



Optimization of Palm Kernel Cake and Cassava Byproduct Fermentation with the Addition of Minerals and Varying Fermentation Durations as Alternative Poultry Feedstuff

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Abstract | This study aims to produce the best fermented product from a mixture of palm kernel cake (PKC) and cassava byproduct (CB) by optimizing the addition of minerals and fermentation duration. The fermentation experiment was designed using a Completely Randomized Design with a 4x6 factorial pattern with three replications for each treatment combination. The first factor was the level of mineral addition (M0 = no mineral addition, M1 = mineral addition with the composition: 2.5 g KCl, 12.5 g ZA, 7.5 g urea, and 2.5 g NPK, M2 = mineral addition with the composition: 5 g KCl, 25 g ZA, 15 g urea, and 5 g NPK, and M3 = mineral addition with the composition: 7.5 g KCl, 37.5 g ZA, 22.5 g urea, and 7.5 g NPK), the second factor was fermentation duration (D0 = 0, D1 = 24, D2 = 48, D3 = 72, D4 = 96, and D5 = 120 hours). The results showed that the best combination for producing the fermented product was the mineral addition level M2 with the composition: 5 g KCl, 25 g ZA, 15 g urea, and 5 g NPK, and the fermentation duration D2 (48 hours). This combination resulted in a product with a high crude protein content of 23.56%, low crude fiber content of 8.83%, low crude fat content of 3.6%, and a fairly high metabolizable energy content of 3,029.33 kcal. The fermented products from this research are expected to be used as non-conventional alternative feedstuff to be tested as feedstuff for various types of poultry.

Keywords | Mineral addition level, Fermentation duration, Palm kernel cake, Cassava byproduct, *Aspergillus niger*, Nutrient value

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INTRODUCTION

One of the problems in the poultry farming industry in Indonesia is the high cost of poultry feed. This is due to approximately 35% of poultry feed ingredients still being reliant on imports. One way to address this issue is by utilizing the potential of by-products from agro-industrial processing, namely palm kernel cake (PKC) and cassava byproduct (CB).

PKC is recognized for its protein-rich composition, ranging from 11.30% to 17.00%. Despite its elevated protein content, this byproduct also contains considerable amounts of crude fat or ether extract (EE) and crude fiber (CF), with values ranging from 4.50% to 17.00% and 16% to 23%, respectively. The substantial CF content in PKC poses a significant challenge for its utilization in poultry feed due to potential digestibility issues (Kompiani *et al.*, 1997; Ahmad *et al.*, 2014; Azizi *et al.*, 2021; Ababor *et al.*, 2023).

Furthermore, the high fat content in PKC may lead to rancidity, affecting the feedstuff's shelf life.

On the other hand, CB presents potential as poultry feedstuff owing to its relatively high carbohydrate or starch content (Chauynarong *et al.*, 2009; Bhuiyan and Iji, 2015; Morgan and Choct, 2016; Abouelezz *et al.*, 2018; Abouelezz *et al.*, 2022). Cassava byproduct's metabolizable energy (ME) content falls within the range of 2562-4562 kcal/kg (Jiwuba *et al.*, 2021; Diarra and Devi, 2015; Adeleye *et al.*, 2021). However, its low crude protein (CP) content, approximately 1.6-2.5%, presents a challenge when considering its use as animal feedstuff (Egbune and Tonukari, 2023; Aro, 2008; Lukuyu *et al.*, 2014; Kompiang, 1994; Morgan and Choct, 2016).

Efforts to overcome the limitations of PKC and CB involve processing the mixture of these two materials using fermentation technology with *Aspergillus niger*. The mold *Aspergillus niger*, known for thriving on substrates rich in starch, has the potential to utilize the starch in CB as an energy source for its growth. Optimal mold growth is expected to result in the production of significant amounts of cellulase and lipase enzymes. These enzymes can break down and reduce the levels of CF and EE in PKC. Therefore, the combination of PKC and CB is anticipated to create a suitable medium for effective fermentation by *Aspergillus niger*, enhancing the nutritional value of the mixed substrate.

The addition of minerals during the fermentation process, along with the duration of fermentation, plays a crucial role in influencing the nutritional quality of the fermentation product. Previous research by Nurhayati *et al.* (2006) demonstrated that fermenting a mixture of 75% PKC and 25% CB using *Aspergillus niger* with specific mineral additions (5 g KCl, 25 g ZA, 15 g urea, and 5 g NPK) and a 60-hour fermentation duration could improve nutritional value, yielding CP 28%, ME 3113 kcal, EE 2.28%, CF 15.1%, and Ash 6.73%. Additionally, Nurhayati (2007) noted that fermenting a mixture of 80% PKC and 20% CB with reduced mineral amounts (2.5 g KCl, 12.5 g ZA, 7.5 g urea, and 2.5 g NPK) and a 72-hour fermentation duration resulted in a product with CP 20%, ME 2780 kcal, EE 6.47%, CF 8.5%, and ash 6.23%.

Given the above considerations, further investigation is needed to explore the influence of mineral addition and fermentation duration on the nutritional value of the PKC and CB mixture. This study aimed to enhance the nutritional value of the PKC and CB mixture through fermentation technology, optimizing mineral addition and fermentation duration. Thus, the objective of this research was to determine the effects of different mineral additions and fermentation durations, as well as the interaction between

these treatments, to produce the best fermentation product in terms of high CP, low CF, low EE, and high ME, as an alternative poultry feedstuff.

MATERIALS AND METHODS

Before the fermentation experiment began, the substrate consisting of a mixture of 75% PKC and 25% CB was homogenously blended. Subsequently, the substrate was fermented with *Aspergillus niger* using the guideline of Nurhayati *et al.* (2006). The observed variables included the nutritional content of the mixed PKC and CB before and after fermentation, covering ash content, CP, EE, CF (AOAC, 1984), and ME (Patrick and Schaible, 1980).

The data from the proximate analysis (ash content, CP, EE, CF), and ME were tabulated and analyzed for variance using a Completely Randomized Design (CRD) with a 4x6 factorial pattern. The first factor was the level of mineral addition (M0 = without mineral addition, M1 = mineral addition with composition: 2.5 g KCl (potassium chloride), 12.5 g ZA (ammonium sulfate), 7.5 g urea, and 2.5 g NPK (combination of nitrogen phosphorus potassium), M2 = mineral addition with composition 5 g KCl, 25 g ZA, 15 g urea, and 5 g NPK, and M3 = mineral addition with composition 7.5 g KCl, 37.5 g ZA, 22.5 g urea, and 7.5 g NPK), and the second factor was fermentation duration (D0 = 0 hours, D1 = 24 hours, D2 = 48 hours, D3 = 72 hours, D4 = 96 hours, and D5 = 120 hours). The randomization process was performed by assigning a unique number to each experimental unit, which were then randomized using a computer-generated random number sequence. Each treatment combination was replicated three times, with replicates randomly assigned to different experimental units to minimize bias. If there was an interaction between treatments, a simple effect test was conducted for each treatment combination. If there was no interaction between treatments, the test was carried out for the main effects of each factor (Dakhlan, 2019). Further tests for simple or main effects were conducted using Duncan's Multiple Range Test (DMRT) according to the instructions of Dakhlan (2019). In our study, we followed steps such as normality test (Shapiro-Wilk test), homogeneity of variances (Levene's Test), and ANOVA before applying DMRT. Data analysis was performed with the help of R program (R Core Team, 2023; Dakhlan, 2019).

RESULTS AND DISCUSSION

This laboratory experiment aimed to determine the optimal mineral addition level and fermentation duration to produce a fermented product with the highest quality in terms of high CP and ME, as well as low CF and EE content. The research results indicated that the mineral addition level M2 with a composition of 5 g KCl, 25 g ZA, 15 g

urea, and 5 g NPK, and a fermentation duration of D2 (48 hours) was the best combination for producing a fermented product. This is evidenced by the high CP content of 23.56%, low CF content (8.83%), low EE content (3.6%), and sufficiently high ME content of 3,029.33 kcal.

THE EFFECT OF TREATMENT ON ASH CONTENT

The research findings regarding the impact of mineral addition levels and fermentation duration on ash content of the fermented product mixture of PKC and CB are presented in Table 1 and Figure 1.

Table 1: The influence of mineral addition levels (M) and fermentation duration (D) on ash content of fermented product (%).

Duration of fermentation	Mineral addition levels				Average
	0	1	2	3	
0	3.83 ^a	4.02 ^a	3.97 ^a	4.02 ^a	3.96
1	3.85 ^a	3.44 ^a	5.05 ^c	4.72 ^b	4.27
2	3.94 ^a	4.98 ^b	6.00 ^d	4.00 ^a	4.73
3	4.01 ^a	5.27 ^c	4.62 ^b	5.00 ^c	4.73
4	4.15 ^b	5.02 ^c	7.00 ^e	5.00 ^c	5.29
5	4.99 ^c	6.06 ^d	7.05 ^e	5.49 ^c	5.90
Average	4.13	4.80	5.62	4.71	

Note: Different superscripts across rows and columns indicate significant differences ($P < 0.01$).

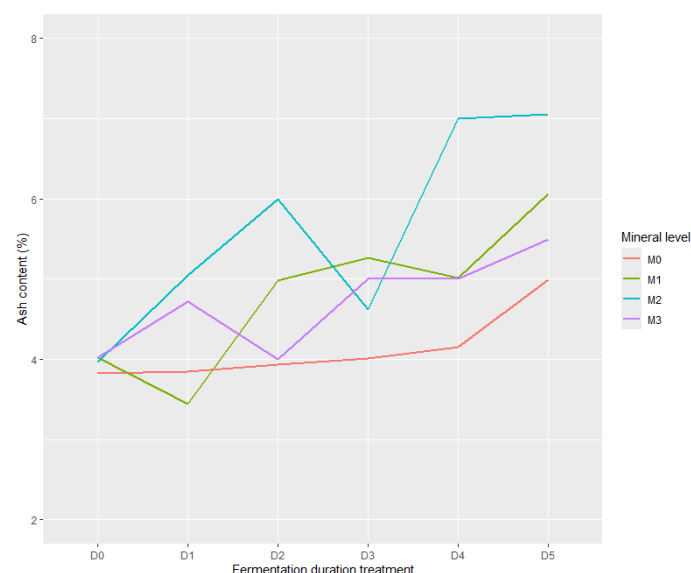


Figure 1: Ash content of fermented product with different fermentation duration and mineral levels.

The data in Table 1 and Figure 1 show that the treatment combination M2D5 (mineral addition level with the composition of 5 g KCl, 25 g ZA, 15 g urea, and 5 g NPK, and fermentation duration of 5 days) produced the fermented product with the highest ash content (7.05%), while the lowest was the combination M1D1 (3.44%). Variance analysis results indicate an interaction between mineral

addition level and fermentation duration ($P < 0.01$) on ash content. The research findings suggest that the longer the fermentation duration and the higher level of mineral addition, the higher the ash content of the fermented product. This is consistent with previous researchers, such as Affah *et al.* (2023), Lubis *et al.* (2007), Naing *et al.* (2019), and Altop *et al.* (2023), who reported that during 5-day and 7-day fermentations, respectively, there was an increase in the ash content of the fermented substrate. This increase in ash content is due to the accumulation of minerals by *Aspergillus niger* during fermentation (Altop *et al.*, 2023). Furthermore, the research results also indicate that higher levels of mineral addition tend to increase the ash content of the PKC and CB mixture up to the M2 treatment level. Abdullah *et al.* (2018) stated that macro and micro minerals are necessary for microbial growth, leading to increased *Aspergillus niger* biomass and resulting in higher mineral accumulation. The decrease in ash content in the M3 treatment is attributed to the slower fermentation process due to excessive mineral addition, which is suspected to be toxic and thus inhibit the growth and development of *Aspergillus niger* biomass.

THE EFFECT OF TREATMENT ON CRUDE PROTEIN (CP) CONTENT

The research outcomes concerning the influence of mineral addition levels (M) and fermentation duration (D) on crude protein (CP) content of fermented product are presented in Table 2 and Figure 2.

Table 2: The influence of mineral dosage (M) and fermentation duration (D) on crude protein (CP) content (%).

Duration of fermentation	Mineral addition levels				Average
	0	1	2	3	
0	9.13 ^a	15.02 ^b	15.37 ^b	17.14 ^c	14.17
1	15.51 ^b	16.87 ^{bc}	17.39 ^c	17.63 ^c	16.85
2	16.72 ^{bc}	20.89 ^e	23.56 ^f	17.33 ^c	19.63
3	17.27 ^c	20.86 ^e	21.19 ^e	18.33 ^d	19.41
4	17.20 ^c	18.52 ^d	21.42 ^e	18.30 ^d	18.86
5	16.81 ^{bc}	18.83 ^d	21.14 ^e	20.32 ^e	19.27
Average	15.44	18.50	20.01	18.18	

Note: Different superscripts across rows and columns indicate significant differences ($P < 0.01$).

The data in Table 2 and Figure 2 show that the combination of mineral addition level M2 with a fermentation duration of 2 days (D2) produced the fermented product with the highest crude protein (CP) content (23.56%), while the lowest was the combination M0D0 (9.13%). Variance analysis results indicate an interaction between the level of mineral addition and fermentation duration ($P < 0.01$) on the CP content of the fermented product. The research findings suggest that higher levels of mineral addition and

longer fermentation durations result in a fermented product with increasingly higher CP content, with the fastest rate of CP increase observed in the M2D2 treatment.

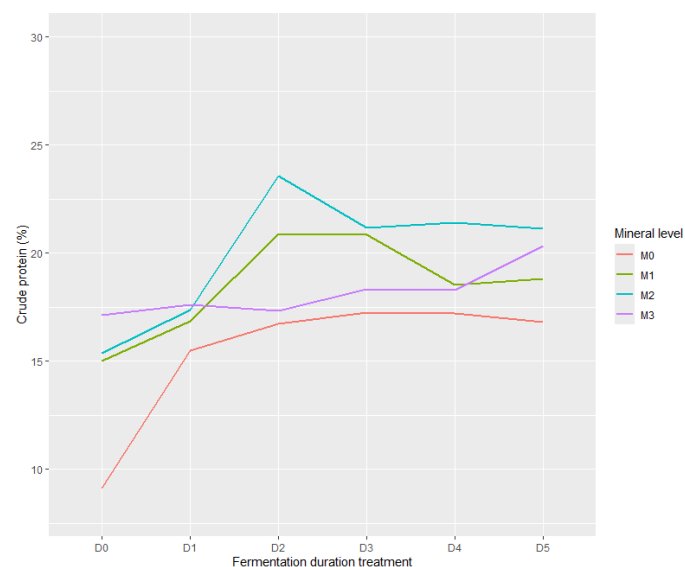


Figure 2: Crude protein content of fermented product with different fermentation duration and mineral levels.

This indicates maximal mold growth, which is a source of single-cell protein. The increase in CP can also be caused by the presence of enzymes produced by microbes. The greater the number of microbes, the more enzymes in the form of proteins and single-cell proteins are produced (Wardono *et al.*, 2021). This maximal mold growth is due to the availability of nutrients from optimal mineral addition. The addition of macro minerals such as carbon, nitrogen, phosphorus, and sulphur, and various other trace minerals, is necessary for the growth of *Aspergillus niger* (Ikram-ul-Haq *et al.*, 2002). Additionally, according to Pasaribu *et al.* (2019), the availability of minerals such as urea, ZA, KCl, FeSO_4 , and NaH_2PO_4 in the fermentation medium of PKC supports more optimal microbial growth. The fungus can synthesize protein by utilizing a carbon source from carbohydrates (glucose, sucrose, and maltose), a nitrogen source from inorganic or organic material, and minerals from its substrate (Kurniati *et al.*, 2017). Regarding the fermentation duration treatment, the results of this study are consistent with the study by Sitindaon *et al.* (2021), which stated that different fermentation durations can increase the nutrient content of PKC. The crude protein content of PKC tends to increase with longer fermentation durations, reaching its maximum at the optimal fermentation duration, and then decreases with further extension of the fermentation period. The optimal fermentation duration in this study was 48 hours, with the highest CP content of 19.63%.

THE EFFECT OF TREATMENT ON CRUDE FAT OR EXTRACT ETHER (EE) CONTENT

The research findings on the effect of mineral addition lev-

els and fermentation duration on the crude fat content of the fermented product mixture of PKC and CB are presented in Table 3 and Figure 3.

Table 3: The influence of mineral addition levels (M) and fermentation duration (D) on crude fat (ether extract = EE) of fermented product (%).

Duration of fermentation	Mineral addition levels				Average
	0	1	2	3	
0	9.70 ^d	10.00 ^d	10.30 ^e	11.00 ^e	10.25
1	9.40 ^d	9.13 ^d	7.50 ^e	9.30 ^d	8.83
2	7.60 ^e	7.30 ^c	3.60 ^{ab}	8.40 ^d	6.73
3	7.20 ^e	7.01 ^c	2.40 ^a	9.00 ^d	6.40
4	6.01 ^{bc}	5.00 ^b	2.53 ^a	6.30 ^{bc}	4.96
5	6.00 ^{bc}	4.00 ^b	1.83 ^a	5.00 ^b	4.21
Average	7.65	7.07	4.69	8.17	

Note: Different superscripts across rows and columns indicate significant differences ($P < 0.01$).

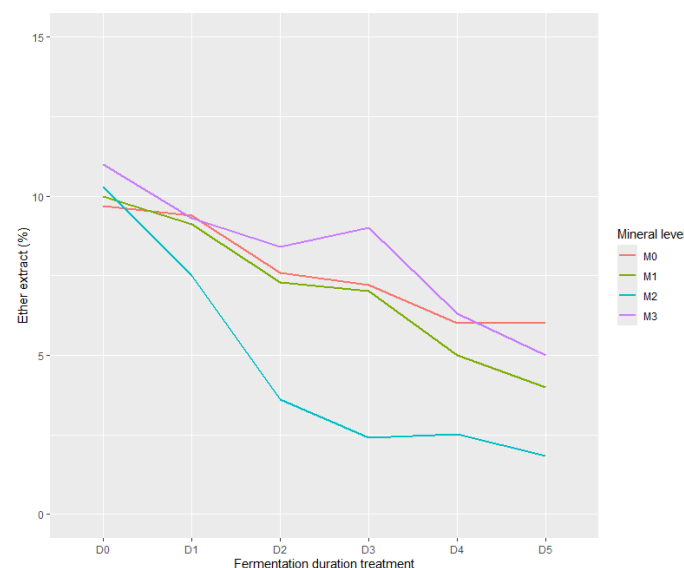


Figure 3: Ether extract content of fermented product with different fermentation duration and mineral levels.

The data in Table 3 and Figure 3 show that the combination of mineral addition level with the composition of 7.5 g KCl, 37.5 g ZA, 22.5 g urea, and 7.5 g NPK, and a fermentation duration of 0 days (M3D0) resulted in the fermented product with the highest EE content (11.00%), while the lowest was the combination M2D5 (1.83%). Variance analysis results indicate an interaction between the level of mineral addition and fermentation duration ($P < 0.01$) on the EE content. The research findings suggest that higher levels of mineral addition and longer fermentation durations result in a fermented product with a decreasing EE content. This is consistent with the findings of Ihtifazhuddin *et al.* (2016), who reported that fermentation duration significantly affects the decrease in EE content of Soybean Husk substrate. The lowest EE content was observed in the

Table 4: Influence of mineral addition levels (M) and fermentation duration (D) on metabolizable energy (ME) of fermented product (kcal/kg).

Duration of fermentation	Mineral addition levels				Average
	0	1	2	3	
0	3,752.67 ^d	3,500.33 ^c	3,626.33 ^c	3,700.00 ^d	3,644.83
1	3,462.67 ^c	3,496.33 ^c	3,379.67 ^c	3,611.67 ^d	3,487.58
2	3,253.33 ^c	3,111.00 ^b	3,029.33 ^b	3,486.00 ^c	3,219.92
3	3,105.00 ^b	3,152.00 ^b	2,788.33 ^a	3,312.00 ^c	3,089.33
4	3,106.33 ^b	2,975.00 ^a	2,716.00 ^a	3,151.33 ^b	2,987.17
5	2,978.00 ^b	2,863.67 ^a	2,692.00 ^a	3,184.67 ^c	2,929.58
Average	3,276.33	3,183.06	3,038.61	3,407.61	

Note: Different superscripts across rows and columns indicate significant differences ($P < 0.01$).

M2 treatment. This is due to the rapid fermentation process in the M2 treatment, characterized by the rapid decrease in EE content in M2 up to a fermentation duration of 120 hours (D5). The level of mineral addition in treatment M2 represents the optimal dose to support the maximum growth and development of *Aspergillus niger*. This condition results in the production of a higher amount of lipase enzyme, which in turn enhances the degradation of fat in the substrate mixture of PKC and CB. This is indicated by the rapid decrease in the fat content (EE) in M2 up to 120 hours of fermentation (D5). This indicates that microbes effectively utilize the fat content in the media for growth (Wardono *et al.*, 2021). According to Knez *et al.* (2006), during the fermentation process, substrate fats are broken down by lipase enzymes, and the resulting products are used as an energy source for microbial (bacterial) growth. Aliyah *et al.* (2016) stated that substrate fats can be used as a carbon source required for the growth of *Aspergillus niger* mold. Costa *et al.* (2017) and Nema *et al.* (2019) reported that *Aspergillus niger* is a promising microbe for producing lipase enzymes in solid-state fermentation with industrial applications. This is due to the ability of *Aspergillus niger* to grow rapidly on solid substrates and synthesize lipase enzymes in large quantities, although some studies involving the optimization of enzyme production using different strains of *Aspergillus* show some variations in results.

EFFECT OF TREATMENT ON METABOLIZABLE ENERGY (ME) CONTENT

The research outcomes concerning the influence of mineral addition levels and fermentation duration on the metabolizable energy (ME) content of the fermented product mixture of PKC and CB are presented in Table 4 and Figure 4.

The data in Table 4 and Figure 4 show that the combination of treatment M0D0 resulted in the fermented product with the highest metabolizable energy (ME) content (3,752.67 kcal/kg), while the lowest was the combination M2D5 (2,691.31 kcal/kg). Variance analysis results indicate an interaction between the level of mineral addition and fermentation duration ($P < 0.01$) on the ME content.

The research findings suggest that longer fermentation durations result in a decreasing ME content of the fermented product. This decrease in ME is caused by the utilization of carbon or energy source compounds such as fats and carbohydrates in the mixture of PKC and CB substrate. Additionally, according to Anyiama *et al.* (2023), prolonged fer-

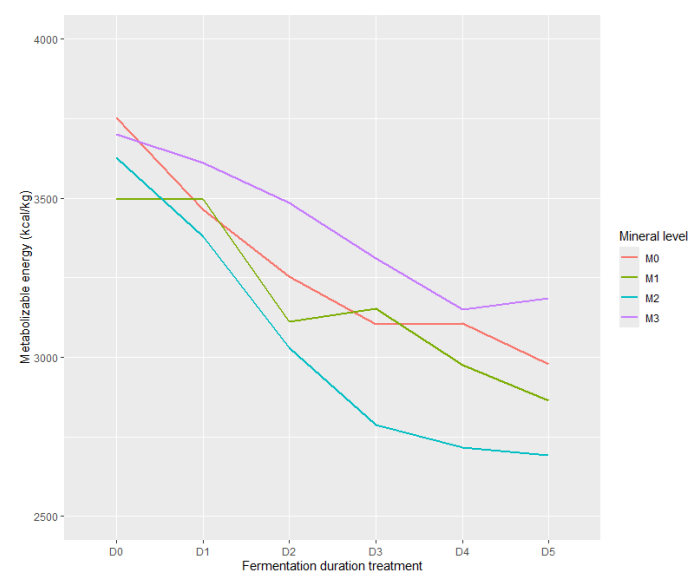


Figure 4: Metabolizable energy content of fermented product with different fermentation duration and mineral levels.

mentation processes will reduce the carbohydrate content of the substrate due to the activity of α -amylase and maltase enzymes that degrade starch into sugars for microbial growth. Abdullah *et al.* (2018) stated that fungal hyphae contain 25–45% protein and 25–30% carbohydrates. During growth, fungi use carbon and nitrogen as components of fungal cell bodies. *Aspergillus niger* during the fermentation process primarily utilizes substrate nutrients, especially carbohydrates, for growth. Furthermore, Wardono *et al.* (2021) stated that fats are the second energy reserve after carbohydrates, stored as triglycerides for microbial growth. M2 mineral addition level is the optimal mineral addition. The energy content of the mixture of PKC and CB sub

Table 5: Influence of mineral addition levels (M) and fermentation duration D) on crude fiber (CF) content of fermented product (%).

Duration of fermentation	Mineral addition levels				Average
	0	1	2	3	
0	16.61 ^h	17.06 ^h	17.39 ^h	15.84 ^g	16.72
1	15.13 ^g	15.09 ^g	14.12 ^f	15.28 ^g	14.90
2	12.42 ^e	11.89 ^e	8.83 ^c	13.48 ^f	11.65
3	11.22 ^e	10.17 ^d	8.01 ^c	12.44 ^e	10.46
4	10.50 ^d	9.66 ^d	5.31 ^a	13.01 ^f	9.62
5	11.75 ^e	9.02 ^c	6.92 ^b	13.03 ^f	10.18
Average	12.94	12.15	10.10	13.85	

Note: Different superscripts across rows and columns indicate significant differences ($P < 0.01$).

strate decreases until the mineral addition level M2. The to supply nutrients, especially nitrogen, for maximal growth and development of *Aspergillus*. The consequence of this condition is the significant breakdown of carbohydrates and fats from the mixture of PKC and CB substrate as a carbon source to meet the energy needs for the growth and development of *Aspergillus niger*. Furthermore, according to Wardono *et al.* (2021), the more microbial biomass growth and the longer the fermentation, the more the easily digestible energy sources such as hemicellulose, starch, fructan sugar, organic acids, pigments, and water-soluble vitamins decrease. These easily digestible energy sources are utilized by microbes for growth, adaptation, and substrate degradation according to their properties. Additionally, Septiani *et al.* (2019) stated that mineral additions such as ammonium sulfate are needed for microbial growth (*Aspergillus niger* and *Trichoderma reesei*), which affects the enzyme activities produced by both microbes. Abdullah *et al.* (2018) also stated that macro and micro minerals are necessary for microbial growth, thus affecting the increase in *Aspergillus niger* enzyme activity.

EFFECT OF TREATMENT ON CRUDE FIBER (CF) CONTENT

The research outcomes regarding the effect of mineral addition levels and fermentation duration on the crude fiber (CF) content of the fermented product mixture of PKC and CB are presented in Table 5 and Figure 5.

The data in Table 5 and Figure 5 show that the combination of treatment M2D0 resulted in the fermented product with the highest crude fiber (CF) content (17.39%), while the lowest was the combination M2D4 (5.31%). Variance analysis results indicate an interaction between the level of mineral addition and fermentation duration ($P < 0.01$) on the CF content. The research findings suggest that higher levels of mineral addition and longer fermentation durations result in a fermented product with decreasing CF content. The CF content decreases until fermentation duration D4 (96 hours) and slightly increases again at fer-

mentation duration D5 (120 hours). This is consistent with the findings of Ihtifazhuddin *et al.* (2016), who reported

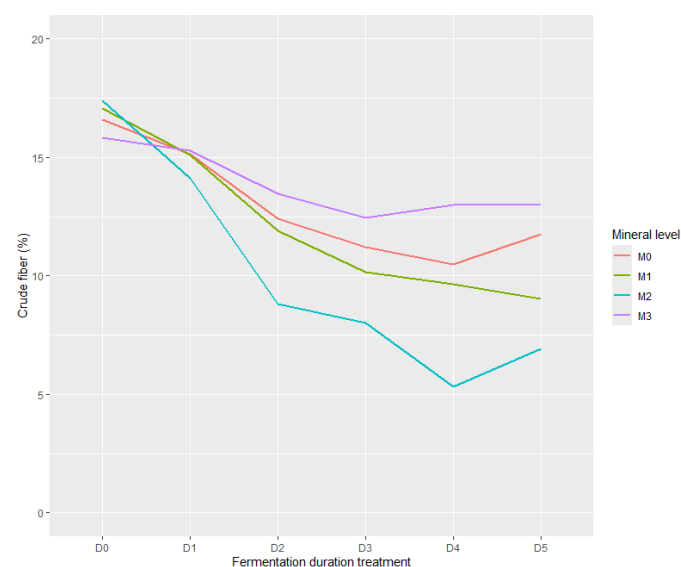


Figure 5: Crude fiber content of fermented product with different fermentation duration and mineral levels.

that the CF content of the fermented substrate decreases until a fermentation duration of 4 days and slightly increases again on the 6th day. The decrease in CF content of the fermented product until D4 (96 hours) is due to the enzyme activity produced by *Aspergillus niger*, such as cellulase, hemicellulose, xylanase, mannanase, and ligninase, during fermentation, which can break down the CF of the PKC and CB substrate (Nurhayati *et al.*, 2018; Do Santos *et al.*, 2015). The breakdown of CF (cellulose and hemicellulose) into disaccharides and monosaccharides (glucose) is used as a carbon and energy source for microbial growth and development (Wardono *et al.*, 2021). Meanwhile, the increase in CF content at the end of fermentation D5 (120 hours) is due to the contribution of CF from the cell walls of *Aspergillus niger*, whose growth and development increase, entering the spore production phase. Leeuwe *et al.* (2020) and Cui *et al.* (2021) stated that the fungal cell wall (*Aspergillus niger*) is composed of dextran, mannan,

chitin, β -glucan, and chitosan. As *Aspergillus niger* grows, the chitin content increases, leading to an increase in the CF content of the PKC and CB substrate. Additionally, Kurniati *et al.* (2017) stated that mycelial cell walls contain a lot of cellulose and chitin, which have similar functions to plant cell walls.

Furthermore, the CF content decreases with increasing mineral addition until level M2 and increases at level M3. The decrease in substrate CF is due to the increasing production of crude fiber-degrading enzymes synthesized by *Aspergillus niger*, which grow and develop more in all substrate areas. Meanwhile, the increase in CF content at level M3 is due to the low production of crude fiber-degrading enzymes caused by slow growth and development of *Aspergillus niger* as a result of excessive mineral addition. Excessive mineral addition to the substrate is suspected to be toxic and inhibits the growth and development of *Aspergillus niger* in the substrate area.

The combination of treatment M2D2 is the optimum combination for reducing the CF content of the mixture of PKC and CB by 50.8% to 8.83% compared to before fermentation, which was 17.39%. This means that mineral addition at level D2 supports rapid growth and development of *Aspergillus niger*, allowing it to produce maximal enzymes to break down CF, coupled with fermentation duration D2, which results in the growth and development of *Aspergillus niger* mycelium with conditions containing less CF (chitin) because not much has entered the spore production phase. The results of reducing crude fiber from fermentation products in this study (8.83%) were better than the results of previous research (15.11%) (Nurhayati *et al.*, 2006). Zhang *et al.* (2023) stated that providing feed containing 7-9% crude fiber to broilers aged 22-42 days can enhance immunity, nutrient digestibility, and growth performance. Therefore, based on the results of this study, it can be concluded that the combination treatment M2D2 produces a fermented product of a PKC and CB mixture that has the potential to be established as an alternative non-conventional feedstuff for poultry, considering its nutritional profile, which includes CP, EE, ME, ash, and CF contents of 23.56%, 3.60%, 3,029.33 kcal/kg, 6.00% and 8.83%, respectively. The nutritional profile of this fermented product meets the recommended nutritional profile based on SNI (Indonesian National Standard) 01-3930-2006 (minimum CP 19%, maximum EE 7.4%, minimum ME 2900 kcl/kg, maximum Ash 8%, and CF 6%) by BSN (National Standardization Agency) for broilers. Although the CF from the research results is higher than the SNI, it still aligns with the recommendations by Zhang *et al.* (2023).

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and discussion, it can be concluded that:

1. The combination of mineral treatments with doses of 5 g KCl, 25 g ZA, 15 g urea, and 5 g NPK and a fermentation duration of 48 hours produced the best nutrient profile of the fermented product, with a crude protein content of 23.56%, a high energy content of 3,029.33 kcal, and low fat (3.6%) and crude fiber (8.83%) contents.
2. The nutrient profile of the fermented product from this research aligns with the nutritional requirements standards for poultry (broilers) (crude protein, crude fat, ash, and metabolizable energy) based on the Indonesian National Standard (SNI) 01-3930-2006 set by the National Standardization Agency (BSN) and the crude fiber content for broilers according to Zhang *et al.* (2023).

The fermented product has the potential to be used as an alternative non-conventional feed ingredient for poultry, which can help reduce feedstuff imports by livestock companies or the feed industry. A recommendation for future research is to test the use of the fermented product as a feed ingredient to enhance the immunity and performance of various poultry livestock.

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NOVELTY STATEMENT

This study identified the optimal combination of mineral supplementation and fermentation time for producing a fermented mix of PKC and CB that has a promising nutritional profile for use as poultry feedstuff. This alternative feed is not only high-quality and cost-effective for farmers, but it also highlights the potential of using organic feed sources that do not compete with human food.

AUTHOR'S CONTRIBUTION

Nurhayati: Responsible for conceptualization, writing the original draft, and performing statistical analyses.

Chandra Utami Wirawati: Handled methodology and supervision.

Dwi Desmiyeni Putri: Conducted review and manuscript

CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest.

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