Mystery of Grass milk: A Deeper Dive into Quality, Quantity and Economics of Grass-milk in Dairy Cows

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Abstract

Consumers perceive 'grass-fed milk' as healthier than conventional ones since grass-fed milk contains higher levels of beneficial fatty acids and lower levels of omega-6. The study highlights the nutritional benefits of feeding green grass, in terms of quality, quantity, and farm economics emphasizing its specific influence on the fatty acid profile of milk, including enrichment of omega-3 fatty acids and conjugated linoleic acids. It also delves into the environmental benefits of green grass, for supporting sustainable agriculture and enhancing pasture development. It highlights the limitations in the current understanding of how green grass affects milk production efficiency and economic outcomes, prompting the need for a comprehensive investigation. The study aims to bridge these gaps by examining the intricate relationship between green grass utilization and its overall impact on the dairy farming ecosystem. The study further addresses the specific benefits of green grass for cattle promoting their health and welfare issues and contributing to environmental sustainability. Additionally, it contrasts the positive attributes of green grass with the potential drawbacks of feeding concentrate, which may lead to imbalances in nutrient intake, metabolic disorders, and various health issues of dairy cows. The study identifies reduced feed costs, lower dependence on purchased feeds, enhanced farm profitability, and improved feed conversion efficiency as the most economic advantages of green grass. The study, thus aims to advance knowledge and provide actionable insights for dairy farmers to optimize sustainability and efficiency in milk production by understanding specific mechanisms through which green grass influences milk

yield and quality. Switching cows to grass and legume-based diets from concentrate will not only enhance the nutritional profile of milk but will also offer potential nutritional, environmental, and economic aspects of sustainable dairy development.

Keywords: Concentrate, economics, grass, milk, quality, yield

Introduction

The grass-fed milk implies milk derived from cows fed on a 100% forage-based diet. Research has consistently demonstrated that green grass positively influences the fatty acid profile of milk, including increasing levels of beneficial omega-3 [1] and other essential fatty acids [2]. In a previous study, it was reported that, in contrast to conventional milk, which contained 0.02 g/100 g of omega-3, grass-fed milk exhibited the highest omega-3 at 0.05 g/100 g of milk, indicating a 147% increment. Furthermore, the omega-6 content in grass-fed milk was 52% lower than that in conventional milk and 36% lower than in organic milk. Unlike conventional whole milk with an omega-6/omega-3 ratio of 5.7 to 1, grass-fed milk had a 1 to 1 ratio. It was also claimed that for omega-3s, three servings of grass-fed milk would provide about 22% of the daily needs for adult men and 32% for adult women. Hence, switching from conventional to grass-fed milk appears nutritionally promising [1], [3], [4], [5], [6], [7], [8], [9], [10], [11] and one of the most cost-effective way of high-quality milk production [12].
On the environmental front, fodder cropping, including green grass production, encourages the development of a robust and high-quality fodder base for cattle, which is particularly crucial in arid regions. Likewise, extensive ruminant production systems that maximize grazing on green grasses can enhance milk quality, reflected in higher concentrations of unsaturated fatty acids, vitamins, and polyphenols [13]. Importantly, the content of fresh grass in dairy cow diets correlates with the presence of certain fatty acids and fat-soluble antioxidants, like lutein and β-carotene, in milk, substantiating the argument for the dietary importance 0of fresh grass [3]. Overall, the voluminous body of research emphasizes the multilayered importance of green grass for dairy cattle, from enriching milk nutritional quality to enhancing sustainability in dairy farming [1], [4], [5], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24].

The current understanding of the influence of green grass on milk production efficiency and economic viability in dairy farming is incomplete, posing challenges for farmers seeking to optimize operations. Existing literature provides fragmented insights into the relationship between green grass and dairy cow productivity, lacking a unified exploration of factors affecting milk yield, quality, and economic outcomes. While some studies have delved into aspects like forage quality and omega-3 fatty acids, a comprehensive understanding of how these factors collectively impact milk yield and quality is still evolving. Moreover, variations in climate, geography, and management practices complicate the assessment of consistent benefits across different dairy farming systems.

This study, therefore, aims to bridge these gaps through a systematic investigation into the intricacies of green grass utilization and its overall impact on the dairy farming ecosystem. By dissecting nutritional components, evaluating influences on milk yield and quality, assessing economic implications, and formulating practical recommendations, the research aims to contribute to a holistic understanding of how green grass influences milk production, providing actionable insights for farmers to enhance sustainability and efficiency. Identifying specific mechanisms by which green grass affects milk production remains a critical gap, and this study seeks to address these research gaps to advance knowledge and support informed decision-making for the dairy industry.

Benefits of Green Grass

CLA Enriched Milk

Conjugated Linoleic Acid (CLA) is a group of geometric and positional isomers of linoleic acid, an essential polyunsaturated fatty acid found in milk, is particularly influenced by the forage diet [3], [4], [5], [6], [7], [8], [9], [10], [11]. The cis-9, trans-11 CLA is the most abundant while cis-10, trans-12 CLA is commonly found in smaller amounts in milk produced by Butyrivibrio, Bacteroides, and Propionibacterium bacteria. These bacteria are anaerobic, fermentative, p^H sensitive, and substrate-specific and possess enzymes capable of catalyzing the hydrogenation of unsaturated fatty acids. They tend to thrive in an environment where the pH is relatively stable by ruminal forage digesta. Extreme pH conditions, induced by fermentable concentrate mixture whether highly acidic or highly alkaline, may impact the activity of these bacteria and disrupt the biohydrogenation process. Therefore, maintaining a stable rumen pH within the appropriate range is crucial for supporting the microbial communities responsible for CLA synthesis in ruminant animals.

Green grass serves as a primary source for promoting higher levels of CLA in milk [25]. The CLAs have recognized health benefits, including potential anti-cancer properties and improvements in body composition. When cows graze on green grass, they ingest specific compounds that contribute to the synthesis of CLA in their digestive system. These compounds are then incorporated into milk fat during the lactation process, resulting in milk with an enriched conjugated fatty acid profile. Green grass provides the necessary precursors and conditions for optimal microbial activity, promoting the synthesis of CLA and other beneficial fatty acids. During periods when cows have access to lush, green pastures, the CLA content tends to be higher compared to times when they are fed conserved forages or grains. This emphasizes the importance of sustainable and well-managed grazing practices to consistently enhance the conjugated fatty acid profile of milk.

Superior Fatty Acid Profile

Green grass plays a crucial role in enhancing the fatty acid profile of milk, contributing to the overall nutritional quality of dairy products [1], [3], [4], [8], [26], [27], [28]. Omega-3 fatty acids, including alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), are known for their health-promoting properties. Firstly, green grass is rich in alpha-linolenic acid (ALA), an essential omega-3 fatty acid. When cows graze on lush, green pastures, they ingest higher amounts of ALA. This essential fatty acid is then incorporated into the milk fat, leading to an increased presence of omega-3s in the milk [1], [2], [3], [26]. Omega-3 fatty acids are well-known for their numerous health benefits, including cardiovascular health, brain function, and anti-inflammatory properties. Therefore, the consumption of milk derived from grass-fed cows provides an excellent source of these beneficial fatty acids. In addition to omega-3s, green grass also influences the ratio of omega-6 to omega-3 fatty acids in milk. A diet primarily based on grains and processed feeds may result in an imbalance, favoring omega-6 fatty acids. However, when cows graze on fresh grass, the omega-6 to omega-3 ratio in their milk tends to be more favorable. Moreover, green grass provides an array of antioxidants, vitamins, and minerals that contribute to the overall health and well-being of the cow. A healthy cow is more likely to produce milk with a superior fatty acid profile .

Nutritional Benefits for Cattle

- More palatable than silage, hay and straw
- Sources of diversified natural fiber
- Principal sources of energy for cattle
- Sources of essential pro-vitamins
- Improves overall digestibility
- Promotes healthy gut
- Rich in bio-active enzymes
- Encourages rumination
- Supports milk production
- Enhances milk quality
- Supports sustainable growth

Health and Welfare of Cattle

- Sources of natural antioxidants
- Boosts immune system
- Reduces inflammation
- Promotes healthy liver function
- Supports joint health
- Acts as a natural calming agent
- Boosts reproductive health
- Supports fetal development
- Improves fertility
- Maintains rumen P^H
- Prevents acidosis
- Reduces bloat

Environmental Benefits

- Supports sustainable agriculture
- Enhances pasture development
- Promotes pasture biodiversity
- Acts as a carbon sink
- Legume fodders improve soil health
- Supports local ecosystems
- Enhances wildlife habitat
- Aids in weed suppression
- Supports soil microbial activity
- Enhances soil water holding capacity
- Supports local wildlife
- Enhances water retention in soil
- Opens new opportunities for fallow land use
- Reduces agricultural runoffs from wastage

Economic Advantages

- Reduces feed costs
- Lower dependence on purchased feeds
- Enhances farm profitability
- Reduces veterinary costs
- Improves feed conversion efficiency
- Enhances reproductive efficiency
- Reduces costs associated with feed supplements
- Supports diverse livestock enterprises
- Increases herd resilience

Climate Impact

- Increases CO_2 use by plants
- Supports sustainable land management
- Reduces nitrous oxide emissions
- Enhances carbon cycling in ecosystems
- Supports climate-resilient agriculture
- Promotes carbon sequestration
- Reduces environmental footprint
- Supports renewable energy production

Livestock Management

- Enhances grazing behavior
- Promotes longevity of dairy cows
- Reduces stress-related issues
- Improves cow comfort
- Enhances cattle welfare
- Supports sustainable milk production
- Reduces antibiotic use
- Supports holistic livestock management
- Improves milk flavor and composition
- Enhances dairy cow behavior

Bio-active compounds

Green grass contains a diverse array of bioactive compounds that contribute to the overall health of cattle. They include Polyphenols, Phytosterols, Flavonoids, Carotenoids, Alkaloids, Terpenes, Saponins, Sterols, Tannins, Lignans, Glycosides, and Peptides which collectively make green grass a valuable component of cattle. Their key functions are as follows (Table.1):

Table-1 Bioactive compounds and their positive rules

Phytochemical	Positive roles
Alkaloids	- Some alkaloids possess anti-parasitic properties. - Defense against herbivores and pathogens in plants. - Potential medicinal properties in specific concentrations.

Carotenoids	- Precursors to vitamin A essential for vision and immunity. - Antioxidant properties. - Positive effects on skin health.
Coumarins	- Anticoagulant properties. - Potential anti-inflammatory effects. - Contribution to overall cardiovascular health.
Glycosides	- Cyanogenic glycosides may have antimicrobial properties. - Cardiac glycosides have positive effects on heart health. - Some glycosides have medicinal properties.
Lignans	- Potential antioxidant and anti-inflammatory effects. - Have anticancer properties. - Positive impact on heart health.
Organosulfur compounds	- Isothiocyanates have potential anticancer properties. - Alliins in garlic have antimicrobial effects. - Contribution to overall health and disease prevention.
Phenolic compounds	- Protects cells from oxidative stress. - Potential anti-inflammatory effects. - Contribution to overall animal health.
Phytosterols	- Beta-sitosterol may contribute to cholesterol reduction. - Positive impact on cardiovascular health.
Quinones	- Naphthoquinones have antimicrobial properties. - Anthraquinones are used in traditional medicine.
Saponins	- Improved nutrient absorption. - Potential anti-parasitic activity. - Positive effects on animal health.
Tannins	- Reduced methane production. - Improved energy efficiency. - Antioxidant properties. - Potential anti-parasitic effects. - Protection of the plant against pathogens.
Terpenoids	- Have anti-inflammatory properties. - Steroids, like sitosterol, contribute to cholesterol balance. - Cardiovascular health benefits.

Demerits of Concentrate

High levels of concentrate in the diet may lead to imbalances in nutrient intake, affecting the overall health and productivity of cows. Excessive concentrates, which are often rich in rapidly fermentable carbohydrates, may lead to subacute ruminal acidosis (SARA). SARA is characterized by prolonged periods of low ruminal pH, negatively impacting the microbial ecosystem responsible for fiber digestion. This disturbance in the rumen may reduce fiber utilization efficiency and compromise the ability of cows to extract nutrients from forages. The disruption in rumen function also affects milk fat synthesis. High-concentrate diets may lead to a decrease in milk fat content, altering the fatty acid profile of the milk. This has implications for milk quality, as consumers often prefer dairy products with a balanced and desirable fat content. Furthermore, excessive concentrate feeding may contribute to metabolic which further impacts health and overall production of cows (Table.2).

Nutritional Concerns

- Inadequate fiber content
- Limited pro-vitamin content
- Reduced rumen function
- Reduced milk fat content
- Impaired milk quality
- Other digestive disorders

Production Challenges

- Reduced milk yield
- Extended dry periods
- Increased somatic cell counts in milk
- Challenges in calving
- Reduced fertility
- Increased culling rates

Health and Welfare of Cattle

- Increased risk of acidosis
- Possibility of lameness
- Increased risk of mastitis
- Heat stress due to increased metabolism
- Respiratory issues because of fine particle
- Reduced saliva production.
- Decreased rumen pH
- Behavioral changes

Economic Considerations

- Increased feed costs
- Reduced profit margins
- Supply chain vulnerabilities
- Dependency on external inputs

Public Health Issues

- Increased deforestation
- Possibility of water scarcity
- Negative impact on forage species
- Global supply chain vulnerabilities
- Increased chemical residues in milk
- Increased antibiotic residues in milk

Concentrate Induced Metabolic Disorders

Acidosis

Concentrate feeding in milking cattle may contribute to the development of acidosis, a metabolic disorder characterized by an imbalance in the acidity of the rumen. High-concentrate diets, particularly those rich in rapidly fermentable carbohydrates like grains, may lead to increased production of lactic acid during microbial fermentation in the rumen. This rapid accumulation of lactic acid lowers the pH of the rumen, creating an acidic environment. Prolonged exposure to low pH levels may disrupt the microbial balance in the rumen and compromise its normal function. This condition, known as ruminal acidosis, not only affects digestion and nutrient absorption but may also lead to systemic acidosis, impacting the overall health of the animal.

Bloat

Concentrate feeding, particularly when rich in rapidly fermentable carbohydrates like grains, may contribute to bloat in milking cattle. Bloat is the abnormal accumulation of gas in the rumen, leading to distension of the abdomen. The rapid fermentation of concentrates in the rumen produces gases, like carbon dioxide and methane. When the rate of gas production exceeds the ability of the cow to release gas, bloat may occur. Concentrate-rich diets may create a frothy layer on top of the rumen contents, hindering the release of gas. This frothy material is resistant to normal gas expulsion, trapping the gas within the rumen and causing bloat. Additionally, the feeding of finely ground concentrates may further contribute to the formation of a stable foam in the rumen, exacerbating the risk of bloat.

Laminitis

Concentrate feeding in milking cattle, particularly with diets high in rapidly fermentable carbohydrates like grains, has been associated with the development of laminitis. Laminitis is a painful inflammatory condition affecting the sensitive laminae within the hooves. The increased intake of concentrates may lead to elevated levels of starches and sugars in the rumen, causing a rapid fermentation process. This, in turn, results in the release of by-products, like lactic acid, which may disrupt the microbial balance in the digestive system. The systemic absorption of these by-products may trigger a cascade of inflammatory responses throughout the body, including the feet. Laminitis may lead to the separation of the hoof wall from the underlying structures, causing pain and lameness.

Rumenitis

Concentrate feeding in milking cattle may be a contributing factor in the development of rumenitis, an inflammatory condition affecting the rumen wall. This phenomenon is often associated with diets rich in rapidly fermentable carbohydrates, like grains. When cattle are subjected to high-concentrate diets, the rapid fermentation of these carbohydrates in the rumen may lead to an accumulation of acidic by-products, particularly lactic acid. This acidic environment may cause irritation and inflammation of the rumen wall, leading to rumenitis. Prolonged exposure to elevated acidity may compromise the microbial balance in the rumen, disrupting normal digestive processes and causing systemic health issues.

Mold Toxicity

Concentrate feeding in milking cattle may potentially contribute to mold toxicity, a condition arising from the ingestion of contaminated feed. Mold growth on grains or forages may produce mycotoxins, harmful substances that may adversely affect the health of cattle. High-concentrate diets, particularly those prone to storage or handling issues, may foster mold growth, increasing the risk of mycotoxin exposure. Common mycotoxins, like aflatoxins and fumonisins, can contaminate grains and negatively impact liver function, immune response, and overall performance of cattle. The ingestion of mold-contaminated feed may lead to various health issues, including reduced milk yield, reproductive problems, and compromised immune function.

Urolithiasis

Concentrate feeding in milking cattle may be a predisposing factor for the development of urolithiasis, a condition characterized by the formation of urinary stones. This ailment is often associated with diets rich in grains and low in forage. The imbalanced mineral composition in high-concentrate diets, particularly an excess of phosphorus relative to calcium, may contribute to the precipitation of minerals in the urine. When cattle consume excess concentrate feeds, the urinary concentration of minerals may increase, leading to the formation of stones in the urinary tract. These stones obstruct the urethra, initiate painful urination, and damage of urinary system.

Ketosis

Ketosis is more common in high-producing dairy cows during early lactation when energy demands for milk production are high and feed intake may not meet the energy requirements. Several factors contribute to ketosis, including negative energy balance, a rapid increase in grain feeding, low fiber intake, and inadequate adaptation periods.

Fatty Liver Syndrome

Concentrate feeding in milking cattle may contribute to the development of fatty liver syndrome (FLS), a metabolic disorder characterized by an excessive accumulation of fat in the liver. During the early lactation period, when energy demands for milk production are high, an intensified concentrate-based diet may lead to an imbalance between energy intake and utilization. This imbalance prompts the mobilization of body fat to meet energy requirements, leading to an increased influx of fatty acids to the liver. The liver, tasked with processing these excess fatty acids, may encounter challenges in metabolizing them efficiently. As a result, fat accumulates within the liver cells, leading to FLS.

Displaced Abomasum

Concentrate feeding in milking cattle may contribute to the occurrence of displaced abomasum (DA), a condition where abomasum, one of the stomach compartments, shifts from its normal position. High-concentrate diets, common during the early lactation period to meet the energy demands of milk production, may result in a rapid fermentation of carbohydrates in the rumen. This fermentation leads to the production of volatile fatty acids and changes the acidity of the rumen contents. As a response to these dietary changes, the abomasum may be displaced, typically moving to the left side of the abdomen. Thus, excessive concentrate feeding may increase the risk of DA.

Mastitis

Concentrate feeding in dairy cattle, when not managed properly, may indirectly contribute to the risk of mastitis, a bacterial infection of the udder. Excessive concentrate feeding may lead to subacute ruminal acidosis, a condition characterized by low rumen pH levels, compromising the immunity of cows and making them more susceptible to infections, including mastitis. Additionally, nutritional imbalances resulting from poor diet formulation may weaken overall health and the immune system, potentially increasing vulnerability to mastitis.

Enterotoxaemia

Concentrate feeding in milking cattle may contribute to the development of enterotoxaemia, a condition caused by the bacterium *Clostridium perfringens*. This bacterium proliferates in the intestines, especially when cattle consume diets rich in carbohydrates, like grains. The bacterium produces toxins that, when absorbed by the intestines, may lead to systemic effects, including damage to blood vessels and neurological tissues.

Milk fever

Concentrate feeding in milking cattle may contribute to the onset of milk fever, also known as hypocalcemia. This metabolic disorder typically occurs around calving, especially in high-producing dairy cows. When cattle are fed high-concentrate diets during the dry period or early lactation, there may be a rapid shift in calcium demand for milk production. This shift may lead to an insufficient calcium intake or an inability of the cow to mobilize enough calcium from its reserves to meet the sudden demand. As a result, blood calcium levels drop, leading to milk fever.

Farm Economics

Excessive concentrate feeding in dairy farms may have detrimental effects on the economic sustainability of operations as it leads to increased feed costs due to the higher expense associated with concentrates compared to forages. This imbalance in the diet may contribute to health issues in dairy cows, including metabolic disorders resulting in additional costs for veterinary care and potential declines in individual cow productivity. Moreover, a concentrate-heavy diet may compromise milk quality, specifically affecting components like fat content, which could diminish marketability and reduce revenue for the dairy farm.

Table 2. Comparison between green grass versus concentrate-based feeding systems

Variables	Feeding systems	
	Green grass	Concentrate
Nutritional benefits		
Enhanced CLA in milk	√	×
Increased omega-3 fatty acids in milk	√	×
Improved omega-6 to omega-3 ratio in milk	√	×
Higher levels of essential fatty acids	√	×
Milk enriched with ALA	√	×
Enhanced levels of antioxidants	√	×
Increased vitamins in milk	√	×
Elevated milk fat content	√	×
Improved protein-to-fat ratio in milk	√	×
Higher content of bioactive enzymes in milk	√	×
Increased levels of polyphenols in milk	√	×
Favorable composition of milk phospholipids	√	×
Balanced nutrient intake by cattle	√	×
Health and welfare of cattle		
Improved gut health in cattle	√	×
Supports healthy rumination	√	×
Prevention of acidosis in the rumen	√	×
Reduction in the risk of bloat	√	×
Enhanced joint health in cattle	√	×
Reduced risk of lameness	√	×
Natural calming effect on cattle	√	×
Improved reproductive health	√	×
Support for fetal development	√	×
Increased fertility in dairy cows	√	×
Maintenance of optimal rumen pH	√	×
Reduction in the risk of mastitis	√	×
Decreased risk of respiratory issues	√	×
Better saliva production in cattle	√	×
Prevention of bloating in cattle	√	×
Environmental benefits		
Promotion of sustainable agriculture	√	×
Enhancement of pasture development	√	×
Increased biodiversity in pastures	√	×
Carbon sequestration in the soil	√	×
Improvement of soil health	√	×
Support for local ecosystems	√	×
Enhanced wildlife habitat	√	×
Weed suppression in pastures	√	×
Promotion of soil microbial activity	√	×
Increased soil water holding capacity	√	×

Support for local wildlife	√	×
Improvement in water retention in soil	√	×
Utilization of fallow land for grazing	√	×
Reduction in agricultural runoff	√	×
Support for renewable energy production	√	×
Economic advantages		
Reduced feed costs for farmers	√	×
Lower dependence on purchased feeds	√	×
Enhancement of farm profitability	√	×
Decreased veterinary costs	√	×
Improved feed conversion efficiency	√	×
Enhanced reproductive efficiency	√	×
Reduction in costs associated with feed supplements	√	×
Support for diverse livestock enterprises	√	×
Increased herd resilience	√	×
Climate impact		
Increased CO_2 absorption by plants	√	×
Support for sustainable land management	√	×
Reduction in nitrous oxide emissions	√	×
Enhancement of carbon cycling in ecosystems	√	×
Promotion of climate-resilient agriculture	√	×
Contribution to carbon sequestration	√	×
Reduction in environmental footprint	√	×
Support for renewable energy production	√	×
Livestock management		
Enhanced grazing behavior in cattle	√	×
Promotion of longevity in dairy cows	√	×
Reduction in stress-related issues	√	×
Improvement in cow comfort	√	×
Support for sustainable milk production	√	×
Decreased antibiotic use in cattle	√	×
Support for holistic livestock management	√	×
Improved milk flavor and composition	√	×
Enhancement of dairy cow behavior	√	×
Bio-active compounds		
Alkaloids with potential anti-parasitic properties	√	×
Defense against herbivores and pathogens	√	×
Carotenoids as precursors to vitamin A	√	×
Antioxidant properties of carotenoids	√	×
Positive effects on skin health	√	×
Coumarins with anticoagulant properties	√	×
Potential anti-inflammatory effects of coumarins	√	×
Contribution to cardiovascular health	√	×

Cyanogenic glycosides with antimicrobial properties	√	×
Cardiac glycosides for heart health	√	×
Medicinal properties of some glycosides	√	×
Antioxidant and anti-inflammatory effects of lignans	√	×
Anticancer properties of lignans	√	×
Isothiocyanates with potential anticancer properties	√	×
Antimicrobial effects of alliins in garlic	√	×
Contribution to overall health and disease prevention	√	×
Beta-sitosterol potential for cholesterol reduction	√	×
Positive impact on cardiovascular health	√	×
Antimicrobial properties of naphthoquinones	√	×
Traditional medicinal use of anthraquinones	√	×
Improved nutrient absorption by saponins	√	×
Potential anti-parasitic activity of saponins	√	×
Positive effects on animal health	√	×
Reduced methane production by tannins	√	×
Improved energy efficiency by tannins	√	×
Antioxidant properties of tannins	√	×
Potential anti-parasitic effects of tannins	√	×

How Green Grass Improves Milk Yield and Quality?

Green grass enhances milk yield and quality in several ways. Firstly, it provides a rich array of nutrients, including essential minerals, vitamins, and proteins, which contribute to the overall health of the cattle. Additionally, the presence of bioactive compounds, such as omega-3 fatty acids and antioxidants in green grass, positively impacts the composition and nutritional value of the milk. The natural forages help maintain a balanced diet for cows, supporting their digestive health and optimizing milk production. Thus, the diverse nutritional profile of green grass ultimately improves milk yield and enhances milk quality.

Hydration Effects

Proper hydration is a critical factor in dairy cow health and, subsequently, in milk production and quality. Cows, like all living beings, require an adequate water supply to maintain essential bodily functions. Water is involved in digestion, nutrient absorption, temperature regulation, and the transportation of nutrients throughout the body. For dairy cows, which are high-producing animals, the importance of water is even more pronounced. When cows graze on green grass, they not only obtain valuable nutrients but also consume a significant amount of water present in the lush vegetation. The moisture content of fresh grass contributes to the overall water intake of the cow. In comparison to a diet solely composed of dry feeds or stored forages, which may have lower water content, grazing on green grass provides a more natural and effective means of maintaining hydration. Proper hydration positively influences milk production and quality in several ways. Firstly, water is a key component of milk itself, comprising a substantial portion of its composition. Inadequate water intake may lead to decreased milk production due to a reduction in the volume of milk produced. Moreover, dehydration may impact overall cow health, potentially leading to stress, decreased feed intake, and compromised immunity. Stressed cows are more prone to various health issues, which may

further diminish milk quality. In summary, access to green grass contributes to improved hydration in dairy cows, supporting their overall health and milk yield.

Increased Palatability

Palatability refers to the taste and acceptability of a feed to animals. Green grass is known for its high palatability compared to processed or stored feeds [14], [29], [30], [31], [32], [33]. The fresh and succulent nature of green pasture is appealing to dairy cows, making them more inclined to consume larger quantities of forage [15], [17], [33], [34], [35], [36], [37], [38]. This increased palatability often translates to higher feed intake. Hence, cows consuming highly palatable forages exhibit greater dry matter intake, which positively correlates with increased milk production. Palatable forages stimulate the appetite of cows, encouraging cows to consume more nutrients, including proteins and energy, essential for milk synthesis [33]. Increased feed intake is directly linked to higher milk production. Dairy cows require a substantial amount of energy and nutrients to support lactation. When cows graze on green grass with high palatability, they are more likely to meet their nutritional requirements, resulting in improved milk yields. Moreover, the enhanced feed intake from green grass may positively influence milk composition. The balance of nutrients, like proteins and fats, in the diet plays a crucial role in determining the quality of milk. Higher nutrient intake, facilitated by the palatability of green grass, contributes to the synthesis of milk with desirable characteristics, including a favorable protein-to-fat ratio [39].

Unique Fibre Quality

High-quality forages with an optimal fiber content stimulate rumination and promote a healthy rumen environment [14], [40], [41]. The structural fiber, including cellulose and hemicellulose, encourages proper chewing, salivation, and rumen contractions. This, in turn, supports the growth and activity of beneficial rumen microbes. The microbial fermentation of forage fiber produces VFAs, like acetate, propionate, and butyrate. These VFAs are important energy sources for the cow which contribute to the synthesis of milk components. Acetate, for example, serves as a precursor for milk fat production. The relationship between forage fiber and milk fat is particularly significant. For example, high-forage diets with an increased proportion of structural fiber have been associated with higher levels of milk fat. Moreover, forage fiber, especially when derived from fresh and green sources, contributes to a more favorable fatty acid profile in milk. This includes an increase in omega-3 fatty acids, which are considered beneficial for human health. The inclusion of these healthy fatty acids in the milk enhances the nutritional quality of dairy products. Beyond its impact on milk fat, forage fiber also influences rumen health, and microbial activity, and contributes to the production of milk with desirable fat composition and overall nutritional quality.

Balanced Nutrients

The nutritional composition of the forage directly affects the overall health of dairy cows, subsequently influencing the composition and quality of the milk they produce. Forage quality is a key factor in providing a balanced and nutritious diet for dairy cows. Green grass, when of high quality, contains essential nutrients like proteins, carbohydrates, vitamins, and minerals in appropriate proportions [42], [43], [44], [45], [46]. High-quality forage, like fresh and lush green grass, contributes to a more balanced nutrient intake for dairy cows [6], [14], [42], [43], [44], [46], [47], [48], [49], [50], [51]. This balance is reflected in the milk produced, resulting in optimal levels of proteins, fats, and other components that contribute to milk quality. The

fiber content in green grass also plays a crucial role in maintaining rumen health. Adequate fiber promotes proper digestion and helps prevent metabolic disorders in dairy cows. A healthy rumen contributes to better nutrient absorption and utilization, positively impacting the quality of milk.

Improved Antioxidants

While there is a limited number of specific studies directly linking antioxidants in green grass to enhanced milk yield in dairy cows, the broader understanding of the positive effects of antioxidants on cow health and performance provides a foundation for this claim. Green grass, as a natural source of antioxidants, contains compounds like beta-carotene, vitamin E, and other polyphenols [3], [52], [53]. These antioxidants play a crucial role in neutralizing free radicals and reducing oxidative stress within in body. Oxidative stress may negatively impact overall health and may lead to various health issues, potentially affecting milk production. Improved overall health in dairy cows is often associated with higher milk production. When cows are supplemented with antioxidants from green grass or other sources, it may contribute to reduced stress, enhanced immune function, and better metabolic stability. These factors collectively support the ability of the cow to maintain higher milk yields.

Reduced Stress

Stress management is crucial in maintaining the overall health and well-being of dairy cows. Stresses may have a direct impact on both milk production and milk quality. When cows are provided with the opportunity to graze on green grass, they engage in natural behaviors like walking, grazing, and socializing. These activities contribute to the expression of normal behaviors, promoting mental stimulation and reducing bore [54]. As a result, cows experience lower stress compared to those confined in more restrictive environments. Reduced stress has a positive effect on milk production. Stressed cows may exhibit decreased feed intake and altered metabolic processes, leading to lower milk yields. By allowing cows to graze on green pastures, dairy farmers may create an environment that aligns with the instincts of cows, minimizing stressors associated with confinement. In addition to its impact on milk yield, stress may also affect milk quality. Stressed cows may experience changes in hormone levels and metabolic processes that may influence the composition of milk. By providing a low-stress environment through access to green grass, dairy farmers may contribute to maintaining the quality of milk produced. Furthermore, reduced stress positively influences the immune system of dairy cows. Stressed animals are more susceptible to diseases and infections, which may have detrimental effects on milk quality. A healthier and less stressed cow is better equipped to resist pathogens and maintain a robust immune response, resulting in better milk yield.

Conclusions

The study sheds light on the intricate relationship between green grass utilization and the holistic sustainability of dairy farming systems. It accentuates the undeniable benefits of green grass, ranging from its key role in enhancing the nutritional quality of milk, and promoting health and welfare of cattle, to contributing to environmental sustainability. The findings emphasize the importance of sustainable grazing practices and the need for a shift towards well-managed green grass diets, considering the myriad advantages they offer over concentrate feeding. By dissecting the nutritional components, assessing influences on milk yield and quality, exploring economic implications, and providing practical recommendations, it aims to empower dairy farmers with a deeper understanding of the multilayered impact of green grass

feeding. By identifying benefits, like enriched conjugated linoleic acid content, superior milk fatty acids, and improved overall cattle health, this study not only contributes to the sustainability and efficiency of dairy farming but also aligns with consumer preferences for high-quality and nutritionally rich dairy products. Navigating the intricate interplay between green grass and dairy farming offers valuable insights to inform the decision-making drive toward a more sustainable and resilient future dairy industry.

Future directions

Long-term studies considering multiple seasons and years may be conducted to provide a more comprehensive understanding of the sustained effects of green grass utilization on milk yield, quality, and overall dairy farming sustainability. Similarly, regional specificity of the impact of green grass on dairy farming systems may be investigated, focusing on how geographical variations, climate, and soil conditions influence the effectiveness of green grass utilization. Additionally, the integration of precision agriculture technologies, like sensor-based monitoring and data analytics, may be explored to optimize green grass utilization. Further, real-time tracking of grazing patterns, the nutritional content of grass, and the health status of cattle may provide actionable insights for more efficient and sustainable management practices. Accordingly, in-depth economic modeling and cost-benefit analyses may be conducted to provide a clearer picture of the financial implications associated with transitioning to green grass-based diets.

Consumer perceptions and preferences regarding dairy products derived from green grass-fed cows may be investigated to understand how consumer attitudes align with the nutritional benefits of green grass-fed milk. This understanding may influence marketing strategies and product positioning in the dairy industry. Similarly, research into innovative forage management practices, including rotational grazing systems, intercropping strategies, and the use of specific grass varieties, may be explored to optimize green grass availability. The contribution of green grass utilization to climate-resilient dairy farming may be assessed, exploring its role in mitigating environmental impact, enhancing carbon sequestration, and promoting adaptive practices in response to changing climatic conditions. Above all, comparative studies that directly contrast the impacts of green grass feeding with other alternative feeding practices, like conventional concentrate diets or organic farming methods, may be conducted to identify the most sustainable and efficient approaches for dairy farming.

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