Research Article

Replacing Elephant Grass with Hydroponic Maize Fodder Improves Friesian Holstein Dairy Calves' Growth Performance

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Abstract | This study investigated the potential of hydroponic fodder as a strategic forage starter to support the post-weaning growth of Friesian Holstein (FH) dairy calves. Providing an appropriate forage starter during this stage is critical to stimulate rumen development, enhance nutrient absorption, and ensure a smooth dietary adaptation. However, forages may lack the digestibility and nutrient density required to meet the metabolic demands of young calves. The study employed a Completely Randomized Design (CRD) with three treatments and three replicates each: three calves fed elephant grass (EG), three calves fed maize fodder (MF), and three calves fed sorghum fodder (SF). Evaluated parameters included feed composition, *In Vitro* digestibility, growth performance, hematological indices, and physiological responses. Hydroponic fodder significantly improved crude protein content and acid detergent lignin digestibility ($P<0.05$). Highly significant enhancements ($P<0.01$) were observed in ash, gross energy, ADF, NDF, ADL, cellulose, and overall digestibility, indicating superior nutritional quality. Calves fed hydroponic fodder also showed increased average daily gain and digestible crude protein intake ($P<0.05$), without adverse effects on hematological or physiological parameters. The MF showed higher ADG than EG and SF. This study highlights MF hydroponics as a promising substitute for elephant grass as a forage starter, providing nutritional benefits for Friesian Holstein dairy calves without causing health issues; with hematological and physiological values remaining within the normal range.

Keywords | Digestibility, Forage starter, Growth performance, Hydroponic fodder, Holstein Friesian dairy calves; Physiological status

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INTRODUCTION

Effective calf management is essential to ensure optimal growth, health, and future productivity in the dairy industry. Among the various aspects of calf rearing, feed management stands out as the most critical factor influencing developmental outcomes (Novitasari *et al.*, 2022). Inadequate feeding practices during early life stages can impair rumen development, reduce growth rates, and compromise long-term performance. The transition from pre-weaning to weaning is particularly sensitive, requiring strategic nutritional interventions to support physiological adaptation and digestive maturation (Doolatabad *et al*., 2020).

Providing high-quality starter feed during this phase is crucial for stimulating reticulo-rumen development and enhancing microbial colonisation. Starter forages with high crude protein (CP) and low crude fibre (CF) content are especially beneficial, as they promote digestibility and nutrient absorption (Xiao *et al*., 2020). However, many farms in tropical regions still rely on elephant grass (*Pennisetum purpureum*), which has high cell wall content including ADF and NDF potentially damaging the digestive organs of calves due to its negative correlation with low forage digestibility (Rusdy *et al*., 2021).

Hydroponic fodder production offers a promising alternative to conventional forage systems. Utilising water-based cultivation without soil, hydroponic systems enable the growth of nutrient-rich fodder such as maize and sorghum with significantly lower CF and higher CP levels. These forages are not only highly digestible but also require minimal land and can be harvested within 7–14 days, making them ideal for intensive calf-rearing systems (Rayani *et al*., 2021). Previous studies have demonstrated that hydroponic fodder enhances feed intake, improves growth performance, and supports rumen development in calves (Yahyaei and Talbi, 2024).

Moreover, hydroponic fodder aligns with sustainable livestock practices by reducing dependency on land and water resources while maintaining consistent nutritional quality. This innovation has the potential to be adopted by smallholder farmers, especially during the dry season when the availability of quality forage is limited. This innovation is therefore a sustainable feed supply system. Additionally, feed costs can be reduced because this technology eliminates the need for pasture management costs. Furthermore, sorghum and corn seeds can be utilized using sorted results that still have good growth potential. The introduction of technology in this innovation will certainly increase its potential. Its application during the weaning transition may mitigate common stressors, such as reduced dry matter intake and digestive inefficiencies in dairy cattle (Kostadinović, 2023), which enhances the feed conversion ratio and improves the overall health of beef calves (Benu *et al*., 2024). However, there has not been any specific research reporting on the effects of maize and sorghum hydroponic fodder as a substitute for elephant grass.

Despite its potential, limited research has explored the use of hydroponic maize and sorghum fodder as starter forages specifically for FH calves during the post-weaning phase. Therefore, this study aims to evaluate the efficacy of hydroponic fodder in enhancing growth performance, feed digestibility, and physiological responses in FH calves aged 60–80 days. The findings are expected to contribute to the development of viable feeding strategies for dairy calf management in tropical environments

MATERIALS AND METHODS

Animals, management, and experimental design

This research was conducted in Panette Hamlet, Cendana Village, Enrekang Regency, South Sulawesi (3°29'12.12" S, 119°51'40.319" E) at an altitude of 47 meters above sea level. The temperature during the research varied from 24 to 31 °C, with humidity ranging from 57% to 87%. The study employed a Completely Randomized Design (CRD) with three treatments and three replicates each: three calves fed elephant grass (EG), three calves fed maize fodder (MF), and three calves fed sorghum fodder (SF). All calves, aged between 60–80 days, representing the transition phase from pre-weaning to weaning, were utilized in this study. Dairy calves must weigh at least 70–80 kg and have been weaned based on dry matter intake. All calves were fed with their respective treatment diets at 2.5% dry matter (DM) of their body weight, and were fed three times daily at 07:00 am, 01:00 pm, and 05:00 pm. Each experimental period lasted 20 days, with a 3-day adaptation period.

The preparation of fodder (maize and sorghum) involved soaking the seeds for 12 hours. Subsequently, the seeds were spread in containers (A plastic container with dimensions of 30 cm in length, 25 cm in width, and 7 cm in height) at a density of 0.45 g/cm^2 for maize (Harwanto *et al*., 2022) and 0.38 g/cm^2 for sorghum (Wahyono *et al*., 2019). The containers were placed in areas with low daylight intensity, and watering was conducted every 3 hours. Liquid fertiliser, mixed with water, was applied daily in the morning during watering. Hydroponic nutrients are typically delivered as a solution made from two components: Stock A mix and Stock B mix with a commercial brand, Goodplant®. These mixes provide a variety of macro- and micronutrients essential for plant growth and development. The nutrients include nitrogen (N) in the forms of nitrate (NO_3^-) and ammonium (NH_4^+), phosphorus (P) as dihydrogen phosphate ($H_2PO_4^-$), hydrogen phosphate (HPO_4^{2-}), or phosphate ($PO4^{3-}$), potassium (K) as potassium ions (K^+), calcium (Ca) as calcium ions (Ca^{2+}), magnesium (Mg) as magnesium ions (Mg^{2+}), sulfur (S) as sulfate (SO_4^{2-}), and microelements such as iron (Fe) from iron sulfate ($FeSO_4$). Both Stock A mix and Stock B Mix are combined in equal proportions (1:1) at a rate of 1.25 grams per liter (g/L)

(Fahmi et al., 2022). After 14 days, the fodder was ready to be harvested and provided to the calves as a forage starter. For a detailed procedure on hydroponic fodder preparation, refer to Figure 1. The elephant grass utilized in this study is a variety known for its ease of cultivation, with a defoliation age ranging from 14 to 20 days.

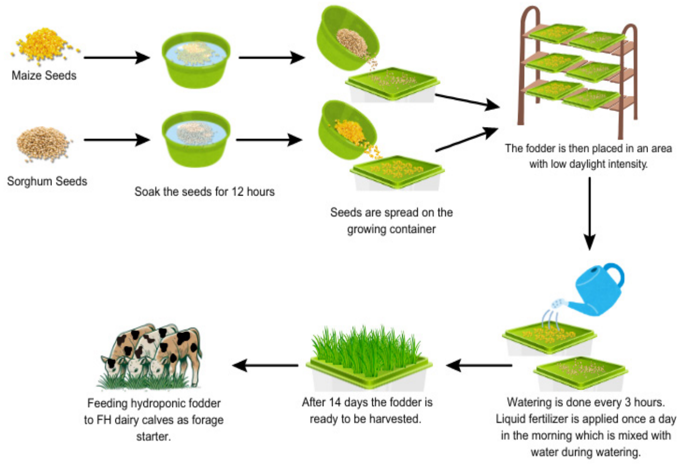

Figure 1: Procedures for hydroponic fodder production.

Chemical analysis of fodder

Feed quality testing was conducted at the Dairy Nutrition Laboratory, Faculty of Animal Science, IPB University. The measurement variables are Crude Protein (CP), Ash, Gross Energy (GE), Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), Acid Detergent Lignin (ADL), and Cellulose. Crude Protein was analyzed using the Indirect Kjeldahl method, ash was determined following the gravimetric method (AOAC, 2005), and GE was tested using a bomb calorimeter. While ADF, NDF, and ADL values were tested using the Van Soest method (VanSoest, 1976).

In vitro digestibility

First, prepare the solution and livestock rumen fluid from a dairy cow that has been fistulated to begin the digestibility test. The cattle used are raised in special pens with attention to animal welfare and health, and are fed common feed three times a day. These cattle have been frequently used for *in vitro* digestibility testing. The collected rumen fluid was then placed in a fermenter tube along with 0.5 g of sample, and 40 mL of McDougall's solution was added. Place the tubes in a shaker set at 39°C. Shake the tubes with a CO_2 flow for 30 seconds, check the pH (target range: 6.5–6.9), seal them with ventilated rubber stoppers, and allow them to ferment for 48 hours. After fermentation, carefully remove the rubber caps from the fermentor tubes and add 2–3 drops of $HgCl_2$ to kill the microbes. Next, centrifuge the tubes at 5,000 rpm for 15 minutes. This will separate the substrate into a precipitate at the bottom and a clear supernatant at the top; discard the supernatant. Transfer the precipitate to a container and add 50 mL of 0.2% pepsin-HCl solution. Incubate this mixture without a rubber lid for another 48 hours. After digestion, filter the remaining material through Whatman No. 41 filter paper (of known weight) using a vacuum pump. Once filtered, place the precipitate on the filter paper into a porcelain cup and dry it in a 105 °C oven for 24 hours. After drying, remove the porcelain cup, filter paper, and residue, then weigh the combined mass to determine the dry matter content. Subsequently, incinerate the material in an electric furnace for 6 hours at a temperature between 450–600°C to assess the level of organic matter. For comparison, use the residue from fermentation without feed ingredients as a blank for the tests on CP and GE. Furthermore, the digestibility of feed nutrients was calculated based on the (Telley and Terry, 1963) equation.

$$\%In\ Vitro\ \text{digestibility} = \frac{\text{Sample (g)} - (\text{Residu (g)} - \text{Blank (g)})}{\text{Sample (g)}} \times 100\ \%$$

Growth performance

Performance measurements, such as Average Daily Gain (ADG), are calculated by subtracting the initial weight of dairy calves before treatment from their final weight after treatment, and then dividing by the duration of the treatment period. Feed intake is determined by subtracting the remaining feed from the total amount of feed provided. Feed Conversion Ratio (FCR) was calculated as the ratio of total FI to ADG, following the method described by Panahiha (Panahiha *et al*., 2022). The daily intake of digestible CP is computed using the following equation (Pariambawea *et al*., 2016):

Daily intake of digestible crude protein (Kg/day) = DMI (kg) × CP% × IVCPD %

Physiological status and hematological profile

Physiological parameters such as rectal temperature, respiratory rate, and heart rate were recorded three times daily at 07:00 a.m., 12:00 p.m., and 05:00 p.m. to capture diurnal variations. Rectal temperature was recorded by inserting a digital rectal thermometer approximately 10 cm into the rectum of the calf until an audible signal indicated completion. Respiratory rate was determined by observing the symmetrical movement of the thoracic and abdominal regions during inhalation. Heart rate was assessed using a stethoscope positioned over the left axillary region, with measurements taken for one minute and repeated three times using a stopwatch for accuracy. Hematological indices, including erythrocyte count, leukocyte count, hemoglobin concentration, and hematocrit levels, were analyzed using a Prokan PE-6100 hematology analyzer (manufactured in China).

Statistical analysis

Data analysis was performed using SPSS software. A one-way analysis of variance (ANOVA) was conducted, followed by the Duncan Multiple Range Test (DMRT) to identify significant differences among the parameters. Additionally, Pearson correlation analyses were carried out to examine the relationship between the daily digestible CP intake and ADG.

RESULTS AND DISCUSSION

Feed quality and digestibility

The analysis of hydroponic fodder quality reveals substantial effects ($P< 0.05$) on CP content and IVADLD. More notably, pronounced impacts ($P<0.01$) were identified on critical nutritional parameters, including ash, GE, NDF, ADF, ADL, and cellulose, alongside a range of *in vitro* digestibility metrics (IVDMD, IVOMD, IVCPD, IVGED, IVADFD, IVNDFD, IVCD) (Table 1). The results show that MF tends to have better quality compared to other treatments.

Table 1: Quality and digestibility of various hydroponic fodder as Calf starter forage.

Parameters	Treatment			p value
	EG	MF	SF	
Feedstuff quality				
CP (%)	18.52^a±0.14	18.36^a±0.28	19.83^b±0.85	0.02
Ash (%)	14.72^c±0.09	7.17^a±0.46	10.12^b±0.03	<0.01
GE (in Kcal/kg)	3454.50^a±3.50	3884.50^b±3.50	4083.50^c±1.50	<0.01
ADF (%)	32.50^c±0.06	10.24^a±0.21	28.90^b±0.11	<0.01
NDF (%)	50.73^c±0.02	26.90^a±0.03	44.00^b±0.02	<0.01
ADL (%)	3.08^b±0.02	1.35^a±0.05	10.97^c±0.08	<0.01
Celulose (%)	21.79^c±0.02	9.08^a±0.05	17.35^b±0.05	<0.01
In Vitro digestibility (%)				
IVDMD	67.14^b±0.67	80.35^c±0.39	61.15^a±0.58	<0.01
IVOMD	69.81^b±0.92	78.61^c±0.45	56.69^a±0.17	<0.01
IVCPD	70.48^b±0.37	81.38^c±0.31	66.51^a±0.73	<0.01
IVGED	63.33^b±0.75	75.15^c±0.51	54.54^a±0.69	<0.01
IVADFD	49.25^a±0.97	66.10^c±0.55	56.97^b±0.43	<0.01
IVNDFD	57.32±0.39	70.61±0.26	59.80±0.28	<0.01
IVADLD	12.14±0.76	14.79±1.27	13.07±1.49	0.01
IVCD	48.48±0.54	60.11±0.32	52.44±0.80	<0.01

Treatment: elephant grass (EG); maize fodder (MF); and sorghum fodder (SF). CP= Crude Protein; GE= Gross Energy; ADF= Acid Detergent Fiber; NDF= Neutral Detergent Fiber; ADL= Acid Detergent Lignin; IVDMD= *In Vitro* Dry Matter Digestibility; IVOMD= *In Vitro* Organik Matter Digestibility; IVCPD= *In Vitro* Crude Protein Digestibility; IVGED= *In Vitro* Gross Energ Digestibility; IVADFD= *In Vitro* Acid Detergent Fiber Digestibility; IVNDFD= *In Vitro* Nutral Detergent Fiber Digestibility; IVADLD= *In Vitro* Acid Detergent Lignin Digestibility. Data is presented as mean±standard deviation

Importantly, the CP content of hydroponic fodder aligns perfectly with the 18% CP standard required for transitional dairy calves (NRC). This compliance indicates that hydroponic fodder can be safely fed at a 100% rate without the necessity of calf starter concentrate for FH dairy calves. This innovative hydroponic fodder technology stands out for its ability to deliver feed rich in CP and GE while maintaining low levels of ash, ADF, NDF, and ADL. Such quality is primarily attributed to younger plants, which inherently possess higher CP and GE levels alongside reduced ash, ADF, NDF, and ADL values. Additionally, plants with softer stems consistently exhibit superior protein content compared to their harder-stem counterparts (Utamy *et al*., 2018). However, it is crucial to note that as the harvesting age of plants increases, a decline in nutritional quality occurs, accompanied by an elevation in CF and overall plant biomass (Tashiro *et al*., 2024). The ash content in EG exceeds the normal threshold for feed. Excessively high ash levels can reduce the digestibility and nutritional value of the feed (BSN, 2017). Essentially, ash is significantly affected by the mineral content in the feed. EG has a high calcium content; however, this calcium is bound to oxalate in the form of calcium oxalate, which is challenging to digest (Liu *et al*., 2024). These anti-nutrients and ash are what need to be avoided when using older elephant grass. Based on these results, MF is safer to use than EG for dairy calves.

Furthermore, MF demonstrates elevated CP and GE concentrations, as well as increased levels of ash, ADF, and NDF, when compared to 40-day-old maize stalks, which contain 10.55% CP, 3020 Kcal GE, 8.92% ash, 63.20% ADF, and 31.30% NDF (Tuturoong *et al*., 2020). A strong positive correlation exists between fiber and ash content; increased fiber content invariably corresponds with higher ash content (Triastuti *et al*., 2022). While sorghum boasts a higher protein content than maize, its skin comprises multiple layers rich in fiber (lignin), rendering it tougher than both maize and rice (Paryoto *et al*., 2018). This structural complexity results in lower digestibility when incorporated into hydroponic fodder.

It's also critical to understand that digestibility declines as fiber content rises. High fiber (lignin) levels complicate the degradation of feed, particularly in calves. Research by Putri *et al* (2021) indicates that older plants, characterized by elevated levels of CF and thicker cell walls, experience reduced digestibility. Conversely, young forages, with their minimal fiber content and thinner cell walls, are more easily degraded by rumen microbes. Lignin acts as a binding agent, creating a dense structure that can significantly impair digestibility in forage (Zain *et al*., 2024).

Growth performance

Feeding fodder forage as a starter feed to dairy calves showed a significant effect (P<0.05) on ADG, FCR, and daily protein intake. However, DMI of FH dairy calves showed similar values (P>0.05) (Table 2). Based on BSN (2014), ADG of dairy calves must have a minimum weight gain of 0.55 kg/day. This can be achieved by using the standard MF feed, unlike other treatments. DMI is important in determining livestock performance. However, feed quality, such as nutritional content and digestibility, is equally important. High feed intake alone does not guarantee optimal performance; if feed quality is inadequate, animal productivity will remain constrained. In this study, quality had a greater influence than DMI. This is because MF has a higher digestibility, especially in terms of protein digestibility, thus calves receive a higher intake of protein and other nutrients. The calculation of daily digestible protein intake reveals that calves fed MF receive a higher protein intake. ADG value with daily protein intake is strongly correlated (R2 = 0.86); an increase in daily digestible protein intake is positively correlated with a higher ADG in dairy calves (Figure 2).

Table 2: Performance of FH dairy calves fed various hydroponic fodder as calf starter forages.

Parameters	Treatment			p value
	EG	MF	SF	
ADG (kg/day)	$0.23^{a}\pm0.02$	$0.57^{b}\pm0.07$	$0.39^{ab}\pm0.10$	0.03
DMI (kg/day)	1,00±0.08	1.12±0.05	1.00±0.00	0.07
FCR	$4.30^{b}\pm0.76$	$1.97^{a}\pm0.16$	$2.67^{a}\pm0.75$	0.01
Daily intake of digestible CP (kg/day)	$0.12^{a}\pm0.01$	$0.16^{b}\pm0.00$	$0.13^{a}\pm0.00$	<0.01

Treatment: elephant grass (EG); maize fodder (MF); and sorghum fodder (SF). ADG= Average daily gain; DMI= dry matter intake; FCR= feed conversion ratio. Data is presented as mean±standard deviation.

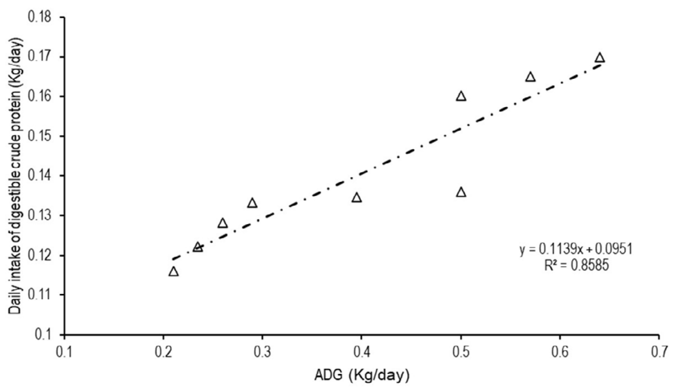

Figure 2: Correlation between daily intake of digestible crude protein with ADG (kg/day)

Although SF contains the highest CP content, it does not result in a high ADG. This limitation is attributed to the low digestibility of CP in SF, leading to inefficient protein utilization. The poor protein digestibility is primarily due to its high CF fraction, including components such as acid ADF, NDF, ADL, and cellulose, which collectively inhibit IVCPD. Protein and energy are crucial components of animal feed, playing essential roles in growth, production, and reproduction (Shahzad *et al*., 2011). Adequate protein intake enhances ADG and reduces FCR values (Brown *et al*., 2004; Liu *et al*., 2021).

Feed conversion ratio is strongly influenced by feed quality parameters, particularly protein content and digestibility. EG exhibits the highest FCR due to its relatively low nutritional quality, which limits its ability to support optimal calf growth and ADG. When calves consume protein, it is broken down into amino acids that are vital for their growth process (Desta, 2024). Specific amino acids, such as lysine and methionine, are particularly important for the growth and development of calves, as they also help regulate growth hormones (Bai *et al*., 2020). One key growth hormone is IGF-1, a peptide comprising 70 amino acids (Bailes and Soloviev, 2021). Deficiency in protein intake can lead to metabolic disorders, such as changes in albumin and blood urea levels, ultimately resulting in growth inhibition and health issues in livestock (Pazla et al., 2024).

The superior performance of MF observed in this study can be attributed not only to its favorable nutrient profile but also to its physical characteristics, which enhance palatability and intake. The soft texture, high moisture, and low fiber content of hydroponic fodder are known to stimulate chewing activity and salivary secretion, both of which are essential for optimal rumen buffering and microbial activity (Khan *et al*., 2011). This may explain the improved feed conversion efficiency and ADG in calves fed MF compared to those receiving EG. However, it is crucial to note that as the harvesting age of plants increases, a decline in nutritional quality occurs, accompanied by an elevation in CF and overall plant biomass (Tashiro *et al*., 2024).

Furthermore, the high digestibility of MF, particularly in terms of CP and NDF, suggests enhanced microbial protein synthesis in the rumen. Microbial protein is a major source of amino acids for ruminants and plays a critical role in supporting tissue growth and immune function (Wang *et al*., 2021). The increased digestible protein intake observed in this study likely contributed to the elevated ADG and may also have supported the synthesis of growth-related hormones such as IGF-1, as previously reported by (Bai *et al*., 2020; Bailes *et al*., 2021).

Hematological profile

Feeding fodder forage as starter feed to dairy calves showed a non-significant effect (P>0.05) on erythrocyte, leukocyte, hemoglobin, and hematocrit (Table 3). Hematological parameters serve as critical indicators for

Table 3: Hematological profile of FH dairy calves fed various hydroponic fodder as calf starter forages.

Parameters	Treatment			p value
	EG	MF	SF	
Erythrocyte($1\times10^6/\mu l$)	6.82±0.77	6.80±0.86	6.50±0.55	0.83
Leukocyte ($1\times10^3/\mu l$)	11.41±1.11	12.71±0.90	10.50±2.15	0.26
Hemoglobin (mg/dl)	8.80±1.00	8.90±0.72	8.66±0.60	0.87
Hematocrit (%)	27.33±2.82	24.70±0.36	25.96±2.02	0.31

Treatment: elephant grass (EG); maize fodder (MF); and sorghum fodder (SF). Data is presented as mean±standard deviation.

Table 4: Physiological status of FH dairy calves fed various hydroponic fodder as calf starter forages.

Parameters	Treatment			p value
	EG	MF	SF	
Rectal temperature (°C)	38.68±0.21	38.92±0.33	38.87±0.27	0.87
Respiratory rate (breaths/ min)	32.44±2.15	32.24±2.63	33.63±2.97	0.31
Heart rate (beats/min)	58.47±0.95	58.47±0.89	58.27±2.78	0.83

Treatment: elephant grass (EG); maize fodder (MF); and sorghum fodder (SF). Data is presented as mean±standard deviation.

evaluating the physiological impact of high-quality feed. In this study, erythrocyte and leukocyte counts remained within the established normal ranges of 4.83–11.33×10⁶/µL and 6.00–15.64×10³/µL, respectively (Ježek *et al*., 2011), suggesting that the inclusion of hydroponic fodder did not induce adverse health effects such as toxicity in dairy calves. On the contrary, the provision of nutritionally rich hydroponic fodder may contribute to the stabilization of erythrocyte and leukocyte levels, as these hematological components are influenced by essential nutrients such as iron and protein present in the feed. Similarly, hemoglobin and hematocrit values observed in this study were within the physiological norms of 8.4–15 g/dL and 20.4–39.7%, respectively (Roland *et al*., 2014; Kim *et al*., 2021). The favorable nutritional profile of hydroponic fodder, characterized by high protein content and low CF likely supports optimal hemoglobin synthesis and hematocrit levels. This finding is consistent with the assertion by Sujono et al. (2021), who noted that hemoglobin synthesis is dependent on adequate iron and protein intake, both of which are essential for effective oxygen transport.

The absence of significant changes in hematological and physiological parameters further reinforces the safety and suitability of hydroponic fodder as a primary feed source. These findings are particularly relevant in the context of calf health management, where nutritional interventions must not compromise immune competence or induce metabolic stress. The maintenance of normal erythrocyte and leukocyte counts, as well as stable hemoglobin and hematocrit levels, indicates that hydroponic was not detrimental to health (Ježek *et al*., 2011; Roland *et al*., 2014; Kim *et al*., 2021).

Physiological status

Feeding fodder forage as starter feed to dairy calves showed a non-significant effect ($P>0.05$) on rectal temperature, respiratory rate, and heart rate (Table 4). Physiological parameters such as rectal temperature, respiratory rate, and heart rate are widely recognized as reliable indicators of animal health and stress, particularly in response to dietary changes or potential feed toxicity. In this study, the administration of hydroponic fodder did not significantly alter these physiological metrics, with recorded values remaining within normal ranges: Rectal temperature (38.2°C–39.10°C), respiratory rate (20–40 breaths/min), and heart rate (54–84 beats/min) (Asmarasari *et al*., 2023). These findings indicate that hydroponic fodder adequately fulfils the nutritional requirements of dairy calves without eliciting stress or toxicological responses. This may be attributed to its relatively low CF content, as excessive fiber intake is known to elevate metabolic heat production, thereby increasing physiological stress indicators in calves (Ramadan *et al*., 2025).

Interestingly, the physiological parameters rectal temperature, respiratory rate, and heart rate remained within the normal physiological range, suggesting that hydroponic fodder does not increase metabolic heat load. This is especially important in tropical climates, where heat stress can impair feed intake and growth performance (Asmarasari *et al*., 2023). The low crude fiber (CF) content of hydroponic MF indicates that it does not cause stress in calves (Arnold, 2020).

From a practical standpoint, the use of hydroponic MF offers several advantages for smallholder and commercial dairy operations. Its rapid growth cycle (7–14 days), minimal land requirement, and consistent nutritional quality make it a viable solution for regions with limited forage availability or degraded land. In summary, the findings of this study underscore the potential of hydroponic maize fodder as a strategic nutritional intervention during the post-weaning phase in Friesian Holstein calves. Its high digestibility, protein content, and physiological safety profile make it a promising alternative to conventional forages.

CONCLUSION

The findings of this study clearly demonstrate that hydroponic fodder, particularly MF, serves as an effective forage starter as a replacement for elephant grass, improving the growth performance of Friesian Holstein dairy calves. MF can support optimal growth performance compared to other treatments. The superior digestibility and nutrient density of hydroponic MF, combined with its low fiber content, contribute to enhanced protein intake and feed conversion efficiency. The ability of MF to support rumen development and maintain hematological and physiological stability further underscores its safety and efficacy as a primary feed source.

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NOVELTY STATEMENT

This study explored the potential of Hydroponic Maize Fodder as a replacement for elephant grass to improve the growth performance of Friesian Holstein dairy calves. The research conducted an in-depth evaluation, starting from the analysis of the content and digestibility of Hydroponic Maize Fodder, performance observation, to hematological analysis and physiological response of FH calves. Hydroponic Maize Fodder is a sustainable feed solution that is not limited by season and has guaranteed feed quality.

AUTHOR'S CONTRIBUTION

Renny Fatmyah Utamy: Conceived and designed the experiments, performed the field experiments, analyzed data, and wrote the paper; Ambo Ako and Zyahrul Ramadan: Conceived and designed the experiments, performed the field experiments, performed, and analyzed data, and wrote the paper; Yasuyuki Ishii, Andi Fitri Nurbina, Aimi Nabilah Hussein, and Kannika Umpuch: Analyzed data and wrote the paper; and Rara Mufliha: Performed the field experiments and data tabulation.

Ethical approval

The Animal Ethics Commission of the Faculty of Veterinary Medicine, Udayana University, has approved the ethical use of research animals (Approval No. B/184/UN14.2.9/2024).

Generative AI and AI-assisted technology statement

Generative artificial intelligence tools are used for language refinement, such as improving grammar, readability, and clarity of expression.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Ako A, Utamy RF, Baba S, Hastang, Rahman AA (2023). The effect of leaf meal supplement on milk yield and quality of Friesian Holstein dairy cow. Livest. Res. Rural Dev., 35(3).

Andjelić B, Djoković R, Cincović M, Bogosavljević-Bošković S, Petrović M, Mladenović J, Čukić A (2022). Relationships between milk and blood biochemical parameters and metabolic status in dairy cows during lactation. Metabolites. https://doi.org/10.3390/metabo12080733.

AOAC (2005). Official methods of analysis, 18th ed. pp. 989-991.

Arnold W (2020). Review: Seasonal differences in the physiology of wild northern ruminants. Animal, 14 (1): 124-132. https://doi.org/10.1017/S1751731119003240

Asmarasari SA, Azizah N, Sutikno S, Puastuti W, Amir A, Praharani L, Rusdiana S (2023). A review of dairy cattle heat stress mitigation in Indonesia. Vet. World, 16(5): 1098–1108. https://doi.org/10.14202/vetworld.2023.1098-1108

Badan Standardisasi Nasional (2014). Standar Nasional Indonesia. Bibit Sapi Perah Holstein Indonesia.

Badan Standardisasi Nasional (2017). Standar Nasional Indonesia. Pakan Konsentrat-Sapi P erah Bagian I.

Bai Y, Liu T, Hultquist K, Wu J, Casper DP (2020). Feeding an amino acid formulated milk replacer for Holstein calves. J. Anim. Sci., 103(11): 10108-10121. https://doi.org/10.3168/jds.2020-18529

Bailes J, Soloviev M (2021). Insulin-like growth factor-1 (IGF-1) and its monitoring in medical diagnostic and in sports. Biomolecules, 11(12): https://doi.org/10.3390/biom11020217

Benu I, Jelantik IGN, Penu CLO, Laut MM (2024). Effect of replacing grass silage with hydroponic maize fodder on nutrient intake and digestibility, rumen parameters and blood metabolites of weaned ongole x brahman calves. J. Anim. Sci. Vet. Med., 29(1): 36–44. https://doi.org/10.14334/jitv.v29i1.3331

Brown EG, VandeHaar MJ, Daniels LS, Keisler LTC, WeberNielsen MS (2004). Effect of increasing energy and protein intake on body growth and carcass composition of heifer calves. J. Dairy Sci., 88(2): 585-594. https://doi.org/10.3168/jds.S0022-0302(05)72722-3

Desta AG (2024). The effect of crude protein and energy on conception of dairy cow: A review. Discover Anim., 1(29): https://doi.org/10.1007/s44338-024-00030-1

Doolatabad SS, Sari M, Ghorbani GR (2020). Effect of partial replacement of dietary starch with fiber and fat on performance, feeding behavior, ruminal fermentation and some blood metabolites of Holstein calves. Anim. Feed Sci., 270: 1114691. https://doi.org/10.1016/j.anifeedsci.2020.114691

Fahmi, K., Yusnizar, Y., Sufardi, S. (2022). Pengaruh Konsentrasi Larutan Hara Ab Mix Terhadap Pertumbuhan Sawi Hijau Pada Media Cocopeat. Jurnal Ilmiah Mahasiswa Pertanian, 7(1), 677– 686. https://Doi.Org/10.17969/Jimfp.V7i1.19009.

Harwanto E, Hendarto B, Bahrun N, Hidayat D, Istiqomah D, Candrasari DP (2022). Productivity and nutrient digestibility od sorghum fodder different urine fertilizers levels and harvest times. Anim. Prod., 24(1): 94-100. https://doi.org/10.20884/1.jap.2022.24.1.94

Ježek J, Nemec M, Starič J, Klinkon M (2011). Age related changes and reference intervals of haematological variables in dairy calves. Bull. Vet. Inst. Pulawy, 55(3): 471-478.

Khan MA, Weary DM, and Keyserlingk MAG (2011). Invited review: Effects of milk ration on solid feed intake, weaning, and performance in dairy heifers. J. Dairy Sci., 94: 1071–1081. https://doi.org/10.3168/jds.2010-3733

Kim UH, Lee SH, Cho SR, Kang SS, Jin S, Ahn JS, Lee SH (2021). Hematological changes and reference intervals in Hanwoo calves during the first 28 weeks of life. J. Multidiscip. Digit. Publ. Inst., 11(6): 1806. https://doi.org/10.3390/ani11061806

Kostadinović L (2023). Hydroponic feed and quality in sustainable dairy animal production. J. Agron. Technol. Eng. Manage., 6(6): 965-974. https://doi.org/10.55817/YSNF9052

Liu E, Hanigan MD, VandeHaar MJ (2021). Importance of considering body weight change in response to dietary protein deficiency in lactating dairy cows. J. Dairy Sci., 104(11): 11567-11579. https://doi.org/10.3168/jds.2020-19566

Liu Y, Wang X, Li G, Gong S, Yang Y, Wang C, Wang H, He D (2024). The impact of replacing corn with elephant grass (*Pennisetum purpureum*) on growth performance, serum parameters, carcass traits, and nutrient digestibility in geese. Heliyon, 10(8): https://doi.org/10.1016/j.heliyon.2024.e29784

Novitasari DA, Wicaksono HAD, Wulandari S, Nurfitrani RA, Syahniar TM (2022). Evaluasi pemberian pakan terhadap performa pedet Sapi Bali lepas sapih di Breeding Center Pulukan BPTUHPT Denpasar. 3rd Natl. Conf. Appl. Anim. Sci., 3(8): 1-9. https://doi.org/10.25047/animpro.2022.344

Panahiha P, Alamouti HM, Bonchenari MK, Aschenbach JR (2022). Growth performance, nutrient digestibility, and ruminal fermentation of dairy calves fed starter diets with alfalfa hay versus maize silage as forage and soybean oil versus palm fatty acids as fat source. J. Dairy Sci., 105(12): 9597-9609. https://doi.org/10.3168/jds.2022-22165

Paryoto RN, Rahmadani, Saputra ST (2018). Uji kualitas organoleptic subtitusi tepung sorgum dalam pembuatan butter cake. J. Culinaria, 1(4): 7-15.

Pazla R, Zain M, Agustin F, Marlida Y, Udin Z, Jaswandi, Masrizal, Hendri, Negara W, Tjiptosumirat T, Putri EM, and Muslim M (2024). Influence of protein-energy balance on growth, production, and reproduction in Pesisir heifers. Adv. Anim. Vet Sci, 12(3): 546-558. https://dx.doi.org/10.17582/journal.aavs/2024/12.3. 546.558

Periambawea DAK, Sutrisna R, Liman (2016). Status nutrien sapi peranakan ongole di kecamatan tanjung bintang kabupaten lampung selatan. Integr. Anim. Husb. Sci. J., 4(3): 11-19.

Putri EM, Zainn M, Warly L, Hermon H (2021). Effects of rumen-degradable-to-undegradable protein ratio in ruminant diet on *in vitro* digestibility, rumen fermentation, and microbial protein synthesis. Vet. World, 14(3): 640-648. https://doi.org/10.14202/vetworld.2021.640-648

Ramadan Z, Utamy RF, Hasbi H, Ako A, Maruddin F, Niode V, Rahmadi A, and Putri IB (2025). Economic feasibility and growth performance of Holstein Friesian calves fed whey-dangke fortified green calf starter. Am. J. Anim. Vet. Sci., 20(2): 159-170. https://doi.org/10.3844/ajavsp.2025.159.170

Rayani TF, Resti Y, Dewi RK (2021). Kuantitas dan kualitas fodder jagung, padi, dan kacang hiijau dengan waktu panen yang berbeda menggunakan smart hydroponic fodder. J. Nutr. Feed Technol., 19(2): 36-41. https://doi.org/10.29244/jintp.19.2.36-41

Roland L, Drillich M, Iwerse M (2014). Hematology as a diagnostic tool in bovine medicine. J. Vet. Diagn. Invest., 26(5): 592-598. https://doi.org/10.1177/1040638714546490

Rusdy M, Hatta M, Rinduwati, Sema (2021). Effect of supplementing elephant grass with gliricidia Sepium, Lannea coromandelica and concentrate feed on Bali cattle performance. Livest. Res. Rural Dev., 33(8).

Shahzad MA, Tauqir NA, Ahmad F, Nisa MU, Sarwar M, Tipu MA (2011). Effects of feeding different dietary protein and energy levels on the performance of 12–15-month-old buffalo calves. Trop. Anim. Health Prod., 43(19): 685–694. https://doi.org/10.1007/s11250-010-9753-5

Sujono TA, Kusumowati IT, and Munawaroh R (2021). Effects of Jamaican cherry (*Muntingia calabura* L.) Fruits Extract on Immunoglobulin G Levels and Hematological Profiles in Mice. Pharmacogn J, 13(2):535-541.

Tashiro K, Ishitani M, Murai S, Niimi M, Tobisa M, Idota S, Hagimori TA, Ishii Y (2024). Effect of defoliation on growth, yield and forage quality in maize, as a simulation of the impact of fall armyworm (*Spodoptera frugiperda*). Agric. Eng., 6(2): 1847-1858. https://doi.org/10.3390/agriengineering6020107

Tilley JMA, Terry RA (1963). A two stage technique for the *in vitro* digestion of forage crop. J. Br. Grass. For. Soc., 18(2): 104−111. https://doi.org/10.1111/j.1365-2494.1963.tb00335.x

Triastuti J, Nashir NGA, Nirmala D (2022). Pengaruh tepung buah api-api (*Avicennia marina*) sebagai substitusi tepung terigu terhadap kualitas dan peningkatan serat crackers. J. Mar. Coast. Sci., 11(2): 74-80.

Tuturoong RAV, Malalantang SS, Moningkey SAE (2020). Assessment of the nutritive value of maize stover and king grass in complete feed on Ongole steer calves productivity. Vet. World, 13(28): 801-806. https://doi.org/10.14202/vetworld.2020.801-806

Utamy RF, Ishii Y, Idota S, Khairani L (2018). Effect of repeated application of manure on herbage yield, quality and wintering ability during cropping of dwarf napiergrass with Italian ryegrass in hilly Southern Kyushu. Agronomy, 8(3): 30. https://doi.org/10.3390/agronomy8030030

VanSoest P (1976). New Chemical methods for analysis of forages for the purose of predicting nutritive value. Pref IX International Grassland Cong.

Wahyono T, Khotimah H, Kurniawan W, Ansori D, Muawanah A (2019). Karakteristik tanaman sorghum green fodder (SGF) hasil penanaman secara hidroponik yang dipanen pada umur yang berbeda. J. Trop. Anim. Sci. Technol., 6(2): 166-174. https://doi.org/10.33772/jitro.v6i2.5722

Wang Q, Zeng Y, Zeng X, Wang X, Wang Y, Dai C, Li J, Huang P, Huang J, Hussain T, Zhu M, Yang M (2021). Effects of

Dietary energy levels on rumen fermentation, gastrointestinal tract histology, and bacterial community diversity in fattening male hu lambs. Front. Microbiol., 10(12): 695445. https://doi.org/10.3389/fmicb.2021.695445

Xiao J, Alugongo GM, Li J, Wang Y, Li S, Cao Z (2020). How forage feeding early in life influences the growth rate, ruminal environment, and the establishment of feeding behavior in pre-weaned calves. Animals, 10(2): 188. https://doi.org/10.3390/ani10020188

Yahyaei M, Talebi B (2024). Hydroponic fodder for livestock production and productivity: A review. J. Greenh. Plant prod., 3(1): 1–12. https://doi.org/10.61186/gppj.1.3.1

Zain M, Tanuwiria UJ, Putri EM, Makmur M, Syamsu JA, Amanah U, Yunilas Y (2024). Nutrient digestibility, characteristics of rumen fermentation, and microbial protein synthesis from Pesisir cattle diet containing non-fiber carbohydrate to rumen degradable protein ratio and Sulfur supplement. Vet. World, 17(3): 672-681. https://doi.org/10.14202/vetworld.2024.672-681