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Effects of compacted forage feeding on Indonesian cattle performance during prolonged sea transport

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ABSTRACT

Compacted forage forms such as wafers and pellets are rarely used in Indonesian cattle transport due to the need for feed adaptation. This study aimed to evaluate the effectiveness of forage-based wafers and pellets in improving cattle performance during prolonged sea transport without the adaptation period to the feed. Two tests, both in vitro and in vivo, were conducted to assess feed quality and its impact on cattle performance. The first study evaluated digestibility of treatment and control feeds (straw and Indigofera) in the rumen. In the first experiment, three treatments (T1: straw, T2: indigofera, T3: straw + indigofera) and three repetitions were conducted, with a duplicate test at each repetition. The second study involved 20 cattle divided into four treatment groups with five duplicates each, testing feed efficiency with straw (control), pellet, wafer, and 10% Indigofera wafer supplementation. In the first experiment, it was observed that Indigofera exhibited the highest levels of Dry Matter Digestibility (DMD), Organic Matter Digestibility (OMD), and gas production, whereas straw production was the lowest (P<0.05). In the second experiment, the wafer feed group exhibited the greatest increase in body weight gain (BWG), as well as the highest levels of feed consumption and drinking water consumption (P<0.05). The study concluded that providing compressed wafer-shaped forage feed can enhance cattle performance during sea transportation.

Introduction

Indonesia continues to face increasing demand for beef, while local production remains inadequate to fulfill consumption needs (Kusriatmi *et al*., 2014). Protein intake in the country also falls below the global average (Faharuddin, 2017). As a result, Indonesia has historically depended on imported cattle (Kusriatmi *et al*., 2014). However, more recent regulatory changes have aimed to boost domestic cattle self-sufficiency (KPMG, 2018). According to Houck (1986), domestic cattle production tends to increase when market prices rise due to limited supply. One region with notable cattle production potential is East Nusa Tenggara (NTT), known for its extensive grasslands (Suharyo *et al*., 2007) and large cattle population (Lole, 2009). Despite this, NTT's challenging environmental conditions such as nutrient-deficient soils and deforestation (Piggin and Parera, 1984) are affecting serious limitations to productivity. To meet the protein demand in high-consumption areas like Jakarta, cattle from NTT are transported over long distances predominantly by sea using vessels such as the Camara Nusantara ship (Priyanto *et al*., 2020; Zulhijariyanto *et al*., 2019).

Prolonged sea transport presents numerous logistical and physiological challenges, especially in feeding management. Indigenous NTT cattle that reared under grazing systems are unfamiliar with non-forage feeds which exhibit low adaptability during transit (Ngongo *et al*., 2022; Squizatti *et al*., 2023). Moreover, commonly used fresh forages such as elephant grass ferment rapidly in the humid ship environment (Malik and Singh, 2004). Straw is more stable against the fermentation, but it is low in nutrient contents and bulkier, creating storage inefficiencies (Li *et al*., 2024).

Previous studies highlight that transport duration, rather than distance, has a more profound effect on cattle welfare (Schwartzkopf-Genswein *et al*., 2016). Cattle transported from NTT to Jakarta typically endure voyages lasting five to seven days (Talithania and Yani, 2020), which often results in elevated stress levels. Proper feed management during this period is crucial for maintaining animal welfare (Kuo and von Keyserlingk, 2023). Evaluating the well-being of livestock during such lengthy journeys is essential to reduce mortality, illness, and weight loss, as emphasized by Phillips and Santurtun (2013). Feed and water scarcity are key factors affecting cattle during transportation (Fike and Spire, 2006). Depriving calves of these essentials can lead to substantial weight loss (Warris, 1990), with weight loss ranging from 3% to 11% during transport (Knowles and Warriss, 2007). Furthermore, severe weight reduction can trigger bovine respiratory illness, potentially increasing cattle mortality during transit (Cernicchiaro *et al*., 2012). Therefore, it is imperative to carefully monitor feeding practices during the journey to minimize weight loss and prevent illness, which, if not addressed, can result in significant financial losses for the cattle industry (Hendricks *et al*., 2023).

In recent years, compacted forage feeds have drawn considerable interest as they offer solutions to two major challenges in livestock logistics. The solutions are limited storage capacity and the need to maintain steady intake during transport. Evidence from studies in Indonesia highlights the distinct advantages of wafer-based diets. Widjaya *et al*. (2022) observed that wafers significantly increased the feeding frequency and duration of Kupang cattle compared with pellets, cubes, or dried pellets. In a complementary study, Despal *et al*. (2022) showed that wafers were the most effective form in eliminating the adaptation period when cattle were introduced to new rations, ensuring immediate acceptance even under stressful shipping conditions. These outcomes resonate with the findings of Retnani *et al*. (2022), who reported that logistic feeds such as wafers and pellets improved dry matter intake, nutrient utilization, and body weight recovery in sheep after transportation, thereby accelerating post-transport performance. Beyond these results, Karimizadeh *et al*. (2017) demonstrated that complete feed blocks provided higher nutrient digestibility, greater rumination activity, and superior daily weight gain in lambs compared to mash or pellet diets. Taken together, these studies underline that compacted forage technologies especially wafers and blocks combine logistical efficiency with strong nutritional and behavioral compatibility, making them highly suitable for advancing sustainable livestock shipping practices.

To address these challenges, compacted forage technologies such as wafers and pellets have emerged as a promising feeding solution during

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livestock shipping. These feeds offer high nutrient density, low moisture, and efficient storage properties, making them suitable for maritime transport (Lewis, 2013). However, adaptation challenges remain, especially for cattle unfamiliar with such feed forms. Therefore, assessing both in vitro feed quality and in vivo cattle performance is essential before implementation. This study investigated whether compacted forage in wafer and pellet forms can improve the feeding efficiency, welfare, and performance of Indonesian cattle during prolonged sea transport. The results are expected to inform future practices in sustainable livestock logistics and supply chain management.

Materials and methods

Feed production

Compressed and dried forage-based feeds were formulated to optimize storage space and nutritional adequacy during prolonged sea transportation of cattle. The formulation was designed using a combination of three primary ingredients: straw (as a source of fiber), Indigofera zollingeriana (as a source of protein and energy), and molasses (as a natural binder). The feed composition was developed in accordance with nutritional standards for livestock shipping established by Meat and Livestock Australia (MLA, 2012), as follows: Total digestibility nutrient: 69.62%; protein; 10.5-1.2%; starch: <20%; calcium; 0.55%; phosphorus 0.25% . The detailed nutrient composition of each treatment formulation is presented in Table 1.

Two physical forms of compacted feed were prepared: pellets and wafers (Figure 1). Pellet production was carried out using a cylindrical pellet mill (1 cm die, 3 cm length) equipped with an integrated hammer mill. For wafer production, a custom-built wafer press was used, producing 25 units per batch with initial dimensions of 7 × 7 × 10 cm (length × width × height). These units were subsequently compressed to a uniform final size of 7 × 7 × 7 cm using a hydraulic press to enhance their density, rigidity, and storability. Each batch of wafer feed required approximately 20 minutes to complete.

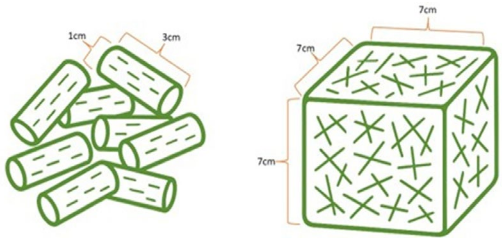

Fig. 1. Pellets and wafers dimensions.

Experimental design

This study consisted of two parts, resulting in two experimental designs for in vitro and in vivo, each designed to capture different aspects of feed evaluation. In the in vitro phase, three treatments were applied: T1 consisted of straw only, T2 of Indigofera only, and T3 of a mixture of straw and Indigofera in proportions consistent with the formulated rations. This arrangement was intended to clarify the degradability of each substrate individually as well as in combination before applying them in vivo. In the in vivo phase, four treatments were tested on Kupang cattle: T0 (control) received straw alone to reflect the common feeding practice among farmers during transport, T1 received the calculated formulated ration in wafer form, T2 received the same formulated ration in pellet form to distinguish the effect of feed form, and T3 received the control straw supplemented with Indigofera wafer as a low-cost supplementation strategy. The rationale for this design was to provide a comprehensive comparison between conventional practice and compacted feeds, while also evaluating whether supplementing straw with a small amount of Indigofera wafer could improve nutrient density and palatability at lower cost. This structure allowed the study to differentiate the influence of feed ingredients and physical form, while ensuring the treatments reflected practical options available to cattle farmers facing the challenges of maritime logistics.

In vitro analysis

The feed samples, consisting of straw, Indigofera, and the formulated feed, underwent in vitro analysis. Each sample was tested duplicate, with three repetitions per sample. Rumen fluid was collected from slaughtered cattle at slaughterhouse in the first week and again in the second week. Parameters measured included dry matter digestibility (DMD), organic matter digestibility (OMD), pH, NH_3 concentration, volatile fatty acids (VFA), total bacterial population, and total protozoa population.

The fermentation process followed the protocol outlined by Tilley and Terry (1963). A 0.5 g sample was placed in a fermentation tube, to which 40 ml of McDougall's solution and 10 ml of rumen fluid were added. After saturating the mixture with CO_2 for 30 seconds, the tube was sealed with a vented rubber stopper and incubated in a water bath shaker at 39°C for 4 hours to collect samples for rumen pH, total VFA, and NH_3 analysis. The fermentation process continued for 48 hours to collect samples for assessing DMD and OMD. The digestibility measurements followed the established Tilley and Terry (1963) technique, where samples were centrifuged at 3,500 rpm for 15 minutes. The supernatant was discarded, and the residue was treated with 50 mL of a pepsin-HCl solution, then incubated for another 48 hours. Post incubation, the precipitate was filtered using Whatman filter paper number 41 and dried in an oven at 105°C for 24 hours, followed by further heating in a furnace at 600°C for 6 hours. The blank utilized originated from the fermentation residue devoid of any samples.

NH_3 concentration was determined utilizing the Conway microdiffusion method as outlined in the General Laboratory Procedure (Millar, 1966). Conway's cup had Vaseline applied to its rim. The supernatant was transferred to a 1 ml volume and added to the left compartment of the Conway cup. A 1 ml portion of saturated Na2CO3 solution was then added to the right compartment. The little cup in the center contained 1 ml of boric acid with methyl red indicator and bromine cresol green. The Conway cup was sealed securely and then stirred thoroughly to combine the supernatant with Na2CO3, and allowed to sit at room temperature for 24 hours. Ammonia complexed with boric acid was titrated with 0.005 N sulfuric acid until a crimson color appeared. The concentration of NH_3 was determined using the following formula:

Ammonia concentration (mM)=(ml H_2SO_4×N H_2SO_4×1000)/(specimen weight×specimen DM)

The VFA analysis was conducted using the Steam Distillation method outlined in the General Laboratory Procedure (Millar, 1966). 5 cc of the supernatant was transferred into a distillation tube and heated using water vapor. 15% H_2SO_4 was added in a volume of one milliliter to the supernatant, and the tube was sealed tightly. The VFA was carried by hot steam via a condensed cooling tube and gathered in an Erlenmeyer flask with 5 ml of 0.5 N NaOH until it reached a volume of around 300 ml. Two drops of phenolphthalein indicator were then added, and the solution was titrated with 0.5 N HCl. The titration concluded when the original red color

Table 1. Nutrient content of each ration formulations.

Nutrients[1]	DM (%)	Ash (%)	CP (%)	Fat (%)	CF (%)	Starch (%)	TDN	Ca (%)	P (%)
Value	38.09	14.54	10.14	0.91	26.74	47.18	53.09	0.79	0.46

1DM: dry matter; CP: crude protein; CF: crude fiber; TDN: total digestibility nutrient; Ca: Calcium; P: Phosphorus transitioned to a clear hue. The blank solution was created by combining 5 ml of 0.5 N NaOH with two drops of PP indicator, followed by titration with 0.5 N HCl. The VFA concentration was determined using the formula: Total VFA (mM)=((a-b) × N HCl ×(1000÷5) ml)/(feed weight × standard solution %DM)

a = standard solution volume; b = specimen volume

All quantitative data were analyzed using a one-way analysis of variance (ANOVA) based on a completely randomized design (CRD). Differences among treatment means were further tested using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level. Statistical analysis was performed using SPSS Statistics software (IBM Corp., Armonk, NY, USA).

Cattle feeding on board (in vivo experiment)

This study evaluated four feed treatments (straw (control), wafers, pellets, and wafers supplemented with Indigofera) and five repetitions for each treatment. Straw was used as a baseline feed since it is commonly provided by commercial entities during sea transportation. The wafer and pellet feeds were formulated according to MLA (2012) standards, while the Indigofera wafer supplement was included as an additional source of nutrients. Cattle receiving the Indigofera wafer supplement were limited to 2.5 kg/day, while other feeds were offered ad libitum. Twenty cattle were randomly assigned to four treatment groups, each with five replicates. Feeds were transported from Bogor to NTT via Camara Nusantara 1 ship, taking the route from Tanjung Priok port (Jakarta) to Kupang port (NTT). The cattle were housed in cattle pens on deck 2 inside the ship and fed during the 8-day return journey to Tanjung Priok port.

The livestock carrier employed in this study was illustrated in Figure 2. Deck 1 lies entirely below the waterline and deck 2 is positioned approximately above the waterline. The aft section of deck 2 contains the main engine room, so air exchange on this level depends on mechanical exhaust fans connected to a longitudinal duct system. Decks 3 and 4 are used exclusively to cattle pens and benefit from natural cross-ventilation provided by lateral openings. Forage bales were stored in a dedicated warehouse directly above the engine room, thereby reducing the vertical distance required for feed handling. Crew cabin and the pilothouse are housed on a superstructure above deck 4, physically separated from animal areas.

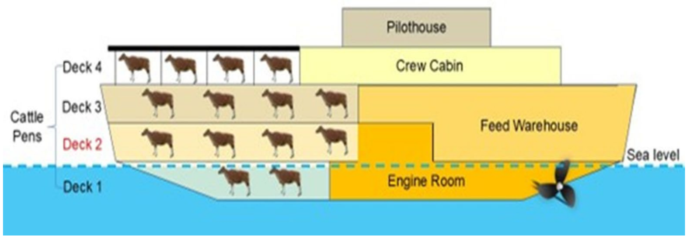

Fig. 2. Side view of the four-deck livestock carrier showing cattle pens, feed store, engine room, and crew areas.

Data collection included measurements of BWG, feed intake, water consumption, and body temperature. These variables were monitored thrice daily (morning, afternoon, and evening) over seven consecutive days, resulting in a total of 21 observations per cattle. Cattle were weighed before departure and upon arrival using a portable scale. All quantitative variables were subjected to one-way analysis of variance (ANOVA) using SPSS Statistics software. When the ANOVA indicated a significant treatment effect ($P < 0.05$), pair-wise comparisons among means were performed with Tukey's honestly significant difference (HSD) test at the 5 % probability level.

All procedures involving animals in this study were carried out in compliance with established animal welfare guidelines. These were approved by the Animal Ethics Committee of Bogor Agricultural University according to the guidelines for the care and use of animals in research (Approval Number: 108-2020 IPB).

Results

In vitro analysis

The in vitro digestibility results are presented in Table 2. There were significant differences ($P < 0.05$) among Indigofera, straw, and the formulated rations in terms of dry matter digestibility (DMD), organic matter digestibility (OMD), pH, and NH_3 concentrations. Indigofera showed the highest digestibility values, with DMD of 84.79±0.55% and OMD of 83.78±0.64%. In contrast, straw had the lowest values, with DMD of 50.17±1.33% and OMD of 53.14±1.23%. The straw treatment also recorded the highest pH (6.59±0.06) and NH_3 concentration (12.23±0.65 mM) compared to other treatments.

Table 2. In vitro results.

Parameters[1]	Indigofera	Straw	Ration
DMD	84.79±0.55^a	50.17±1.33^c	60.61±1.54^b
OMD	83.78±0.64^a	53.14±1.23^c	61.41±1.83^b
pH	6.51±0.06^b	6.59±0.04^a	6.27±0.09^c
NH_3	8.75±0.56^b	12.23±0.65^a	7.40±0.72^b

1DMD: dry matter digestibility; OMD: organic matter digestibility. Values within a row/column followed by different superscript letters (a, b, c) differ significantly at the 5 % significance level ($p < 0.05$)

Results of gas production during fermentation Revealed that Indigofera produced the highest volume of gas (78.48±1.87 ml), followed by soybean (60.63±2.87 ml), the formulated ration (58.12±1.14 ml), straw (52.04±0.62 ml) and Elephant grass (43.12±3.15 ml). The differences among these treatments were statistically significant ($P < 0.05$).

In vivo Performance

Cattle performance results during the sea transportation phase are detailed in Table 3. The control group (T0), which received only straw, experienced the greatest reduction in body weight, with an average loss of 16.50±4.12 kg over the voyage. The wafer-fed group (T1) exhibited the highest average body weight gain of 3.00±3.34 kg, while the Indigofera-supplemented wafer group (T3) gained 1.38±1.89 kg. The pellet-fed group (T2) showed a slight weight loss of 0.38±5.96 kg. Feed intake data indicated that T1 had the highest intake (3.61±0.43 kg/day), followed by T3 (2.50±0.00 kg/day), T2 (2.39±0.54 kg/day), and T0 (2.00±0.00 kg/day).

Water intake data from Table 3 show that T1 and T2 treatments,

Table 3. Cattle performance during voyage.

Treatments	BWG (kg)	consumption (kg/day)	Water consumption (L/day)	Temperature (°C)
T0	-16.50±4.12^a	2.00±0.00^b	19.71±0.50^c	37.02±0.03
T1	3.00±3.34^b	3.61±0.43^a	35.46±0.73^a	37.10±0.14
T2	-0.38±5.96^b	2.39±0.54^b	34.71±1.49^a	37.08±0.15
T3	1.38±1.89^b	2.50±0.00^b	21.32±1.13^b	37.14±0.07

T0 (control): straw feeding; T1: wafer complete feed; T2: pellet complete feed; T3: straw+10% Indigofera. Values within a row/column followed by different superscript letters (a, b, c) differ significantly at the 5 % significance level ($p < 0.05$)

which involved low-moisture feeds (wafers and pellets), had the highest average water intake, with values of 35.46±0.73 L/day and 34.71±1.49 L/day, respectively. The T3 group, which received a combination of wafer and straw, consumed 21.32±1.13 L/day. The control group (T0), which received only straw with higher moisture content, had the lowest water consumption at 19.71±0.50 L/day.

Environmental Temperature and Body Temperature

Temperature readings from the ship's decks and cattle body temperatures are shown in Figure 3a and 3b. Deck 2 exhibited the highest ambient temperature (32.44±0.01°C), followed by deck 1 (30.92±0.01°C), deck 3 (29.64±0.01°C), and deck 4 (29.43±0.01°C). Cattle body temperatures across treatments and decks were generally maintained within normal ranges, with T0 recording 37.02±0.03°C, T1 at 37.10±0.14°C, T2 at 37.08±0.15°C, and T3 at 37.14±0.07°C (Figure 3c). An outlier was recorded on the 8th observation at deck 4 during daylight, when body temperature rose briefly.

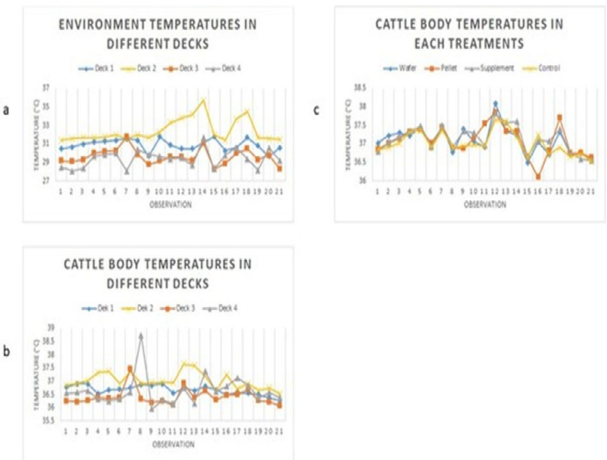

Fig. 3. Environment temperature in different decks (a); Cattle body temperatures in different decks (b); Cattle body temperatures in each treatment (c).

Discussion

The in vitro results showed that Indigofera exhibited significantly higher dry matter digestibility (DMD) and organic matter digestibility (OMD) compared to straw and the formulated rations. This finding is consistent with Suharlina *et al.* (2016), who reported that the higher fiber content in straw impedes microbial access to nutrients, thereby reducing digestibility. Conversely, Indigofera, with its lower fiber and higher nutritional content, facilitates microbial breakdown, resulting in greater digestibility efficiency. These findings align with Gibbs and Roche(2016), who emphasized that feeds with reduced fiber content tend to achieve better digestibility, making them more suitable for ruminant nutrition. The observed pH and NH_3 concentrations further reflect the efficiency of fermentation across treatments. Straw exhibited the highest pH and NH_3 levels, suggesting less efficient fermentation and potential protein degradation without corresponding microbial assimilation. An excessively high pH may reflect poor microbial activity, while elevated NH_3 concentrations can indicate inefficient nitrogen utilization, leading to undesirable rumen conditions over extended periods.

Gas production, as an additional indicator of fermentation activity, followed a similar trend. Indigofera produced the highest volume of gas, which can be attributed to its rich protein and carbohydrate composition that supports microbial fermentation (Getachew *et al.*, 1998). However, gas production must be interpreted with caution. As stated by Mauricio *et al.* (2001), excessively high gas output may predispose cattle to rumen acidosis, whereas insufficient gas generation can imply poor fermentation. A balanced formulation of Indigofera and straw resulted in moderate gas production, indicating an optimal fermentation rate that supports rumen health and cattle performance. This finding is supported by Jayanegara *et al.* (2019) who noted that protein and carbohydrate levels directly influence gas production, while high fiber content such as that found in straw is reducing gas output (Ndlovu and Nherera, 1997).

The removal of a feed adaptation period in this study was deliberate, as it reflects a common practice among livestock farmers in Kupang. Most smallholder farmers are reluctant to place livestock in quarantine or adaptation facilities prior to shipment due to the additional costs of feed and labor, as well as the considerable distance between the farm and the port. Consequently, livestock are typically shipped directly on the day of departure, a cost-saving but high-risk strategy (Njisane *et al.*, 2019).

International recommendations, particularly from major live livestock exporting countries, emphasize that livestock should be offered the same shipboard ration several days before departure to minimize feed rejection and unavailability during long voyages (Caulfield *et al.*, 2014). Empirical observations of shipments in Indonesia indicate that when no adaptation is provided, only about 13–14% of Bali cattle consume the feed on board, resulting in substantial weight loss during the voyage (Wibawanti *et al.*, 2021). These findings highlight the risks of neglecting adaptation, including reduced intake, increased stress, and compromised animal welfare.

Nevertheless, our results show that Kupang cattle are still able to consume solid feed, particularly wafers, without an adaptation period. This demonstrates the importance of feed format in facilitating abrupt dietary transitions, as wafers more closely resemble natural forage and thus facilitate immediate acceptance. While this aligns with the logistical realities of the region, it also underscores the need for further studies directly comparing gradual versus abrupt transitions to balance practicality with long-term performance and welfare outcomes.

In the in vivo analysis, the cattle fed with wafer-based rations demonstrated a high performance in terms of body weight gain. This was likely due to the favorable texture and palatability of wafers, which are easier to disintegrate and more familiar to grazing cattle compared to pellets (Widjaya *et al.*, 2022). In contrast, pellet-based feeds are more compact and resistant to breakdown, making them less acceptable to animals unfamiliar with processed feed forms (Harahap *et al.*, 2024). The preference for wafers can be leveraged to improve intake and performance during transportation. Although the Indigofera wafer supplement group achieved lower gains than the full wafer ration, it presents a cost-effective compromise for stakeholders aiming to reduce transport expenses while still supporting cattle nutrition (Retnani *et al.*, 2020).

Body weight loss during sea transportation is a major concern due to restricted feed and water access, as well as continuous excretion of urine and feces (Hogan *et al.*, 2007). Marques *et al.* (2012) emphasized that limited intake during transit is the primary contributor to body weight decline. This weight loss not only diminishes performance but also increases the likelihood of disease and mortality (Cernicchiaro *et al.*, 2012). Some cattle initially refused the new feeds, likely due to limited adaptive capacity when exposed to unfamiliar feed types (Higgs *et al.*, 1991; Richards *et al.*, 1991).

Water intake among the treatment groups was closely related to both environmental temperature and feed moisture content. As shown by Wickramasinghe *et al.* (2023), cattle consuming dry, compacted feed forms such as wafers and pellets require more water to maintain hydration and thermoregulation. Meyer *et al.* (2004) and Beatty *et al.* (2006) also noted that high environmental temperatures increase water loss via respiration, leading to dehydration if not compensated. However, our findings show that all feed treatments had maintained body temperature within normal limits, indicating that none of the rations imposed additional thermal stress on the cattle. This reinforces the assertion that processed feed forms such as wafers and pellets do not contribute to physiological stress during transit.

The experimental trial was conducted on deck 2 of the livestock carrier, which is considered the harshest environment within the ship due to proximity to the engine room, limited ventilation, and high ambient temperatures. Nugraha *et al.* (2020) reported that temperature and humidity gradients significantly affect livestock performance, with the lower decks of ships often experiencing the most extreme conditions. Therefore, the successful outcomes observed on deck 2 can reasonably be extrapolated to more favorable deck environments. The stressors associated with livestock transportation are multifaceted, including noise, vibrations, unfamiliar surroundings, stocking density, limited diet and water access, and heat exposure (Swanson and Morrow-Tesch, 2001). This study aimed to mitigate some of those stressors, particularly those related to feed intake and nutritional adequacy, by evaluating compacted feed options that are nutritionally dense, easy to store, and acceptable to cattle.

These findings underscore the value of using compacted feed, especially wafers for long-distance sea transport of cattle from regions like NTT. The wafer feed not only improved intake and body weight but also maintained animal welfare under challenging transit conditions, offering a promising alternative for future livestock logistics systems.

Conclusion

This study demonstrates that compacted forage feeds, particularly in wafer form, are more readily consumed by Kupang cattle compared with pellets or conventional straw. The ability of cattle to accept wafers without a prior adaptation period highlights their potential as a practical solution under real shipping conditions, where farmers often bypass adaptation due to cost and logistical barriers. From a broader perspective, these findings suggest that compacted feeds could enhance the sustainability of livestock shipping by reducing feed wastage, improving intake, and supporting animal welfare during long-distance maritime transport. In addition to their logistical efficiency, compacted feeds may also contribute to more resilient supply chains by allowing nutrient-dense rations to be transported and stored in smaller volumes, which is critical in archipelagic regions like Indonesia. Future studies should evaluate the economic feasibility of scaling up wafer-based rations for commercial shipping, explore long-term physiological impacts of abrupt versus gradual feed transitions, and integrate life-cycle or cost–benefit analyses to better quantify their role in sustainable cattle logistics. By addressing both practical and welfare concerns, compacted feed technologies hold promise as a cornerstone for advancing sustainable livestock transport systems in tropical regions.

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Conflict of interest

The authors confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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