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Original article

Impact of essential oil feed supplementation during transition period on health and metabolic parameters in dairy cows

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Abstract

This study evaluated the impact of essential oil supplementation, primarily containing seed oil from coriander, along with eugenol, geranyl acetate and geraniol, on the blood metabolic profile and overall health of dairy cattle during the transition period. Milking was done using a milking robot, all cows were given total mixed ration (TMR) twice a day, at 07:00 a.m. and 07:00 p.m. A total of 140 multiparous Holstein cows were divided into two groups: a test group (n=70) receiving essential oil supplementation (1 g/cow/day) and a control group (n=70). The cows were monitored from 30 days before calving to 90 days post-calving. Results showed that cows in the test group produced 4.5% to 7% more milk compared to the control group across different lactation periods (5-90 days in milk). Milk composition was also improved with higher milk fat and protein percentages. Essential oil supplementation positively influenced feed efficiency and metabolic indicators such as albumin. These results suggest that essential oil supplementation enhances milk yield, composition, and efficiency during the critical transition period.

Keywords: bovine nutrition; dairy cattle; metabolic profile; milk yield

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Introduction

The interval between three weeks before and three weeks following parturition in dairy cows is known as the transition period and is one of the most critical physiological stages since most metabolic and infectious problems develop during this time (Cardoso 2017). The health of dairy cows during the transition phase is a key factor in productive and reproductive success (Pascottini et al. 2019). The postpartum phase is characterised by significant physiological changes, such as calving, uterine involution and the commencement (and maintenance) of lactation. Thus, the vast majority of metabolic and infectious diseases of dairy cattle occurs during this period (LeBlanc 2010). Health problems that arise during the transition phase pose a significant danger to future productivity and reproductive performance (Van Saun et al. 2014). The periparturient phase in dairy cows is characterised by substantial endocrine and metabolic changes to fulfil the demands of early lactation milk production (Arfuso et al. 2016). This approach typically entails selecting variables based on their potential causal association with the outcome (Trevisi et al., 2025). However, it lacks depth in describing the physiological changes that drive variations in metabolic markers during the prepartum period.

Early lactation is commonly defined as the first 100 days of calving. Cows will reach peak milk production in the middle of this period (around 50-80 days), but feed intake will lag, and cows will typically lose weight (Hasegawa1993). Rations for dairy cows are typically designed to meet protein and energy (e.g., net energy for lactation) needs. Feed intake is the key factor in maintaining high milk production: each additional kg of dry matter consumed can support 2-2.4 kg more milk (Andjelić et al. 2022). Feed intake by the dairy cow is influenced by many factors including level of production, forage quantity and quality, feed digestibility, feed processing, feeding frequency, consistency of ration ingredients (Andjelić et al. 2022).

A poor transition from pregnancy to the lactating period frequently leads to a loss of 4.54-9.07 kg of peak milk output which could equate to 907.18-1814.37 kg of untapped milk yield (Van Saun et al. 2014). Despite major gains in the understanding of transition cow biology, early lactation has been associated with a greater prevalence of metabolic and viral illnesses (Trevisi et al. 2025). The incidence of metabolic disorders (such as milk fever, displacement of abomasum, fatty liver syndrome and ketosis), mammary gland infections (mastitis and udder edema) and reproductive disorders (such as dystocia, retained placenta and uterine infections) have been reported to be in the ranges of 7.8 to 16.8, 2.8 to 12.6, and 6.7 to 19.2%, respectively, in high- producing herds (Bakshi et al. 2017). Therefore, a smooth transition is important for minimizing health problems and optimizing productivity and profitability for the forthcoming lactation. Early identification of these disorders may be useful in overcoming future production losses (Huzzey et al. 2006).

The essential oils tested, primarily *Coriandrum sativum* and eugenolcinnamaldehyde and eugenol, altered rumen fermentation by modulating acetate and propionate ratios. This improvement in fermentation processes facilitated enhanced nutrient absorption at the rumen wall and increased metabolic efficiency (Belanche et al. 2020). Essential oils also influenced blood metabolic profiles, notably improving albumin levels and regulating glucose and urea. These enhancements are linked to improved milk production and quality, providing evidence for their beneficial effects during the transition period (Uyarlar et al. 2024).

The impact of an essential oil blend was examined on Holstein dairy cows during the dry and transition periods (Wells 2023). The findings revealed that cows supplemented with essential oils exhibited enhanced immune responses, including increased total IgG levels and reduced total leukocyte counts after calving (Kim et al. 2019). Additionally, the essential oil blend appeared to benefit energy metabolism, as evidenced by decreased concentrations of non-esterified fatty acids (NEFA) and beta-hydroxybutyrate (BHBA) in the bloodstream (Wells 2023).

Our hypothesis was that a blend of essential oils fed during the transition period would have an impact on health parameters and the metabolic profile in dairy cattle. Therefore, the aim of the current study was to investigate the impact of a blend ofessential oils supplementation during the transition period on productivity and metabolic profile in dairy cattle.

Materials and Methods

Animals, Experimental Design, and Diets

This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee (approval number PK016965, dated 6 June 2017). Location of the experiment: the investigation was conducted between 2023.03.10 – 2023.07.27 at the Lithuanian University of Health Sciences and on one Lithuanian dairy farm (54.9754°N, 23.7684°E). During the course of the study, the animals exhibited favorable health conditions and were subjected to diligent monitoring by competent staff to identify any potential health issues. The average milk production per cow was 10,500 kg per year. The study selected

Table 1. Nutrient specification of feed ration.

Parameters	Units	Quantity
Dry matter	%	45.0
Matter intake (DM)	kg DM/d	27.3
Net energy lactation	MJ/kg DM	6.42
Protein	g/kg DM	173
Fat	g/kg DM	45
Acids	g/kg DM	37
Neutral detergent fiber	g/kg DM	285
Starch	g/kg DM	206

140 Holstein dairy cows, 3-7 years old, all multiparous (2–5 lactations), based on their similar milk yield in the previous lactation. Prior to the commencement of the trial, the cows were confined to one pen. 30 days before their anticipated calving, the cows were segregated into distinct enclosures, namely the treatment group and the control group (CG): the first group consisted of 70 cows to which Agolin Ruminant was supplemented in their diet, while the second group, also consisting of 70 cows, served as the control group with no changes made to their feed. All cows enrolled in the study remained until its completion, with no exclusions or incidences of postpartum complications observed. The cows were housed in a free stall barn that provided ample ventilation.

The farm milked 700 cows using Lely astronaut ® A4 (Lely Campus, Cornelis van der Lely an 1, 3147, PB MAASALUIS, The Netherlands) milking robot. The milking robots employed in the study, operated on a free-traffic system. Individual attribute data (lactation number, breed, last calving date and milk yield) was obtained from the farm's computer system. Animals were selected for this study from 30 days before expected calving to 90 days post-calving. Agolin Ruminant was supplemented at a dose of 1 g per cow per day, which corresponds to the manufacturer's recommended effective dose. The product was weighed daily and thoroughly incorporated into the mineral mix to ensure uniform distribution before being added to the TMR. Compliance with supplementation was ensured by preparing the mineral mix fresh each day and verifying that the full ration was consumed by each group. Two separate pens housed these two groups of cows. The cows were kept in free-stall barns that had ventilation systems. They were given a balanced TMR twice a day, at 07:00 a.m. and 07:00 p.m., which was specifically designed to meet their physiological needs. The robot pushes up feed leftovers approximately eight times per day. This ensures that the animals always have access to fresh food and prevents any mould or bacteria from growing in the feeders. Dry cows received a ration composed of 1.2 kg/d rapeseed meal (36% CP), 8.0 kg/d grass silage (27% DM), 1.2 kg/d maize silage (27% DM) and 7.5 kg/d wheat straw, together with 0.25 kg/d of a commercial mineral – vitamin supplement. Approximately 4.3 kg/d of water was added to improve mix structure and reduce sorting. This diet provided an overall roughage-to-concentrate ratio of approximately 85:15 and supplied adequate fibre, energy, and protein for dry cows. During the transition period, animals were gradually adapted to the lactating-cow diet, which consisted of a higher-energy TMR (about 60:40 roughage-to-concentrate ratio) with known nutritional composition (CP 15.8% DM, NDF 29% DM, ADF 17.5% DM, NFC 38.6% DM, DM 47.8%). The lactating cow diet consisted of 25% corn silage, 5% alfalfa grass hay, 20% grass silage, 15% sugar beet pulp silage, 30% grain concentrate mash and 5% mineral mix, into which 1 g of Agolin was mixed daily per cow. The purpose of this diet was to meet the nutritional needs of a 500 kg Holstein cow that produces 37 kg of milk each day. Table 1 presents the nutrient specification of the lactating cow's ration. A portion (4.5 kg/d) of the concentrate feed was provided to cows in the robot. The animals were provided with unrestricted access to both feed and water throughout the duration of the study. There was sufficient bunk space for all cows to simultaneously access the feed, approximately 0,8-1,0 meters per cow. A portion (4.5 kg/d) of the concentrate feed was provided to cows in the robot.

Measurements of milk yield and composition

During each milking session, the Lely Astronaut® A4 milking robots and Lely T4C management system collected data on various parameters, including, milk yield (MY), somatic cell count (SCC), and electrical conductivity (EC) for all quarters of the udders, namely the front left (FL), front right (FR), rear left (RL), and rear right (RR). These measurements were collected at every milking event (typically 2-3 times per day) from 5 to 90 days after calving, and the values obtained throughout each day were averaged to produce a single daily mean for each parameter.

Table 2. Impact of essential oils (Agolin Ruminant®) feed supplementation during lactation period (5-90 days post-partum, DM basis) on health parameters in dairy cattle.

Parameter	Control (Mean ± SEM)	Test (Mean ± SEM)	p-value
Milk yield (kg/d)	46.50 ± 0.18	49.97 ± 0.16	<0.001
Body weight (kg)	600 ± 2.09	525 ± 2.22	<0.001
Milk fat (%)	4.25 ± 0.01	4.21 ± 0.01	0.13
Milk protein (%)	3.73 ± 0.005	3.72 ± 0.01	0.007
Milk lactose (%)	4.58 ± 0.001	4.59 ± 0.002	<0.001
Rumination duration (min/d)	530 ± 1.70	531 ± 1.48	0.179
Somatic cell count (thousand/mL)	105 ± 5.02	148 ± 5.90	<0.001
Concentrated feed left (kg/d)	1.05 ± 0.02	1.61 ± 0.02	<0.001
Milk electrical conductivity	68.05 ± 0.05	68.19 ± 0.06	0.942

Cows were allowed to be milked six hours after their previous milking, unless a milking failure occurred, in which case the cows would be instantly granted permission to be milked again. Cows that did not visit the robot within 12 hours were manually guided to the milking unit by a herdsman. Cows were examined daily by a local veterinarian. From calving until 90 days in milk, cow health was monitored via the automatic milking system data, as well as milk yield and behavioral parameters. Any cows showing signs of illness were subjected to a clinical examination and treated accordingly.

Measurement of blood samples

The blood biochemical profile was measured 30 days before calving and 90 days after calving. 20 clinically healthy cows, with similar parity participating in the study were selected for blood tests. 10 from the test group and 10 from the control group. The selected cows were in the adaptation period a week before the study. During the week, two cows from the test group became ill; therefore, blood samples were not collected from them. Blood samples were taken via jugular venipuncture using vacuum tubes without anticoagulant and were analysed at the Laboratory of the Lithuanian University of Health Science, Veterinary Academy. The samples were collected in containers maintained at a temperature of 4°C and promptly transported to the laboratory for examination. Iron (Fe), urea (UREA), glucose (GLU), magnesium (Mg), calcium (Ca), phosphorus (P), potassium (K), β-hydroxybutyrate (BHB), aspartate aminotransferase (AST), gamma glutamyl transferase (GGT), albumin (ALB) and total protein (TP) in early lactation were determined in the blood serum using commercial kits. Spinreact (Spain) reagents were use to conduct biochemical blood assays on all collected blood serum samples using an automated computerised biochemistry analyzer, the SELECTRA Junior (AC Dieren, The Netherlands, 2006). The MediSense and FreeStyle Optium H systems, manufactured by Abbott in Great Britain, were used to quantify the concentrations of plasma BHBA and glucose.

Data analysis and statistics

IBM SPSS Statistics for Windows, version 25.0 (SPSS Inc., Chicago, IL, USA; IBM Corp., 2017), was used for all statistical analyses. The normality of the data distribution was evaluated using the Shapiro-Wilk test. The data were displayed as the mean (M ± S.E.M.) plus or minus the standard error of the mean. All data were normally distributed so average group values were compared using Student's t-test. Statistical significance was defined as a p- value of less than 0.05 ($p<0.05$). To determine whether there was a linear relationship between the variables from the automatic milking system, the Pearson's correlation coefficient was computed.

After this analysis, automatic milking system data were divided into six equal timeframes according to the lactation days: 5-15; 16-30; 31-45; 46-60; 61-75; 76-90 days post-partum. Data were recorded from day 5, since the automatic milking system requires time to calibrate itself and provide accurate measurements and an adaptation period for the animal is required. The average mean of the parameters between groups during each time period were compared using Student's t-test. Statistical significance was defined as $p<0.05$. Blood serum parameter data were also compared using Student's t-test analysis. Two different timepoints were compared – 30 days pre-partum and 90 post-partum. Statistical significance results were presented with a p-value of less than 0.05 ($p<0.05$).

Results

The test group exhibited significantly higher ($p<0.001$) daily milk yield (49.97±0.16 kg/d) compared

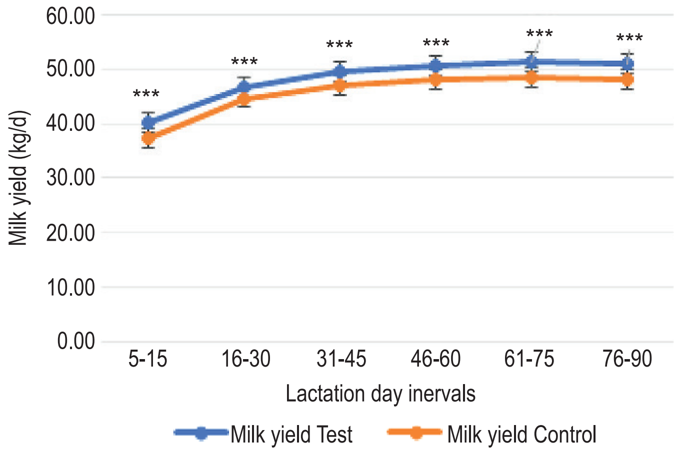

Fig. 1. Milk yield comparison between cows groups during lactation day intervals, (*** results are statistically significant).

to the control group (46.50±0.18 kg/d). In contrast, mean body weight was significantly lower ($p<0.001$) in the test group (525±2.22 kg) relative to controls (600±2.09 kg) (Table 2). Analysis of milk composition revealed no significant difference in milk fat percentage between the test (4.21±0.01%) and control (4.25±0.01%) groups ($p=0.13$). However, the test group exhibited significantly lower ($p=0.007$) milk protein percentage (3.72±0.01%) compared with controls (3.73±0.005%). Milk lactose percentage was significantly higher ($p<0.001$) in the test group (4.59±0.002%) relative to the control group (4.58±0.001%), though the absolute difference was minimal. With respect to behavioral and health-related metrics, no significant difference was observed in rumination duration (531±1.48 min/d in the test group vs. 530±1.70 min/d in the control group; $p=0.179$). The somatic cell count, however, was notably higher ($p<0.001$) in the test group (148±5.90×10^3 cells/mL) compared to controls (105±5.02 ×10^3 cells/mL). Further, the quantity of concentrated feed refusal was significantly greater ($p<0.001$) among test group cows (1.61±0.02 kg/d) compared to controls (1.05±0.02 kg/d). Meanwhile, no significant differences were detected in milk electrical conductivity (68.19±0.06 vs. 68.05± 0.05; $p=0.942$) or the milk fat-to-protein ratio (1.149±0.003 vs. 1.151±0.004; $p=0.719$) between groups (Table 2).

Between days 5 and 15 of lactation, the Test group (TG) produced 2.78 kg/d (7%) more milk compared with the Control group (CG). During 16-30 lactation days TG produced 2.13 kg/d (4.5%) more milk in comparison with the CG. Furthermore, during the interval of 31-45, the TG maintained a higher milk yield 2.41 kg/d (5%) compared with the CG. This difference of 2.41 kg/d (5%) remained throughout the 46-60 lactation day interval between TG and CG. From 61 to 75 lactation days the difference between TG and CG groups was 2.88 kg/d (5.6%). This difference also remained during the last interval of our study (76-90 days post-partum) ($p<0.001$) (Fig. 1).

Body weight between groups differed significantly throughout all lactation intervals, except for the beginning of lactation (days 5-15). During 16-30 lactation days, the TG had a mean weight of 565kg and the CG a mean of 589.48kg, which was 4% higher than the TG. During the 31-45 lactation day interval, the difference between the CG (598.7kg) and TG (533.63kg) increased to 11%. The difference during 46-60 lactation days between the CG (595.3 kg) and TG (539.20 kg) was 9%. CG (604.41 kg) mean weight remained higher by 11%, compared to TG (535.28kg) during the 61-75 lactation day interval. By the end of the study (days 76-90), the CG reached a mean body weight of 619.09 kg, which was 15% higher than that of the TG (526.60 kg) (Fig. 2). A statisticaly significant difference between milk fat percentage means between groups was only found during 16-30 and the 31-45 lactation day intervals. Milk fat percentage mean was higher in the TG (4.47%) by 3% compared to CG (4.19%) during the 16-30 lactation days. Throughout the 31-45 lactation days, TG (4.19%) mean milk fat percentage remained higher by 2% compared to CG (4.1%) (Fig. 3).

Milk lactose concentration differed statistically significantly during the intervals of 5-15 and 31-45 lactation days. TG (4.59%) mean milk lactose concentration was 0.5% higher than CG (4.57%) during 5-15 lactation days. During 31-45 lactation day intervals, TG (4.6%) milk lactose was 0.4% higher compared to CG (4.58%) (Fig. 4).

Milk somatic cell count was significantly different between groups during the intervals of 16-30, 46-60, 61-75 and 76-90. During 16-30 lactation days TG (89×103 cells/mL) had a mean somatic cell count which was lower than CG (141 thousand/mL) by 37%. The situation changed during the 46-60 lactation day

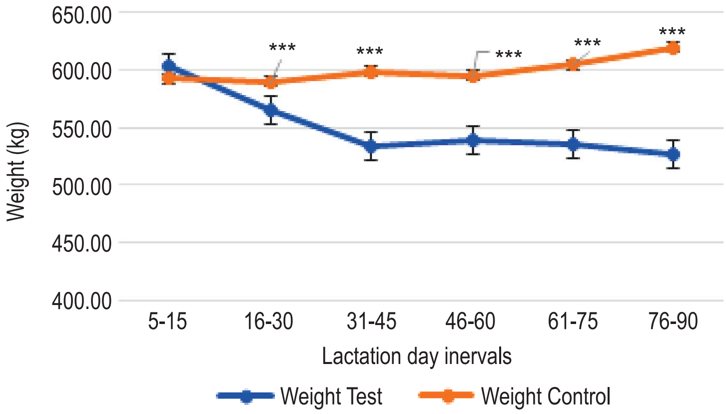

Fig. 2. Body weight comparison between cow groups during lactation day intervals, (*** results are statistically significant).

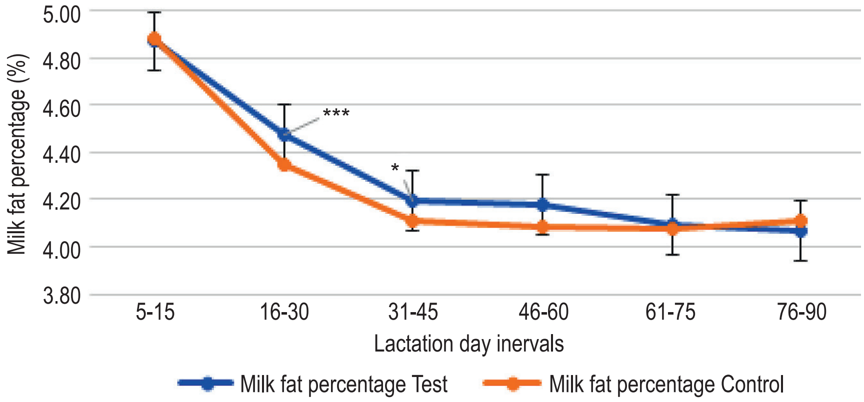

Fig. 3. Milk fat comparison between groups during lactation day intervals, (*** results are statistically significant).

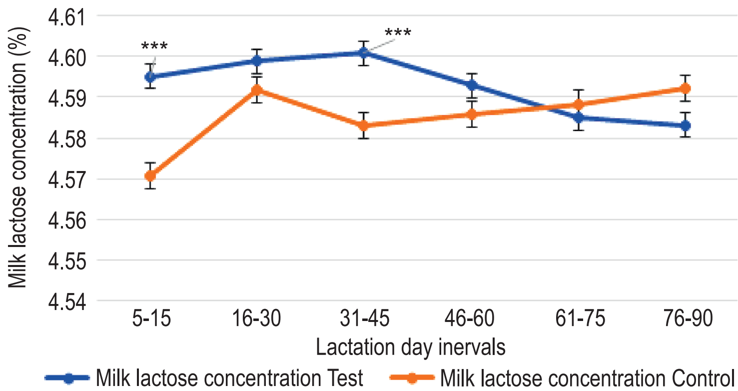

Fig. 4. Milk lactose comparison between cow groups during lactation day intervals. (*** results are statistically significant).

interval – TG (131 thousand/mL) was higher by 41% compared to CG (59 thousand/mL). This difference between groups increased up to 51% during the 61-75 lactation day interval – TG had a somatic cell count mean of 167 thousand cells whilst CG had 49 thousand cells. During the last interval TG (182 thousand/mL) was 39% higher compared to CG (61 thousand/mL) (Fig. 5).

The mean amount of concentrated feed left uneaten differed significantly between groups during most lactation intervals. During the 16-30 interval TG cows left a mean of 1.73kg of feed which was 24% more compared to CG (1.31 kg). TG left more feed (1.86 kg) compared to CG (1.25 kg), during the 31-45 lactation day interval. During the 46-60 lactation day interval, TG left more feed (1.78 kg) by 35% compared to CG (1.15 kg). TG (1.67 kg) remained higher by 33% compared to CG (1.12 kg) during the 61-75 lactation day interval (Fig. 6).

There were no significant differences in any blood parameters with the exception of albumin (Alb) at day 30 pre-partum where the Test animals had higher (p=0.001) levels compared with the control animals (Table 3).

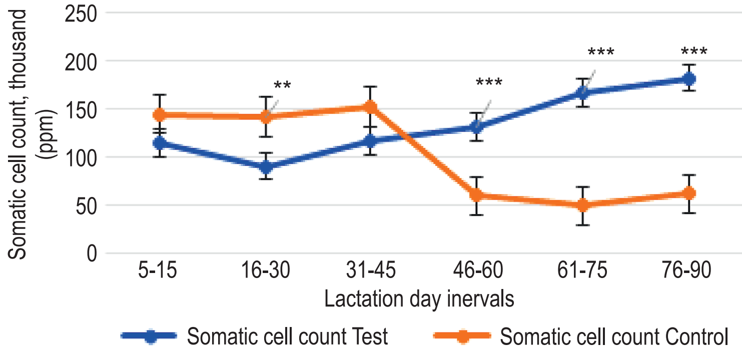

Fig. 5. Milk somatic cell count comparison between cow groups during lactation day intervals. (*** results are statistically significant).

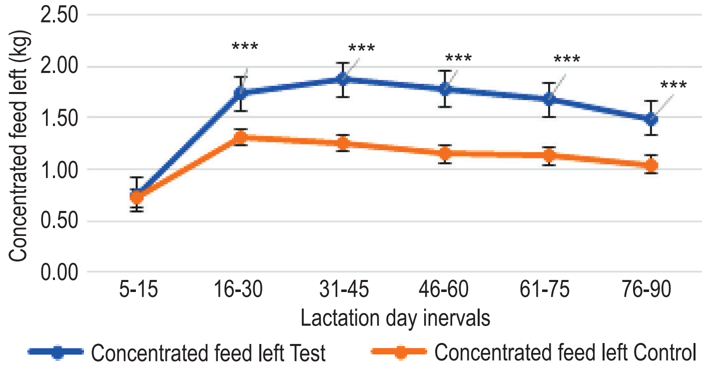

Fig. 6. Concentrated feed left comparison between cow groups during lactation day intervals. (*** results are statistically significant).

Table 3. The impact of essential oils (Agolin ruminant®) feed supplementation on blood parameters in dairy cattle at 30 days pre-partum and 90 days post-partum.

Parameter	Control (Mean ± SEM)	Test (Mean ± SEM)	p-value
Glu 30d pre p.	4.02 ± 0.06	4.56 ± 0.07	0.067
Glu 90d post p.	4.00 ± 0.09	3.69 ± 0.14	0.085
Urea 30d pre p.	5.14 ± 0.19	6.43 ± 0.24	0.152
Urea 90d post p.	5.42 ± 0.19	5.96 ± 0.38	0.192
AST 30d pre p.	116.38 ± 12.96	146.43 ± 21.47	0.254
AST 90d post p.	100.91 ± 6.92	101.14 ± 9.06	0.984
Fe 30d pre p.	139.19 ± 9.29	157.34 ± 8.16	0.161
Fe 90d post p.	124.18 ± 13.09	118.28 ± 8.57	0.711
Ca 30d pre p.	2.49 ± 0.03	2.72 ± 0.03	0.424
Ca 90d post p.	2.62 ± 0.04	2.57 ± 0.06	0.524
Mg 30d pre p.	0.67 ± 0.01	0.83 ± 0.03	0.084
Mg 90d post p.	0.94 ± 0.02	0.93 ± 0.03	0.662
P 30d pre p.	2.17 ± 0.06	2.31 ± 0.04	0.074

Glu- glucose, AST – aspartate aminotransferase, Fe – iron, Ca – calcium, Mg – magnesium, P – phosphorus, TP – total protein, GGT – gamma glutamyl transferase, Alb – albumin, BHB – β-hydroxybutyrate, K – potassium, pre p. – prepartum, post p. – post-partum, Test – test group, Control – control group, N – number of cows, p – coefficient of significance

Discussion

The hypothesis we proposed was that EO (Agolin Ruminant®) supplied during the transition phase can beneficially support milk production and the metabolic profile of dairy cattle. This was supported by our findings, as cows receiving EO supplementation demonstrated consistent improvements in milk yield, higher lactose concentration, and differences in body weight and feed intake behavior. Plant-derived EO may be a helpful way to lessen the environmental effect of ruminant production and increase the efficiency with which they utilize nutrients (Wells 2023). Although the majority of research conducted so far has been short-term and laboratory-based (i.e., in vitro), it appears that EO and their active ingredients may positively affect ruminal fermentation (Kim et al. 2019). Numerous investigations have demonstrated that EO have potent bactericidal action against a variety of food-borne pathogens (Ju et al. 2019). These effects suggest a shift in energy allocation towards productive functions, possibly mediated through improved rumen fermentation and nutrient partitioning (Rayana Brito et al. 2020).

Compared to the Control group, the Test group continuously produced more milk at all lactation intervals, ranging from 4.5% to 7% higher. These significant increases in milk production ($p<0.001$) corroborate previous findings that essential oils can improve rumen fermentation efficiency and nutrient utilization, thereby supporting enhanced lactational performance (Al-Suwaiegh et al. 2020). Numerous investigations into the effects of essential oils on dairy cow milk production have found that the effects vary based on the particular oils and dosages used. One study evaluated how a blend of essential oils, specifically Agolin Ruminant, affects the milk production and feed efficiency of Holstein cows that are nursing. Although overall milk yield differences were not statistically significant throughout the study, the results showed that cows receiving the essential oil blend produced more milk after about three weeks of treatment (Alnemr and Sallam 2020). The results of this study confirm the results of our study. Also, essential oil supplementation has been associated with improved nutrient utilization, which may contribute to enhanced milk production by supporting more efficient metabolic processes (Braun et al. 2019).

The body weight of the TG cows was consistently lower than that of the CG, with differences ranging from 4% to 15% ($p<0.001$). In contrast, a different study that included a meta-analysis of essential oils found that adding essential oils to cattle's diet increased their daily weight gain and final body weight (Orzuna et al. 2022). This suggests that while some essential oils may have a positive effect on weight gain, the results can vary depending on the specific oil used and the context of the study. It has also been reported that these supplements may not improve weight indicators under experimental conditions (Wandsheer et al. 2024). Results may depend on the specific essential oils used, the animal's diet, and the conditions under which the study is conducted. Therefore, further studies investigating the effects of essential oils on cattle body weight would be needed in the future.

During particular periods, the Test group displayed higher percentages of 0.8-2% milk fat, respectively ($p<0.05$). These results are consistent with research showing that adding essential oils can increase milk fat content. To illustrate improved feed efficiency, studies have found that cows given a blend of essential oils produced milk with a higher fat content than unsupplemented cows, even when there were no differences in dry matter intake. The increase in milk fat content raises the possibility that essential oils can improve milk synthesis pathways by having a beneficial effect on rumen fermentation and nutrient partitioning (Braun et al. 2019). Furthermore, dietary modifications can affect the fatty acid profile of milk, according to a review on the use of fatty acid-rich oilseed industry byproducts. This review highlighted the possibility that dietary components could improve the fatty acid composition of milk, indicating that essential oils might play a role, even though the review did not focus exclusively on essential oils (Kokić et al. 2024). The precise effects of essential oils on milk fat are still not well defined in the literature, despite evidence that dietary oils may affect the composition of milk fat. To clarify these relationships, more investigation is required.

In most of the periods, mean milk lactose concentration was 0.4-0.5% higher in the Test group compared to the Control group ($p<0.001$). These findings are supported by other research showing that supplementation with essential oil blends can lead to an increase in milk lactose concentration, likely due to enhanced nutrient utilization and improved rumen fermentation (Al-Suwaiegh et al. 2020). This is in line with our observations, where the Test group consistently demonstrated higher lactose levels compared to the Control group. On the other hand, another study did not provide evidence that essential oil supplementation had any effect on milk lactose levels (Daning et al. 2021). In conclusion, the current literature provides little evidence that essential oils increase lactose content in milk. Instead, studies highlight their potential effects on milk production and other fermentation parameters.

Compared to the Control group, the Test group left 24–35% more concentrated feed uneaten ($p<0.001$). According to other studies, these results support enhanced feed efficiency, either as a result of better nutrient absorption or reduced feed consumption, while maintaining higher milk yield (Castillejos et al. 2006). This, however, is in contrast to other findings that showed no significant effect of essential oils on feed intake, suggesting that reactions vary depending on the nature of the diet and the health of the animal (Yang et al. 2011). Although the publications highlight the benefits of essential oils (EOs) for animal health and feed quality, they do not provide precise information on how EOs directly affect uneaten feed. Understanding the connection between EOs and feed consumption may improve their use in livestock nutrition, and therefore more investigation may be required to fully examine this specific aspect.

Understanding the immunomodulatory effects of essential oils and possible uses in animal health will require more investigation. It can also be difficult to draw general conclusions since different studies may have inconsistent results due to differences in essential oil composition, dosage, and delivery methods. Optimizing the use of essential oils in dairy production may be possible if we understand how they interact molecularly with the immune and gastrointestinal systems, especially during the metabolically demanding transition period. To fully harness their potential benefits and ensure their safe and effective application in ruminant nutrition, future research should integrate metabolic, immunological, and microbiome-related parameters within carefully designed, long-term in vivo studies.

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Author Declarations

Ethics approval

This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee (approval number PK016965, dated 6 June 2017).

Use of generative artificial intelligence

No generative artificial intelligence tools were used in the preparation of this manuscript.

Conflict of interest

The authors declare no conflicts of interest

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