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Dietary Fiber Content And Bulk Density In Analog Rice Formulation From Corn Flour With Tofu Dreg Substitution And Carrageenan Addition

Kandungan Serat Pangan Dan Densitas Kamba Pada Formulasi Beras Analog Dari Tepung Jagung Dengan Substitusi Ampas Tahu Dan Penambahan Karagenan

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ABSTRACT

Low dietary fiber intake remains a nutritional concern associated with an increased risk of constipation, colorectal cancer, and obesity. Developing analog rice from local food resources is a promising strategy to improve dietary fiber intake while supporting food diversification. This study aimed to evaluate the effects of tofu dregs flour substitution and carrageenan addition on the dietary fiber content and bulk density of corn-based analog rice and to identify the formulation with the highest dietary fiber content among the tested treatments. A 3×3 factorial randomized block design was applied using the ratio of corn flour to tofu dreg flour (C) (90:10, 80:20, 70:30) and carrageenan addition (K) (2%, 2.5%, and 3%) as the treatment factors. Dietary fiber content was analyzed with the enzymatic-gravimetric method, while bulk density was determined using the volumetric method. The results showed that tofu dregs flour substitution, carrageenan addition, and their interaction significantly affected soluble dietary fiber content (p<0.05), whereas no significant effect was observed on insoluble dietary fiber, total dietary fiber, and bulk density (p>0.05). The highest dietary fiber content (10.03%) was obtained from the formulation C3K3 (70% corn flour: 30% tofu dreg flour with 3% carrageenan), consisting of 2.20% soluble dietary fiber and 7.83% insoluble dietary fiber. Bulk density result ranged from 0.625 to 0.666 g/mL and didn't differ significantly among treatments. C3K3 showed the highest total dietary fiber content among the tested formulations and potential for further development as a high-fiber analog rice product based on local food resources for future food diversification.

Keywords: *analog rice, bulk density, carrageenan, dietary fiber, tofu dreg.*

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ABSTRAK

Rendahnya konsumsi serat pangan masih menjadi salah satu permasalahan gizi yang berkaitan dengan meningkatnya risiko konstipasi, kanker kolorektal, dan obesitas. Pengembangan beras analog berbasis sumber daya lokal menjadi satu upaya untuk meningkatkan asupan serat sekaligus mendukung diversifikasi pangan. Penelitian ini

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bertujuan menganalisis pengaruh substitusi tepung ampas tahu dan penambahan karagenan terhadap kandungan serat pangan dan densitas kamba beras analog berbasis tepung jagung serta menentukan formulasi dengan serat pangan tertinggi. Penelitian menggunakan desain Rancangan Acak Kelompok (RAK) faktorial 3×3 dengan faktor rasio tepung jagung : tepung ampas tahu (90:10, 80:20, 70:30) dan penambahan karagenan (2%, 2,5%, dan 3%). Kandungan serat pangan dianalisis dengan metode enzimatik-gravimetri, sedangkan densitas kamba dianalisis dengan metode volumetrik. Hasil penelitian menunjukkan substitusi tepung ampas tahu, penambahan karagenan, dan interaksi keduanya berpengaruh nyata terhadap kandungan serat larut ($p<0,05$), tetapi tidak berpengaruh terhadap kandungan serat tidak larut, serat total, dan densitas kamba ($p>0,05$). Kandungan serat pangan tertinggi sebesar 10,03% diperoleh pada perlakuan C3K3 (70%: 30% rasio tepung dengan karagenan 3%), yang terdiri atas 2,20% serat larut dan 7,83% serat tidak larut. Densitas kamba berkisar antara 0,625–0,666 g/mL dan tidak berbeda nyata antar perlakuan. C3K3 menunjukkan kandungan total serat pangan tertinggi di antara formulasi yang diuji serta memiliki potensi untuk dikembangkan lebih lanjut sebagai produk beras analog tinggi serat berbasis sumber pangan lokal guna mendukung diversifikasi pangan.

Kata kunci: ampas tahu, beras analog, densitas kamba, karagenan, serat pangan

INTRODUCTION

Low dietary fiber consumption is a nutritional problem in Indonesia, linked to an increased risk of various digestive diseases, such as constipation, obesity, and colorectal cancer. Indonesians consume only around 10–14 g of fiber per day, far below the Recommended Daily Intake (RDI) and the World Health Organization (WHO) recommendation of 25–30 g per day [1]. This situation is further exacerbated by changes in consumer habits, which tend to consume foods high in carbohydrates, high in fat, and low in fiber [2].

Against this background, rice consumption as a staple food in Indonesia remains relatively high, reaching 94.0 kg/capita/year. To reduce dependence on rice, the government promotes food diversification through the utilization of local food ingredients, including corn, as stipulated in Indonesian Minister of Agriculture Regulation Number 15 of 2013 [3,4]. One potential form of diversification is analog rice, a non-rice food product designed to resemble rice grains and formulated using various local food ingredients to enhance its nutritional value (Budijanto & Yuliana, 2015; Noviasari et al., 2017).

Corn was selected as the main raw material because it is a plentiful local food item and has the ability to serve as an alternative carbohydrate source. The functional value of analog rice can be further improved by substituting tofu dregs flour, a by-product of tofu production, with high dietary fiber content, particularly insoluble fiber such as cellulose and hemicellulose [7–9]. In addition to increasing fiber content, utilizing tofu dregs also supports the valorization of an agro-industrial by-product. Meanwhile, carrageenan can function as a hydrocolloid and binding agent due to the capability to bind water, form a gel, and increase the stability and cohesiveness of the dough during the analog rice formation process [10–12]. In addition to improving the product's physical characteristics, carrageenan is also a polysaccharide that contributes to its soluble dietary fiber content.

Previous studies have established the potential of corn, tofu dregs, and carrageenan for food product development, although their functions have generally been investigated separately or in different food matrices. Corn has been widely explored as a local carbohydrate source for analog rice development and as an alternative material to support food diversification [6]. On the other hand, tofu dregs (okara), a by-product of tofu production, have been used as a functional food ingredient because they still contain dietary fiber, protein, and bioactive compounds that have the potential to increase the product's nutritional value [7]. Tofu dregs have also been incorporated into various food products to increase fiber content and functional value such as cookies and cakes, and have been reported to improve nutritional and fiber related characteristics [NO_PRINTED_FORM] [13][NO_PRINTED_FORM] [14]. Furthermore, recent research has shown that processing tofu dregs into flour can improve its physicochemical characteristics and functional properties, thus making it a potential raw material for value-added foods [9,15].

Despite these established functions, the scientific evidence regarding the combined use of corn flour, tofu dregs flour, and carrageenan in analog rice remains limited. In particular, previous studies have not sufficiently clarified how tofu dregs flour, as a source of dietary fiber, and carrageenan, as a hydrocolloid and potential contributor to soluble dietary fiber, interact within a corn-based analog-rice matrix. It is also unclear whether changes in dietary fiber content resulting from this combination are accompanied by changes in bulk density, an important physical characteristic related to product handling, packaging, and storage. Therefore, the specific scientific gap addressed in this study is the lack of evidence on the individual and interactive effects of tofu dregs flour substitution and carrageenan addition on the dietary fiber profile and bulk density of corn-based analog rice.

Therefore, this study was conducted to examine the effects of tofu dregs flour substitution and carrageenan addition on the soluble, insoluble, and total dietary fiber content and bulk density of corn-based analog rice, as well as to identify the formulation with the most favorable dietary fiber content and bulk density among the tested treatments, with potential for further development as a high fiber food product based on local food resources. The factorial formulation allows the independent effects of tofu dregs flour substitution and carrageenan addition, as well as their interaction, to be evaluated. This approach provides new evidence on the potential of combining a fiber-rich agro-industrial by-product with a hydrocolloid to enhance the dietary fiber content of analog rice while maintaining its bulk density.

METODE

Research Type

This study using a quantitative research with experimenta methods. It began with the production of tofu dregs flour around a week. The next stage was the production of analog rice and laboratory testing.

Research Time and Place

The entire research process was conducted from february to april 2026. The bulk density test was conducted in the Nutrient Analysis Laboraroty of the undergraduated nutrition study program, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya. Meanwhile, the dietary fiber test was conducted in the Jember State Polytechnic Food Analysis Laboratory.

Research Design

This study was performed by using a randomized block design (RBD) method with 2 factors namely proportion of corn flour with tofu dreg flour formulation (C) and carrageenan addition (K). The experimental design for the study is shown in Table 1. The factorial design was selected to distinguish the independent effects of tofu dregs subtitution and carrageenan addition from their interaction, which has not been adequately characterized in corn-based analog rice. This design was used to evaluate the effect of each factor and their interaction on the dietary fiber content and bulk density of analog rice.

Table 1. Experimental Design for Corn Analog Rice with Tofu Dregs Subtitute

Treatments (C)	**Carrageenan (K)**		
Corn Flour / Tofu Dregs Flour	**K1 (2%)**	**K2 (2,5%)**	**K3 (3%)**
C1 (90:10%)	C1K1	C1K2	C1K3
C2 (80:20%)	C2K1	C2K2	C2K3
C3 (70:30%)	C3K1	C3K2	C3K3

The two factors were combined into nine treatments, each repeated three times, resulting in 27 experimental units. All treatments were replicated thrice based on Federer formula (1).

$(r-1)(t-1) \geq 15$ *(1)* $(r-1)(9-1) \geq 15$ $(r-1)(8) \geq 15$ $r-1 \geq \frac{15}{8}$ $r-1 \geq 1.875 + 1$ $r \geq 2{,}875$ $\mathbf{r \geq 3}$	$\boldsymbol{n = t \times r}$ $n = 9 \times \mathbf{3}$ $n = 27$	Note: r = total replication t = total treatment combination 15 = minimum statistic border n = total sample

Procedur

Method of Production of Tofu Dreg Flour

The ingredients for making tofu dreg flour were fresh tofu dreg and yeast (fermipan) for fermentation. Based on [NO_PRINTED_FORM] [16] research with modification on fermentation process, fresh tofu dreg was squeezed out until dry but still moist. Then steam at 100°C for 15-20 minutes after that let it dry and cool it down; next, add yeast to the tofu dreg at rate of 1 gram/kg weight and mixed until evenly distributed then place it on a room temperature or incubator for at least 6 hours fermentation. Fermentation of this tofu dregs is carried out to enhance nutritional value and reduce the unpleasant odor produced by the tofu dregs (Shi et al., 2020). After fermentation, the tofu dregs are dried in the oven at 70°C for 7 hours. Once the tofu dregs completely dried, grind and sieve it with 80-mesh sieve. The flour that has been produced is stored in an airtight container so that it can be used in the analog rice formulation process.

Dried tofu dregs are known to consist largely of dietary fiber, particularly insoluble fiber components such as monosaccharides—specifically arabinose (1.52–6.64%), glucose (7.95–14.86%), galactose (4.35–10.43%), xylose (0.41–10.72%), and uronic acid (3.1–7.73%) (Privatti & Rodrigues, 2023). Regarding polysaccharides, tofu dregs possess a favorable dietary fiber profile, with insoluble fiber—primarily cellulose—making up the major proportion, ranging from 13.43–76.38% and 56.6–58.6%. [NO_PRINTED_FORM] [8] found that the insoluble fiber content in dried tofu dregs (40.4–50.8%) was higher than the soluble fiber content (1.3–14.6%). The high dietary fiber content in dried tofu dregs offers potential for preventing various health issues, as dietary fiber is a functional compound that plays a role in the physiological functions of the human body.

Method of Production of Analog Rice

n the present study, analog rice was produced using a non-extrusion process involving pre-gelatinization, steaming, manual molding using a noodle-making tool, and drying. Based on [NO_PRINTED_FORM] [18] research, the production of analog rice begins with mixing dry ingredients, including corn flour, tofu dregs flour (proportions according to treatment), and carrageenan (according to treatment). The mixed ingredients are then added with water (T = 50°C) 60% of the weight of the ingredients and stirred until smooth. The ingredients are then roasted for 15 minutes. After roasting, water is added as much as 80% of the weight of the ingredients. Next, the dough is steamed for 15 minutes, stirring every 5 minutes. While hot, the dough is then molded into a plate shape using a noodle/pasta molding tool with a thickness of ± 3 mm each. After being molded, the plate is then sliced small and molded into a grain shape resembling rice. Then dried the product using a dryer oven at a temperature of 70°C for 7 hours.

Dietary Fiber Analysis

Dietary fiber content was analyzed in the laboratory using the AOAC (1995) enzymatic-gravimetric method, which includes measuring soluble, insoluble, and total dietary fiber. The results were expressed as a percentage (%), then used to evaluate the effect of tofu dregs flour substitution and carrageenan addition on rising the dietary fiber content of analog rice.

Bulk Density Analysis

The bulk density of rice is calculated based on the ratio of the sample's weight to the volume it occupies and is expressed in g/mL. The sample is placed in a measuring cylinder, while being tapped on a flat surface 3 to 5 times until it reaches a volume of 100 mL. Then the sample is weighed and the density of rice is calculated by dividing the weight and volume (2). Measurements are carried out to determine the density level of analog rice as one of the physical quality parameters related to the characteristics of storage, packaging, and product handling.

$$(2)\ \textbf{Bulk Density (g/mL)} = \frac{\textbf{sample weight (g)}}{\textbf{volume (mL)}}$$

Data Analysis

This study was designed as a randomized block design (RBD). All treatments were replicated thrice, resulting in 27 experimental units. The data were analyzed using univariate analysis and Two Way ANOVA at a 95% confidence level to determine the effect of tofu dregs flour substitution, carrageenan addition, and the interaction of the two factors. If the differences between parameters were significant, a Duncan Multiple Range Test (DMRT) was conducted at the 5% significant level to determine differences between treatments. All statistical analyses were performed using SPSS software

RESULT

Dietary Fiber Content of Analog Rice

The results indicated that the substitution of tofu dregs flour (C) and the addition of carrageenan (K) significantly affected the content of soluble fiber, insoluble fiber, and total dietary fiber ($p<0.05$). The interaction of the two factors only significantly affected soluble fiber ($p<0.05$), while no significant interaction was found for insoluble fiber and total dietary fiber ($p>0.05$). Therefore, the discussion of soluble fiber refers to the results of the treatment interaction (Table 2), while the discussion of insoluble fiber and total dietary fiber refers to the influence of the main factors of tofu dregs flour substitution and carrageenan addition (Table 3).

Table 1. Average Results of Dietary Fiber Content Test of Analog Rice

Treatments	Soluble Fiber (%)	Insoluble Fiber (%)	Total Dietary Fiber (%)
C1K1	0,650 ± 0,017	2,467 ± 0,011	3,110 ± 0,026
C1K2	0,937 ± 0,015	3,400 ± 0,355	4,120 ± 0,020
C1K3	1,023 ± 0,015	3,313 ± 0,011	4,333 ± 0,025
C2K1	1,263 ± 0,015	4,693 ± 0,005	5,950 ± 0,026
C2K2	1,513 ± 0,011	5,510 ± 0,000	7,023 ± 0,011
C2K3	1,623 ± 0,030	5,610 ± 0,017	7,233 ± 0,015
C3K1	1,867 ± 0,005	6,883 ± 0,025	8,743 ± 0,025
C3K2	2,030 ± 0,017	7,730 ± 0,030	9,760 ± 0,045
C3K3	2.203 ± 0,146	7,833 ± 0,015	10,030 ± 0,010

Soluble Fiber

Table 2. Duncan's Multiple Test Results: The Effect of Tofu Dregs Flour*Carrageenan Substitution Interaction on the Fiber Content of Analog Corn Rice

Treatments	Soluble Fiber (%)
C1K1	0,650 ± 0,017 [a]
C1K2	0,937 ± 0,015 [b]
C1K3	1,023 ± 0,015 [c]
C2K1	1,263 ± 0,015 [d]
C2K2	1,513 ± 0,011 [e]
C2K3	1,623 ± 0,030 [f]
C3K1	1,867 ± 0,005 [g]

Treatments	Soluble Fiber (%)
C3K2	2,030 ± 0,017 [h]
C3K3	2.203 ± 0,146 [i]

Insoluble Fiber

Table 3. Results of Further Tests on The Effect of Fiber on the Substitution of Tofu Dregs and Carrageenan

Treatments	Tofu Dregs Flour Substitution			Carrageenan		
	C1 (90:10)	C2 (80:20)	C3 (70:30)	K1 (2%)	K2 (2,5%)	K3 (3%)
Soluble Fiber	0,870[c]	1,466[b]	2,033[a]	1,260[c]	1,493[b]	1,616[a]
Insoluble Fiber	3,060[c]	5,271[b]	7,482[a]	4,681[b]	5,546[a]	5,585[a]
Total Dietary Fiber	3,854[c]	6,735[b]	9,511[a]	5,934[c]	6,967[b]	7,198[a]

Bulk Density

Bulk density is the ratio of a food's weight to its volume and is an important physical parameter related to the packaging, storage, and transportation of food products. Test results showed that the bulk density of analog rice ranged from 0.625±0.009 g/mL to 0.666±0.012 g/mL (Table 4).

Table 4. Average Value of Analog Rice Bulk Density

Treatments	Bulk Density (g/mL)
C1K1	0,625 ± 0,009
C1K2	0,639 ± 0,015
C1K3	0,646 ± 0,005
C2K1	0,649 ± 0,027
C2K2	0,666 ± 0,012
C2K3	0,649 ± 0,031
C3K1	0,660 ± 0,009
C3K2	0,631 ± 0,006
C3K3	0,652 ± 0,029

DISCUSSION

Dietary Fiber Content of Analog Rice

The results indicated that the substitution of tofu dregs flour (C) and the addition of carrageenan (K) significantly affected the content of soluble fiber, insoluble fiber, and total dietary fiber ($p<0.05$). The interaction of the two factors only significantly affected soluble fiber ($p<0.05$), while no significant interaction was found for insoluble fiber and total dietary fiber ($p>0.05$). Therefore, the discussion of soluble fiber refers to the results of the treatment interaction (Table 2), while the discussion of insoluble fiber and total dietary fiber refers to the influence of the main factors of tofu dregs flour substitution and carrageenan addition (Table 3).

Soluble Fiber

Duncan's multiple range test (table 2) showed that all treatment combinations significantly differed in soluble fiber content. The C3K3 combination produced the highest soluble fiber content (2.203%), while the C1K1 combination produced the lowest soluble fiber content (0.650%). The higher the proportion of tofu dregs flour and the concentration of carrageenan added, the higher the resulting soluble fiber content. This indicates that tofu dregs flour substitution and carrageenan addition interact in enhancing the soluble dietary fiber content of analog rice.

Soluble fiber is a fraction of dietary fiber that can bind water and form a gel in the digestive tract, thus playing a role in slowing gastric emptying, slowing glucose absorption, and binding bile acids, which contribute to lowering cholesterol levels [19]. The increase of soluble fiber content in this study, was primarily due to the increased proportion of tofu dregs flour, which still contains soluble fiber by 1.3–14.6%, depending on the soybean variety and processing method [8]. Furthermore, carrageenan is a sulfated polysaccharide classified as a soluble dietary fiber, so its addition also increases the soluble fiber content of analog rice (Prihastuti & Abdassah, 2019).

The significant interaction between tofu dregs flour and carrageenan indicates that the gel matrix formed by carrageenan is able to interact with the soluble fiber components of tofu dregs, thereby increasing the measured soluble fiber fraction. This finding is supported by [NO_PRINTED_FORM] [20] who reported that carrageenan can form a protective layer that maintains the stability of bioactive components during processing. [NO_PRINTED_FORM] [9] reported that the use of tofu dregs as a functional food ingredient can increase fiber content and improve the nutritional characteristics of the product, thus offering potential for development in various cereal-based products.

Insoluble Fiber

Substitution of tofu dregs flour and addition of carrageenan had a significant effect on the amount of insoluble fiber, while the two factors combined, it didn't show a significant effect ($p>0.05$) (table 3). This shows that the increase in insoluble fiber content was influenced independently by each treatment factor.

The more proportion of tofu dregs flour used, the more insoluble fiber content is in the analog rice. This is because tofu dregs are the main source of insoluble fiber which is composed of cellulose, hemicellulose and lignin. [NO_PRINTED_FORM] [7] reported that the insoluble fiber content in tofu dregs reached 40.4–50.8%, much higher than the soluble fiber content. Therefore, increasing the substitution of tofu dregs flour directly increases the insoluble fiber content of the product.

The addition of carrageenan also increases the insoluble fiber content, although the effect is smaller than that of tofu dregs flour. This is thought to be because carrageenan acts more as a soluble dietary fiber than as a contributor to the insoluble fiber fraction. These results are in line with [NO_PRINTED_FORM] [15] who reported that okara flour has physicochemical characteristics that supports its use as high-fiber food raw material and can improve the nutritional value of food products.

Total Dietary Fiber

Total dietary fiber is a combination of insoluble and soluble fiber fractions that cannot be digested by human digestive enzymes but provide various physiological health benefits. The results showed that the substituition of tofu dregs flour and the addition of carrageenan significantly affected total dietary fiber content, while the interaction of the two factors was not significant. Thus, the increase in total dietary fiber content was influenced by the independent contribution of each factor.

The increase in dietary fiber content was primarily influenced by the high fiber content of tofu dregs flour. Tofu dregs is a residue from soybean processing that still contains cell wall components, such as cellulose, hemicellulose, and some lignin, making it potentially useful as a source of dietary fiber in various processed products [7–9]. The higher the proportion of tofu dregs flour used, the greater the contribution of the fiber fraction to the final composition of analog rice.

In addition to the substitution of tofu dregs flour, the increase in fiber content was also influenced by the addition of carrageenan. Carrageenan is a sulfated polysaccharide extracted from red seaweed and belongs to the hydrocolloid group that functions as a source of soluble dietary fiber. In analog rice formulations, carrageenan not only acts as a binding agent that increases dough cohesiveness but also contributes to increasing the soluble dietary fiber fraction in the final product [10,12].

The significant interaction between tofu dregs flour substitution and carrageenan addition indicates that the increase in dietary fiber content is influenced by the combination of the two ingredients. Tofu dregs flour contributes as the primary source of insoluble fiber, while carrageenan contributes the soluble fiber fraction and helps form a more stable dough matrix during the molding and drying processes. The formulation with a proportion of 30% tofu dregs flour and 3% carrageenan produced the highest total dietary fiber content at 10.03%, representing an increase compared to the corn-based analog rice study reported by [NO_PRINTED_FORM] [6], which did not utilize tofu dregs flour as a fiber source. Conversely, the results of this study align with those of [NO_PRINTED_FORM] [14] which showed that adding tofu dregs to food products can increase fiber content and improve the nutritional quality of the product. Differences in fiber content between studies may be influenced by the type of raw material, the proportion of substitutions, and the formulation and processing methods used.

Based on the Indonesian Food and Drug Authority (BPOM) regulations regarding nutritional claims, food can be categorized as a source of fiber if it contains at least 3g fiber/100 g of product and is categorized as high in fiber if it contains at least 6g of fiber/100 g of product. This study showed that all formulations past the requirements for being a source of fiber, while formulations with a dietary fiber content of ≥6% past the requirements for being a high-fiber food. Increasing the dietary fiber content in analog rice has the potential to provide physiological benefits, including helping improve digestive health, slowing glucose absorption, increasing satiety, and reducing the risk of metabolic diseases [1,21,22]. These findings indicate that the selected formulations not only fulfill the regulatory criteria for high-fiber claims but also demonstrate promising potential for commercialization as functional food products based on locally available ingredients. Further evaluation of sensory acceptability and consumer acceptance is needed to determine the product's suitability for broader application.

These research results support the use of tofu dregs as a raw material for value-added foods and as an alternative source of dietary fiber based on local ingredients. In addition to increasing dietary fiber content, the use of tofu dregs also supports efforts to reduce agro-industrial waste through the development of high fiber food products. Thus, analog rice based on corn flour substituted with tofu dregs flour and added with carrageenan potentially developed as a high-fiber food to support food diversification based on local resources.

Interestingly, increasing the dietary fiber content did not significantly alter the bulk density of analog rice, indicating that nutritional improvement could be achieved without compromising the product's physical characteristics related to packaging, storage, and handling. This finding demonstrates that the incorporation of tofu dregs flour and carrageenan can enhance the functional value of analog rice while maintaining its physical quality, making it a promising alternative for local food diversification.

Bulk Density

Bulk density is the ratio of a food's weight to its volume and is an important physical parameter related to the packaging, storage, and transportation of food products. A high bulk density indicates fewer interparticle voids, resulting in a denser product structure [23–25].

Test results showed that the bulk density of analog rice ranged from 0.625±0.009 g/mL to 0.666±0.012 g/mL (Table 4). This value is higher than the 0.39 g/mL of analog rice based on corn flour with added κ-carrageenan reported by [NO_PRINTED_FORM] [26] and is within the range of the research results of [NO_PRINTED_FORM] [27] on analog rice based on cassava flour enriched with shrimp protein, namely 0.57–0.73 g/cm³. However, this value is still lower than the bulk density of paddy rice, which is around 0.83–0.88 g/mL.

The results showed that tofu dregs flour substitution, carrageenan addition, and the relation between the two factors had no significant effect on bulk density ($p>0.05$). This indicates that varying the proportions of tofu dregs flour and carrageenan in this study was unable to significantly change the bulk density characteristics of analog rice. Although the increase in tofu dregs flour tended to increase bulk density, the effect was not statistically significant because the starch matrix formed during steaming and drying was still dominated by corn starch gelatinization. In addition, the relatively low concentration of carrageenan (2–3%) was likely insufficient to substantially modify particle packing and internal structure, resulting in comparable bulk density values among treatments.

The lack of a significant effect is likely due to the relatively narrow range of substitution treatments, meaning that changes in ingredient composition were not sufficient to produce differences in physical structure between treatments. [NO_PRINTED_FORM] [28] reported that variations in composite flour composition can affect the physical properties of the product, including bulk density, if the compositional differences between treatments are significant.

In addition to ingredient composition, the processing process is also suspected to be a more dominant factor influencing rice bulk density. In this study, the molding process was carried out manually under the same processing conditions for all treatments, ensuring relatively uniform temperature, pressure, dough moisture content, and molding conditions.[NO_PRINTED_FORM] [29] stated that extrusion temperature, dough moisture content, and amylose content are the main factors determining the physical quality of analog rice, including rice bulk density and grain shape. During the heating process, starch granules undergo gelatinization, forming a more compact matrix, reducing the effects of small changes in raw material composition.

Although not statistically significant, the rice bulk density value tended to increase with increasing proportion of tofu dregs flour. This increase is suspected to be related to the increased fiber content in the formulation. [NO_PRINTED_FORM] [30] stated that increasing fiber content can increase particle density, reducing the void space between particles. During the heating process, starch granules expand and fill the voids between particles, resulting in a denser product structure[31].

In extruded analog rice products, the density is related to the porosity of the material. The higher the density, the fewer voids formed within the product [32]. Conversely, high porosity is generally influenced by the characteristics of the raw materials and the processing process, including the drying process, which reduces water content and creates voids in the product matrix (Sumardiono et al., 2021).

Overall, the results of the study indicate that increasing fiber content through the substitution of tofu dregs flour and the addition of carrageenan did not significantly change the density of the rice analogue. These findings indicate that the developed formulation can increase nutritional value without compromising the product's physical characteristics related to storage and handling.

CONCLUSSION

The substitution of tofu dregs flour and the addition of carrageenan significantly affected the dietary fiber content of cornstarch-based analog rice, while neither significantly affected the bulk density. Increasing the proportion of tofu dregs flour and carrageenan concentration increased the fiber content. Among the tested formulations, C3K3 (70% corn flour:30% tofu dregs flour with 3% carrageenan) produced the highest total dietary fiber content (10.03%), consisting of 2.20% soluble fiber and 7.83% insoluble fiber. The bulk density values for all formulations ranged from 0.625–0.666 g/mL and showed no significant differences between treatments.

The results of this study indicate that the use of tofu dregs flour as a fiber source and carrageenan as a binding agent can enhanced the functional value of cornstarch-based analog rice without affecting the bulk density, thus potentially developing it as a high-fiber food based on local food ingredients to support food diversification.

RECOMENDATION

Further research is recommended to evaluate the characteristics of analog rice more comprehensively, including sensory acceptability, starch digestibility, glycemic index, shelf life, and consumer acceptance to support product development and application on an industrial scale.

CONFLICT OF INTERESTS

The author of this article has no conflict of interest.

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