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Enhancing the nutritional value of preserved rice straw with calcite-based minerals for cattle in volcanic eruption-affected areas

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ABSTRACT

The December 2023 Mount Marapi eruption likely disrupted the mineral balance in tethered cattle by altering soil and forage composition. This study examined (1) mineral imbalances in tethered cattle and (2) the effectiveness of calcite-based mineral supplements in preserved rice straw to correct these imbalances. Hair samples from 45 cattle farms were also analyzed for minerals such as P, K, S, Na, and Cu. Rice straw was preserved with 1.2% molasses, 0.15% urea, and one of four mineral additives: calcined calcite (CC), enriched calcined calcite (eCC), enriched raw calcite (eRC), or commercial premix (UM). The preserved straw was fed to bulls in a 4 × 4 Latin Square design. Hair analysis revealed phosphorus deficiency in 82.2% of samples, copper deficiency in 31.1%, and excesses of sulfur and sodium in 100% and 71.1% of samples, respectively. Enriched additives improved the straw's sensory qualities and mineral profiles, reduced fungal contamination, and preserved the palatable stem portion. Blood hematology and mineral levels remained unchanged; bulls fed eCC gained 332 g/day, equal to the 354 g/day gain with UM. In conclusion, the Mount Marapi eruption significantly disrupts the mineral status of tethered cattle, causing critical P/Cu deficiencies and S/Na excesses. eCC proves to be an effective mineral supplement, enhancing the quality of preserved straw and cattle performance in regions affected by the eruption.
Keywords: Calcined calcite, Mount Marapi, Oyster shell, Pesisir cattle, Rock flour, Tethering

INTRODUCTION

Mount Marapi, located in West Sumatra's Agam and Tanah Datar districts, erupted in December 2023, releasing pyroclastic flows, volcanic gravel, and ash for six months. This extended eruption severely affected agriculture, causing widespread crop failures, forage shortages, and health problems in humans and livestock (Pranata *et al*., 2025). Mount Marapi, one of Indonesia's most active stratovolcanoes, has erupted more than 50 times since the 18th century

(Sugianto *et al*., 2023). Unlike other natural disasters, volcanic eruptions in Indonesia rarely result in the direct loss of livestock, and farmers often strive to maintain their animals as valuable economic assets following the eruption (Khalil *et al*., 2024). However, ash-contaminated or destroyed vegetation results in severe feed shortages, leading to weight loss, health problems, and decreased productivity in cattle (Khalil *et al*., 2024).

Volcanic eruptions significantly affect soil and forage mineral profiles, causing nutritional imbalances in grazing animals. A nationwide study of volcanic regions in Indonesia found that forage after eruptions generally lacks phosphorus (P) and sodium (Na). Conversely, it tends to be overly rich in potassium (K), sulfur (S), and copper (Cu), sometimes reaching toxic levels for cattle (Khalil *et al*., 2025a). These imbalances can result in mineral deficiencies or toxicities (Linhares *et al*., 2021) and impair rumen microbial activity, metabolism, immunity, and reproduction (McDowell, 2003).

Rice straw, an abundant post-harvest by-product, offers a low-cost feed alternative to address cattle feed shortages and mineral imbalances in eruption-affected regions. It is readily available during the rice harvesting season and could be preserved as a reserve or emergency feed during and after a volcanic eruption. Rice straw can be preserved in its fresh, intact form by manual compacting and wrapping to produce straw silage, which maintains moisture content, palatability, and minimizes physical and microbial contamination as well as nutrient loss (Sultana *et al*., 2020; Khalil *et al*., 2023). Since it's a hollow stem with high moisture content and low levels of water-soluble carbohydrates, minerals, and protein, it needs to be supplemented with minerals, molasses, and urea as sources of minerals, energy, and protein before storage.

West Sumatra has abundant natural rock deposits and oyster shells rich in calcium carbonate (calcite) (Khalil *et al*., 2021). When calcined at 700–900°C, calcite transforms into fine, high-calcium powders with antifungal properties (Khalil *et al*., 2021; Ha *et al*., 2019). The local calcites could be formulated and designed to boost their effectiveness as mineral sources and preservative agents for preserved rice by mixing and enriching them with other essential minerals such as calcium (Ca), P, Cu, Na, zinc (Zn), and cobalt (Co). Adding the enriched raw calcites (eRC) and calcined calcites (eCC) to preserved rice straw enhances storage stability by preventing microbial contamination. It supplies vital minerals including Ca, P, S, magnesium (Mg), Cu, and Zn, which are important for rumen microbial activity and host metabolism (McDowell, 2003).

The objectives of this study were (1) to evaluate the mineral status of tethered cattle in eruption-affected areas and (2) to develop and test calcite-based mineral mixes for use both as preservatives and as nutritional supplements in rice straw-based cattle feed. It is hypothesized that volcanic material might alter the mineral status of tethered cattle, and eCC mixes will perform as well as commercial premixes in enhancing the preservative qualities of rice straw and improving cattle performance. The results are expected to offer a practical solution for addressing feed shortages and mineral deficiencies in tethered cattle following volcanic eruptions by utilizing locally available resources.

MATERIALS AND METHODS

Description of the Study Sites

Mount Marapi is located within the Agam and Tanah Datar Regencies in West Sumatra, Indonesia. Geographically, this cone-shaped stratovolcano reaches an elevation of 2,891 meters above sea level (m asl) (9,484 feet) and is situated at coordinates 0°22'47.72" S, 100° 28'16.71" E (Edwiza *et al*., 2016). Mt. Marapi is known as the most active volcano in West Sumatra and is classified as a complex stratovolcano, exhibiting both explosive and effusive eruptions, with an average recurrence interval of about four years (Global Volcanism Program, 2023). Historical records indicate that Marapi has erupted over 50 times since the 18th century, with notable eruptions in 1822, 1979, 2004–2005, 2006–2007, 2011, 2012, 2014, 2017, and most recently, 2023–2024 (Sugianto *et al*., 2023).

The area surrounding Mount Marapi is mainly characterized by agricultural and livestock activities, particularly rice farming, horticulture, and cattle raising, due to the nutrient-rich volcanic soil and the region's cool climate (Pranata *et al*., 2025). Crossbreeds such as Simmental and Limousine, Brahman, Onggole, and local Pesisir cattle are common on small farms. Livestock is kept in simple stalls throughout the day and tethered around villages during daylight hours. However, the recent eruption from December 2023 to June 2024, which caused ashfall and sand rain, had serious socio-economic impacts. About 250,000 people within a 10-kilometer radius were affected, and crops and forage were damaged or contaminated (Mahli *et al*., 2024). The disruptions to agriculture and forage were especially severe in districts like Canduang, Sungai Pua, and Ampek Angkek (Agam Regency), as well as X Koto and Batipuh (Tanah Datar Regency) (Kadiwaru and Darmawan, 2024). These areas experienced varying levels of damage depending on their distance from the eruption site and wind patterns.

Collection, Preparation, and Analysis of Hair Samples

A field survey was conducted to evaluate the impact of the Mount Marapi eruption on the mineral status of tethered cattle. Hair samples were collected from 45 smallholder farms in five affected sub-districts: Sungai Pua, Canduang, and Ampek Angkek (Agam Regency), along with X Koto and Batipuh (Tanah Datar Regency). With farmers' consent, samples were obtained from cattle regardless of breeds, ages, and sexes due to the limited cattle population. Using sterilized stainless-steel scissors, approximately 3–5 g of hair was clipped from the head, neck, and shoulder (Saharan *et al*., 2024), while avoiding areas prone to contamination. Samples were stored in sealed, labeled plastic bags.

Hair samples were sequentially washed in acetone and distilled water to remove external contaminants, then cut into 1 cm lengths and oven-dried at 80°C for 48 hours. The dried samples were digested and analyzed for P, K, Na, S, and Cu using the method described by Saharan *et al*. (2024).

Preparation of Mineral Formula

Four mineral mixtures were prepared: three self-formulated mixtures utilized local materials, and one used a commercial cattle premix. The self-formulated mixtures consisted of calcined calcites (CC), enriched calcined calcites (eCC), and enriched raw calcites (eRC), primarily made up of rock flour and roasted oyster shell meal in either raw or calcined form. The composition and mineral profiles for each mineral formula is shown in Table 1.

The eCC and eRC mixtures were enriched with essential minerals based on the National Research Council (NRC) (2000), to address the mineral status of grazing cattle in the study sites, and the mineral profile of forages in the erupted-affected areas (Khalil *et al*., 2025a). The additives included dicalcium phosphate (40%), iodized salt (10%), cobalt carbonate (0.1%), copper sulfate (1%), zinc sulfate (1%), and a 5% inclusion of a commercial cattle premix. Calcination of raw materials followed the method described by Khalil *et al*. (2021). The commercial cattle premix, Ultra Mineral® (UM), produced by Eka Farma (Indonesia), served as a positive control and included $CaCO_3$ (50%), P (25%), manganese (0.35%), iodine (0.20%), K (0.1%), Cu (0.15%), sodium chloride (23.05%), iron (0.8%), Zn (0.2%), and Mg (0.15%).

Preparation, Supplementation, and Preservation of Rice Straw

The preservation trial aimed to evaluate the beneficial effects of mineral additives on the quality and nutritive value of preserved rice straw. Approximately 1 ton of fresh rice straw was collected and preserved over five harvest periods and divided into four 50-kg batches. Each batch was arranged on ropes, compacted manually using a concrete culvert, and treated with 1.2% molasses and 0.15% urea solutions mixed in 15 L of water (Khalil *et al*., 2023). Each batch received one of four mineral treatments (1% inclusion): CC, eCC, eRC, or UM.

The treated straw was manually rolled, compacted, encased in airtight plastic sheets (3 × 1.5 m), and kept at room temperature for 60 days. On day 60, samples were taken from each ball at three depths: surface, middle, and core. Fifteen trained panelists evaluated the organoleptic properties and microbial status of color, flavor, texture, and fungal spoilage using a 5-point hedonic scale (Table 2) (Khalil *et al*., 2023).

Samples were separated into botanical frac-

Table 1. Composition of Mineral Formula (% as fed)

Ingredients	Calcined Calcites (CC)	Enriched Calcined Calcites (eCC)	Enriched Raw Calcites (eRC)
Rock flour	-	-	21.9
Roasted oyster shell meal	-	-	21.0
Calcined rock flour	47.5	21.9	-
Calcined shell meal	47.5	21.0	-
Dicalcium phosphate (DCP)	-	40.0	40.0
Kitchen salt	-	10.0	10.0
$CoCO_3.6H_2O$	-	0.1	0.1
$CuSO_4.5H_2O$	-	1.0	1.0
$ZnSO_4.7H_2O$	-	1.0	1.0
Commercial cattle mix Ultra Mineral®.	5.0	5.0	5.0
Total	100.0	100.0	100.0
Macro minerals (g/kg):			
Calcium	409.1	301.4	259.9
Phosphorus	2.7	77.1	77.1
Potassium	0.1	0.1	0.1
Sulfur	1.2	4.1	4.3
Sodium	8.1	39.5	47.3
Micro minerals (ppm):			
Zinc	272.1	3905.0	3899.3
Copper	127.4	2920.3	2665.9

Table 2. Description of the Organoleptic Evaluation of Preserved Rice Straw

Hedonic scale	Physical characteristics and microbial status:			
	Color	Flavor	Texture	White fungal spot
7.1-9.0	Bright greenish yellow, specific to the color of fresh straw	Typical, specific smell of fresh rice straw	Regular, specific fresh rice straw	Fungal spot-free, specific fresh straw
5.1-7.0	Light yellow	Pleasant aromas like fermented sugar, fragrance, specific, and typical fermentation smell	Soft, wet, and brittle	A few fungal spots on the straw surface
3.1-5.0	Pale brown	Bland, tasteless, minimal smell	Clumping, slightly wet, and soft	More fungal spots on the surface and in the inner pile
1.1-2.9	Dark brown	Ammonia smell	Slightly clumpy, slightly dry, and tough	Lots of fungal spots outside and inside the pile
≤1	Black, like the color of a coffee drink	A musty and rotten smell	Dry and clay	Full of fungal spots all over the straw

tions (stem, leaf, panicle) and weighed. The botanical portion (in %) was calculated by dividing the weight of the part by the weight of the whole straw and multiplying it by 100. The straws were chopped to a size of about 2-3 cm, mixed, and dried for 72 hours in the oven. The air-dried samples were ground to pass through a 1-mm sieve using a hammer mill to determine their moisture, nutrient, and fiber fraction content. The moisture and crude nutrients were analyzed using proximate analysis, as outlined in the procedures of the Association of Official Agricultural Chemists (AOAC) (2016). Fiber fractions (Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF)), hemicellulose, cellulose, lignin, silica) were determined using the methods of Goering and Van Soest (1970). Digestibility of dry and organic matter was assessed *in vitro* using the gas production technique described by Menke *et al*. (1979).

Feeding Trial

The feeding trial followed the national ethical guidelines for animal care, as outlined in the Republic of Indonesia's Law No. 18 of 2009. It received approval from the Ethics Committee for the Control of Animal Experimentation at Andalas University, under protocol number 51/ UN16.10.D.KEPK-FF/2025. A 4×4 Latin square Design was used to assess the impact of supplemented preserved straw on cattle performance. Four indigenous Pesisir bulls (7-8 months old; average body weight of 85.5 ± 15.6 kg) were housed individually at night and tethered during the day for grazing. The animals were kept in individual pens with feed troughs and water buckets. They were offered 500 g per head per day of concentrate composed of palm kernel meal (44.3%), cassava peel (19.18%), soybean meal (17.28%), and rice bran (17.68%), providing 13% CP, 22% CF, 0.71% Ca, 1.21% P, and 66% TDN.

Subsequently, in the late afternoon, each animal was assigned one of the four preserved straw treatments (CC, eCC, eRC, or UM) in pens after being tethered around the farm. Each trial period lasted seven days for adaptation, followed by seven days for data collection and analysis by following the method described Budiono *et al*. (2000). The measured parameters included straw intake, weight gain, and blood profiles. Blood samples were drawn from the jugular vein at the end of each period. Blood sample preparation and analysis were carried out at the Chemical Laboratory of the National Veterinary Service Institute in Baso, Bukittinggi, West Sumatra, Indonesia. Hematological examination was performed directly after the samples were received by the research laboratory by using the Medonic Veterinary Hematology analyzer (Medonic CA 620, Sweden). The hematological parameters measured included hemoglobin concentration (HGB), hematocrit (HCT), total Red Blood Cell (RBC) count, total White Blood Cell (WBC) count, mean corpuscular volume (MCV), platelet number (PLT), and the count of lymphocytes (LYM). Serum was collected to analyze total protein, calcium, and phosphorus using a Mindray BC-2800 autoanalyzer.

Statistical Analysis

Hair mineral concentrations were reported as means and percentages and compared to standard reference values. Feeding trial data were assessed through a 4×4 Latin Square design. Significant differences ($p < 0.05$) among treatments were identified using Duncan's multiple range test. All results are presented as mean ± standard deviation (SD). Data were analyzed statistically with SPSS software version 18.

RESULTS AND DISCUSSION

Impact of Volcanic Eruption on the Mineral Status of Cattle

Mineral concentration in tethered cattle hair is presented in Table 3. The post-eruption mineral profiles of cattle hair showed significant disruptions, especially in phosphorus, sulphur, sodium, and copper. As shown in Table 3, phosphorus (133.14 ± 72.38 ppm) was deficient in 82.2% of samples. Potassium averaged 169.95 ± 142.17 ppm, with 66.7% of the values within and 31.1% below the normal range. Sulfur (2.64 ± 0.55%) and sodium (439.12 ± 231.34 ppm) were consistently elevated in all and 71.1% of samples, respectively. Copper (7.55 ± 10.18 ppm) was within normal limits in 64.5% of samples, while 31.1% were deficient.

The widespread phosphorus deficiency

Table 3. Mean Mineral Concentrations in Cattle Hair Samples (mean ± standard deviation, n=45) Compared to the Normal Ranges in the Eruption-affected Area of Mount Marapi

	Minerals:				
	Phosphorus (ppm)	Potassium (ppm)	Sulphur (%)	Sodium (ppm)	Copper (ppm)
Mean concentration	133.14±72.38	169.95±142.17	2.64±0.55	439.12±231.34	7.55±10.18
Normal concentration (ppm)	150–400[1]	100–500[2]	0.1-0.5[3]	50–300[4]	5–15[5]
Distribution of samples compared to the standard mineral concentration in cattle hair (%) (*range*):					
Within the normal range:	15.6 (151.3-172.8)	66.7 (102.9-461.5)	0.0	28.9 (124.0-291.5)	64.5 (5.1-10.1)
Below the normal range	82.2 (26.1-140.9)	31.1 (39.6-97.2)	0.0	0.0	31.1 (1.0-4.9)
Above the normal range	2.2 (566.4)	2.2 (884.5)	100.0 (0.5-3.3)	71.1 (304.1-1100.9)	4.4 (38.2-64.7)

[1] Underwood and Suttle (1999), [2] McDowell (2003), [3] NRC (2000), [4] Suttle (2010), [5] Combs (1987)

(82.2% of samples) matches reports that cattle grazing on volcanic-ash-derived Andisol soils often suffer from mineral deficiencies, particularly phosphorus, because of the limited bioavailability of soil P in these environments (Linhares *et al*., 2021). The high rate of phosphorus deficiency reflects conditions in Semeru-impacted areas (Setyawati *et al*., 2024). Similarly, forage crops like Napier grass grown on Mount Merapi's volcanic slopes have noticeably lower phosphorus levels, contributing to systemic phosphorus deficiencies in grazing livestock (Hartati *et al*., 2023).

The most notable change in sulphur levels is that all samples (100%) exceeded the upper standard limit of 0.5% (NRC, 2000), strongly indicating environmental overexposure, likely caused by high sulphur content in volcanic ash and gases that can be absorbed by pasture plants or eaten directly by animals. Forage in volcanic-risk areas can accumulate significant sulphur from ash deposits, since about 43% of volcanic SO_2 is deposited on the surface through wet and dry processes (Lamotte et al., 2021). Similarly, sodium levels were elevated in 71.1% of samples, exceeding the upper reference limit of 300 ppm (NRC, 2000), indicating increased sodium content in soils and water following ashfall and pyroclastic flow deposition. Paez *et al*. (2021) reported that sodium (207.8 mg/kg) was a major mineral component of ash leachate from Copahue volcano.

In contrast, copper levels showed a mixed pattern: while most (64.5%) of the cattle had copper within the normal range (5-15 ppm), nearly one-third (31.1%) were deficient, and a small percentage (4.4%) had excessive levels. These differences could result from inconsistent copper availability in the altered soil environment and variations in forage composition. Linhares *et al*. (2021) demonstrated that hair copper variation reflects soil geochemistry in cattle grazing on volcanic soils (basaltic vs. trachytic). This supports the idea that low hair copper levels probably result from an environmental mineral imbalance.

Efficacy of Mineral Formula in Straw Preservation

Table 4 presents the beneficial effects of mineral supplementation on the physical characteristics and proportion of botanical components of preserved rice straws. Enriched calcite additives (eCC, eRC) and a commercial premix (UM) improved rice straw quality. While color remained similar, eCC, eRC, and UM significantly enhanced flavor and texture ($p < 0.05$), with eRC having the highest texture score (7.54). Fungal contamination was lowest in eCC and eRC. The leaf portion decreased significantly in the eCC. Palatable stem and panicle proportions were unaffected.

Using eCC proved helpful in improving the preservation quality of rice straw, as shown by better organoleptic physical traits, increased resistance to fungal contamination, and improved cattle growth performance, similar to the commercial cattle mix. Similar results are seen in silage systems, where additive-induced pH reduction and moisture retention inhibit fungi and

Table 4. Mean Values of Physical Characteristics and Components (means ± standard deviation) of Preserved Rice Straws Supplemented with Various Mineral Formulas

Parameter	CC	eCC	eRC	UM	SEM	P-value
Physical characteristics						
Colour	5.42±0.75	5.30±1.20	5.72±1.11	5.78±1.27	0.23	0.71
Flavor	4.65^{c}±0.77	5.67^{ab}±1.54	6.21^{a}±1.03	5.51^{b}±1.05	0.26	0.00
Texture	6.86^{c}±0.35	7.30^{ab}±0.28	7.54^{a}±0.17	7.14^{bc}±0.32	0.08	0.00
Fungal contaminant	7.10^{b}±0.19	7.60^{a}±0.20	7.79^{a}±0.36	7.40^{ab}±0.34	0.08	0.01
Botanical components (%)						
Stem	54.13±5.15	59.06±8.16	57.54±11.42	54.52±5.38	1.69	0.24
Leaf	36.43^{a}±7.12	30.46^{b}±6.33	33.61^{ab}±9.32	33.81^{ab}±3.56	1.49	0.24
Panicles	9.44±2.35	8.83±3.21	15.00±13.51	11.67±4.49	1.61	0.45

CC - calcined calcites, eCC - enriched calcined calcites, eRC - enriched raw calcites; UM – ultra mineral (commercial premix); SEM - standard error of the means; ^{abc} means in the same row without a common superscript are significantly different at P < 0.05

yeast growth, thus maintaining feed quality and extending shelf life (Paradhipta *et al*., 2021). Additionally, studies with silage additives like organic acids and buffers have shown that altering the chemistry of high-moisture feed prevents spoilage microbes from developing, stabilizes the structure, and preserves feed quality (Qiu *et al*., 2024). These mechanistic similarities support the effectiveness of eCC and UM formulations in improving storage outcomes for preserved rice straw.

Notably, reducing fungal contamination in eCC and eRC treatments further emphasizes the importance of local calcite enrichment for maintaining hygienic quality. Fungal suppression likely results from the antimicrobial properties of CC and specific mineral elements (e.g., zinc, copper), as well as their role in creating unfavourable conditions (e.g., lower moisture activity or pH buffering) for mold growth. This is especially important in tropical climates or post-disaster environments, such as volcanic eruption zones, where high humidity and organic debris can greatly increase the risk of fungal contamination.

The botanical component results suggest that the reduced leaf portions in eCC-treated straw may indicate improved lignocellulosic degradability under these mineral conditions. Leaves and panicles, being more lignified, are naturally more resistant to microbial degradation (Vadiveloo, 2000).

Table 5 presents the crude nutrients, digestibility, fiber fractions, and mineral content of preserved rice straw. There was no statistical difference in crude protein, crude fiber, mineral content, and DM and OM digestibility regarding nutritional value. eRC had the lowest crude fat and ADF content, while CC and UM had the highest crude ash and fat, respectively. Except for ADF, the fiber fraction fiber content was similar. eRC had the lowest ADF content (49.60%). The eCC formulation (high in calcite/alkali) promotes fiber breakdown and rumen fermentability, consistent with the improved NDF/ADF digestibility observed in $CaO/Ca(OH)_2$-treated straw (Wanapat *et al*., 2009). The UM premix, similar to complex silage additives, increased crude fat and slightly improved fiber and mineral content, as shown in studies on mixed-straw silage. Finally, CC alone, while enriching mineral content, lacked components that enhance digestibility, leading to lower fiber quality, which is expected for unamended calcite additions.

Animal Health and Growth Responses to Mineral-treated Straw

Results of the feeding trial on the straw intake, body weight gain, and blood biochemical and hematological values are presented in Table 6. There was no significant difference in dry matter intake and blood biochemical profiles, presumably due to high data variation. As shown in Table 6, Pesisir bulls fed on UM and eCC-treated straw achieved the highest weight gain (309.9 and 329.4 g/day, respectively; $p< 0.05$). Blood analysis indicated low RBC and hemoglobin levels in CC and UM compared to the standard values, while WBC counts were elevated in eRC and eCC. Calcium was below normal in eRC and UM, while phosphorus levels exceeded

Table 5. Mean Values of Nutrient, Digestibility, Fiber Fractions, and Mineral Content (means ± standard deviation) of Preserved Rice Straws Supplemented with Various Mineral Formulas.

Parameter	CC	eCC	eRC	UM	SEM	P-value
Proximate component						
Moisture (% FW)	71.47±4.55	67.81±5.60	64.56±7.10	65.21±8.25	1.47	0.12
Dry matter (% FW)	28.53±4.55	32.19±5.60	35.44±7.10	34.79±8.25	1.47	0.12
Crude ash (% DM	24.05^{a}±3.80	22.52^{ab}±2.57	21.50^{ab}±3.07	20.39^{b}±1.92	0.67	0.05
Crude protein (% DM)	5.40±0.60	6.11±1.21	5.14±0.42	5.34±1.02	0.19	0.34
Ether extract (% DM)	2.37^{b}±0.95	4.39^{a}±1.53	1.93^{b}±1.11	5.20^{a} ±0.29	0.38	0.00
Crude fiber (% DM)	28.58±2.26	28.00±1.98	29.27±3.54	27.67±2.85	0.57	0.61
In vitro digestibility (%)						
DM digestibility	35.95±9.06	36.64±5.03	40.84±16.55	33.90±7.69	2.23	0.46
OM digestibility	40.63±5.39	41.33±2.50	43.43±7.96	41.08±3.71	1.11	0.57
Fiber fraction (% DM)						
NDF	74. 36±2.22	71.70±1.80	70.85±3.26	72.69±5.12	0.29	0.75
ADF	54.88^{a}±3.60	51.72^{a}±1.79	49.60^{b}±2.92	51.21^{a}±2.31	0.71	0.01
Hemicellulose	19.48±2.89	19.98±2.10	21.24±2.07	21.48±3.23	0.57	0.60
Cellulose	31.83±3.57	31.82±1.75	31.14±2.95	31.39±1.85	0.54	0.95
Lignin	8.20±1.99	6.19±0.72	5.97±1.26	7.09±1.81	0.37	0.15
Silica	14.86±2.03	13.87±2.43	13.73±1.55	13.24±1.47	0.41	0.54
Mineral (% DM)						
Calcium	0.72±0.54	0.70±0.32	0.90±0.31	0.55±0.35	0.08	0.33
Phosphorus	0.28±0.05	0.30±0.12	0.23±0.10	0.22±0.10	0.02	0.30
Ca/P ratio	2.71±2.02	2.44±1.03	4.56±2.62	3.00±2.09	0.45	0.33

CC - calcined calcites, eCC - enriched calcined calcites, eRC - enriched raw calcites; UM – ultra mineral (commercial premix); FW – fresh weight, DM – dry matter, OM – organic matter; NDF - neutral detergent fiber, ADF - acid detergent fiber; SEM - standard error of the means; [ab] means in the same row without a common superscript are significantly different at $P < 0.05$

normal limits in all treatments (peaking in UM: 7.85 mg/dL). Except in CC, total protein levels remained within the normal range.

The feeding trial results showed improved growth in bulls receiving UM and eCC, which can be linked to their more complete and bioavailable mineral compositions. As a commercial premix, UM likely includes a well-balanced mix of essential, trace, and macro minerals that enhance absorption and retention. Similarly, eCC appears to have enriched mineral profiles beyond the basic calcined form, potentially boosting ruminal microbial activity and nutrient use. These findings support earlier reports of significant improvements in feed intake and growth in cattle supplemented with properly balanced locally formulated mineral blocks on forage-based diets (Khalil *et al*., 2015). Additionally, Astawa *et al*. (2024) found that even small amounts of supplementation (0.2% vitamin-mineral mix) in Bali cattle significantly improved rumen fermentation parameters, which are closely linked to weight gain and nutrient efficiency.

The hematological data further support the physiological effects of these treatments. Although all treatments resulted in hemoglobin levels below normal ranges (Roland *et al*., 2014), bulls fed eCC had slightly better hematological profiles than the others, indicating improved erythropoietic support. Compared to local Indonesian cattle, which typically have RBC counts of approximately 5.0–6.5 $\times 10^6/\mu L$ and HGB levels of about 11–12 g/dL, our eruption-impacted bulls fed on eCC-treated straw exhibit normal RBC counts (5.54 $\times 10^6/\mu L$) but lower HGB levels (8.55 g/dL), suggesting mild anemia. Anemia -like profiles may reflect deficiencies in iron, copper, or vitamins (especially B12), which may not be sufficiently supplied. This supports the understanding that proper mineral nutrition is vital for blood cell production and immune health. The increased WBC counts, particularly in the eRC (10.25 $\times 10^3/\mu L$) and eCC (10.10 $\times 10^3/\mu L$) groups, are slightly above the average for local Aceh cattle (~10 $\times 10^3/\mu L$) (Sofyan *et al*., 2019), indicating a possible immune response related to dietary or environmental stressors. Elevated WBCs without clinical

Table 6. Mean Values of Straw Intake, Body Weight Gain, and Blood Biochemical and Hematological Values (means ± standard deviation) for Cattle Fed Preserved Rice Straw Supplemented with Various Mineral Formulas

Parameter	CC	eCC	eRC	UM		SEM	P-value
Rice straw intake (g DM/head/d)	273.99±148.75	309.93±132.99	364.05±150.73	329.38±192.48		35.26	0.90
Body weight gain (g/h/d)	285.71^{a}±11.66	332.14^{a}±39.34	292.86^{b}±14.29	353.57^{a}±24.40		9.11	0.01
Blood hematology:					Normal Standard		
RBC (X10^{6}/µL)	4.55±1.09	5.54±0.59	5.30±1.31	4.97±1.10	5.30-7.90$^{*)}$	0.25	0.69
WBC (x10^{3}/µL)	7.30±3.96	10.10±5.10	10.25±4.02	9.55±5.52	5.2-9.8$^{*)}$	1.09	0.63
HGB (g/dL)	7.00±1.28	8.55±1.12	8.03±1.49	7.80±1.88	9.7-13.7$^{*)}$	0.35	0.56
HCT (%)	16.33±2.67	18.90±2.00	19.80±2.20	21.00±4.75	23.0-43.0$^{*)}$	0.83	0.15
MCV (fL)	36.88±4.36	35.60±2.31	36.93±6.04	37.78±3.14	36-50$^{*)}$	0.96	0.94
PLT (x10^{3}/µL)	248.50±181.88	251.50±136.63	201.75±60.52	172.75±125.24	160-650$^{*)}$	31.00	0.42
LYM (x10^{3}/µL)	4.43±3.27	6.60±1.69	7.48±2.56	6.15±2.82	1.8-8.1$^{*)}$	0.65	0.30
Blood mineral and protein:							
Calcium (mg/dL)	9.33±3.52	9.38±3.72	7.88±1.95	8.00±2.18	8.5-11.5$^{**)}$	0.69	0.47
Phosphorus (mg/dL)	6.30±1.66	7.10±3.62	7.40±2.30	7.85±2.19	3.2-6.0$^{**)}$	0.44	0.85
Total protein (mg/dL)	6.30±1.44	7.10±1.00	7.13±1.05	7.28±2.25	6.5-8.5$^{*)}$	0.35	0.41

CC - calcined calcites, eCC - enriched calcined calcites, eRC - enriched raw calcites; UM – ultra mineral (commercial premix); DM – dry matter; RBC - total red blood cell, WBC - total white blood cell (WBC), HGB - hemoglobin concentration, HCT - hematocrit count, MCV - mean corpuscular volume, PLT - platelet number, LYM – count of lymphocytes; SEM - standard error of the means; ^{ab} means in the same row without a common superscript are significantly different at $P < 0.05$; $^{*)}$ Roland *et al*. (2014); $^{**)}$ McDowell (1997) symptoms are common in growing cattle and may represent adaptive physiological responses (Smith, 2009).

Blood calcium levels were normal in the eCC group, indicating better bioavailability from this formulation. Simultaneously, elevated serum phosphorus levels (up to 7.85 mg/dL) in the UM -treated rice straw reflect high dietary phosphorus intake, which impairs calcium absorption and worsens mineral imbalance (Keanthao *et al*., 2024). The imbalance of dietary calcium and phosphorus could lead to metabolic problems, such as hypocalcemia or impaired bone growth (McDowell, 2003). Additionally, within established reference ranges, total blood protein levels in the eCC group (7.10 g/dL) confirm that dietary protein intake was sufficient.

Preserved rice straw supplemented with eCC shows strong potential as an effective method to address mineral deficiencies and seasonal feed shortages in cattle confined in regions affected by volcanic eruptions. The eCC is a promising, locally adaptable alternative to commercial mineral premixes, aiding in the nutritional recovery of tethered livestock and promoting the sustainable use of agricultural residues in disaster-prone areas. Such mineral-enriched preservation strategies could enhance forage utilization, improve cattle performance, and support resource sustainability in vulnerable agricultural systems.

CONCLUSION

The December 2023 Mt. Marapi eruption significantly changed the mineral profile in tethered cattle, especially with widespread deficiencies in phosphorus and copper, along with excess sulfur and sodium. Using a locally available enriched calcined calcite mixture (eCC) to preserve rice straw improves its nutritional value, physical qualities, and mineral balance. Feeding the eCC-treated preserved rice straw enhanced cattle health and performance. These findings suggest that enriched calcined calcite formulas are effective options for boosting the feed value of simple bulk preserved rice straw, particularly in areas affected by volcanic ash, where forage resources are scarce.

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