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Research Article

Effects of Dietary Nano-Zinc Oxide on Growth Metrics and Blood Indices in Assam Hill Goat

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ABSTRACT

Introduction: The Assam hill goat, an indigenous breed known for its small body structure compared to other goat breeds, thrives in the hilly terrains of Assam, India. In the present study, nano zinc oxide was supplemented in the Assam hill goat diet to explore its effects on improving body weight gain in a shorter period, aiming to enhance Assam hill goats' growth, health, and productivity.

Materials and methods: Twenty-four three-month-old Assam hill goats were selected and studied over 120 days. The animals were randomly divided into four groups, including Control, T1, T2, and T3, each consisting of six goats (three males and three females) with an average initial body weight of 5.83 kg. Group C (Control) received a standard basal diet with no supplementation, Group T1 was given a basal diet plus 30 mg/kg nano zinc oxide orally, Group T2 received a basal diet plus 40 mg/kg nano zinc oxide orally, and Group T3 was given a basal diet plus 50 mg/kg nano zinc oxide orally. Average body weight gain and changes in hematological and biochemical parameters were recorded and analysed at the end of the trial.

Results: Body weight in treatment groups (T1, T2, T3) significantly increased from 5.800 ± 0.037 kg, 5.833 ± 0.033 kg, and 5.833 ± 0.049 kg at the first of the trial (0) to 8.433 ± 0.042 kg, 8.617 ± 0.095 kg, and 9.067 ± 0.056 kg on day 120, respectively. Hematological parameters (hemoglobin, packed cell volume, erythrocyte and leukocyte counts) indicated no significant differences. Total protein levels rose significantly in T1, T2, and T3 from 6.400 ± 0.019, 6.395 ± 0.037, and 6.383 ± 0.020 g/dl to 7.135 ± 0.015, 7.332 ± 0.010, and 7.412 ± 0.012 g/dl, respectively. Serum zinc also increased markedly from 0.900 ± 0.019, 0.895 ± 0.037, and 0.892 ± 0.015 mg/L to 1.135 ± 0.015, 1.332 ± 0.010, and 1.405 ± 0.006 mg/L, respectively. In contrast, serum glucose and cholesterol concentrations did not indicate any statistically significant differences among the groups.

Conclusion: Supplementation of nano-zinc oxide at the dose rate of 50 mg/kg feed improved the growth performance and the serum total protein concentration in the body of Assam hill goats.

1. Introduction

India is an agricultural country. For more than 80% of rural India's population, agriculture and related activities such as animal rearing are their primary source of income. Among the reared animals, goat rearing is easier and is more profitable than rearing of any other animal as since it is a multifunctional animal, providing meat, milk and also wool and due to its high prolificacy and short growing period, it is becoming increasingly popular among landless and

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marginal farmers in the country and in the state of Assam. While cattle serve as a "big savings account", many poor families cannot afford it, so goats serve as a more affordable "small savings" account[1,2]. Thus, the goat is frequently referred to as the "Poor Man's Cow"

The North-Eastern part of India is proud of having a proper quality goat breed, the Assam Hill Goat. This native breed of goat is a popular breed known for superior quality of chevon, pleasant quality of skin, and encouraging reproductive traits such as early sexual maturity, low kidding interval, and high prolificacy[3,4,5,6].

Zinc (Zn) is a vital component of animal nutrition metabolism and is found in a wide range of metallo-enzymes and transcription factors[7,8]. Because Zn is not stored in the body, it is necessary to consume it regularly in order to maintain normal physiological processes[9]. Despite its low solubility, zinc oxide is the most common source of Zn in the animal feed industry[10]. Nano zinc oxide (nZnO) has recently been widely used to supplement ruminant diets because of the advantages such as improved bioavailability by enhanced aqueous solubility, higher absorption rate because of smaller size (1–100 nm in diameter), requires at a very low concentration due high surface area to volume ratio, more stable at high temperature and pressure distinguishes nanosized compounds from normal compounds[11].

Recently, Belewu[12] conducted an experiment on West African Dwarf goats and found that the average daily gain (ADG) significantly increased across the groups with increasing levels of nano zinc oxide. Similarly, many studies have been carried out to study the effect of nano-Zinc oxide on ruminants, but very limited studies have been done on the effect of nano-zinc on Assam Hill Goats. Thus, a study on how nano-Zinc oxide benefits in uplifting the physiological and biochemical parameters of the Assam Hill goats is beneficial. Therefore, the present study aimed to assess the effects of nano zinc oxide supplemented in the Assam Hill goat diet on improving body weight gain, growth, health, and productivity of Assam Hill goats in a short period.

2. Materials and Methods

2.1. Ethical approval

The present experiment was reviewed and approved by Institutional Animal Ethics Committee (IAEC), AAU, Khanapara, Guwahati, India (Approval no. 770/GO/Re/S/03/CPCSEA/FVSc/AAU/IAEC/20-21/861).

2.2. Study area

The feeding trial was carried out for four months from February 2021 to June 2021 at the Goat Research Station, Assam Agricultural University, Burnihat, Kamrup (M), Assam, India. All the laboratory experiments were carried out in the Department of Veterinary Physiology, collaborating with the Department of Veterinary Biochemistry, College of Veterinary Science, Khanapara, Guwahati-781022, Assam, India.

2.3. Experimental design

A total of 24 Assam Hill Goats aged 2 to 3 months old, all of approximately similar body weight (average body weight of 5.83 Kg), were selected for the study and maintained at the Goat Research Station, Assam Agricultural University, India. The animals were taken immediately after weaning, at around 2 to 3 months of age. The goats were randomly allocated into four experimental groups, each comprising six goat kids, three males and three females. The animals were housed in pens provided by the research station along with other non-experimental goats. To distinguish the experimental animals, colored ribbons were tied around their necks; yellow for Group T1, green for T2, red for T3, and white for the control group (Figure 1). All animals were administered appropriate vaccinations, PPR and ET vaccines were given as per the age of the goats, as per the Indian Veterinary Research Institute schedule, and dewormed on schedule according to the established protocol of the research station. The goats were closely monitored throughout the four-month study period. The group names, along with their respective treatments, are described in Table 1.

Figure 1. Experimental Assam Hill goats. Colored ribbons were tied around the goats' necks. Group T1: Yellow ribbons, Group T2: Green ribbons, Group T3: Red ribbons, and control group: White ribbons.

Table 1. The group names and the treatment for each group of the 2-3 months Assam hill goat

Group	Treatment
Control (C)	With a normal basal diet and no nano-zinc supplementation
Treatment 1 (T1)	With a normal basal diet and 30 mg nano-zinc oxide/Kg diet orally
Treatment 2 (T2)	With a normal basal diet and 40 mg nano-zinc oxide/Kg diet orally
Treatment 3 (T3)	With a normal basal diet and 50 mg nano-zinc oxide/Kg diet orally

2.4. Basal feed preparation

All animals were fed with feed blocks that were prepared in the research station itself as per the schedule of the farm, along with a wholesome amount of drinking water. The feed blocks were prepared by thoroughly mixing locally available ingredients in specific proportions to ensure balanced nutrition (Table 2). The mixture was then compacted into block molds using a hydraulic press and left to dry in the shade until the block molds hardened, making them easy to store and feed to goats (Figure 2B). In addition, the animals were allowed to graze for eight hours daily from 7:00 to

15:00 on freshly cut Napier grass (*Pennisetum purpureum*), which was cultivated within the research station premises. The concentrate mixture for the kids was prepared with the following composition as per the Indian Council of Agricultural Research (ICAR) standard, which is followed in the research station. For the preparation of feed blocks, a concentrate mixture of 85%, molasses 5%, and paddy straw 10% was used.

Table 2. The ingredients of the feeding block for the Assam Hill goats aged two to three months, according to the Indian Council of Agricultural Research

Ingredients	Amount (%)
Yellow maize	50
Wheat bran	5
Rice polish	7
Groundnut cake	20
Soyabean	15
Mineral mixture*	2
Common salt	1

* Mineral mixture included Calcium carbonate, dicalcium phosphate, common salt, magnesium oxide, calcium sulfate, iron sulfate, copper sulfate, zinc sulfate, manganese sulfate, iodized salt, cobalt sulfate, and selenium.

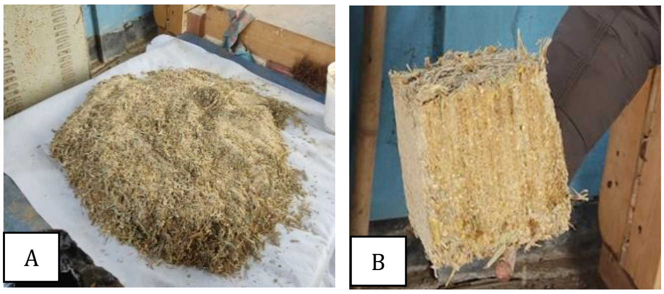

Figure 2. Basal feed for the Assam Hill goats. A: Basal feed mixture, B: feed block

2.5. Collection of samples

The individual body weight of the kids was recorded initially on the first day of trial (0), and subsequent body weights of the kids were noted fortnightly for four months of trial using a spring balance of 100 Kg capacity (Figure 3). In the present study, 2 ml of blood was collected from the jugular vein of each experimental goat (24 in number) at fortnightly intervals in EDTA vials (for Haematological tests) and in Clot Activator vials (for Serum preparation).

Figure 3. Using a spring balance and weighing of Assam hill goats for four months

2.6. Haematological and biochemical parameters analysis

All the Haematological parameters (Hemoglobin, packed cell volume, total erythrocyte count, and total leukocyte count test) were recorded using the conventional laboratory methods. Haemoglobin estimation test was done using Sahli's method or Acid Hematin method and was expressed in grams per deciliter (g/dl). Packed cell volume (PCV) was estimated manually using centrifugation and was expressed in percentage (%). Total erythrocyte count (TEC) was done manually by using the Neubauer chamber and was expressed as million/mm^3. Total leucocyte count (TLC) was done manually by using the Neubauer chamber and was expressed as per cubic mm (/mm^3).

All the biochemical parameters (Total protein, serum zinc, glucose, and cholesterol estimation test) were estimated using commercially available kits produced in India. Total protein was estimated by the Biuret method using an *in vitro* quantitative kit (Aspen Laboratories Pvt. Ltd., B-82, G.T. Karnal Road, Industrial Area, Delhi-33, India) and was expressed in g/dl. Glucose was estimated by the GOD-POD method using an in vitro quantitative kit manufactured by Aspen Laboratories Pvt. Ltd. and was expressed in mg/dl. Cholesterol was estimated by the CHOD-POD method using an *in vitro* quantitative kit manufactured by Aspen Laboratories Pvt. Ltd. and was expressed in mg/dl. Serum zinc was estimated by the Colorimetric method using the *in vitro* Diagnostic kit (Coral Clinical Systems, Bldg, 'C' Plot No M-46, Verna Industrial Estate, Verna, Goa-403722, India) and was expressed in µg/dl.

2.7. Statistical analysis

The statistical analysis of the experimental data was carried out using SPSS (Statistical Package for Social Science version 22, Chicago, USA). The one- and two-way analysis of variance (ANOVA) was used to compare the means at a 5% level of significance according to Duncan's multiple range test (DMRT).

3. Results

3.1. Growth performance

The mean body weight of the experimental Assam Hill Goats on the first day of the trial (0) and at the end of the trial (day 120) is presented in Table 3 and Figure 4.

Table 3. Effect of nano-zinc oxide on the growth performance of Assam Hill goat aged 2-3 months in 120 days

Groups	Initial mean body weight (Kg)	Final mean body weight (Kg)
Control	5.83 ± 0.03[a]	7.40 ± 0.04[a]
Treatment1 (T1)	5.80 ± 0.04[a]	8.43 ± 0.04[b]
Treatment2 (T2)	5.83 ± 0.03[a]	8.62 ± 0.09[c]
Treatment3 (T3)	5.83 ± 0.05[a]	9.07 ± 0.06[d]

Values are presented as mean ± standard error (SE). different superscript letters (a, b, c, d) in the same column differed significantly ($P < 0.05$) and indicated no significant difference among groups.

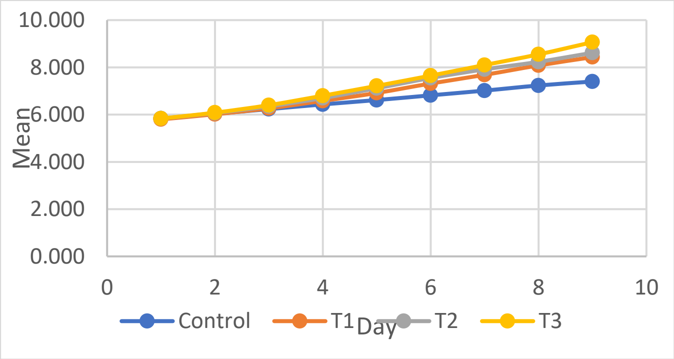

Figure 4. Mean body weight of 24 3-month-old Assam hill goats

The mean body weight of the animals differed significantly ($p < 0.05$) among the treatment groups (T1, T2, and T3), and a significant variation ($p < 0.05$) was observed across the fortnightly intervals. The interaction between group and day was found to be significant ($p < 0.05$).

3.2. Haematological parameters

The mean haematological value of the experimental Assam Hill Goats at the first day and at the end of the trial is presented in Table 4.

Table 4. Effect of nano-zinc oxide on the haematological parameters of Assam hill goat aged three months. TLC: Total leucocyte count, TEC: Total erythrocyte count, PCV: Packed cell volume

Groups	Parameters							
	TLC (/mm³)		TEC (million/mm³)		PCV (%)		Haemoglobin (g/dl)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Control	9.05 ± 0.33^{a}	9.55 ± 0.62^{a}	6.00 ± 0.88^{a}	15.12 ± 0.23^{a}	34.00 ± 1.71^{a}	34.50 ± 0.73^{a}	9.23 ± 0.46^{ab}	9.23 ± 0.17^{a}
T1	9.29 ± 0.42^{b}	9.32 ± 0.31^{b}	16.63 ± 0.51^{a}	16.10 ± 0.29^{b}	35.00 ± 0.86^{a}	35.33 ± 0.50^{a}	9.93 ± 0.17^{b}	10.23 ± 0.14^{b}
T2	9.29 ± 0.38^{b}	9.03 ± 0.23^{a}	12.58 ± 0.66^{b}	13.25 ± 0.33^{c}	31.33 ± 1.20^{a}	33.67 ± 0.67^{a}	8.63 ± 0.22^{a}	9.13 ± 0.22^{a}
T3	9.17 ± 0.48^{c}	8.41 ± 0.27^{d}	12.85 ± 0.37^{b}	13.84 ± 0.25^{c}	33.50 ± 1.15^{a}	34.67 ± 0.71^{a}	9.70 ± 0.17^{b}	10.07 ± 0.41^{b}

Values are presented as mean ± standard deviation (SD). Different superscript letters (a, b, c, d) in the same column differed significantly ($p < 0.05$) and indicated no significant difference among groups

The mean haematological values did not indicate any significant difference ($p > 0.05$) among the groups and were not significant when it was checked for fortnightly variation. The interaction between groups and days also did not differ significantly ($p > 0.05$).

3.3. Biochemical parameters

The mean biochemical parameter of the experimental Assam Hill Goats on the first day and at the end of the trial is presented in Table 5. The mean glucose and cholesterol levels of the experimental goats indicated no significant difference ($p > 0.05$) among the treatment groups. The mean total protein of the animals demonstrated a significant difference ($p < 0.05$) among the T2 and T3 groups (Figure 5), and a significant difference ($p < 0.05$) was observed when it was checked for fortnightly variation. The interaction between group and day was found to be significant ($p < 0.05$).

The mean serum zinc of the animals indicated a significant difference ($p < 0.05$) among the T2 and T3 treatment groups, and a significant difference ($p < 0.05$) was observed when it was checked for fortnightly variation (Figure 6). The interaction between group and day was found to be highly significant ($p < 0.01$).

Table 5. Effect of nano-zinc oxide on the biochemical parameters of Assam hill goat aged three months

Groups	Parameters							
	Total Protein (g/dl)		Serum Zinc (mg/L)		Cholesterol (mg/dl)		Glucose (mg/dl)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Control	6.22 ± 0.03^{a}	6.28 ± 0.01^{a}	0.72 ± 0.03^{a}	0.78 ± 0.01^{a}	88.97 ± 4.53^{a}	97.41 ± 3.99^{a}	53.53 ± 3.89^{a}	53.78 ± 3.06^{a}
T1	6.40 ± 0.02^{b}	7.13 ± 0.02^{b}	0.90 ± 0.02^{b}	1.13 ± 0.02^{b}	96.91 ± 4.10^{a}	99.43 ± 3.94^{a}	54.60 ± 4.28^{a}	65.17 ± 3.59^{b}
T2	6.39 ± 0.04^{b}	7.33 ± 0.01^{c}	0.89 ± 0.04^{b}	1.33 ± 0.01^{c}	102.53 ± 5.44^{a}	113.24 ± 3.50^{b}	59.14 ± 3.25^{a}	63.75 ± 3.62^{b}
T3	6.38 ± 0.02^{b}	7.41 ± 0.01^{d}	0.89 ± 0.01^{b}	1.40 ± 0.01^{c}	101.77 ± 6.02^{a}	112.69 ± 4.71^{b}	56.13 ± 4.34^{a}	68.83 ± 2.89^{b}

Values are presented as mean ± standard deviation (SD). Different superscript letters (a, b, c, d) in the same column differed significantly ($p < 0.05$) and indicated no significant difference among groups

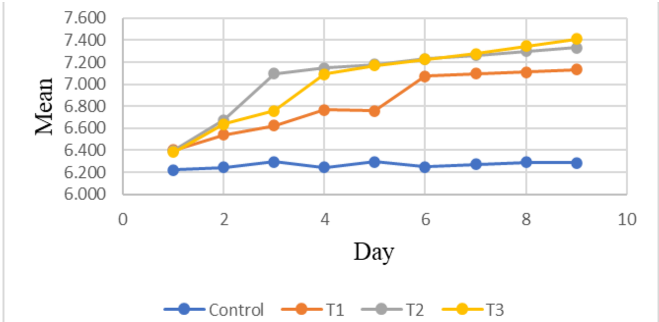

Figure 5. Mean total protein concentration at a fortnightly interval of 24 3-month-old Assam hill goats

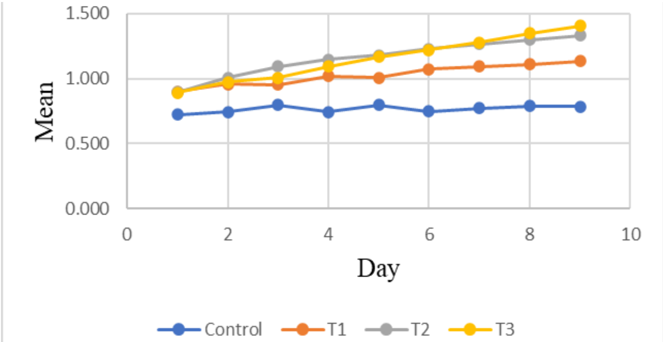

Figure 6. Mean serum zinc concentration at a fortnightly interval of 24 3-month-old Assam hill goats

4. Discussion

4.1. Growth performance

The average body weight of the animals differed significantly ($p < 0.05$) between the groups, and there was also a significant difference ($p < 0.05$) in their fortnightly weight gain. Additionally, a significant interaction ($p < 0.05$) was observed between the group and the day of measurement. The average body weight of all treatment groups (T1, T2, and T3) indicated a significant increase ($p < 0.05$) from the 30th day of the trial onwards at each fortnightly interval compared to the control group (C); however, there were no significant differences observed among the treatment groups themselves. This lack of significant difference remained consistent when statistical analysis was conducted specifically among the treatment groups. Starting from the 105th day of treatment, the mean body weights of the treatment groups began to differ significantly from one another. Among them, Group T3, which received 50 mg of zinc per kg of feed, exhibited a greater increase in body weight by the end of the trial compared to Groups T1 and T2 and the control group.

Zinc participates in the regulation of cell proliferation. It is essential to the enzyme system that influences cell division and proliferation. Zinc also influences hormone regulation of cell division. Specifically, the pituitary growth hormone (GH)-insulin-like-growth-factor-1 (IGF-1) axis is responsive to zinc status[13]. It is also evident that reduced Zinc availability affects membrane signaling systems and intracellular second messengers that coordinate cell proliferation in response to IGF-1. It appears that supplementation of Zinc has a positive effect on growth and IGF-1 levels.

This result was found to be in accordance with the results of Mohamed et al.[14], who experimented on fifteen Ossimi ewes and found that the percentage of body weight during the experimental period increased ($p < 0.05$) by 4.96% and 12.54 % for ewes treated by LP-Zn and NP-Zn, respectively. Belewu[12] also reported similar findings that supplementation of nano zinc oxide at the dose of 0.004% and 0.008% increased ($p < 0.05$) the average daily gain (ADG) significantly across the groups with increasing levels of nano zinc oxide in 12 West African Dwarf (WAD) goats. Contrary to the present study, Aliarabi et al.[15] did not find any effect of 20 or 40 ppm nZnO on average daily gain in Iranian Angora goat kids fed a control diet containing 22 ppm nano zinc.

4.2. Haematological parameters

The mean haematological parameters did not exhibit any statistically significant differences among the experimental groups, nor were any significant variations observed across the fortnightly intervals. Furthermore, the interaction effect between treatment groups and sampling days was also found to be non-significant.

The results were in accordance with the findings from the research work done by Sethy et al.[16], who found that the effect of Zn supplementation on Hb and PCV was non-significant ($p \geq 0.05$). Sethy et al.[16] experimented on 15 Black Bengal kids and fed 40mg /kg DM as ZnO and zinc methionine (Zn-Met) to the treatment groups. Similar results were reported by Swain et al.[17], who found that supplementation of zinc from either inorganic or nano Zn had no effect ($p > 0.05$) on RBC and WBC levels of goat blood. Contrary to the present study, Ulutas et al.[18] found that the haemoglobin, PCV, and TEC levels increased ($p < 0.05$) as compared to a control group on the 30th day with Zn supplementation in Angora goats. Whereas, Belewu[12] reported a significant difference ($p < 0.05$) in white blood cell counts among the different groups.

4.3. Biochemical parameters

The mean glucose and cholesterol concentrations did not exhibit any statistically significant variation across the fortnightly intervals among the treatment groups.

The results were in accordance with the findings from the research work done by Abdollahi et al.[19], who found that the glucose concentration in the blood of the treatment animals fed with inorganic, nano, or organic Zn supplements was the same. Moreover, increasing Zn level in the diet did not affect glucose. Similar results were also obtained by Belewu[12], who found that the mean values of serum glucose also did not differ among the groups. Contrary to this study, Elamin et al.[20] found that the dietary treatment of zinc had a significant ($p=0.05$) effect on blood serum glucose than the control group.

The mean total protein levels of the animals showed a significant difference ($p < 0.05$) among the groups, and significant variation ($p < 0.05$) was also observed when assessed for fortnightly increments. The interaction between treatment groups and day was found to be significant ($p < 0.05$). Group T2 exhibited a significant increase in total protein concentration from the 30th day onward, compared to both the other treatment groups and the control group (C). By the 45th day, Group T3 indicated a significant increase in total protein concentration, with the difference between T2 and T3 becoming non-significant, though both still differed significantly from the T1 and control groups. Starting from day 105 of treatment, the mean total protein concentrations among all treatment groups (T1, T2, and T3) indicated significant differences, with Group T3 demonstrating the highest increase by the end of the trial when compared to the other treatment groups and the control group.

Zinc is an integral part of DNA and RNA polymerase[21]. It is also required for binding of a specific gene with tetrahedral bonds that result in transcription. By this means, the polypeptide chain forms a loop of 11 to 13 amino acid residues, which binds the specific DNA sequences. Zinc is therefore directly involved in the translation step of gene expression of DNA elements in these DNA-binding metalloproteins. Moreover, Zinc is also the structural component of the ribosome and is responsible for its structural integrity and ribosome functions as a micro-machine for making proteins in the body. Ribosome disintegrates in the absence of Zinc, but reconstitutes with the resupply of zinc. Tsui[22] experimented on tomato plants to study the role of zinc in auxin synthesis, and found that Amino acid accumulated in the zinc-deficient plants as protein content decreased. Protein synthesis resumed when zinc was resupplied.

The results were in accordance with the findings of Swain et al.[17], who reported that total protein (g/dL) varied significantly among the treatment groups ($P < 0.01$). Swain et al.[17]conducted a study to assess the effectiveness of nano zinc (NZn) as a feed supplement on the haematological and blood biochemical profiles of 24 non-descriptive local goats (*Capra hircus*) and fed at the dose rate of 50 mg/kg zinc of inorganic ZnO (IZn-50), 50 mg/kg zinc of nZnO (nZn-50), and 25 mg/kg zinc from nZnO (NZn-25) for about four months to the treatment groups. This result was consistent with the report of Belewu[12], who studied the effect of nano zinc oxide on 12 West African Dwarf (WAD) goats at the doses of 0.004% and 0.008% and noticed a significant variation in total protein. Contrary to the present study, Sethy et al.[16] reported that the change in total protein concentration was non-significant ($p > 0.05$).

The mean serum zinc concentrations of the animals demonstrated a significant difference ($p < 0.05$) among the groups, with notable differences also observed when assessed for fortnightly increments. The interaction between group and day was found to be highly significant ($p < 0.01$). In Group T2, the mean serum zinc concentration increased significantly from day 30 onward, in comparison to groups T1, T3, and the control group. By day 45, the serum zinc concentration in the Group T3 indicated a significant increase, and the difference between T2 and T3 became non-significant. However, groups T2 and T3 exhibited significantly higher serum zinc concentrations than the T1 and control groups throughout the trial period.

The current results were in accordance with the findings of Kumar et al.[23], who fed 12 bucks aged between two to four years with the dose of 150 ppm zinc sulphate, reported that after 60 days of supplementation, the concentration of Zn in seminal plasma and serum increased significantly ($p < 0.05$) as compared to control. This result was also consistent with the report of Belewu[12], who studied the effect of nano Zinc oxide on 12 West African Dwarf (WAD) goats at the dose of 0.004% and 0.008% and found that the serum Zn level was significantly higher ($p < 0.05$) in the treatment groups as compared to the control diet. Zinc concentrations in blood serum or plasma are the most widely used indicator of Zn status, as low values are to be expected as an early change during Zn deficiency[24], but it does not give certainty and sensitivity as a diagnostic tool. Increased serum zinc concentration may be attributed to the fact that higher doses of nano Zinc particles were fed to the treatment groups, which may have resulted in an increased absorption of the nano zinc particles. It has been reported that nanoparticles are absorbed in the duodenum by active transport, and nano elemental forms can cross the small intestine and further distribute into the blood[25] and indicating higher availability of Zn for different metabolic functions. The current findings were in agreement with those of Najafzadeh et al.[26], who observed increased serum zinc levels after oral administration of nano zinc oxide in lambs.

5. Conclusion

The present investigation can be concluded that supplementation of Nano-Zinc Oxide to Assam Hill Goats at the dose rate of 50 mg per kg feed improved the growth performance, total protein concentration, as well as serum Zn levels. Also, feeding of nano-zinc oxide was found not to affect the Haematological parameters of the experimental Assam Hill Goats. Nano-particulated minerals have a higher absorption rate as compared to conventionally sized minerals, and feeding minerals with a higher bioavailability reduces not only the expense of supplementing but also the excretion of surplus minerals, reducing environmental pollution.

Moreover, the use of nano-sized minerals potentially improved the overall efficiency of nutrient utilization in livestock, leading to healthier animals and potentially more sustainable farming practices. The positive effects on serum zinc and protein concentrations suggested a beneficial role of nano-zinc oxide in supporting the metabolic and immune functions of goats, which contributed to their overall health and productivity. Future studies could explore long-term effects and the impact on other health markers to further validate the use of nano-zinc oxide in livestock nutrition.

Declarations

Ethical consideration

The present experiment was reviewed and approved by Institutional Animal Ethics Committee (IAEC), AAU, Khanapara, Guwahati, India (Approval no.: 770/GO/Re/S/03/CPCSEA/FVSc/AAU/IAEC/20-21/861).

Competing interests

The authors declared no competing interests.

Authors' contributions

Iqbal Salik Minhaz, the corresponding author, was primarily responsible for conducting the animal trials, performing all laboratory tests, and drafting the manuscript. Arundhati Bora served as the principal guide and provided key insights and supervision throughout the research, particularly in particle-related aspects. Anubha Baruah offered essential support as a co-guide and facilitated the laboratory work within the Department of Physiology. Arup Dutta and Champak Barman contributed as supporting guides, providing overall guidance during the study. Pranjal Borah offered specific direction and mentorship during the animal trials in the Goat Research Station. Rita Nath acted as a minor guide, supporting the progress of the study and facilitating the laboratory work for biochemical tests within the Department of Biochemistry. Rumi Saikia Borah guided the data analysis process. Salima Siddika provided technical assistance during the laboratory experiments. All authors reviewed and approved the final edition of the manuscript.

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Availability of data and materials

The data are available upon a reasonable request.

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