flour resulted in a firmer and less sticky product with more pronounced seaweed aroma and flavor.

4.2 Starch Content

The variation in starch content among the instant analog rice formulations may be attributed to the different nutritional compositions of edamame and seaweed. Although a previous study [18] reported that increasing the proportion of seaweed could increase total carbohydrate content, total carbohydrates should be distinguished from digestible starch. Seaweed predominantly contains indigestible dietary fibers, such as carrageenan, rather than glycemic starch. Consequently, the incorporation of edamame and seaweed flour reduced or diluted the overall starch concentration of the analog rice compared with conventional commercial rice.

The differences between P0 and the instant analog rice formulations were also influenced by the composition of their respective raw materials. P1, P2, and P3 were formulated using edamame and seaweed flour, whereas conventional rice contains a relatively high starch content of approximately 80–85%, equivalent to 80–85 g per 100 g of rice. Accordingly, the starch contents of P1, P2, and P3 were approximately two times lower than that of P0.

From clinical and nutritional perspectives, starch content is an important determinant of the postprandial glycemic response. Starch can be rapidly hydrolyzed into absorbable glucose monomers, making foods with high starch contents important contributors to postprandial blood glucose elevations [12], [32]. Therefore, the significantly lower starch contents of the edamame–seaweed formulations may represent a functional advantage. By reducing the amount of readily digestible starch, instant analog rice may limit rapid glucose absorption and potentially serve as a lower-glycemic staple food alternative for the dietary management of type 2 diabetes mellitus (T2DM).

Nevertheless, the present study did not directly measure glycemic index, resistant starch, or starch digestibility. Therefore, the potential glycemic benefits of the product should be confirmed through further laboratory and clinical evaluations.

4.3 Amylose Contents

The absence of significant differences in amylose content among P1, P2, and P3 may be related to the baseline amylose characteristics of the raw materials. Edamame contributes approximately 19–22% amylose [22], whereas seaweed flour contains negligible amounts of amylose and primarily functions as a fibrous bulking material [33].

The relatively low measurable amylose content in the final products may also be associated with thermal processing and interactions within the food matrix. During hydrothermal treatment, including steaming and dehydration, amylose may interact with proteins and lipids derived from edamame to form inclusion complexes. In addition, dietary fiber from seaweed may entrap starch granules or coat their surfaces.

These interactions may restrict amylose leaching and reduce its availability to bind with iodine during spectrophotometric analysis, resulting in a lower apparent amylose measurement [10], [34]. Thus, the measured amylose content may not represent the entire amylose fraction originally present in the ingredients.
As with starch content, the difference in amylose content between P0 and the analog rice formulations was influenced by the different raw materials used. The amylose contents of P1, P2, and P3 were approximately three times lower than that of the commercial control.
Conventionally, a high amylose-to-amylopectin ratio is considered beneficial for diabetic diets because amylose is more resistant to rapid enzymatic digestion [35]. Although the instant analog rice formulations had relatively low amylose contents, their potential role in T2DM management may be supported by a different mechanism. In this product, glycemic control may be influenced more strongly by the substantial reduction in total starch and the presence of indigestible dietary fiber from seaweed than by a high amylose proportion.
The fibrous seaweed matrix may delay gastric emptying and impede glucose absorption, thereby partially compensating for the low amylose content. However, these mechanisms were not directly examined in the present study and should therefore be interpreted as potential explanations rather than confirmed physiological effects.

4.4 Correlation Between Starch and Amylose Contents

In isolated native starches, amylose content would theoretically be expected to correlate proportionally with total starch content. However, this relationship was not observed in the present study, as indicated by the absence of a significant correlation between total starch and measurable amylose contents.
The lack of correlation may be explained by the complexity of the edamame–seaweed food matrix and the structural modifications occurring during processing. Edamame contributes proteins and lipids, whereas seaweed contributes dense non-starch polysaccharides and dietary fiber. During steaming and drying, starch undergoes gelatinization, allowing free amylose chains to interact with surrounding nutrients.
A proportion of the amylose may form inclusion complexes with proteins and lipids or become physically entrapped within the carrageenan-rich fibrous network. These interactions may restrict amylose accessibility to iodine during analysis independently of the total starch concentration. Therefore, in a formulated functional food such as edamame–seaweed instant analog rice, total starch content may not directly predict the analytically measurable amylose content.

4.5 Selected Formulation and Comparison with Commercial Instant Rice

P3 was selected as the optimal formulation using the Multiple Attribute Zeleny Method because it achieved the highest overall score based on the evaluated carbohydrate characteristics. Compared with commercial instant rice, P3 contained approximately half the amount of starch and substantially less amylose.

These differences were primarily associated with the raw materials used. Conventional rice grains are predominantly composed of starch, which accounts for approximately 80–85% of their dry weight [32]. Replacing white rice with a combination of edamame and seaweed flour substantially reduced the starch content of P3 compared with the commercial control and raw rice grains.

Previous studies have reported that conventional instant white rice may contain amylose levels as high as 39.32% [36]. However, the P3 formulation appears to rely on a different nutritional mechanism. Rather than depending on a high amylose proportion to slow digestion, P3 combines a low total starch content with dietary fiber from the seaweed matrix.

Reducing the amount of readily digestible starch may help limit rapid increases in blood glucose. Therefore, the optimized edamame–seaweed instant analog rice has the potential to be developed as a lower-glycemic staple food alternative for individuals with T2DM [36]. However, this potential requires confirmation through direct evaluation of glycemic response.

4.6 Implications for Nutrition and Health

The nutritional characteristics of P3 indicate its potential as an alternative carbohydrate source for individuals requiring dietary glycemic management. Its lower starch content compared with commercial instant rice may support the development of functional staple foods based on locally available ingredients.

Nevertheless, the relatively low protein content per 50 g serving should also be considered when positioning the product nutritionally. Instant analog rice should be consumed as part of a balanced meal containing adequate protein, vegetables, and other nutrient-dense foods rather than regarded as a complete food source.

Further studies should evaluate the glycemic index, resistant starch content, in vitro starch digestibility, postprandial glucose response, and clinical effectiveness of the formulation in individuals with T2DM.

This study has several limitations. First, starch and amylose contents were not measured directly in the edamame and seaweed flours. Consequently, the specific contribution of each ingredient to the starch and amylose contents of the final product could not be determined.

Second, the commercial instant rice used as the control differed from the analog rice formulations in terms of composition and moisture content. These differences may have influenced the comparison of starch and amylose contents between the control and intervention products.

Third, parameters directly related to glycemic response, including resistant starch, glycemic index, and starch digestibility, were not evaluated. Therefore, although the lower starch content suggests potential nutritional benefits for individuals with T2DM, claims regarding low glycemic response or clinical effectiveness cannot yet be confirmed.

5 Conclusion

This study demonstrates that formulating instant analog rice with edamame and seaweed flour effectively lowers its total starch content, even though the amylose levels remain relatively unchanged. Interestingly, the typical linear relationship between starch and amylose was not observed in our samples, likely due to the complex fiber and protein interactions within the raw materials.

Overall, the P3 formulation (60% edamame flour and 40% seaweed flour) was selected as the best product. While its amylose content is on the lower side (2.16 g/100 g), what makes P3 stand out is its greatly reduced total starch content, which drops to just 14.84 g/100 g. Ultimately, rather than relying on high amylose to slow digestion, this analog rice works by minimizing the amount of easily digestible starch while providing natural dietary fiber. This makes it a very promising and practical staple food alternative for people managing T2DM.

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