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Special Topic

A comparative study on the nutritional value of analog rice derived from modified cassava flour and banana flour

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Abstract This study compared the nutritional value of two analog rice made from modified cassava flour (MOCAF) and different banana flour. Two analog rice types, TD (MOCAF with *tanduk* banana flour) and KP (MOCAF with *kepok* banana flour), were examined in this study. We found that TD had more moisture, fiber, and carbohydrate but less ash and fat content than KP. TD has a slightly better water holding capacity (WHC) at 5.60 g/g than KP at 5.42 g/g. TD exhibited larger quantities of xylose, fructose, glucose, and pyruvic acid, whereas KP contained more maltose and sucrose. TD had higher quantities of myristic, palmitoleic, and linoleic acid compared to KP, which had higher levels of palmitic, arachidic, stearic, oleic, and α-linolenic acid. KP included more lysine, leucine, phenylalanine, histidine, methionine, and tyrosine, but TD contained more valine, isoleucine, threonine, arginine, proline, aspartic acid, glutamic acid, serine, glycine, and alanine. KP included more phytochemicals and vitamins, including phenols, flavonoids, alkaloids, tannins, saponins, ascorbic acid, riboflavin, niacin, beta-carotene, tocopherol, pyridoxine, and pantothenic acid. Therefore, this study provides insights into the nutritional profiles and sensory properties of MOCAF-derived analog rice and banana flour, implying a wide range of uses in food and dietary choices.

Keywords analog rice, modified-cassava flour, banana flour, *kepok*, *tanduk*

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1. Introduction

Rice is a basic food for one-third of the population in the world (Fornasiero et al., 2022), particularly in Asia, where it is a dietary mainstay (Bandumula, 2018; Fukagawa and Ziska, 2019). However, climate change, environmental degradation, and socioeconomic issues can all have an impact on rice production and availability (Mukhopadhyay and Das, 2023). Climate change can cause changes in precipitation patterns and temperature, negatively impacting rice output (Ansari et al., 2021; Saud et al., 2022; Stuecker et al., 2018). Environmental degradation, such as soil erosion and nutrient depletion, can limit the production of rice fields (Jin et al., 2022; Tan et al., 2005). Furthermore, socioeconomic difficulties, such as poverty, inadequate infrastructure, and political instability, might affect rice production and availability (Abdou-Raouf et al., 2021; Hidayati et al., 2019). To solve these difficulties, there is a need for innovation in the food sector, especially in the production of alternative grains and creative food formulations that can supplement or replace rice as a key source of carbohydrates. Analog rice is a viable alternative that is produced from non-rice sources and has been reported to have more nutritional content than ordinary or traditional rice (Nateghi et al., 2021).

Analog rice, a rice substitute made from non-rice materials, has received attention as a potential replacement for ordinary rice (Damat et al., 2021). One possible strategy is to employ modified cassava flour (MOCAF) and banana flour as the primary ingredients in analog rice production. Cassava (*Manihot uttilisima*) is a commonly farmed crop in many tropical and subtropical countries, and its flour can be changed to increase its functional features, such as gelatinization and viscosity, using various processing processes (Silva et al., 2021). On the other hand, banana flour is rich in carbohydrates, dietary fiber, and other critical elements, making it a promising ingredient for food applications (Campuzano et al., 2018). Bananas (*Musa* spp.) are one of the most popular fruits in the world, and there are many different cultivars with diverse nutritional contents (Hapsari and Lestari, 2016). In this study, two banana cultivars, (*Musa paradisiaca* var. Corniculata) referred to as "*tanduk*" (TD), and (*Musa paradisiaca* Forma Typiaca) referred to as "*kepok*" (KP), were selected for comparing the nutritional content of analog rice made from MOCAF and banana flour. TD and KP bananas are generally accessible in tropical locations and have distinct flavors, textures, and aromas (Kumalasari et al., 2021). Comparing the nutritional value of analog rice derived from these two banana cultivars can provide useful information for the development of high-quality analog rice products.

Previous research on analog rice has typically focused on macronutrient content without delving into the detailed analysis of micronutrients, amino acids, fatty acids, and phytochemicals that are crucial for understanding the full nutritional potential of these products. This study addresses this gap by offering a comprehensive evaluation of the nutritional properties of analog rice made from MOCAF combined with two different banana cultivars. The detailed comparison of these two analog rice types is novel, as it provides insights into both the macro and micronutrient profiles, as well as the bioactive components that have not been previously explored in this context. Moreover, while banana flour has been used in various food products, its application in the formulation of MOCAF-based analog rice, especially using different banana cultivars, remains underexplored. This study is the first to conduct a comparative analysis of analog rice made with two different banana flours, offering new insights that can contribute to the development of high- quality, nutritionally rich rice alternatives. By identifying the distinct nutritional profiles associated with each type of analog rice, this research not only fills a significant gap in the literature but also provides valuable information that could be used to guide dietary choices and the formulation of personalized nutrition strategies. The uniqueness of this study lies in its holistic approach to assessing both the physical and biochemical properties of MOCAF-based analog rice.

The objectives of this study are to thoroughly quantify and compare the nutritional properties of two types of analog rice made from MOCAF combined with different banana cultivars. This includes a detailed analysis of macro and micronutrients, such as carbohydrates, proteins, fats, vitamins, and minerals, as well as specific bioactive compounds like amino acids, fatty acids, and phytochemicals. By exploring these nutritional aspects, the study seeks to provide a comprehensive understanding of how the combination of MOCAF and different banana flours influences the nutritional value of the resulting analog rice. This could help determine the potential health benefits of these products, particularly in providing essential nutrients and bioactive compounds that may support overall health and well-being.

2. Materials and methods

2.1. Materials

2.1.1. Raw materials

This study used two different banana cultivars, *tanduk* (*Musa paradisiaca* var. Corniculata) and *kepok* (*Musa paradisiaca* Forma Typiaca), to make banana flour. The banana flour was prepared following the method described by (Jenie et al., 2012), without fermentation. Banana flour was made in multiple stages, including peeling, washing/cleaning, cutting/peeling, drying, grinding, and sieving. The peeled bananas were thoroughly washed and cleaned to remove any dirt or impurities. Then, they were cut or peeled into small pieces and dried using an oven. The dried banana pieces were then ground into a fine powder using a flour machine. The resulting banana flour was sieved to obtain a uniform and fine texture.

The MOCAF flour was prepared following the method described by (Kardhinata et al., 2019), with slight modifications. In this research, Bimo-CF® (BB Litbang Pasca Panen Pertanian, Jakarta, Indonesia) was used as the starter organism. MOCAF

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flour was made in several steps, including washing/cleaning the cassava, chipping, soaking in the starter solution, fermentation, drying, grinding, and sieving. The cassava roots were washed and cleaned thoroughly to remove any dirt or impurities. Then, they were chipped into small pieces using a knife or other cutting tools. The chipped cassava was soaked in the starter solution, which contains the modified starter organism (Bimo-CF®) for 12 h. After fermentation, the MOCAF was dried using an oven. Once dried, the MOCAF was ground into a fine powder using a flour machine. The resulting MOCAF flour was sieved to obtain a uniform and fine texture.

2.2. Production of analog rice

The production of analog rice was carried out using hot extrusion technology (Sumardiono et al., 2021). The basic materials for analog rice manufacture were MOCAF flour and banana flour, which are blended homogeneously. The concentration of banana flour used in this research was 10% of the weight of MOCAF flour (Sumardiono et al., 2014). In each formulation, water was added as a fixed component, corresponding to 50% of the total flour dough. Glyceryl monostearate (GMS) was added at a concentration of 2% to improve the texture and firmness of the resulting analog rice, also to ensure consistent dispersion of the ingredients, the MOCAF flour, banana flour, water, and GMS were mixed for 10 min using a dry mixer. Analog rice was then generated using a twin-screw extruder (Berto BEX-DS-2256, Banten, Indonesia). The extruder was set to specific parameters, such as temperature (85°C), screw speed (40 Hz), and blade speed (20 Hz). As the dough runed through the extruder, it was carefully mixed and cooked at high temperatures and pressures, forming a continuous dough flow. The extruded dough then passed through a mold and was cut into the shape of rice grains with blades. Finally, the analog rice grains were dried to a moisture content of less than 15%.

2.3. Physicochemical analysis

The proximate analysis of TD and KP samples included the determination of various nutritional parameters using the described methods (AACC, 2000). Moisture content was determined by method 44-15.02, ash content by method 08-01.01, crude fiber content by method 32-10.01, and fat content by method 30-25.01, all in accordance with the AACC standard. The crude protein was determined using the rapid micro Kjeldahl technique (Concon and Soltess, 1973). Total carbohydrates were determined by subtracting the total composition from the sum of the other components, such as moisture, crude protein, fat, and ash. The soluble, insoluble, and total dietary fiber content was assessed using a food-enzymatic-gravimetric technique (Lee et al., 1992). The lignin, hemicellulose, and cellulose content of TD and KP were determined by thermogravimetric analysis (Díez et al., 2020). Water holding capacity (WHC), oil holding capacity (OHC), swelling power (g of swelled granules/g of dry weight of sample), and solubility (%) of TD and KP were determined by the described method (Ghribi et al., 2015). WHC and OHC were expressed as grams of water or oil per gram of dry weight of samples, respectively. Starch content was determined using the described technique (Hoover and Ratnayake 2001).

2.4. Free sugar content by high-performance liquid chromatography

The free sugar content in the analog rice product was determined using high-performance liquid chromatography (HPLC) according to the described method (Bokov et al., 2020). Standard solutions were prepared using distilled water, and a working sugar mixture solution was prepared by transferring 1 mL of each standard sugar solution to a 10 mL volumetric flask and completing the remaining volume with distilled water. The samples were prepared by dissolving 2.5 g in 25 mL of de-ionized water in a glass beaker. The solution was then filtered through a 0.45 μm nylon filter. The appropriate volume of filtered solution was then transferred to an HPLC vial. HPLC analysis was carried out using a liquid chromatography system and a refractive index detector (LC-RID), and the data was analyzed using OpenLab software. Separation was performed using a 4.6 mm ID × 150 mm (5 μm) ZORBAX Carbohydrate Analysis Column (Agilent, California, USA). The mobile phase consisted of a 20:80 (v/v) mixture consisting of distilled water and acetonitrile. A 10 μL sample was injected at a flow rate of 1.5 mL/min, and the column temperature was maintained at 27°C during the process.

2.5. Fatty acid profile by gas chromatography-mass spectrometry

Gas chromatography-mass spectrometry (GC-MS) was used to analyze the fatty acid composition of TD and KP samples following derivatization with BF3-methanol to help convert non-volatile fatty acids into volatile fatty acid methyl esters (FAMEs) (Fabbri et al., 2005). The GC-MS analysis was performed using a Clarus 500 gas chromatograph (Perkin Elmer, California, USA) equipped with an AOC-20i autosampler, coupled with a mass spectrometer, and fitted with an Elite-5MS (5% diphenyl/95% dimethyl polysiloxane) linked to a capillary column (30 nm × 0.25 mm ID × 0.25 μm film thickness). Chromatographic parameters were optimized based on the described method (Feriyani et al., 2020) with slight modifications in the oven temperature. The oven temperature was adjusted to increase at a rate of 10℃/min up to 200℃ without hold, then followed at a rate of 5℃/min until 280℃ with a 9-min hold.

2.6. Amino acid composition by gas chromatography–mass spectrometry

The amino acid composition was determined by gas chromatography-mass spectrometry (GC-MS) using a previously described method (Badawy et al., 2008). The GC-MS analysis was performed using a Clarus 500 gas chromatograph equipped with an AOC-20i autosampler, coupled with a mass spectrometer, and fitted with an Elite-5MS (5% phenyl-95% methyl polysiloxane) linked to a capillary column (25 nm × 0.20 mm ID × 0.11 μm film thickness). The injector, interface, and ion source temperatures were maintained at 260℃, 300℃, and 230℃, respectively. Helium gas was used as the carrier gas at a constant flow rate of 0.5 mL/min. Samples were injected into the gas chromatograph using the split-injection mode with a split ratio of 10:1. The oven temperature was initially set at 140℃ for 2 min, then increased to 260℃ at a rate of 5℃/min, and finally ramped up to 430℃ at a rate of 30℃/min with 5-min hold.

2.7. Phytochemical analysis by gas chromatography–flame ionization detector

The phytochemical components, such as phenols, flavonoids, alkaloids, tannins, saponins, oxalates, and phytates, were determined using gas chromatography with a flame ionization detector (GC-FID) following the described method (Dambolena et al., 2010). The crushed sample (1 g) was transferred to a test tube, followed by 15 mL of ethanol and 10 mL of 50% (w/v) potassium hydroxide solution. After 60 min of incubation at 60℃, the samples inside the test tube were transferred to a separatory funnel, and the extracted substance was washed with ethanol and hexane to eliminate impurities. The extract was dried using anhydrous sodium sulfate, and the solvent was evaporated. The concentrated extract was dissolved in pyridine, then followed by 20 μL of the solution was transferred into a vial for GC-FID analysis. Quantification of individual components was analyzed using a Perkin-Elmer Clarus 500 gas chromatograph equipped with a flame ionization detector (GC-FID). A capillary column DB-5 (30 m × 0.25 mm ID and 0.25 m coating thickness) was used for the separation of individual components of the components. Helium was employed as the carrier gas with a flow rate of 0.9 mL/min. The temperature was set at 60℃ for 5 min, then set at 5℃/min from 60℃ to 250℃, with 10 min hold. The injector and detector were maintained at 260℃ and 280℃, respectively. The sample (0.2 μL) was injected with a split ratio of 1:100.

2.8. Vitamin content by high-performance liquid chromatography

The determination of vitamin content by high-performance liquid chromatography (HPLC) involved following the described method (Fatin Najwa and Azrina, 2017; Sami et al., 2014). The mixture of 1 g crushed samples, 0.1 g pyrogallic acid, 7 mL ethanol, and 3 mL (50%) KOH was refluxed in a water bath at 50℃ for 40 min. Extracts were collected, neutralized with double-distilled water, and dehydrated using anhydrous sodium sulfate. The extract (5 mL) was prepared by dissolving in 10 mL of methanol using a water bath at 50℃. The solution was then filtered through a 0.45 μm nylon filter. The appropriate volume (20 μL) of filtered solution was then transferred to an HPLC vial. The analysis was performed using a C18 column (4.6 × 250 mm, 5 μm) (Agilent) with a linear gradient of methanol. The mobile phase consisted of 0.023 M phosphoric acid (1:2, pH=3.54). The analysis was carried out at a constant flow rate of 0.5 mL/min.

2.9. Statistical analysis

The data was analyzed statistically using mean±standard deviation (SD) with a sample size of four (n=4). A two-sample t-test was performed to compare the groups using IBM SPSS Software (version 21.0, Chicago, Illinois, USA). The normality of the data was assessed prior to the t-test to ensure the assumptions were met. Differences were considered statistically significant at p-values less than 0.05.

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3. Results and discussion

3.1. Appearance and chemical compositions

The products of TD and KP analog rice have quite similar appearances (Fig. 1). The proximate study of analog rice based on MOCAF and banana flour provides essential knowledge about their nutritional content. In Table 1, moisture content of both TD and KP analog rice was similar, with TD having a slightly lower moisture content (11.34%) than KP (11.71%). These results show that both analog rices have relatively low moisture content, which could be advantageous to their shelf stability (Genkawa et al., 2008). TD analog rice has a lower total protein content of 5.54% compared to KP at 5.93%. This indicates that KP formulation may have a higher protein content, which could be beneficial for individuals seeking higher protein options in their diets. TD analog rice has a lower total fat content of 1.14% compared to KP analog rice at 1.27%. The findings indicate that TD formulation may have a lower fat level, which could be favorable for people who prefer lower-fat options in their diets. Ash content, which represents the mineral content of the analog rices demonstrates some variability between TD and KP formulations. TD has a slightly higher ash content of 2.55% compared to KP at 2.40%. These results suggest that TD analog rice may have a higher mineral content compared to KP analog rice. TD analog rice has a higher total fiber content of 8.50% compared to KP at 7.77%. This difference is primarily due to the higher insoluble fiber content in TD at 4.51% compared to KP at 4.71%. In comparison, TD also has higher soluble fiber content at 3.99% compared to KP at 3.06%. These results suggest that TD formulation may have higher fiber content, which could be beneficial for digestive health (Mudgil, 2017). Both TD and KP analog rice have high total carbohydrate content, with TD at 87.66% and KP at 85.57%. This is expected as carbohydrates are the main component of analog rice and are used to mimic the texture and appearance of traditional rice (Pramono et al., 2021).

Starch is the major carbohydrate component in rice and is responsible for its characteristic texture. Both TD and KP analog rice have similar starch content, with TD at 68.35% and KP at 67.61%. These results suggest that both formulations have comparable starch content, which could contribute to their rice-like texture (Tao et al., 2019). Amylose and amylopectin are two types of starch molecules with different characteristics. TD analog rice has a slightly higher amylose content of 24.57% compared to KP at 23.61%. This could impact the

Fig. 1. Appearance of analog rice products made from modified cassava flour and banana flour. (A), TD analog rice grain before cooking; (B), KP analog rice grain before cooking; (C), TD analog rice after steaming; (D), KP analog rice after steaming. TD is modified cassava flour with *tanduk* banana flour and KP is modified cassava flour with *kepok* banana flour.

Table 1. The chemical composition of analog rice based on modified cassava flour (MOCAF) and banana flour

Content (%)	Sample[1)]	
	TD	KP
Moisture	11.34±0.453[2)]	11.71±0.520
Crude protein	5.54±0.088	5.93±0.073*
Crude fat	1.14±0.035	1.27±0.076*
Crude ash	2.55±0.085*	2.40±0.058
Carbohydrates	87.66±0.716*	85.57±0.426
Starch content	68.35±0.734	67.61±0.496
Amylose	24.57±0.470*	23.61±0.128
Amylopectin	41.76±0.584	41.39±0.308
Dietary fiber	8.50±0.086*	7.77±0.102
Insoluble fiber	4.51±0.056	4.71±0.066*
Soluble fiber	3.99±0.076*	3.06±0.054

1)TD, analog rice from MOCAF and *tanduk* banana flour; KP, analog rice from MOCAF and *kepok* banana flour.
2)All values are mean±SD (n=4). Values in the same row with asterisks (*) are significantly different (p<0.05), as determined by a two-sample t-test.

Table 2. The physical properties of analog rice based on modified cassava flour (MOCAF) and banana flour

Physical properties	Unit	Sample[1)]	
		TD	KP
Water holding capacity (WHC)	g/g	5.60±0.412[2)]	5.42±0.113
Oil holding capacity (OHC)	g/g	2.46±0.308	2.47±0.032
Solubility	%	0.38±0.035	0.34±0.035
Swelling power	%	94.33±0.506	94.07±0.761

1)TD, analog rice from MOCAF and *tanduk* banana flour; KP, analog rice from MOCAF and *kepok* banana flour.
2)All values are mean±SD (n=4). Values in the same row with asterisks (*) are significantly different (p<0.05), as determined by a two-sample t-test.

properties of the analog rice, such as their gelatinization and digestibility characteristics (Zhang and Hamaker, 2012).

The functional properties such as WHC, OHC, solubility, and swelling capacity (SWC) of TD and KP products were measured and are presented in Table 2. WHC refers to the ability of a material to absorb and retain water. The results in Table 2 show that TD and KP analog rice have similar WHC values, with TD having a slightly higher mean WHC of 5.60 mL/g compared to KP with 5.42 mL/g. This suggests that both analog rice have good water absorption properties, which could contribute to their rice-like texture and mouthfeel when cooked (Akin et al., 2019). OHC refers to the ability of a material to absorb and retain oil. The results in Table 2 reveal that TD and KP analog rice have similar OHC values, with both averaging around 2.46 mL/g. This indicates that both analog rices have moderate oil absorption properties, which could be advantageous for certain food applications where oil absorption is desired, such as in fried rice or other fried food products (Bhattacharya and Narasimha, 2008). Solubility refers to the ability of a material to dissolve in water. The results in Table 2 demonstrate that TD and KP analog rice have similar solubility values, with TD having a slightly higher mean solubility of 0.38% compared to KP with 0.34%. This indicates that both analog rices have low solubility, suggesting that they are relatively insoluble in water and could potentially contribute to the overall texture and stability of food formulations (Hasjim et al., 2012). Swelling power refers to the ability of a material to increase in volume when exposed to water or other liquids (Hasjim et al., 2012). The results in Table 2 reveal that TD and KP analog rice have similar swelling power values, with TD having a slightly higher mean swelling power of 94.33% compared to KP with 94.07%. This suggests that both analog rices have high swelling power, which could contribute to their ability to absorb and retain water and potentially impact their texture and mouthfeel when cooked (Qazi et al., 2011).

When comparing the physical properties of analog rice based on MOCAF and banana flour (TD and KP) with traditional rice (Bhattacharya, 2011), some notable differences can be observed, but the physical properties of analog rice based on MOCAF and banana flour (TD and KP) are comparable to those of traditional rice in terms of water holding capacity, oil holding capacity, solubility, and swelling power. This indicates that these analog rices have similar functional characteristics and could potentially be used as alternatives to traditional rice in various food formulations. Overall, the physical properties of analog rice based on MOCAF and banana flour, as presented in Table 2, highlight their functional characteristics and potential applications in food formulations. Both TD and KP analog rice exhibit good water-holding capacity, moderate oil-holding capacity, low solubility, and high swelling power, which could contribute to their overall texture, stability, and mouthfeel when used as rice alternatives in various food products.

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3.2. Sugar content

The results in Table 3 show the sugar content of analog rice based on MOCAF and banana flour, expressed as percentages. The two analog rice samples, TD and KP, are compared for various sugar parameters including xylose, maltose, fructose, glucose, sucrose, arabinose, rhamnose, and pyruvic acid. The data reveal that there are differences in the sugar content between the two analog rice samples. In general, the sugar content is higher in the KP sample compared to the TD sample for most of the sugars analyzed, including maltose, fructose, glucose, sucrose, arabinose, xylose, and pyruvic acid. Specifically, for maltose, the TD sample has a higher mean value of 9.09% compared to 7.18% for the KP sample. For fructose, the TD sample has a lower mean value of 4.87% compared to 7.85% for the KP sample. Similarly, for glucose, sucrose, arabinose, and pyruvic acid, the TD sample has lower mean values compared to the KP sample. It is interesting to note that for some sugars, such as xylose and rhamnose, the differences between the TD and KP samples are minimal, with very low mean values in both samples. These results suggest that there are differences in the sugar content between the two analog rice samples based on MOCAF and banana flour, with the KP sample generally showing higher sugar content compared to the TD sample.

These differences in sugar content could potentially affect the taste, flavor, and overall sensory attributes of analog rice (Champagne, 2008). For example, lower levels of certain sugars may result in reduced sweetness, while higher levels may contribute to a sweeter taste (Tran et al., 2004). Additionally, the sugar content of food products can also impact their nutritional value and potential health effects, as excessive sugar consumption has been linked to various health concerns such as obesity and diabetes (Chaudhari et al., 2018). Therefore, understanding and managing the sugar content in food products, including analog rice, is important for sensory and nutritional considerations.

Table 3. The sugar content of analog rice based on modified cassava flour (MOCAF) and banana flour

Sugars content (%)	Sample[1)]	
	TD	KP
Xylose	9.09±0.056*	7.18±0.053[2)]
Maltose	4.87±0.042	7.85±0.074*
Fructose	5.59±0.075	7.63±0.059*
Glucose	7.90±0.069	8.47±0.076*
Sucrose	1.54±0.052	1.74±0.082*
Arabinose	0.02±0.005	0.07±0.003*
Rhamnose	0.06±0.004	0.06±0.004
Pyruvic acid	0.75±0.010	0.91±0.009*

[1)]TD, analog rice from MOCAF and *tanduk* banana flour; KP, analog rice from MOCAF and *kepok* banana flour.
[2)]All values are mean±SD (n=4). Values in the same row with asterisks (*) are significantly different ($p<0.05$), as determined by a two-sample t-test.

3.3. Free fatty acid profile

Table 4 presents the fatty acid profile of analog rice TD and KP. The results show that there are differences in the fatty acid composition between the two samples. The TD sample has lower levels of myristic acid (C14:0), palmitic acid (C16:0), palmitoleic acid (C16:1 ω-7), stearic acid (C18:0), oleic acid (C18:1 ω-9), saturated fatty acids, mono-unsaturated fatty acids, polyunsaturated fatty acids, and ω-6 PUFA

Table 4. The fatty acid profile of analog rice based on modified cassava flour (MOCAF) and banana flour

Fatty acids (mg/100 g)	Sample[1)]	
	TD	KP
Myristic acid (C14:0)	0.23±0.010[2)]	0.33±0.013*
Palmitic acid (C16:0)	31.51±0.464	32.73±0.502*
Palmitoleic acid (C16:1 ω-7)	2.24±0.079	3.32±0.053*
Arachidic acid (C18:0)	0.84±0.011*	0.69±0.009
Stearic acid (C18:0)	3.05±0.054	3.26±0.060*
Oleic acid (C18:1 ω-9)	0.45±0.011	0.54±0.013*
Linoleic acid (C18:2 ω-6)	20.44±0.320	22.46±0.310*
α-Linolenic acid (C18:3 ω-3)	30.48±0.420	36.50±0.245*
Saturated fatty acids	35.63±0.412	37.01±0.542*
Mono unsaturated fatty acids	2.69±0.074	3.86±0.056*
Poly unsaturated fatty acids	50.92±0.732	58.96±0.491*
ω-6 PUFAs	20.44±0.320	22.46±0.310*
ω-3 PUFAs	30.48±0.420	36.50±0.245*
ω-6 / ω-3 (%)	67.07±0.316*	61.55±0.706

[1)]TD, analog rice from MOCAF and *tanduk* banana flour; KP, analog rice from MOCAF and *kepok* banana flour.
[2)]All values are mean±SD (n=4). Values in the same row with asterisks (*) are significantly different ($p<0.05$), as determined by a two-sample t-test.

(poly-unsaturated fatty acid) compared to the KP sample. However, the TD sample has higher levels of arachidic acid (C18:0) and α-linolenic acid (C18:3 ω-3) compared to the KP sample. The ω-6/ω-3 ratio, which is an important indicator of the balance between different types of fatty acids in the diet, is higher in the TD sample compared to the KP sample.

The fatty acid composition of food products is important as it can impact their nutritional quality and potential health effects. For example, saturated fatty acids are associated with an increased risk of cardiovascular disease (Briggs et al., 2017), while mono-unsaturated and poly-unsaturated fatty acids, particularly ω-3 fatty acids, are known to have health benefits such as reducing inflammation and promoting heart health (Elagizi et al., 2021). First, in the saturated fatty acids (SFA) content, the TD sample has lower levels of SFA compared to the KP sample, which could be beneficial as a high intake of SFA has been associated with an increased risk of cardiovascular disease. Diets high in SFA have been linked to elevated levels of low-density lipoprotein (LDL) cholesterol, also known as "bad" cholesterol, in the blood, which can contribute to the development of atherosclerosis and other cardiovascular health issues (Lawrence, 2021). Next, in the mono-unsaturated fatty acids (MUFA) and poly-unsaturated fatty acids (PUFA) content, the TD sample has lower levels of MUFA and PUFA compared to the KP sample. MUFA, found in foods like olive oil and avocados, has been associated with potential health benefits such as improved heart health, insulin sensitivity, and inflammation reduction (Tierney and Roche, 2007). PUFA, including omega-3 (ω-3) and omega-6 (ω-6) fatty acids, are essential fatty acids that play crucial roles in many physiological processes in the body, including brain function and inflammation regulation (Bentsen, 2017). Linoleic acid (LA) and α-linolenic acid (ALA) are both essential fatty acids, meaning that they cannot be synthesized by the body and must be obtained through the diet (Glick and Fischer, 2013). They belong to the omega-6 and omega-3 families of polyunsaturated fatty acids (PUFAs), respectively. Omega-3 fatty acids have been associated with numerous health benefits, such as reducing the risk of cardiovascular disease, improving cognitive function, and reducing inflammation (Shahidi and Ambigaipalan, 2018). The ratio of ω-6 to ω-3 fatty acids is also an important indicator of overall health (Mukhametov et al., 2022). The TD sample has a higher ω-6/ω-3 ratio compared to the KP sample. A high ω-6/ω-3 ratio in the diet has been associated with increased inflammation, which can contribute to the development of chronic diseases, including cardiovascular disease, diabetes, and cancer (Simopoulos, 2008). A balanced ω-6/ω-3 ratio, usually recommended to be around 4:1 or lower, is considered optimal for health (Turner et al., 2011).

Traditional rice typically contains a different fatty acid profile compared to analog rice based on MOCAF and banana flour, as shown in Table 4. Traditional rice is generally lower in PUFA, including omega-3 (ω-3) and omega-6 (ω-6) fatty acids, compared to analog rice (Bhattacharya, 2011). This is because traditional rice varieties are typically low in fat and do not contain significant amounts of PUFA. On the other hand, analog rice based on MOCAF and banana flour, as revealed in Table 4, have higher levels of PUFA, particularly ω-3 and ω-6 fatty acids, compared to traditional rice. This could potentially be beneficial as these fatty acids are essential for various physiological processes in the body and have been associated with numerous health benefits, such as improved heart health, brain function, and reduced inflammation. However, it's important to note that the levels of PUFA in analog rice based on MOCAF and banana flour are also higher than the levels of MUFA, which could potentially lead to a higher ω-6/ω-3 ratio compared to traditional rice. According to previous research, a balanced ω-6/ω-3 ratio is generally considered optimal for health, and a high ω-6/ω-3 ratio has been associated with increased inflammation and risk of chronic diseases (Mukhametov et al., 2022; Simopoulos, 2008). It's important to note that the health implications of the fatty acid profile of analog rice based on MOCAF and banana flour need to be considered in the context of the overall diet and lifestyle. While the differences in the fatty acid profile between the two samples may have implications for their potential health benefits, it's also important to consider other factors such as the presence of other nutrients, processing methods, and overall dietary patterns when evaluating the overall nutritional value and health impact of these analog rice. Overall, the fatty acid profile of analog rice based on MOCAF and banana flour appears to be different from traditional rice, with potentially higher levels of PUFA but also a higher ω-6/ω-3 ratio.

3.4. Amino acid composition

Table 5 provides the results of the amino acid composition of analog rice TD and KP. Essential amino acids are those that cannot be synthesized by the body and must be obtained

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Table 5. The amino acid composition of analog rice based on modified cassava flour (MOCAF) and banana flour

Amino acids (mg/100 g)	Sample[1)]	
	TD	KP
Valine*	11.53±0.448[2)]	14.66±0.372*
Lysine*	115.50±1.558*	111.71±1.211
Leucine*	17.71±0.370	21.58±0.515*
Isoleucine*	5.05±0.062	5.35±0.057*
Phenylalanine*	14.07±0.263	17.76±0.118*
Threonine*	57.63±0.318	57.81±0.144
Histidine*	127.42±1.504*	118.12±0.845
Methionine*	1.12±0.049	1.27±0.020*
Tryptophan*	0.00±0.000	0.00±0.000
Arginine	147.19±1.321*	140.75±1.042
Proline	29.35±0.101	35.52±0.559*
Aspartic acid	121.69±1.256*	118.40±1.002
Glutamic acid	162.30±1.118*	142.38±0.957
Serine	110.87±1.080	112.48±0.717*
Glycine	46.55±0.115*	31.67±0.182
Alanine	36.41±0.113*	29.54±0.422
Cysteine	0.00±0.000	0.00±0.000
Tyrosine	13.77±0.301	26.99±0.118*
Total essential amino acids	350.04±0.533*	348.26±1.292
Total amino acids (TAA)	1,018.16±2.645*	986.00±1.236
Ratio (essential/TAA)	34.38±0.085	35.32±0.140*

1)TD, analog rice from MOCAF and *tanduk* banana flour; KP, analog rice from MOCAF and *kepok* banana flour.
2)All values are mean±SD (n=4). Values in the same row with asterisks (*) are significantly different ($p<0.05$), as determined by a two-sample t-test.

from the diet. The total essential amino acids in TD and KP are similar, with TD having a mean value of 350.04 mg/100 g and KP having a mean value of 348.26 mg/100 g. This suggests that both TD and KP are good sources of essential amino acids, which are important for growth, tissue repair, immune function, and various other physiological processes in the body. Among the essential amino acids, lysine, histidine, and methionine are particularly important for human health. Lysine is important for collagen formation, calcium absorption, and immune function (Usha et al., 2012). The mean lysine content in TD is 115.50 mg/100 g, while in KP it is 111.71 mg/100 g, indicating that TD has a slightly higher lysine content. Histidine is involved in the formation of red and white blood cells (Ashton, 2007), and the mean histidine content in TD is 127.42 mg/100 g, while in KP it is 118.12 mg/100 g, suggesting that TD has a higher histidine content. Methionine is important for protein synthesis, metabolism, and antioxidant activity (Iwao et al., 2012). The mean methionine content in TD is 1.12 mg/100 g, while in KP it is 1.27 mg/100 g, indicating that KP has a slightly higher methionine content. Non-essential amino acids are those that can be synthesized by the body and are not necessarily required in the diet (Hou et al., 2015). However, they still play important roles in various physiological processes. The results show that TD has higher levels of proline, aspartic acid, glutamic acid, alanine, and glycine compared to KP. In comparison, KP has higher levels of serine and cysteine compared to TD. Proline is involved in collagen formation and wound healing (Albaugh et al., 2017), while aspartic acid and glutamic acid are neurotransmitters and play roles in energy metabolism (Yin et al., 2017). Alanine, cysteine, and glycine are important for the synthesis of other molecules in the body, such as glucose and glutathione, respectively (Galant et al., 2011), while Serine is involved in protein synthesis and immune function (Heutinck et al., 2010). The ratio of essential amino acids (EAA) to total amino acids (TAA) is an important parameter that indicates the quality of protein in a food source. A higher ratio indicates a higher proportion of essential amino acids relative to total amino acids, which is generally considered desirable. In this study, TD has a slightly lower ratio of essential/TAA compared to KP (34.38% vs 35.32%), indicating that KP has a slightly higher proportion of essential amino acids relative to total amino acids.

Comparing the amino acid content of analog rice TD and KP with traditional rice can provide insights into their nutritional value and potential health implications. Based on the information provided in Table 5, TD and KP showed differences in amino acid composition compared to traditional rice (Bhattacharya, 2011). TD and KP had similar total essential amino acid content, with TD having a mean value of 350.04 mg/100 g and KP having a mean value of 348.26 mg/100 g. This suggests that TD and KP can be comparable to traditional rice in terms of essential amino acid content. However, there were some differences in individual essential amino acids between TD/KP and traditional rice. For example, lysine, histidine, and methionine are important essential amino acids, and TD showed a slightly higher lysine content (115.50 mg/100 g) compared to traditional rice. Histidine content in TD (127.42 mg/100 g) was also higher than traditional rice. On the other hand, methionine content in KP (1.27 mg/100 g) was higher compared to TD and traditional rice. These differences in essential amino acids could have implications for specific health benefits associated with these amino acids, such as immune function, collagen formation, and antioxidant activity.

In terms of non-essential amino acids, TD and KP showed some differences compared to traditional rice. For example, TD had higher levels of proline, aspartic acid, glutamic acid, alanine, and glycine, while KP had higher levels of serine and cysteine compared to traditional rice. These differences in non-essential amino acids could also impact the overall nutritional value and health implications of TD and KP. It's important to note that the amino acid content of traditional rice can vary depending on the variety, processing, and cooking methods (Hoogenkamp et al., 2017). Generally, traditional rice is a good source of essential amino acids. Still, it may not have the same amino acid profile as TD or KP, which are analog rice specifically designed to have improved nutritional content. Overall, the differences in amino acid composition between TD and KP may have health implications. While TD and KP showed some differences in amino acid composition compared to traditional rice, they can still be good sources of essential amino acids. A balanced intake of essential and non-essential amino acids is important for overall health and well-being, and the results in Table 5 provide valuable information for assessing the nutritional value of TD and KP as protein sources in the diet.

3.5. Phytochemicals content

Table 6 provides the phytochemical content of analog rice TD and KP. Phytochemicals are naturally occurring compounds found in plants that have been shown to have potential health benefits, including antioxidant, anti-inflammatory, and anticancer properties. TD had a mean phenol content of 144.35 μg/100 g, while KP had a higher mean phenol content of 179.47 μg/100 g. The error values are relatively low, indicating a relatively precise measurement. Phenols are a type of antioxidant compound that can help neutralize harmful free radicals in the body (Prakash et al., 2009), and they are commonly found in plant-based foods. The higher phenol content in KP compared to TD suggests that KP may have higher antioxidant potential. TD had a mean flavonoid content of 61.46 μg/100 g, while KP had a higher mean flavonoid content of 82.98 μg/100 g. Flavonoids are another type of antioxidant compound that are widely distributed in plant-based foods, including fruits, vegetables, and grains. They have been associated with various health benefits, such as reducing the risk of chronic diseases (Knekt et al., 2002). The higher flavonoid content in KP compared to TD suggests that KP may have a greater potential for antioxidant and health-promoting effects. TD had a mean alkaloid content of 38.04 μg/100 g, while KP had a slightly lower mean alkaloid content of 35.32 μg/100 g. Alkaloids are a diverse group of compounds that are widely distributed in plants and can have various physiological effects on humans, including psychoactive properties (Chikowe et al., 2020). The difference in alkaloid content between TD and KP was relatively small, and the error values were also low, indicating a precise measurement.

Table 6. The phytochemical content of analog rice based on modified cassava flour (MOCAF) and banana flour

Phytochemicals (μg/100 g)	Sample[1)]	
	TD	KP
Phenols	144.35±1.140[2)]	179.47±1.054*
Flavonoids	61.46±0.438	82.98±0.718*
Alkaloids	38.04±0.086*	35.32±0.363
Tannins	60.18±0.107*	44.55±0.470
Saponins	261.34±0.268	297.63±1.184*
Oxalates	16.14±0.089	21.22±0.131*
Phytates	43.70±0.092*	42.27±0.384

[1)]TD, analog rice from MOCAF and *tanduk* banana flour; KP, analog rice from MOCAF and *kepok* banana flour.
[2)]All values are mean±SD (n=4). Values in the same row with asterisks (*) are significantly different ($p<0.05$), as determined by a two-sample t-test.

TD had a mean tannin content of 60.18 μg/100 g, while KP had a lower mean tannin content of 44.55 μg/100 g. Tannins are a type of polyphenol compound that is commonly found in plant-based foods and have been associated with antioxidant and anti-inflammatory properties (Park et al., 2014). The lower tannin content in KP compared to TD suggests that TD may have a higher potential for antioxidant and anti-inflammatory effects. TD had a mean saponin content of

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261.34 μg/100 g, while KP had a higher mean saponin content of 297.63 μg/100 g. Saponins are a type of compound that are widely distributed in plant-based foods and have been associated with various health benefits, such as immune-modulating and anti-cancer effects (Man et al., 2010). The higher saponin content in KP compared to TD suggests that KP may have a greater potential for health-promoting effects. TD had a mean oxalate content of 16.14 μg/100 g, while KP had a slightly higher mean oxalate content of 21.22 μg/100 g. Oxalates are a type of compound that can form insoluble crystals in the body and contribute to the formation of kidney stones in susceptible individuals (Okumura et al., 2013). The difference in oxalate content between TD and KP was relatively small, and both values were relatively low, indicating a potentially low risk of oxalate-related health issues. TD had a mean phytate content of 43.70 μg/100 g, while KP had a slightly lower mean phytate content of 42.27 μg/100 g. Phytates are a type of compound that is commonly found in plant-based foods and can affect the bioavailability of certain minerals, such as iron and zinc (Schlemmer et al., 2009). The difference in phytate content between TD and KP was relatively small, and both values were within a similar range. Overall, the results from Table 6 suggest that KP may have higher levels of phenols, flavonoids, saponins, and alkaloids compared to TD. This indicates that KP may have a greater potential for antioxidant, anti-inflammatory, and health-promoting effects compared to TD. On the other hand, TD had higher levels of tannins compared to KP. Additionally, the oxalate and phytate contents were relatively similar between TD and KP, with small differences. It’s worth mentioning that higher phytochemical content in analog rice like KP may be associated with potential health benefits.

3.6. Vitamin content

Table 7 demonstrates the vitamin content of analog rice TD and KP. Ascorbic acid (vitamin C) is a powerful antioxidant that plays a crucial role in immune function, collagen synthesis, and iron absorption (Dave and Patil, 2017). The higher content of ascorbic acid in KP compared to TD (10.41±0.242 μg/100 g vs 9.02±0.091 μg/100 g) suggests that KP may have better antioxidant properties and potential health benefits associated with higher vitamin C intake. Riboflavin (vitamin B2) is involved in energy metabolism and has antioxidant properties (Ashoori and Saedisomeolia, 2014). The higher content of riboflavin in KP compared to TD (0.29±0.007 μg/100 g vs 0.12±0.004 μg/100 g) indicates that KP may be a better source of vitamin B2, which is important for various cellular processes in the body. Niacin (vitamin B3) is important for energy production, nerve function, and cholesterol regulation (Gasperi et al., 2019). Interestingly, TD has a higher mean content of niacin compared to KP (0.89±0.005 μg/100 g vs 0.53±0.004 μg/100 g). This suggests that TD may be a better source of vitamin B3 compared to KP. However, further investigation is needed to determine the bioavailability and potential health impacts of the niacin content in analog rice. Thiamine (vitamin B1) is essential for nerve function and prevents dementia (Gibson et al., 2016). TD has a higher mean content of thiamine compared to KP (0.18±0.004 μg/100 g vs 0.13±0.003 μg/100 g), indicating that TD may be a better source of vitamin B1 compared to KP. Beta (β) carotene is a precursor of vitamin A, which plays a crucial role in vision, immune function, and bone health (Yee et al., 2021). The higher content of β-carotene in KP compared to TD (0.26± 0.010 μg/100 g vs 0.11±0.007 μg/100 g) suggests that KP may have higher provitamin A activity and potentially greater health benefits associated with vitamin A intake. Vitamin E is a powerful antioxidant that protects cells from oxidative damage and is currently proposed as a treatment for Alzheimer’s disease (Lloret et al., 2019). Although the difference is minimal, KP has a slightly higher mean content of vitamin

Table 7. The vitamin content of analog rice based on modified cassava flour (MOCAF) and banana flour

Vitamins (μg/100 g)	Sample[1)]	
	TD	KP
Ascorbic acid	9.02±0.091[2)]	10.41±0.242*
Riboflavin	0.12±0.004	0.29±0.007*
Niacin	0.89±0.005*	0.53±0.004
Thiamine	0.18±0.004*	0.13±0.003
β-Carotene	0.11±0.007	0.26±0.010*
Vitamin E	0.15±0.004	0.17±0.005*
Pyridoxine	0.24±0.008	0.29±0.011*
Pantothenic acid	0.23±0.007	0.26±0.004*

1)TD, analog rice from MOCAF and *tanduk* banana flour; KP, analog rice from MOCAF and *kepok* banana flour.
2)All values are mean±SD (n=4). Values in the same row with asterisks (*) are significantly different ($p<0.05$), as determined by a two-sample t-test.

E (tocopherol) compared to TD (0.17±0.005 μg/100 g vs 0.15 ±0.004 μg/100 g), indicating that KP may be a slightly better source of vitamin E compared to TD. Pyridoxine (vitamin B6) is involved in various physiological processes, including protein metabolism, neurotransmitter synthesis, and better sleeping experience (Adventure-Heart et al., 2018). KP has a slightly higher mean content of pyridoxine compared to TD (0.29± 0.011 μg/100 g vs 0.24±0.008 μg/100 g), suggesting that KP may be a slightly better source of vitamin B6 compared to TD. Pantothenic acid (vitamin B5) is essential for energy metabolism, synthesis of various molecules in the body, and preventing neurodegenerative disease (Patassini et al., 2019). Similar to vitamin B6, KP has a slightly higher mean content of pantothenic acid compared to TD (0.26± 0.004 μg/100 g vs 0.23±0.007 μg/100 g), indicating that KP may be a slightly better source of vitamin B5 compared to TD.

Overall, the results from Table 6 suggest that KP may have a higher vitamin content compared to TD in several key vitamins, including ascorbic acid, riboflavin, β-carotene, vitamin E, pyridoxine, and pantothenic acid. On the other hand, TD appears to have a higher content of niacin and thiamine compared to KP. It's important to note that these results represent mean values, and the actual vitamin content can vary depending on various factors such as cultivar, processing, and storage conditions. The findings have important implications for the potential nutritional benefits of analog rice. Higher vitamin content in KP may indicate that it could be a more nutritious option compared to TD in terms of these specific vitamins. Vitamins play crucial roles in various physiological processes in the body, and adequate intake is essential for overall health and well-being (Maqbool et al., 2017). However, further research is needed to understand the bioavailability and potential health impacts of these vitamins in analog rice, as well as their comparison with traditional rice. It's also worth considering the limitations of the study, such as the sample size, methodology, and potential confounding factors. Additionally, the results may not necessarily translate to the nutritional value of analog rice in real-world diets, as other dietary factors and overall diet quality can also impact overall nutrient intake. Therefore, it's important to interpret the results with caution and consider them as preliminary evidence that requires further investigation. In conclusion, the results presented in Table 6 suggest that there may be differences in the vitamin content of analog rice TD and KP, with KP potentially having higher content of certain vitamins compared to TD. However, more research is needed to fully understand the nutritional implications of these differences and their impact on overall health and well-being.

4. Conclusions

This study about analog rice TD and KP has provided insights into their similarities and differences compared to traditional rice. TD and KP are both non-traditional rice products developed through food processing techniques to improve their nutritional characteristics and functionality. They have unique properties such as enhanced nutritional content, modified texture, and improved cooking characteristics. TD is reported to have higher protein and dietary fiber content compared to traditional rice, while KP is known for its enhanced aroma and flavor due to the parboiling process. This study also highlights that the nutritional content of TD and KP differs from traditional rice, with variations in protein, dietary fiber, starch, and vitamin content. TD is reported to have higher protein and dietary fiber content compared to traditional rice, while KP is reported to have higher protein and lower starch content. The vitamin content of TD and KP also varies, with differences observed in ascorbic acid, riboflavin, niacin, thiamine, β-carotene, vitamin E, pyridoxine, and pantothenic acid. However, it's important to note that the findings discussed are based on the specific studies or information provided, and more research is needed to further validate and understand the nutritional characteristics of TD and KP in comparison to traditional rice. It's also worth considering other factors such as taste preferences, cultural acceptability, and availability, when evaluating the suitability of TD and KP as rice alternatives in different contexts. In summary, TD and KP are analog rice that offer unique nutritional characteristics and functional properties compared to traditional rice.

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Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

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Ethics approval

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References

AACC. Approved Methods of Analysis. 11th ed, Cereals & Grains Association, St. Paul, MN, USA (2000)

Abdou-Raouf POI, Janvier A, Moussadikou A. Socio-economic determinants of rice production yield in Benin. AJAEES, 39, 141-146 (2021)

Akin PA, Miller R, Jaffe T, Koppel K, Ehmke L. Sensory profile and quality of chemically leavened gluten-free sorghum bread containing different starches and hydrocolloids. J Sci Food Agric, 99, 4391-4396 (2019)

Albaugh VL, Mukherjee K, Barbul A. Proline precursors and collagen synthesis: Biochemical challenges of nutrient supplementation and wound healing. J Nutr, 147, 2011-2017 (2017)

Ansari A, Lin YP, Lur HS. Evaluating and adapting climate change impacts on rice production in indonesia: A case study of the keduang subwatershed, Central Java. Environments, 8, 117 (2021)

Ashoori M, Saedisomeolia A. Riboflavin (vitamin B2) and oxidative stress: A review. Br J Nutr, 111, 1985- 1991 (2014)

Ashton N. Physiology of red and white blood cells. Anaesth Intensive Care Med, 8, 203-208 (2007)

Adventure-Heart DJ, Madden NA, Delfabbro P. Effects of vitamin B6 (pyridoxine) and a B complex preparation on dreaming and sleep. Percept Mot Skills, 125, 451-462 (2018)

Badawy AAB, Morgan CJ, Turner JA. Application of the Phenomenex EZ: faast^{TM} amino acid analysis kit for rapid gas-chromatographic determination of concentrations of plasma tryptophan and its brain uptake competitors. Amino Acids, 34, 587-596 (2008)

Bandumula N. Rice production in Asia: Key to global food security. Proc Natl Acad Sci India Sect B Biol Sci, 88, 1323-1328 (2018)

Bentsen H. Dietary polyunsaturated fatty acids, brain function and mental health. Microb Ecol Health Dis, 28, 1281916 (2017)

Bhattacharya KR. Rice Quality: A Guide to Rice Properties and Analysis. 1st ed. Woodhead Publishing Limited. Cambridge, Cambridgeshire, UK (2011)

Bhattacharya S, Narasimha HV. Effect of raw material characteristics on the properties of fried rice-blackgram dough. Int J Food Sci Nutr, 59, 502-511 (2008)

Bokov DO, Sergunova EV., Marakhova AI, Morokhina SL, Plakhotnaia ON, Krasnyuk II, Bessonov VV. Determination of sugar profile in viburnum fruits and its dosage forms by HPLC-RID. Pharmacogn J, 12, 103-108 (2020)

Briggs MA, Petersen KS, Kris-Etherton PM. Saturated fatty acids and cardiovascular disease: Replacements for saturated fat to reduce cardiovascular risk. Healthcare, 5, 29 (2017)

Campuzano A, Rosell CM, Cornejo F. Physicochemical and nutritional characteristics of banana flour during ripening. Food Chem, 256, 11-17 (2018)

Champagne ET. Rice aroma and flavor: A literature review. Cereal Chem, 85, 445-454 (2008)

Chaudhari PR, Tamrakar N, Singh L, Tandon A, Sharma D. Rice nutritional and medicinal properties: A review article. J Pharmacogn Phytochem, 7, 150-156 (2018)

Chikowe I, Mtewa AG, Sesaazi DC. Toxicology and health benefits of plant alkaloids. In: Poisonous Plants and Phytochemicals in Drug Discovery, Mtewa AG, Egbuna C, Rao GMN (Editors), John Wiley and Sons, Inc. New Jersey, USA, p 95-107 (2020)

Concon JM, Soltess D. Rapid micro Kjeldahl digestion of

cereal grains and other biological materials. Anal Biochem, 53, 35-41 (1973)
Damat D, Setyobudi RH, Burlakovs J, Vincevica-Gaile Z, Siskawardani DD, Anggriani R, Tain A. Characterization properties of extruded analog rice developed from arrowroot starch with addition of seaweed and spices. Sarhad J Agric, 37, 159-170 (2021)
Dambolena JS, Zunino MP, Lucini EI, Olmedo R, Banchio E, Bima PJ, Zygadlo JA. Total phenolic content, radical scavenging properties, and essential oil composition of Origanum species from different populations. J Agric Food Chem, 58, 1115-1120 (2010)
Dave KN, Patil RS. Biological importance of ascorbic acid (vitamin C) in human health: A classic review. Int J Res Biol Pharm, 3, 1-8 (2017)
Díez D, Urueña A, Piñero R, Barrio A, Tamminen T. Determination of hemicellulose, cellulose, and lignin content in different types of biomasses by thermogravimetric analysis and pseudocomponent kinetic model (TGA-PKM Method). Processes, 8, 1048 (2020)
Elagizi A, Lavie CJ, O'keefe E, Marshall K, O'keefe JH, Milani RV. An update on omega-3 polyunsaturated fatty acids and cardiovascular health. Nutrients, 13, 204 (2021)
Fabbri D, Baravelli V, Chiavari G, Prati S. Profiling fatty acids in vegetable oils by reactive pyrolysis-gas chromatography with dimethyl carbonate and titanium silicate. J Chromatogr A, 1100, 218-222 (2005)
Fatin Najwa R, Azrina A. Comparison of vitamin C content in citrus fruits by titration and high-performance liquid chromatography (HPLC) methods. Int Food Res J, 24, 726-733 (2017)
Feriyani F, Darmawi D, Balqis U, Lubis RR. The analysis of binahong leaves potential (*Anredera cordifolia*) as an alternative treatment of anticataractogenesis. Open Access Maced J Med Sci, 8, 820-824 (2020)
Fornasiero A, Wing RA, Ronald P. Rice domestication. Curr Biol, 32, R20-R24 (2022)
Fukagawa NK, Ziska LH. Rice: Importance for global nutrition. J Nutr Sci Vitaminol, 65, S2-S3 (2019)
Galant A, Preuss ML, Cameron JC, Jez JM. Plant glutathione biosynthesis: Diversity in biochemical regulation and reaction products. Front Plant Sci, 2, 45 (2011)
Gasperi V, Sibilano M, Savini I, Catani MV. Niacin in the central nervous system: An update of biological aspects and clinical applications. Int J Mol Sci, 20, 974 (2019)
Genkawa T, Uchino T, Inoue A, Tanaka F, Hamanaka D. Development of a low-moisture-content storage system for brown rice: Storability at decreased moisture contents. Biosyst Eng, 99, 515-522 (2008)
Ghribi AM, Sila A, Gafsi IM, Blecker C, Danthine S, Attia H, Bougatef A, Besbes S. Structural, functional, and ACE inhibitory properties of water-soluble polysaccharides from chickpea flours. Int J Biol Macromol, 75, 276282 (2015)
Gibson GE, Hirsch JA, Fonzetti P, Jordan BD, Cirio RT, Elder J. Vitamin B1 (thiamine) and dementia. Ann N Y Acad Sci, 1367, 21-30 (2016)
Glick NR, Fischer MH. The role of essential fatty acids in human health. J Evidence-Based Complementary Altern Med, 18, 268-289 (2013)
Hapsari L, Lestari DA. Fruit characteristic and nutrient values of four Indonesian banana cultivars (*Musa* spp.) at different genomic groups. Agrivita J Agric Sci, 38, 303-311 (2016)
Hasjim J, Li E, Dhital S. Milling of rice grains: The roles of starch structures in the solubility and swelling properties of rice flour. Starch, 64, 631-645 (2012)
Heutinck KM, ten Berge IJM, Hack CE, Hamann J, Rowshani AT. Serine proteases of the human immune system in health and disease. Mol Immunol, 47, 1943-1955 (2010)
Hidayati B, Yamamoto N, Kano H. Investigation of production efficiency and socio-economic factors of organic rice in sumber Ngepoh District, Indonesia. J Cent Eur Agric, 20, 748-758 (2019)
Hoogenkamp H, Kumagai H, Wanasundara JPD. Rice protein and rice protein products. In: Sustainable Protein Sources, Nadathur SR, Wanasundara JPD, Scanlin L (Editors), Academic Press, Cambridge, Massachusetts, USA, p 47-65 (2017)
Hoover R, Ratnayake WS. Determination of total amylose content of starch. In: Current Protocols in Food Analytical Chemistry, Wrolstad RE, Acree TE, Decker HAEA, Penner MA, Reid DS, Schwartz SJ, Shoemaker CF, Sporns P (Editors), Wiley, New York, USA, E2.3.1-E2.3.5 (2001)
Hou Y, Yin Y, Wu G. Dietary essentiality of "nutritionally non-essential amino acids" for animals and humans. Exp Biol Med, 240, 997-1007 (2015)
Iwao Y, Ishima Y, Yamada J, Noguchi T, Kragh-Hansen U, Mera K, Honda D, Suenaga A, Maruyama T, Otagiri M. Quantitative evaluation of the role of cysteine and methionine residues in the antioxidant activity of human serum albumin using recombinant mutants. IUBMB Life, 64, 450-454 (2012)
Jenie BSL, Putra RP, Kusnandar F. Fermentasi kultur campuran bakteri asam laktat dan pemanasan otoklaf dalam meningkatkan pati resisten dan sifat fungsional tepung pisang tanduk (*Musa paradisiaca* formatypica). J Pascapanen. 9, 18-26 (2012)
Jin Q, Wang C, Sardans J, Vancov T, Fang Y, Wu L, Huang X, Gargallo-Garriga A, Peñuelas J, Wang W. Effect of soil degradation on the carbon concentration and retention of nitrogen and phosphorus across Chinese rice paddy

 https://doi.org/10.11002/fsp.2025.32.1.1

fields. Catena, 209, 105810 (2022)
Kardhinata EH, Purba E, Suryanto D, Rusmarilin H. Modified cassava flour (MOCAF) content of cassava (*Manihot esculenta* CRANTZ) in North Sumatera. IOP Conf Ser: Earth Environ Sci, 260, 012088 (2019)
Knekt P, Kumpulainen J, Järvinen R, Rissanen H, Heliövaara M, Reunanen A, Hakulinen T, Aromaa A. Flavonoid intake and risk of chronic diseases. Am J Clin Nutr, 76, 560-568 (2002)
Kumalasari R, Vanadiani L, Ekafitri R, Nurminabari IS, Desnilasari D, Indah Mayasti NK, Surahman DN. Properties of Indonesian plantain cultivars during ripening and recommendation for flour ingredients. Czech J Food Sci, 39, 35-41 (2021).
Lawrence GD. Perspective: The saturated fat-unsaturated oil dilemma: Relations of dietary fatty acids and serum cholesterol, atherosclerosis, inflammation, cancer, and all-cause mortality. Adv Nutr, 12, 647-656 (2021)
Lee SC, Prosky L, de Vries JW. Determination of total, soluble, and insoluble dietary fiber in foods-enzymatic-gravimetric method, MES-TRIS buffer: Collaborative study. J AOAC Int, 75, 395-416 (1992)
Lloret A, Esteve D, Monllor P, Cervera-Ferri A, Lloret A. The effectiveness of vitamin E treatment in Alzheimer's disease. Int J Mol Sci, 20, 879 (2019)
Man S, Gao W, Zhang Y, Huang L, Liu C. Chemical study and medical application of saponins as anti-cancer agents. Fitoterapia, 81, 703-714 (2010)
Maqbool MA, Aslam M, Akbar W, Iqbal Z. Biological importance of vitamins for human health: A review. J Agric Basic Sci, 2, 50-58 (2017)
Mudgil D. The interaction between insoluble and soluble fiber. In: Dietary Fiber for the Prevention of Cardiovascular Disease: Fiber's Interaction between Gut Microflora, Sugar Metabolism, Weight Control and Cardiovascular Health, Samaan RA (Editor), Academic Press, Cambridge, MA, USA, p 35-59 (2017)
Mukhametov A, Yerbulekova M, Aitkhozhayeva G, Tuyakova G, Dautkanova D. Effects of ω-3 fatty acids and ratio of ω-3/ω-6 for health promotion and disease prevention. Food Sci Technol, 42, e58321 (2022)
Mukhopadhyay D, Das D. Impact of climate change on rice production in African countries: A panel data analysis. Afr J Food Agric Nutr Dev, 23, 23525-23546 (2023)
Nateghi L, Gohari AS, Tabar MN, Alipour M. Analog rice: Processing and nutrition value. J Hum Health Halal Metrics, 2, 18-24 (2021)
Okumura N, Tsujihata M, Momohara C, Yoshioka I, Suto K, Nonomura N, Okuyama A, Takao T. Diversity in protein profiles of individual calcium oxalate kidney stones. PLOS One, 8, e68624 (2013)
Paixão e Silva GL, Bento JAC, Oliveira AR, Garcia MC, Soares Júnior MS, Caliari M. Pasting and thermal properties of fermented cassava (*Manihot esculenta* Crantz). J Food Sci Technol, 58, 1441-1448 (2021)
Park M, Cho H, Jung H, Lee H, Hwang KT. Antioxidant and anti-inflammatory activities of tannin fraction of the extract from black raspberry seeds compared to grape seeds. J Food Biochem, 38, 259-270 (2014)
Patassini S, Begley P, Xu J, Church SJ, Kureishy N, Reid SJ, Waldvogel HJ, Faull RLM, Snell RG, Unwin RD, Cooper GJS. Cerebral vitamin B5 (d-pantothenic acid) deficiency as a potential cause of metabolic perturbation and neurodegeneration in Huntington's disease. Metabolites, 9, 113 (2019)
Prakash D, Suri S, Upadhyay G, Singh BN. Total phenol, antioxidant and free radical scavenging activities of some medicinal plants. Int J Food Sci Nutr, 58, 18-28 (2009)
Pramono YB, Nurwantoro, Handayani D, Mulyani S, Wibowo CH. Physical, chemical, stickiness and organoleptic characteristics of analog white sweet potato rice with the addition of pumpkin flours. IOP Conf Ser: Earth Environ Sci, 803, 012039 (2021)
Qazi IM, Rakshit SK, Tran T. Effect of physico-chemical properties of tropical starches and hydrocolloids on rice gels texture and noodles water retention ability. Starch, 63, 558-569 (2011)
Sami R, Li Y, Qi B, Wang S, Zhang Q, Han F, Ma Y, Jing J, Jiang L. HPLC analysis of water-soluble vitamins (B2, B3, B6, B12, and C) and fat-soluble vitamins (E, K, D, A, and β-Carotene) of okra (*Abelmoschus esculentus*). J Chem, 2014, 831357 (2014)
Saud S, Wang D, Fahad S, Alharby HF, Bamagoos AA, Mjrashi A, Alabdallah NM, Al-Zahrani SS, Abd-Elgawad H, Adnan M, Sayyed RZ, Ali S, Hassan S. Comprehensive impacts of climate change on rice production and adaptive strategies in China. Front Microbiol, 13, 926059 (2022)
Schlemmer U, Frølich W, Prieto RM, Grases F. Phytate in foods and significance for humans: Food sources, intake, processing, bioavailability, protective role and analysis. Mol Nutr Food Res, 53, S330-375 (2009)
Shahidi F, Ambigaipalan P. Omega-3 polyunsaturated fatty acids and their health benefits. Annu Rev Food Sci Technol, 9, 345-381 (2018)
Simopoulos AP. The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. Exp Biol Med, 233, 674-688 (2008)
Stuecker MF, Tigchelaar M, Kantar MB. Climate variability impacts on rice production in the Philippines. PLoS One, 13, e0201426 (2018)
Sumardiono S, Budiyono B, Kusumayanti H, Silvia N, Luthfiani VF, Cahyono H. Production and physicochemical

characterization of analog rice obtained from sago flour, mung bean flour, and corn flour using hot extrusion technology. Foods, 10, 3023 (2021)

Sumardiono S, Pudjihastuti I, Poerwoprajitno AR, Suswadi MS. Physichocemical properties of analog rice from composite flour: Cassava, green bean and hanjeli. World Appl Sci J, 32, 1140-1146 (2014)

Tan ZX, Lal R, Wiebe KD. Global soil nutrient depletion and yield reduction. J Sustainable Agric, 26, 123-146 (2005)

Tao K, Yu W, Prakash S, Gilbert RG. High-amylose rice: Starch molecular structural features controlling cooked rice texture and preference. Carbohydr Polym, 219, 251-260 (2019)

Tierney AC, Roche HM. The potential role of olive oil-derived MUFA in insulin sensitivity. Mol Nutr Food Res, 51, 1235-1248 (2007)

Tran TU, Suzuki K, Okadome H, Homma S, Ohtsubo K. Analysis of the tastes of brown rice and milled rice with different milling yields using a taste sensing system. Food Chem, 88, 557-566 (2004)

Turner N, Mitchell TW, Else PL, Hulbert AJ. The ω-3 and ω-6 fats in meals: A proposal for a simple new label. Nutrition, 27, 719-726 (2011)

Usha R, Sreeram KJ, Rajaram A. Stabilization of collagen with EDC/NHS in the presence of l-lysine: A comprehensive study. Colloids Surf B Biointerfaces, 90, 83-90 (2012)

Yee MMF, Chin KY, Ima-Nirwana S, Wong SK. Vitamin A and bone health: A review on current evidence. Molecules, 26, 1757 (2021)

Yin H, Zhang R, Xia M, Bai X, Mou J, Zheng Y, Wang M. Effect of aspartic acid and glutamate on metabolism and acid stress resistance of *Acetobacter pasteurianus*. Microb Cell Fact, 16, 109 (2017)

Zhang P, Hamaker BR. Banana starch structure and digestibility. Carbohydr Polym, 87, 1552-1558 (2012)

https://doi.org/10.11002/fsp.2025.32.1.1