JMBFS
Journal of Microbiology, Biotechnology and Food Sciences
International peer-reviewed scientific online journal
Published by Faculty of Biotechnology and Food Sciences

EFFECT OF TRADITIONAL KALIO AND RENDANG SLOW-COOKING PROCESSES ON THE NUTRITIONAL QUALITY OF RED KIDNEY BEANS (*PHASEOLUS VULGARIS L.*)

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https://doi.org/10.55251/jmbfs.14527

ARTICLE INFO

Received 16. 6. 2026
Revised 9. 8. 2026
Accepted 18. 8. 2026
Published xx.xx.201x

Regular article

OPEN ACCESS

ABSTRACT

Red kidney bean kalio and rendang are popular traditional Indonesian foods traditionally prepared through prolonged slow-cooking. However, information on the nutritional changes occurring in red kidney beans during the production of these products remains limited. This study aimed to evaluate the changes in proximate composition, soluble dietary fiber (SDF), insoluble dietary fiber (IDF), total dietary fiber (TDF), pepsin digestibility, and amino acid profiles during traditional processing into kalio and rendang. The proximate composition changed significantly during processing. Moisture contents of raw beans, kalio and rendang were 16.60%, 55.60%, 41.69%, respectively, while ash contents were 4.25%, 2.25%, 3.65%. Protein content decreased from 24.11% in raw beans to 12.97% in kalio and increased to 14.18% in rendang, whereas fat content decreased from 2.46% to 1.26% and subsequently increased to 5.34%. Carbohydrate content decreased from 52.58% in raw beans to 27.92% in kalio and 35.14% in rendang. On a dry-weight basis, SDF changed from 5.28% in raw beans to 4.56% in kalio and 5.86% in rendang, while IDF increased from 12.57% to 14.67% and 15.89%, respectively, resulting in an increase in TDF from 17.85% to 19.23% and 21.75%. Pepsin digestibility increased from 49.15% in raw beans to 56.05% in kalio and subsequently decreased to 52.62% in rendang. The amino acid profiles of all samples showed a predominance of non-essential amino acids, with methionine identified as the primary limiting amino acid. These findings provide a basis for future studies evaluating functional properties and potential health benefits of kidney bean kalio and rendang.

Keywords: amino acid profile; dietary fiber; kalio; rendang; red kidney beans; traditional processing

INTRODUCTION

Rendang is a traditional dish from West Sumatra, Indonesia, and represents a distinctive element of the Minangkabau ethnic culture. In general, rendang is prepared using animal-based protein, coconut milk, chili, and a variety of spices, which are cooked for an extended period until the product becomes thick, dry, and brownish in color **(Rini *et al.*, 2016)**. Rendang preparation involves two processing stages. The initial cooking stage, produces a product known as kalio, characterized by a semi-moist texture and relatively high moisture content. Continued cooking for a longer duration, results in rendang, which is characterized by a thicker sauce and lower moisture content. Both products are widely consumed in Indonesia, and their characteristics are largely determined by the cooking duration. Over time, rendang has evolved beyond the use of animal-based proteins such as beef, buffalo, and goat and is now also prepared using plant-based protein sources, particularly legumes, including red kidney beans.

In addition to serving as an alternative source of plant-based protein, red kidney bean rendang offers the advantage of preserving the distinctive sensory characteristics of traditional rendang and enhancing its nutritional value by increasing the intake of bioactive compounds and dietary fiber, both of which may provide health benefits. Dietary fiber can promote prolonged satiety and contribute to glycemic control, reduction of blood cholesterol levels, and lower risk of coronary heart disease **(Jayachandran *et al.*, 2023)**. Inadequate fiber intake over the long term may adversely affect the population of bifidobacteria in the gut and contribute to the development of various non-communicable diseases **(Li *et al.*, 2023)**. Red kidney beans contain approximately 22.53% protein, 1.06% fat, and 15.20% dietary fiber, and are rich in minerals, including Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn, and Se, as well as phenolic compounds, predominantly gallic acid, chlorogenic acid, and catechin **(Xu *et al.*, 2022)**.

Various studies have reported changes in the nutritional components, dietary fiber, bioactive compounds, and amino acid composition of different types of legumes as a result of processing, including variations in the pre-processing stages, such as washing, dehulling, and soaking **(Tan and Azrina, 2017; Yalcin and Unsal, 2026)**. Sterilization of canned whole winged bean seeds has been shown to alter soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) composition compared to fresh whole seeds, whereas fermentation, defatting, and protein isolation have been reported to modify the relative amino acid composition of *Parkia biglobosa* seeds **(Aulia *et al.*, 2024; Osunsanmi *et al.*, 2024)**. **King *et al.* (2024)** reported that processing can improve the bioavailability of legume proteins and enhance their functional effectiveness in food products.

Previous studies on kidney beans have also demonstrated that cooking can modify their proximate composition, amino acid composition, and dietary fiber **(Venketeish *et al.*, 2025)**. In parallel, **Rini *et al.* (2016)** reported that traditional kalio and rendang processing alters the proximate composition, protein digestibility, and amino acid profile of beef tenderloin. However, these two research areas have been investigated separately. Information on how the traditional slow-cooking process from kalio to rendang affects plant-based traditional kalio and rendang, particularly those using red kidney beans, which are also among the well-known traditional foods in Indonesia, remains limited. In particular, simultaneous changes in dietary fiber fractions, susceptibility to pepsin-mediated proteolysis, and amino acid composition across the raw, kalio, and rendang stages have not been well characterized. Therefore, this study aimed to evaluate changes in proximate composition, soluble, insoluble, and total dietary fiber, pepsin digestibility, and amino acid composition of red kidney beans during traditional processing into kalio and rendang.

MATERIAL AND METHODS

Materials

Dried whole red kidney beans, used as the main raw material, were obtained from a local market in Padang, Indonesia. Other ingredients used for the preparation of kalio and rendang included coconut milk, red chili, shallots, garlic, ginger, galangal, pepper, coriander, candlenut, grated coconut, and spices and aromatic leaves comprising cloves, cinnamon, star anise, cardamom, turmeric leaves, bay leaves, kaffir lime leaves, and lemongrass, all of which were also purchased from a local market.

Experimental design

The study was conducted using three independently prepared processing batches. Each batch consisted of red kidney beans that were processed into kalio and rendang. For each batch, the dried red kidney beans before soaking were designated as the raw sample. The beans (500 g) used for subsequent processing into kalio and rendang were washed and soaked in water at a ratio of 1:4

(bean:water) for 3.5 h. After soaking, the beans were drained. Kalio and rendang sauce preparation began with mixing fresh red chillies, shallots, garlic, pepper, coriander, and candlenuts, which were then ground using a chopper. The spice mixture was subsequently sautéed in vegetable oil at 120°C for approximately 8 min until aromatic. Ginger, galangal, cloves, cinnamon, star anise, cardamom, turmeric leaves, bay leaves, kaffir lime leaves, lemongrass, and coconut milk were then added, and the mixture was cooked at 90°C for 120 min until the sauce thickened. Thereafter, grated coconut (finely ground and dry roasted) and soaked raw beans were added. Cooking was continued for 90 min until the sauce became thicker and brownish in color, this stage was defined as kalio. The red kidney bean kalio sample (250 g) was then separated, and the remaining mixture was further cooked for 120 min at a reduced temperature of 80°C until the sauce became dry, thick, and dark brown, which was defined as rendang (total cooking time of 210 min). For both the kalio and rendang samples, the red kidney beans were separated from the spice mixture, and all subsequent analyses were conducted only on the bean fractions. The same preparation and cooking procedures were independently applied to all three batches. The formulation and amounts of ingredients used for the preparation of red kidney bean kalio and rendang are provided in Supplementary Table S1. For the proximate analysis, samples were analyzed in their as collected form without prior oven drying and for the determination of dietary fiber, pepsin digestibility, and amino acid profile, the samples were cut into smaller pieces, arranged on drying trays, and oven-dried at 52°C for 24 h. The dried samples were then ground using a blender, passed through a 30-mesh sieve, and stored in a desiccator until further analysis. The three independently prepared batches represented independent processing replicates (n = 3). Samples obtained from the three batches were analyzed separately and not pooled. Each analysis was performed in triplicates.

Determination of proximate composition

The proximate composition of red kidney beans was determined according to the **AOAC (2005)** methods. The moisture content was analyzed gravimetrically by drying the samples in an oven at 105°C for up to 6 h. The protein content was determined using the standard Kjeldahl method with a Kjeltec apparatus. Fat content was measured using the Soxhlet extraction method with hexane as the solvent, and extraction was carried out for 6 h. The ash content was determined by direct incineration in a muffle furnace at a maximum temperature of 550°C until complete ashing was achieved. The carbohydrate content was calculated by difference using the following equation: 100 − (moisture + protein + fat + ash).

Determination of dietary fiber content (SDF, IDF, and TDF)

Dietary fiber analysis was performed using an enzymatic–gravimetric method on the defatted samples. Briefly, 1 g of the sample was placed in an Erlenmeyer flask, followed by the addition of 40 mL MES/TRIS buffer (pH 8.2) and 0.05 mL thermostable α-amylase. The mixture was incubated in a water bath at 95°C for 30 min and then cooled to 60°C. Subsequently, 0.1 mL of protease was added, and the mixture was incubated again at 60°C for 30 min. After cooling, 5 mL of 0.561 N HCl was added to adjust the pH to 4.0–4.5, followed by the addition of 0.3 mL amyloglucosidase and further incubation at 60°C for 30 min. To determine IDF, 225 mL of 95% ethanol preheated to 60°C was added to the mixture, which was then allowed to stand for 60 min before filtration through a pre-weighed filter paper. The residue was washed sequentially with 78% ethanol, 95% ethanol, and acetone and then dried at 105°C to a constant weight. The dried residue was corrected for residual protein and ash content, and the IDF value was calculated based on the corrected residue weight relative to the initial sample weight. The filtrate obtained from the IDF determination was diluted to 70 mL, followed by the addition of 279 mL of 95% ethanol at 60°C, and allowed to stand for 60 min to precipitate the SDF fraction. The SDF residue was then filtered, washed, dried, and corrected for protein and ash content in the same manner as described for IDF. TDF was calculated as the sum of IDF and SDF according to **AOAC 991.43 (1995)**.

In vitro pepsin digestibility analysis

In vitro pepsin digestibility was determined according to the method described by **Andualem and Gessesse (2013)** with slight modifications, using a pepsin digestibility test as a preliminary comparative approach to determine whether traditional processing altered the susceptibility of red kidney bean protein to pepsin-mediated hydrolysis. Pepsin was dissolved in 0.1 M HCl to obtain a final concentration of 1.5 mg/mL. A 250 mg sample was then suspended in buffer, followed by the addition of pepsin solution. The suspension was incubated at 37°C for 24 h to allow protein hydrolysis during the pepsin digestion phase. After incubation, the reaction was terminated by neutralization or by adding 10% TCA. The filtrate was collected, and its protein content was determined using the Kjeldahl method to quantify the soluble protein fraction. Pepsin digestibility was expressed as the percentage ratio of soluble protein after hydrolysis to the initial total protein content.

Amino acid profiling

Amino acid profiling was performed using high-performance liquid chromatography (HPLC). Sample preparation was initiated by adding 5 mL of 6 N HCl to 0.1 g of the sample. The mixture was then hydrolyzed at 112°C for 22 h. After hydrolysis, the solution was cooled and diluted to a final volume of 25 mL using distilled deionized water. The solution was subsequently diluted twofold and filtered through a 0.22 µm PTFE syringe membrane filter. For derivatization, 70 µL of borate buffer was mixed with 10 µL of the filtered sample solution and 20 µL of AccQ-Fluor reagent was added. The resulting mixture was incubated at 55°C for 10 min. The same procedure was applied to the standard solutions. Amino acid analysis was performed using an HPLC system equipped with a fluorescence detector (FLD) and a C18 column (3.9 × 150 mm). The mobile phase consisted of acetonitrile and eluent A, delivered at a flow rate of 0.8 mL/min. A sample volume of 2.5 µL was injected, and the column temperature was maintained at 40°C. Amino acids were quantified by comparing the chromatographic peak areas of the samples with those of the standards, and the amino acid content was expressed as a percentage (%) **(Khayour *et al*., 2023)**.

Data Analysis

Statistical analysis was performed using SPSS version 21. Data were analyzed by one-way analysis of variance (ANOVA), followed by Duncan's multiple range test when significant differences were observed among samples at a 95% confidence level ($p < 0.05$).

RESULTS AND DISCUSSION

Proximate composition

The proximate composition of the kidney beans showed significant differences ($p < 0.05$) among the raw, kalio-cooked, and rendang-cooked treatments **(Figure 1 and Table S2)**. These differences indicate that traditional kalio and rendang processing significantly alters the composition of red kidney beans. In this study, the moisture content of raw kidney beans was 16.60%, which significantly increased to 55.60% in the kalio kidney beans. Compared with the raw beans, this represented a 234.94% increase in the moisture content. This increase was attributed to the soaking process prior to the preparation of kalio and rendang. The raw material used in this study was dried raw kidney beans, which are commonly available in local Indonesian markets. Soaking is part of the traditional processing step in the preparation of kalio and rendang kidney beans. The soaking process promotes water absorption, leading to the hydration and softening of the seed tissues. In addition, cooking in a coconut milk and spice-based medium may further enhance liquid absorption into the seed matrix **(Da Silva *et al*., 2018; Koriyama and Kasai, 2019)**. This may explain the higher moisture content observed in kalio kidney beans compared to the other samples, as kalio is characterized by a moist texture with a thick coconut milk-based sauce that has not undergone further drying. The moisture content of the rendang kidney beans decreased to 41.69% compared to that of the kalio kidney beans. Nevertheless, the moisture content of rendang remained 151.14% higher than that of the raw beans. This reduction was due to further cooking from kalio to rendang, resulting in greater water evaporation. Rendang is cooked for a long period until the sauce is reduced, the spices become concentrated, and some water is lost through evaporation. In general, prolonged heating reduces moisture content and increases the concentration of solids in food products **(Venketeish *et al*., 2025)**.

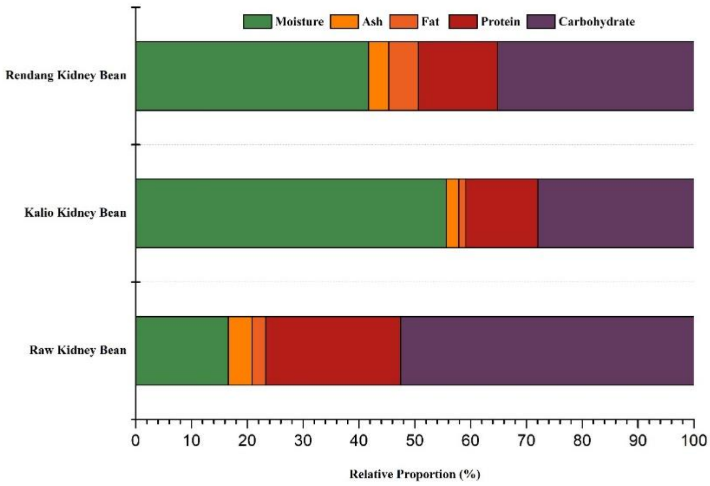

Figure 1 Relative proportion of proximate composition in raw, kalio, and rendang red kidney beans

Ash and protein contents showed a similar pattern, with the highest values observed in raw kidney beans (4.25% for ash and 24.11% for protein), whereas the lowest values were observed in kalio kidney beans (2.25% and 12.97%, respectively). Compared with raw kidney beans, the ash content decreased by 47.06% in kalio and 14.12% in rendang, whereas the protein content decreased by 46.20% and 41.19%, respectively. For fat content, the highest value was observed in rendang kidney beans (5.34%), followed by raw kidney beans (2.46%) and kalio kidney beans (1.26%). Relative to the raw beans, the fat content decreased by 48.78% in kalio but increased by 117.07% in rendang. The reduction in ash, protein, and fat content after processing into kalio may be attributed to soaking and wet cooking, which can promote the leaching of water-soluble minerals, soluble nitrogenous compounds, or simple proteins into the soaking water and cooking medium, as well as the possible losses or degradation of lipid components **(Huma *et al*., 2008; Roy *et al*., 2021)**. In contrast, the ash, protein, and fat contents were higher in the rendang kidney beans than in the kalio kidney beans. This increase was likely associated with moisture reduction and concentration effects resulting from water evaporation during prolonged cooking. In particular, the higher fat content of the rendang kidney beans may be due to the longer cooking process involving coconut milk. During rendang cooking, coconut milk becomes concentrated, and water evaporates, making the lipid fraction dominant. Coconut milk is a fat-rich ingredient, and its use during cooking, along with water evaporation, can increase the fat content of the final product **(Abdullah *et al*., 2022)**.

The high fat content observed in rendang kidney beans in this study is consistent with the findings of **Rozi *et al*. (2025)** on rendang tempeh production, in which rendang had the highest fat content compared to the gulai and kalio stages, due to concentration effects during prolonged cooking. A similar trend was observed for carbohydrate content, which decreased in kalio kidney beans compared with the raw kidney beans but increased again in rendang kidney beans. Relative to raw kidney beans, the carbohydrate content decreased by 46.90% in kalio and 33.17% in rendang. In this study, the carbohydrate content was calculated by difference; therefore, its value was influenced by changes in other proximate components. Soaking and wet cooking may also promote the solubilization and leaching of soluble carbohydrate fractions into the soaking water and cooking medium. The greater carbohydrate loss observed in this study is also in line with **Huma *et al.* (2008)**, who reported that cooking caused greater sugar losses than mineral and protein losses in legumes.

Dietary fiber content (SDF, IDF, TDF)

All samples showed significant differences ($p < 0.05$) in SDF, IDF, and TDF contents as affected by processing, except for IDF, in which red kidney bean kalio and rendang did not differ significantly on a dry-weight basis (DW) ($p > 0.05$) **(Table 1)**. The processing up to the rendang stage caused fluctuations in the SDF content. On a DW basis, the SDF content of raw red kidney beans decreased after cooking to the kalio stage but increased again during further cooking to rendang, where it reached the highest value among all samples. In contrast, IDF and TDF tended to increase progressively as red kidney beans were processed from the raw state to kalio and rendang.

Table 1 Dietary fiber fractions (SDF, IDF, and TDF) and pepsin digestibility of raw, kalio, and rendang red kidney beans

Sample	SDF (%)		IDF (%)		TDF (%)		Pepsin Digestibility (%)
	(DW)	(FW)	(DW)	(FW)	(DW)	(FW)	
Raw	5.28±0.11^{b}	4.40±0.09c	12.57±0.06^{a}	10.49±0.04^{c}	17.85±0.06^{a}	14.89±0.06^{c}	49.15±1.39^{a}
Kalio	4.56±0.17^{a}	2.02±0.08^{a}	14.67±1.16^{b}	6.51±0.50^{a}	19.23±1.04^{b}	8.54±0.43^{a}	56.05±1.24^{c}
Rendang	5.86±0.09^{c}	3.42±0.05^{b}	15.89±0.14^{b}	9.26±0.08^{b}	21.75±0.22^{c}	12.69±0.13^{b}	52.62±1.67^{b}

The data are presented as mean ± standard deviation (SD). Different superscript letters within the same column indicate significant differences ($p < 0.05$). DW: dry-weight basis; FW: fresh-weight basis.

The decrease in SDF during the kalio cooking stage may be attributed to the semi-moist characteristics of kalio, which are associated with a shorter cooking duration and relatively high moisture content, thereby allowing the release and degradation of the SDF. SDF degradation may produce smaller fragments and promote the solubilization of polysaccharides from the SDF fraction **(Dueñas *et al*., 2016)**. On the other hand, the cooking process may alter the cell wall structure through the depolymerization and solubilization of hemicellulose and insoluble pectic substances **(Magallanes López *et al*., 2024)**, which may explain the increase in SDF during further cooking to the rendang stage. Similar decreases in SDF after cooking have also been reported in red kidney beans and lentils **(Dueñas *et al*., 2016; Tan and Azrina, 2017)**, whereas increases in SDF due to cooking have been observed in yellow and winged beans **(Aulia *et al*., 2024)**.

On a DW basis, the increase in the measured IDF after processing in this study may reflect changes in the insoluble fraction induced by prolonged cooking. Cooking can induce protein unfolding, thereby facilitating interactions between proteins and other components such as dietary fiber **(Wang *et al*., 2010)**. In addition, cooking-induced disruption of the bean cell wall structure may increase IDF content **(Chauhan *et al*., 2024)**. **Sadohara *et al.* (2025)** reported a positive correlation between IDF content and cooking time in beans, with beans requiring less than 20 min of cooking (fast-cooking) exhibiting lower IDF content than those requiring more than 30 min (slow-cooking). In the present study, changes in the composition of SDF and IDF affected the resulting TDF content, which increased significantly from 17.85% in raw beans to 19.23% in kalio and 21.75% in rendang samples. A high dietary fiber content, particularly IDF, is advantageous because of its associated health benefits, including improved gut microbiota development and a reduced risk of cardiovascular disease and diabetes **(Liu *et al*., 2024)**. Changes in dietary fiber components depend on the composition of the cell wall matrix and the type of processing applied, including temperature, pressure, shear force, and chemical modification **(Yu *et al*., 2025)**.

In contrast, on an FW basis, raw kidney beans showed the highest SDF, IDF, and TDF contents, whereas kalio exhibited the lowest values. The lower FW values observed in kalio were associated with its substantially higher moisture content. Further cooking from kalio to rendang reduced the moisture content, resulting in higher FW dietary fiber values in the rendang. The FW results represent the dietary fiber content of the products in their as-consumed form.

In vitro pepsin digestibility

Pepsin digestibility was evaluated to assess the susceptibility of proteins to initial proteolysis following traditional processing into kalio and rendang. This assay was not intended to represent intestinal absorption capacity but served as a comparative indicator of processing-induced changes in protein susceptibility to gastric proteolysis. The pepsin digestibility values of raw red kidney beans, red kidney bean kalio, and red kidney bean rendang are presented in **Table 1**. Significant differences ($p < 0.05$) were observed among the samples, with the highest pepsin digestibility found in the kalio sample, followed by the rendang and raw red kidney bean samples. These results indicate that traditional processing significantly affects the susceptibility of red kidney bean proteins to pepsin-mediated hydrolysis under the assay conditions. Pepsin digestibility increased after cooking, with the kalio treatment showing an increase of 14.04%, while the rendang treatment showed an increase of 7.06% compared to that of raw red kidney beans. This increase in pepsin digestibility suggests that thermal processing may enhance protein accessibility to proteolytic enzymes through protein denaturation, cellular matrix weakening, and antinutritional factor inactivation **(Duijsens *et al*., 2023; King *et al*., 2024)**.

Red kidney bean rendang exhibited lower pepsin digestibility than kalio, which may be attributed to the longer cooking duration during rendang processing, allowing the formation of new protein complexes with other compounds due to protein aggregation, thereby increasing the resistance of the protein to digestion. Heat treatment under moist conditions may also induce gelatinization and promote cross-linking between proteins and starch, resulting in a complex matrix structure **(Ohanenye *et al*., 2022)**. These findings indicate that prolonged and intensive heating at high temperatures does not necessarily lead to a linear increase in the protein susceptibility to pepsin-mediated proteolysis **(Drulyte and Orlien, 2019)**. The pepsin digestibility values observed in this study ranged from 49.15% to 56.05%, which are considerably lower than the protein digestibility values obtained using two or more enzymes that involve both the gastric and intestinal phases of digestion. Significant improvements in protein digestibility following processing have also been reported for treatments such as baking, cooking, and extrusion of black, faba, pinto, and red kidney beans **(Nosworthy *et al*., 2018)**. In contrast, **Andualem and Gessesse (2013)** reported a decrease in protein digestibility after cooking defatted brebra flour, both in terms of pepsin digestibility (from 72.4% to 55.1%) and pepsin-pancreatin digestibility (from 97.2% to 69.1%). Textured vegetable proteins composed of various mixtures of faba beans, peas, quinoa, oats, and hemp showed pepsin digestibility values of only 3.80%-4.17% after 1 h of digestion **(Duque-Estrada *et al*., 2023)**, which are substantially lower than those obtained in the present study. This difference may be attributed to variations in incubation time, as the present study employed a digestion time of 3 h. During gastric digestion, pepsin hydrolyzes proteins into long polypeptide chains, shorter peptide fragments, and small amounts of free amino acids **(Joye, 2019)**.

Amino acid profile

The amino acid profiles of raw red kidney beans, red kidney bean kalio, and red kidney bean rendang are shown in **Figure 2**. In general, the results showed that non-essential amino acids predominated in red kidney beans, with glutamic and aspartic acids present at the highest levels. In addition, several essential amino acids, particularly leucine and valine, were found at relatively higher levels than those of other essential amino acids. The glutamic acid content ranged from 4.29% to 4.46%, with the highest value observed in raw red kidney beans (4.46%), followed by a slight decrease after processing to 4.42% in kalio and 4.29% in rendang samples. Glutamic acid is commonly one of the predominant non-essential amino acids in legumes and serves as a metabolic precursor for γ-aminobutyric acid (GABA) through the glutamate decarboxylase pathway, as demonstrated in several legumes **(Carbas *et al*., 2020; Jiang *et al*., 2021).** A similar pattern was observed for several other amino acids, such as serine and tyrosine, which tended to decrease after the processing. In contrast, certain amino acids, such as alanine, showed an increasing trend, from 1.57% in raw beans to 2.36% in kalio and 2.64% in rendang. Among the essential amino acids, leucine ranged from 2.07% to 2.48%, with values of 2.45% in raw beans, 2.48% in kalio, and 2.07% in rendang. Valine ranged from 2.13% to 2.31% and remained relatively stable across treatments, whereas lysine decreased from 1.87% in raw beans to 1.86% in kalio and 1.69% in rendang. The complete quantitative amino acid data and statistical differences among the raw, kalio, and rendang samples are provided in Supplementary Table S3.

The observed decrease and increase in amino acid levels in this study indicate that the amino acid composition was altered by heat treatment. Changes in amino acid composition during heating may occur as a result of protein structural modifications and Maillard reactions during prolonged thermal processing. Heat treatment can modify nitrogen-containing compounds, including the formation of bonds between side chains, thereby altering amino acid composition **(Słupski *et al*., 2010)**. However, processing may reduce the activity of protease inhibitors, thereby facilitating more effective protein breakdown into amino acids **(Venketeish *et al*., 2025)**.

During prolonged cooking, such as in rendang preparation, Maillard reactions may occur, leading to reductions in certain amino acids, particularly lysine, whereas other amino acids that are more heat-stable may remain less affected. On the other hand, the increase in certain amino acids, such as alanine, may also be associated with their thermal stability and compositional changes in the seed matrix during processing, resulting in a concentration effect. **Han *et al*. (2025)** reported that dry-heat processing resulted in more pronounced increases in several amino acids than moist-heat processing, which was attributed to protein unfolding and substantial moisture loss, thereby increasing their concentrations. Similar findings have been reported, in which wet heat treatments, such as boiling and pressure cooking, reduced both essential and non-essential amino acids, whereas dry heat processing, such as roasting, tended to increase the levels of essential amino acids **(Cargo-Froom *et al*., 2020)**. Sulfur-containing amino acids, namely methionine and cysteine, showed the lowest concentrations and the most pronounced decrease after processing. Methionine content ranged from 0.05% to 0.09%, decreasing from 0.09% in raw beans to 0.06% in rendang, while cysteine decreased from 0.79% in raw beans to 0.29% in rendang. The reduction in sulfur amino acids is particularly important because methionine and cysteine are generally the limiting amino acids in legume proteins, and their reduction may constrain the biological quality of proteins, even when the overall protein digestibility increases **(Carbonaro and Nucara, 2022)**. In the present study, methionine was identified as the primary limiting amino acid, and together with cysteine, it indicated that the sulfur amino acid group was the most affected by thermal processing.

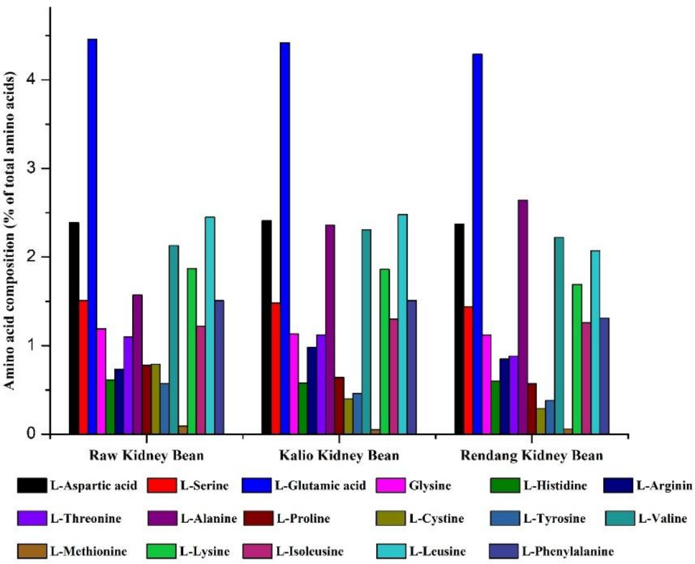

Figure 2 Amino acid profile of raw, kalio, and rendang red kidney beans

CONCLUSION

Processing red kidney beans into kalio and rendang resulted in significant changes in their chemical composition, amino acid composition, and susceptibility to pepsin-mediated proteolysis. Cooking into kalio increased the moisture content but reduced the other proximate components, whereas further cooking into rendang decreased the moisture content and increased the proportions of ash, protein, fat, and carbohydrate. On a dry-weight basis, IDF and TDF increased significantly following processing, while SDF decrease in kalio and subsequently increased in rendang, which showed the highest values for all dietary fiber fractions. Susceptibility to pepsin-mediated proteolysis improved following processing, with the highest pepsin digestibility observed in kalio compared with rendang and raw red kidney beans. The amino acid profile was dominated by non-essential amino acids, and methionine was identified as the primary limiting amino acid, the levels of which decreased after heating. Based on these findings, the processing conditions for red kidney bean kalio and rendang should be considered according to the desired nutritional characteristics, as kalio stage resulted in higher susceptibility to pepsin-mediated proteolysis, whereas further processing into rendang resulted in higher dietary fiber content on a dry-weight basis. However, the functional implications of these properties in relation to their health benefits were not evaluated in the present study. Therefore, further studies are needed to assess changes in bioactive compounds, metabolic responses, and glycemic index resulting from the processing of kalio and rendang.

Acknowledgments: The authors express their gratitude to the Institute for LPPM of Universitas Andalas for funding this research (Contract No. 63/UN16.19/PT.01.03/PDP/2025) for the 2025 fiscal year.

Declarations Conflict of interest: The authors declare no competing interests.

Compliance with ethics requirements: This study does not contain any studies with human participants or animals performed by any authors.

Availability of data and material: The datasets generated during the current study are made available by the corresponding author upon reasonable request.

Code availability: Not applicable

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