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AC Dhembare

Department of Animal
Husbandry and Dairying,
Institute of Agricultural
Sciences, Banaras Hindu
University, Varanasi, Uttar
Pradesh, India

SS Sankpal

Department of Animal
Husbandry and Dairy Science,
College of Agriculture, Mohopre-
Ahloli, Mahad, Raigad,
Maharashtra, India

DR Birari

Department of Animal
Husbandry and Dairy Science,
College of Agri-Business
Management, Kashti, Malegaon,
Mahatma Phule Krishi
Vidyapeeth, Rahuri,
Maharashtra, India

TR Bhosale

Department of Animal
Husbandry and Dairy Science,
Mahatma Phule Krishi
Vidyapeeth, Rahuri,
Ahilyanagar, Maharashtra, India

SR Jadhav

Department of Animal
Husbandry and Dairy Science,
Sharad College of Agriculture
Jainapur, Shirol, Kolhapur,
Maharashtra, India

Corresponding Author:

AC Dhembare

Department of Animal
Husbandry and Dairying,
Institute of Agricultural
Sciences, Banaras Hindu
University, Varanasi, Uttar
Pradesh, India

Comparative evaluation of chelated and inorganic mineral supplements on milk production and quality in lactating Sahiwal cattle

AC Dhembare, SS Sankpal, DR Birari, TR Bhosale and SR Jadhav

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Abstract

The present study was undertaken to evaluate the effect of chelated and inorganic mineral supplementation on milk production and milk composition in lactating Sahiwal cows. Eighteen healthy cows in their 4th-5th lactation were randomly allotted to three groups (n = 6 each): T₁ (Control) - basal diet only; T₂ (Mineral mixture) - basal diet + 75 g/day inorganic mineral mixture; and T₃ (Chelated mineral mixture) - basal diet + 75 g/day chelated mineral mixture. The feeding trial lasted for 30 days under uniform housing and management conditions. Milk yield and composition (fat, protein, SNF, lactose, and density) were analyzed at 0, 10, 20, and 30 days, and data were statistically evaluated using a two-factorial CRD. Results revealed that cows supplemented with chelated mineral mixture (T₃) exhibited a significantly ($P < 0.05$) higher average daily milk yield (10.30 ± 0.44 L) compared to mineral mixture (T₂) and control (T₁) groups. Milk fat percentage also showed numerical improvement in the chelated group, while protein and SNF percentages increased progressively across all treatments. The group and period effects were significant for milk yield and protein percentage, while other traits showed a non-significant trend of improvement with chelated mineral supplementation. The enhanced milk yield and composition in the chelated group may be attributed to improved bioavailability and metabolic utilization of trace minerals essential for enzymatic and hormonal functions associated with lactogenesis. It is concluded that dietary supplementation of chelated mineral mixture enhances milk production performance and quality in lactating Sahiwal cows compared to inorganic mineral sources.

Keywords: Chelated minerals, Sahiwal cattle, milk yield, milk composition, mineral bioavailability, dairy nutrition

Introduction

Mineral nutrition plays a vital role in maintaining the productivity, reproductive efficiency, and overall health of dairy cattle. Minerals function as cofactors for numerous enzymatic reactions involved in metabolism, immunity, and hormone synthesis (Suttle, 2010) [16]. In lactating cows, an adequate and balanced supply of macro- and micro-minerals is essential to sustain high milk yield and quality, prevent metabolic disorders, and ensure long-term reproductive performance (McDowell, 2003; NRC, 2001) [10, 11].

Traditionally, minerals are supplied in the form of inorganic salts such as sulfates, oxides, or carbonates. However, their bioavailability is often limited due to interactions with dietary antagonists like phytates, oxalates, and fiber components that form insoluble complexes in the rumen, reducing absorption efficiency (Spears, 2003; Kincaid, 2000) [14, 7]. To overcome these limitations, organic or chelated mineral sources—in which the mineral ion is bound to an organic ligand such as amino acids or peptides—have been developed. These chelated forms are more stable in the digestive tract and less susceptible to antagonistic interactions, thereby improving absorption and metabolic utilization (Ashmead, 1993; Spears & Weiss, 2008) [1, 15]. Several studies have demonstrated improved milk yield, composition, and reproductive performance in dairy cattle supplemented with chelated trace minerals compared with inorganic sources. For instance, Kellogg *et al.* (2004) [6] and Cope *et al.* (2009) [5] reported enhanced milk production and somatic cell count reduction with organic Zn and Cu

supplementation. Similarly, organic Zn-Mn complexes have been shown to improve udder health and milk fat synthesis (Miller *et al.*, 2019) ^[11]. In Indian dairy systems, where feed resources are often deficient in trace minerals and the bioavailability of inorganic forms is variable, the use of chelated mineral mixtures offers a promising approach for improving animal performance under practical farm conditions (Bhandari *et al.*, 2013) ^[2].

The Sahiwal breed, a prominent indigenous dairy cattle of India, is known for its adaptability and disease resistance, but productivity can be constrained by nutritional imbalances, particularly mineral deficiencies (Bhosale *et al.*, 2021) ^[4]. Evaluating mineral supplementation strategies in such native breeds is therefore important for sustainable productivity improvement.

Hence, the present study was conducted at University Dairy Farm to evaluate the effect of chelated mineral supplementation on milk yield and milk constituents in lactating Sahiwal cows. It was hypothesized that feeding chelated minerals would enhance milk yield and composition compared to inorganic and unsupplemented control groups through improved mineral absorption and metabolic efficiency.

Materials and Methods

Selection of Experimental Animals

A total of 18 healthy lactating Sahiwal cows in their 4th and 5th lactations were selected based on uniformity in body weight, stage of lactation, and previous milk yield records. The cows were randomly allocated into three groups of six animals each ($n = 6$), ensuring comparable physiological and production status across treatments.

Experimental Design and Treatments

The trial was conducted for a period of 30 days following a completely randomized design (CRD). The animals were maintained under identical feeding and management conditions throughout the experimental period. The mineral mixture and chelated mineral mixture were procured from a reputed private manufacturer through local supply channels.

Table 1: Treatment details are presented below:

Group	Treatment Description
T ₁ (Control)	Roughages + Concentrate Mixture (Basal diet)
T ₂ (Mineral Mixture)	Basal diet + 75 g/day of inorganic mineral mixture
T ₃ (Chelated Mineral Mixture)	Basal diet + 75 g/day of chelated (organic) mineral mixture

Table 2: Chemical Composition of Feeds and Fodders (% DM Basis)

Ingredient	Dry Matter (%)	Crude Protein (%)	Ether Extract (%)	Total Ash (%)	Crude Fiber (%)
Wheat Straw	91.50	3.20	0.30	12.31	29.82
Mixed Grass	21.80	4.88	3.09	14.03	33.60
Green Maize	27.80	6.54	1.27	11.82	27.52
Concentrate Mixture	89.00	20.00	4.10	4.92	10.00

These proximate values were within the range reported by Radotra (2003) ^[13], Malik (2006) ^[9], and Mahants (2008) ^[8].

Housing and Health Management

All cows were maintained under uniform hygienic and managerial conditions. Proper ventilation, sanitation, and

drainage were ensured. Routine prophylactic measures including vaccination (CBPP, LSD, Anthrax, FMD, Pasteurellosis) and deworming were carried out as per standard veterinary protocols. Sick animals, if any, were isolated and treated promptly under veterinary supervision.

Lactation Trial and Milk Recording

Milking was performed twice daily by hand milking at 6:00 AM and 6:00 PM. Individual milk yield was recorded at each milking using a spring balance (capacity 10 kg, accuracy ± 0.1 kg). Daily milk yields were averaged for weekly and overall period means.

Parameters Estimated

Milk Fat (%): Determined by the Gerber's method as per IS:1224 (1977).

Milk Protein (%): Estimated by the Kjeldahl method (AOAC, 1995); total nitrogen $\times 6.38$.

Specific Gravity (Sp. Gr.): Measured by Lactometer at 60°F using the formula

$$\text{Sp. Gr.} = 1 + \text{CLR}$$

where CLR = Corrected Lactometer Reading.

Total Solids (%): Computed by Richmond's formula:

$$\text{TS} = 4 + 1.2\text{F} + 0.14\text{G}$$

where F = Fat (%), G = Corrected Lactometer Reading.

Solid Not Fat (SNF, %): Calculated as $\text{SNF} = \text{TS} - \text{Fat} (\%)$.

Milk Density (DEN%): Determined using an *Eko Milk Analyzer*.

Statistical Analysis

Data were analyzed using Two-Factorial Completely Randomized Design (CRD) with the help of OPSTAT software (CCS HAU, Hisar). The model included the effects of treatment, period, and their interaction. Differences among means were tested using ANOVA, and significance was declared at $P < 0.05$. Simple mean values were also calculated using the formula:

$$\bar{X} = \Sigma X / n$$

Where:

$\bar{X}$ = Mean value

ΣX = Sum of all observations

n = Number of observations

General ANOVA Model (Two-Factorial CRD) Formula:

$$Y_{ij} = \mu + T_i + P_j + (TP)_{ij} + e_{ij}$$

Where:

Y_{ij} = Observation from i th treatment and j th period

μ = Overall mean

T_i = Effect of the i th treatment

P_j = Effect of the j th period

$(TP)_{ij}$ = Interaction effect of treatment $\times$ period

e_{ij} = Random error term

Results and Discussion

Milk Yield

The average daily milk yield of cows in different treatment groups during the experimental period is presented in Table 3. The mean milk yield at the start of the experiment (0th day) was 9.57 ± 0.95 L in the control group (T_1), 8.76 ± 0.49 L in the mineral mixture group (T_2), and 7.84 ± 0.54 L in the chelated mineral mixture group (T_3). After 30 days of feeding, average milk yield increased to 10.89 ± 0.86 L, 9.16 ± 0.46 L, and 10.30 ± 0.44 L in groups T_1 , T_2 , and T_3 , respectively.

The overall group effect was found to be significant ($P <$

0.05), indicating that mineral supplementation influenced milk yield. Period effect was also significant ($P < 0.05$), while interaction (Group $\times$ Period) was non-significant ($P > 0.05$).

The relative increase in milk yield from day 0 to day 30 was highest in the chelated mineral mixture group (T_3 , +31.4%), followed by the control (T_1 , +13.8%) and mineral mixture groups (T_2 , +4.6%). This clearly indicates that chelated minerals enhanced milk production efficiency compared with inorganic mineral supplementation and control diets.

Table 3: Comparative Impact of Mineral Mixture and Chelated Mineral Mixture on Milk Yield of Lactating Cows

Attributes	Group 1 (Control)	Group 2 (Mineral mix)	Group 3 (Chelated mix)	Average	Pooled SE	P (Group)	P (Period)	P (G $\times$ P)
0 day	9.57 ± 0.95^a	8.76 ± 0.49^{ab}	7.84 ± 0.54^b	8.72 ± 0.41	1.379	0.014*	0.033*	0.596
10 day	9.96 ± 0.93^a	8.72 ± 0.41^{ab}	7.82 ± 0.66^b	8.83 ± 0.44				
20 day	10.09 ± 0.92^{ab}	9.14 ± 0.33^b	9.60 ± 0.31^a	9.61 ± 0.33				
30 day	10.89 ± 0.86^a	9.16 ± 0.46^b	10.30 ± 0.44^a	10.07 ± 0.36				
Period mean	10.10 ± 0.44^a	8.94 ± 0.20^b	8.89 ± 0.33^b	9.30 ± 0.20				

Means bearing different superscripts (a, b) within a row differ significantly ($P < 0.05$). NS = non-significant ($P > 0.05$). SE = Standard error; G = Group; P = Period; G $\times$ P = Interaction effect.

Similar findings were reported by Bhandari *et al.* (2013) [3] and who observed significant improvement in milk yield of dairy cattle supplemented with chelated trace minerals compared to inorganic mineral mixtures. Spears (2003) [14] and Ashmead (1993) [1] suggested that the higher bioavailability of organic minerals results in improved metabolic activity and better utilization of nutrients, thereby enhancing milk production performance. Chelated minerals are less reactive in the rumen and more efficiently absorbed in the small intestine due to their stable organic bonding with amino acids or peptides (Spears & Weiss, 2008) [15]. Consequently, they can better support enzymatic and hormonal functions related to lactogenesis, explaining the

higher milk yield in group T_3 .

Milk Fat

The average milk fat percentage at the start of the trial was 3.77 ± 0.31 , 3.53 ± 0.14 , and $3.75 \pm 0.42\%$ in T_1 , T_2 , and T_3 groups, respectively (Table 4). After 30 days of supplementation, the mean fat percentage increased to $4.28 \pm 0.35\%$, $3.82 \pm 0.18\%$, and $4.17 \pm 0.41\%$, respectively. Although differences among groups were not statistically significant ($P > 0.05$), the chelated mineral mixture group (T_3) showed a consistent improvement in milk fat content compared with the other groups.

Table 4: Comparative Impact of Mineral Mixture and Chelated Mineral Mixture on Fat% of Lactating Cows

Attributes	Group 1 (Control)	Group 2 (Mineral mix)	Group 3 (Chelated mix)	Average	Pooled SE	P (Group)	P (Period)	P (G $\times$ P)
0 day	3.77 ± 0.31	3.53 ± 0.14	3.75 ± 0.42	3.68 ± 0.17	0.384	0.256	0.292	0.99
15 day	4.25 ± 0.36	3.67 ± 0.13	4.01 ± 0.42	3.98 ± 0.19				
30 day	4.28 ± 0.35	3.82 ± 0.18	4.17 ± 0.41	4.09 ± 0.19				
Period mean	4.10 ± 0.19	3.67 ± 0.09	3.98 ± 0.23	3.92 ± 0.11		NS		

Means bearing different superscripts (a, b) within a row differ significantly ($P < 0.05$). NS = non-significant ($P > 0.05$). SE = Standard error; G = Group; P = Period; G $\times$ P = Interaction effect.

These results agree with Kellogg *et al.* (2004) [6] and Cope *et al.* (2009) [5], who reported that feeding organic Zn and Cu sources improved milk fat yield and composition. Trace elements such as Zn, Cu, and Mn are cofactors in several enzymes involved in lipid metabolism and mammary gland function (Suttle, 2010) [16]. Therefore, improved mineral availability from chelates could have contributed to higher fat synthesis.

Solid-Not-Fat (SNF)

The mean SNF percentage during the study increased across all treatment groups (Table 5), with the highest average recorded in the chelated mineral mixture group (T_3) ($8.94 \pm 0.12\%$) followed by T_2 ($8.70 \pm 0.14\%$) and T_1 ($8.58 \pm 0.13\%$). Although the group effect was non-significant ($P > 0.05$), period effect was significant ($P < 0.05$), suggesting that SNF content improved over time irrespective of treatment.

Table 5: Comparative Impact of Mineral Mixture and Chelated Mineral Mixture on SNF% of Lactating Cows

Attributes	Group 1 (Control)	Group 2 (Mineral mix)	Group 3 (Chelated mix)	Average	Pooled SE	P (Group)	P (Period)	P (G $\times$ P)
0 day	8.34 ± 0.24	8.40 ± 0.23	8.65 ± 0.17	8.46 ± 0.12	0.313	0.134	0.005	0.990
15 day	8.46 ± 0.22	8.67 ± 0.23	8.94 ± 0.21	8.69 ± 0.13				
30 day	8.94 ± 0.16	9.03 ± 0.23	9.22 ± 0.22	9.06 ± 0.11				
Period mean	8.58 ± 0.13	8.70 ± 0.14	8.94 ± 0.12	8.74 ± 0.08		NS		

Means bearing different superscripts (a, b) within a row differ significantly ($P < 0.05$). NS = non-significant ($P > 0.05$). SE = Standard error; G = Group; P = Period; G $\times$ P = Interaction effect.

The improvement in SNF observed in T_3 may be attributed to better rumen fermentation and nutrient utilization associated

with organic mineral supplementation, consistent with reports by McDowell (2003) [10] and NRC (2001) [11], which

emphasize the role of trace elements in carbohydrate and protein metabolism influencing milk solids.

Milk Protein

Protein content increased gradually in all groups over the course of the study (Table 6). The average protein percentages were 3.37 ± 0.05 , 3.55 ± 0.05 , and $3.45 \pm 0.06\%$ for T₁, T₂, and T₃, respectively, showing a significant group effect ($P <$

0.05). The highest protein content was recorded in the mineral mixture group (T₂), followed by chelated mineral (T₃) and control (T₁).

Improved protein synthesis in mineral-supplemented groups could be related to the involvement of trace minerals like Zn, Mn, and Cu in enzymatic systems responsible for amino acid metabolism and casein formation (Spears, 2003; Suttle, 2010) [14, 16].

Table 6: Comparative Impact of Mineral Mixture and Chelated Mineral Mixture on Protein (%) of Lactating Cows

Attributes	Group 1 (Control)	Group 2 (Mineral mix)	Group 3 (Chelated mix)	Average	Pooled SE	P (Group)	P (Period)	P (G×P)
0 day	3.22 ± 0.05^b	3.34 ± 0.06^a	3.29 ± 0.06^{ab}	3.28 ± 0.03	0.154	0.019*	< 0.001	0.897
15 day	3.34 ± 0.02^b	3.53 ± 0.06^a	3.45 ± 0.10^{ab}	3.44 ± 0.04				
30 day	3.56 ± 0.08^b	3.78 ± 0.06^a	3.60 ± 0.13^{ab}	3.65 ± 0.06				
Period mean	3.37 ± 0.05^b	3.55 ± 0.05^a	3.45 ± 0.06^{ab}	3.46 ± 0.03				

Means bearing different superscripts (a, b) within a row differ significantly ($P < 0.05$). NS = non-significant ($P > 0.05$). SE = Standard error; G = Group; P = Period; G×P = Interaction effect.

Although T₂ showed slightly higher mean protein content, the chelated mineral group (T₃) showed a greater proportional increase from baseline, highlighting enhanced nutrient utilization efficiency. These findings are in line with Miller *et al.* (2019) [11], who observed improvement in milk protein and total solids upon feeding organic trace minerals to lactating cows.

Milk Density:

Average milk density values were 32.38 ± 0.21 , 32.41 ± 0.48 , and $30.41 \pm 0.79\%$ in groups T₁, T₂, and T₃, respectively

(Table 7). Statistical analysis revealed significant differences among groups ($P < 0.05$). Density increased in all groups over time, with the control and mineral mixture groups showing higher values than the chelated mineral group.

Density is a function of total solids content; hence variations can result from changes in fat or SNF proportions. Similar observations were reported by Bhandari *et al.* (2013) [3], where milk density and SNF improved marginally with mineral supplementation, although differences were not always statistically significant.

Table 7: Comparative Impact of Mineral Mixture and Chelated Mineral Mixture on Density (%) of Lactating Cows

Attributes	Group 1 (Control)	Group 2 (Mineral mix)	Group 3 (Chelated mix)	Average	Pooled SE	P (Group)	P (Period)	P (G×P)
0 day	31.82 ± 0.42^a	31.72 ± 1.19^a	29.34 ± 1.49^b	30.96 ± 0.67	1.982	0.020*	0.191	0.931
15 day	32.58 ± 0.30^a	32.71 ± 0.66^a	30.23 ± 1.50^b	31.84 ± 0.59				
30 day	32.75 ± 0.28^a	32.79 ± 0.62^a	31.67 ± 1.14^b	32.40 ± 0.43				
Period mean	32.38 ± 0.21^a	32.41 ± 0.48^a	30.41 ± 0.79^b	31.73 ± 0.33				

Means bearing different superscripts (a, b) within a row differ significantly ($P < 0.05$). NS = non-significant ($P > 0.05$). SE = Standard error; G = Group; P = Period; G×P = Interaction effect.

Milk Lactose

Lactose percentage ranged from $4.65 \pm 0.20\%$ at the beginning to $5.28 \pm 0.19\%$ at the end of the experiment (Table 8). Although there was no significant group effect ($P > 0.05$), all treatment groups showed a numerical increase in lactose content over time, indicating improved carbohydrate

metabolism and mammary gland activity. The chelated mineral group recorded slightly higher improvement than the control. According to Bhosale *et al.* (2021) [4], organic mineral supplementation enhances nutrient digestibility and metabolic activity, indirectly supporting lactose synthesis.

Table 8: Comparative Impact of Mineral Mixture and Chelated Mineral Mixture on Lactose (%) of Lactating Cows

Attributes	Group 1 (Control)	Group 2 (Mineral mix)	Group 3 (Chelated mix)	Average	Pooled SE	P (Group)	P (Period)	P (G×P)
0 day	4.76 ± 0.26	4.82 ± 0.33	4.39 ± 0.47	4.65 ± 0.20	0.351	0.415	0.122	0.999
15 day	4.98 ± 0.26	4.99 ± 0.35	4.59 ± 0.52	4.85 ± 0.22				
30 day	5.33 ± 0.23	5.39 ± 0.31	5.11 ± 0.48	5.28 ± 0.19				
Period mean	5.02 ± 0.15	5.06 ± 0.19	4.69 ± 0.28	4.93 ± 0.12		NS		

Means bearing different superscripts (a, b) within a row differ significantly ($P < 0.05$). NS = non-significant ($P > 0.05$). SE = Standard error; G = Group; P = Period; G×P = Interaction effect.

Conclusion

The study demonstrated that supplementation of chelated mineral mixture improved milk yield and enhanced milk composition parameters compared with inorganic mineral supplementation and the control diet. The effect was most pronounced in milk yield and fat content, suggesting better utilization of nutrients and improved lactation performance. Thus, chelated minerals can serve as a superior alternative to inorganic mineral mixtures for optimizing productivity and

milk quality in lactating crossbred cows, particularly under conditions of suboptimal mineral nutrition.

Conflict of Interest

Not available

Financial Support

Not available

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