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Impact on nutrient uptake and quality of multicut oat cultivar with zinc application

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Abstract

The research was conducted to biofortify Oat forage by applying Zn besides evaluating the reflex of Zn applications on quality and nutrient uptake by the Oat cultivars under study. Experimental soil was sandy clay loam in texture, slightly alkaline, having available N low, with medium available P & K. Design of the experiment was split plot with two varieties of Oats in Main Plots (JHO-851 and OL-10) while variable applications of Zinc sulphate were arranged in Subplots, having 8 treatments with total treatment combinations of 16, replicated thrice. Zn was supplied through zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) @ 25 kg ha^{-1}. Among the Oat varieties, JHO-851 performed best in all the parameters under investigation. In subplots, a significant enhancement was recorded in nutrient uptake and quality parameters under all the Zinc application treatments concerning the control Trt_1 where Zn was not applied, at both harvests 60 DAS and 105 DAS (final cutting). Among different Zinc applications, sole treatments of Zinc either through soil @ 25 kg Zinc sulphate or by foliar applications 0.5% Zinc, did not prove to be much effective in the nutrient uptake and quality parameters in fodder. However, Zinc augmentation of soil with foliar sprays both at 45 days after sowing and 90 days after sowing recorded significant improvement in all nutrient and quality parameters, N: P: K and Zinc uptake. The best treatment at 60 days after sowing was $Trt_{6,\ while}$ Trt_8 emerged as the best treatment. Concerning quality parameters, zinc applications significantly improved crude protein (CP) under treatments T6 and Trt8 at both cuts 60 days after sowing and 105 DAS, respectively. However, other quality parameters like NDF, ADF and Hemicellulose by different treatments of Zn were not influenced significantly. In a nutshell, the present investigation reveals that the enrichment of Zinc in Oats with agronomical means is useful as it enriches the fodder with Zinc and helps improve the nutrient uptake and the overall quality of the fodder besides being economically beneficial.

Introduction

It is a well-known fact that livestock production directly relates to fodder availability. Forages are the foundation of the animal wealth and their production is the backbone of the livestock industry. According to the 20th Livestock Census (2019), India’s total livestock population stands at 536.76 million, accounting for 11.54% of the global livestock population, marking a 4.6% increase compared to 2012. The population pressure is causing large areas of land to be used for food production and cash crops, which leaves little arable land for fodder production.Currently, the country has 462 MT of green fodder and 394 MT of dry fodder available, reflecting a net deficit of 35.6% in green fodder, 11% in dry crop residue, and 44% in concentrate feed ingredients. (Makhdoomi, 2022).In Jammu and Kashmir, 4.5% of arable land is allocated for fodder production, resulting in a 67.5% deficit in green fodder and a 27.3% deficit in dry fodder production. (Makhdoomi, 2022). For this reason, fodder cultivation in the Jammu and Kashmir region has great significance because it compensates for fodder scarcity during lean periods to encounter the demand for animal products, maintain good health, and maximize the value of livestock products such as wool, milk and meat. Currently, fodder production falls short of meeting demand, as 60 crore animals require 1,097 million tons of green fodder and 1,170 million tons of dry

fodder, making the situation highly challenging. (Ahmad et al., 2014). With the country's present feed and fodder resources, only 48 per cent of the country's feed and fodder requirements can be met. Green and dry fodder are both in deficit by 35 per cent and 11 per cent respectively. (Meena et al., 2019). In North-West India, central India, and now in the eastern and peninsula regions, oat (*Avena sativa* L) is a cereal fodder of great importance during the long winter season. In 2019, the global production of Oats was 23 million tonnes (FAO, 2019). In winter months, the animal faces a lack of green and nutritive fodder and mainly depends on semi-dried standing grasses and cereal straws/stovers, due to this livestock performance is reduced,like production of wool, milk, meat etc. Oat forage is a good choice for growing during lean periods to alleviate the scarcity of green fodder. During the winter time, oats provide many essential nutrients to livestock, which makes them an excellent and healthy feed. As a fodder crop, oats production is constrained by an imbalanced soil profile and overuse of fertilizers, which results in micronutrient deficiencies including zinc, copper, and iron. There are three major nutrients (N, P and K) that have the greatest effect on crop yield but zinc is the fourth most significant. (Chaudhary et al., 2021), play a vital role for various enzymatic and metabolic activities of animals. Inadequacy of these micronutrients in soil leads to reduction in milk productivity and affect the health of animals. Zinc plays a vital role in plants, supporting essential metabolic processes such as tryptophan and chlorophyll synthesis, starch and nitrogen metabolism, and the transport of assimilates. Additionally, zinc supports protein synthesis, gene expression, enzyme structure, energy production, and the activity of the Krebs cycle. (Mousavi et al., 2013). Oat is more susceptible to zinc (Zn) deficiency than other crops.Zinc deficiency in plants leads to slower growth, reduced tillering, shorter internodes, and chlorosis in new leaves and leaf sheaths. Zinc applications significantly enhance various agronomic traits, i.e., leaves length, leaf area, and shoot length resulting to improve photosynthetic activity and shoot fresh weight of oat. Since Zn influences N metabolism, it impacts crude protein concentration. Since Zn affects absorption and protein quality, it influences crude protein concentration. In order to alleviate micronutrient deficiency bio-fortification has been considered to be one of the new alternative approaches (Bouis, 2013). There are three main ways to achieve bio-fortification the first being food supplements (Ahmed 2008 and Prasad 2009), the second being genetic bio-fortification and the third being agronomic manipulation through micronutrient fertilization (Shivay, 2008). Applying Zn-containing fertilizers as an agronomic approaches was found as a rapid and simple solution to overcome Zn deficiency problem (Das *et al*.,2018; Singh *et al*.,2020) and increase fodder growth and productivity in multi cut Oat cultivars.

Objectives

- **Evaluate Nutrient Uptake**: Assess the impact of zinc application on the uptake of essential nutrients in crops.
- **Enhance Crop Quality**: Investigate how zinc influences key quality parameters such as

grain size, color, and nutritional content.

- **Optimize Dosage**: Determine the optimal zinc application rates for maximizing nutrient

absorption and crop quality.

- **Compare Varietal Responses**: Analyze the differential response of various crop varieties to

zinc supplementation.

- **Understand Mechanisms**: Explore the physiological and biochemical mechanisms underlying zinc-enhanced nutrient uptake and quality improvement.
- **Assess Soil Health**: Investigate the impact of zinc application on soil health and its role in sustaining crop productivity.
- **Environmental Impact**: Investigate the environmental implications of zinc supplementation and its sustainability in agricultural practices.

These objectives aim to comprehensively understand the role of zinc in transforming nutrient uptake and improving crop quality.

MATERIAL AND METHODS

Experimental site:

The experimental site is situated in the subtropical Shiwalik foothills of Jammu and Kashmir, at 32º40'N latitude and 74º82'E longitude, with an altitude of 293 meters above mean sea level. A field experiment was conducted during the Rabi season of 2021-22 at the Research Farm of the Department of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Main Campus Chatha. A total of 238.2 mm of rainfall fell during the crop growing season and the range of rainfall was between 0.0 and 110 mm. The highest weekly rainfall of 110 mm was received in the 2nd SMW. Significantly higher rainfall of 64.38% and well-distributed rainfall was received above normal (144.9 mm) during the experimental period. According to the Rabi season forecast, the weekly maximum temperature in the experimental area normally reaches as high as 28^{o}C in the 45th SMW in November and drops to as low as 2.8oC in the 51st SMW in December. During the normal weekly average maximum and minimum relative humidity periods, the relative humidity ranged from 78 to 96.1%. The oat crop grown during *Rabi* 2021-22, recorded a maximum relative humidity of 96.1% in the 5th SMW and a minimum relative humidity of 32% in the 47th SMW falling in November.

Experimental Details:

The soil at the experimental site was characterized as sandy clay loam in texture, slightly alkaline in nature, with low levels of available nitrogen, moderate phosphorus availability, and high potassium content. The study comprised eight treatments as follows: Trt1: Recommended Dose of Fertilizers (RDF)

at 80:40:220 kg/ha (no zinc applied), Trt2: RDF + soil application of $ZnSO_4$ at 25 kg/ha, Trt3: RDF + foliar application of $ZnSO_4$ at 0.5% concentration at 45 days after sowing (DAS), Trt4: RDF + foliar application of $ZnSO_4$ at 0.5% at 90 DAS, Trt5: RDF + foliar applications of $ZnSO_4$ at 0.5% at both 45 DAS and 90 DAS, Trt6: RDF + soil application of $ZnSO_4$ at 25 kg/ha combined with a foliar application of $ZnSO_4$ at 0.5% at 45 DAS, Trt7: RDF + soil application of $ZnSO_4$ at 25 kg/ha combined with a foliar application of $ZnSO_4$ at 0.5% at 90 DAS, and Trt8: RDF + soil application of $ZnSO_4$ at 25 kg/ha along with foliar applications of $ZnSO_4$ at 0.5% at both 45 DAS and 90 DAS. The experiment was conducted using two oat varieties, JHO-851 and OL-10. A split plot design was laid for the experiment with two varieties of Oats in Main Plots (JHO-851 and OL-10) while variable applications of Zinc sulphate were arranged in Subplots, having 8 treatments with total treatment combinations of 16, replicated thrice. Zn was supplied through zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) @ 25 kg ha^{-1}). Plots were 48 in total number. Gross and net plot size of each plot were $12m^2$ and $6.4m^2$ respectively. Seeds were sown using the Kera method, with furrows manually created using a liner at a seed rate of 100 kg/ha and a row spacing of 20 cm. After sowing, the rows were closed using a light planker.

Data Observation:

As per the programme of experimentation, the observations were recorded at 60 and 105 DAS. From each plot a representative sample was taken for the study of plant characteristics at 60 days after sowing and 105 DAS. Plants were cut at 10 cm above the ground surface to allow the smooth regeneration of the crop.

Statistical Analysis:

Cochran and Cox, 1963 described a statistical analysis procedure for identifying treatment effects based on data recorded for various traits. Interpretation of treatment effects was based on critical differences, and all comparisons were performed at the 5% significance level.

Result and Discussion

Nutrient uptake studies

Nitrogen uptake (kg/ha)

The data in the table below indicates that in the main plots, the cultivar JHO-851 recorded significantly higher nitrogen uptake of 33.98 kg/ha at 60 days after sowing and 48.05 kg/ha at the final cutting, compared to the OL-10 variety at both observation intervals.

In the subplot treatments with RDF supplemented by various zinc applications, the highest nitrogen uptake (40.43 kg/ha) was observed in Trt6 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of

$ZnSO_4$ at 0.5% at 45 days after sowing) at 60 days after sowing. This was statistically comparable to Trt8 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 and 90 days after sowing), which recorded a nitrogen uptake of 36.46 kg/ha. At the final cutting, Trt8 showed the highest nitrogen uptake (54.62 kg/ha), which was statistically similar to Trt7 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 90 days after sowing). The lowest nitrogen uptake values (24.42 kg/ha and 17.70 kg/ha) were recorded in Trt1 (RDF without zinc) at 60 days after sowing and the final cutting, respectively. The interaction effects between the multicut forage oat cultivars and the RDF with zinc applications on nitrogen uptake were found to be non-significant.

Impact of Zinc application on nitrogen uptake of multicut oat cultivars

Treatment	N uptake (kg ha^{-1})	
	60 DAS	At final cutting
Variety		
JHO-851	33.98	48.05
OL-10	26.43	16.00
SEm (±)	0.49	1.04
Least significant diff.(p = 0.05)	1.44	3.09
Nutrient management		
Trt_1	24.42	17.70
Trt_2	27.25	22.47
Trt_3	27.59	24.73
Trt_4	25.47	27.66
Trt_5	29.86	31.89
Trt_6	40.43	36.23
Trt_7	30.16	43.92
Trt_8	36.46	54.62
SEm (±)	1.56	1.80
Least significant diff.(p = 0.05)	4.56	5.24
Interaction	NS	NS

Phosphorus uptake (kg/ha)

The phosphorus uptake data presented below indicates that neither the varieties nor the zinc bio-fortification treatments had a significant effect on phosphorus uptake. In the main plot treatments, variety JHO-851 showed numerically higher phosphorus uptake of 0.32 kg/ha at 60 days after sowing and 0.49 kg/ha at the final cutting. Similarly, in the subplot treatments with RDF and zinc applications, there was no significant effect on phosphorus uptake. However, treatment Trt6 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 days after sowing) recorded the highest phosphorus uptake of 0.33 kg/ha at 60 days after sowing. At the final cutting, Trt8 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at both 45 and 90 days after sowing) showed the

highest phosphorus uptake of 0.49 kg/ha. The interaction effect for phosphorus uptake was non-significant.

Impact of Zn application on phosphorus uptake of multi cut oat cultivar

Treatment	P uptake (kg ha $^{-1}$)	
	60 DAS	At final cutting
Variety		
JHO-851	0.32	0.49
OL-10	0.26	0.33
Sem(±)	0.03	0.02
Least significant diff.(p = 0.05)	Non-significant	Non-significant
Nutrient Management		
Trt_1	0.27	0.34
Trt_2	0.28	0.36
Trt_3	0.29	0.39
Trt_4	0.28	0.40
Trt_5	0.30	0.42
Trt_6	0.33	0.43
Trt_7	0.30	0.46
Trt_8	0.31	0.49
SEm (±)	0.07	0.03
Least significant diff.(p = 0.05)	NS	NS
Interaction	NS	NS

Potassium uptake(kg/ha)

The potassium uptake data presented in the table below shows that in the main plot treatments, variety JHO-851 recorded the highest potassium uptake of 96.20 kg/ha at 60 days after sowing and 95.86 kg/ha

at the final cutting. In the subplot treatments with zinc applications combined with RDF, the highest potassium uptake of 99.17 kg/ha was observed in Trt6 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 days after sowing) at 60 days after sowing. This was statistically similar to Trt8 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at both 45 and 90 days after sowing), which recorded a potassium uptake of 98.16 kg/ha. At the final cutting, Trt8 showed the highest potassium uptake of 99.17 kg/ha, which was statistically similar to Trt7 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 90 days after sowing) and Trt6, with potassium uptakes of 96.16 kg/ha and 94.68 kg/ha, respectively. Minimum potassium uptake (84.33 kg/ha and 85.38 kg/ha) at 60 days after sowing and at final cutting was recorded under Trt_1 (RDF-No Zinc). Non-significant interactions were obtained concerning potassium uptake.

Effect of zinc application on potassium uptake of muticut oat cultivars

Treatment	K uptake (kg ha $^{-1}$)	
	60 DAS	At final cutting
Variety		
JHO-851	96.20	95.86
OL-10	87.40	88.50
SEm (±)	0.60	1.03
Least significant diff.(p = 0.05)	1.7	3.02
Nutrient management		
Trt_1	84.33	85.38
Trt_2	90.86	87.01
Trt_3	91.52	
		89.49
Trt_4	85.79	
		91.66
Trt_5	92.70	
		93.88
Trt_6	99.17	
		94.68
Trt_7	91.85	
		96.16
Trt_8	98.16	
		99.17
SEm (±)	1.78	1.60
Least significant diff.(p = 0.05)	5.18	4.67
Interaction	Non significant	Non significant

Zn uptake(g/ha)

The zinc uptake in the green fodder of multicut oat, as shown in the table below, reveals that variety JHO-851 recorded the highest zinc uptake of 65.32 g/ha at 60 days after sowing and 98.98 g/ha at the final cutting. In the subplot treatments with RDF combined with various zinc applications for zinc bio-fortification, treatment Trt6 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 days after sowing) exhibited the highest zinc uptake of 82.45 g/ha at 60 days after sowing. This was statistically similar to Trt8 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 and 90 days after sowing), which recorded a zinc uptake of 81.06 g/ha. At the final cutting, Trt8 showed the highest zinc uptake of 114.68 g/ha, which was statistically similar to Trt7 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 90 days after sowing), with a zinc uptake of 93.55 g/ha. The lowest zinc uptake values (45.19 g/ha and 32.18 g/ha) at 60 days after sowing and the final cutting, respectively, were observed in Trt1 (RDF without zinc). The interaction effects between the multicut forage oat cultivars and RDF with zinc applications were found to be non-significant.

Zinc application effect on Zn uptake of multi cut oat cultivars

Treatment	Zn uptake (g ha^{-1})	
	60 DAS	At final cutting
Variety		
JHO-851	65.32	98.98
OL-10	53.54	36.14
SEm (±)	0.83	1.63
Least significant diff.(p = 0.05)	2.40	4.80
Nutrient management		
Trt_1	45.19	32.18
Trt_2	50.37	42.07
Trt_3	58.75	52.00
Trt_4	47.58	58.77
Trt_5	56.27	69.51
Trt_6	82.45	77.71
Trt_7	52.97	93.55
Trt_8	81.06	114.68
SEm (±)	1.01	3.60
Least significant diff.(p = 0.05)	2.94	10.48
Interaction	NS	NS

Quality parameters

NDF

Neutral detergent fibre (NDF), primarily composed of hemicellulose, cellulose, and lignin, showed no significant differences between the multicut oat cultivars and the zinc application treatments in terms of NDF content at both 60 days after sowing and the final cutting. However, the highest NDF values of 51.55% at 60 days after sowing and 55.51% at the final cutting were recorded under Trt6 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 days after sowing) and Trt8 (RDF +

soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 and 90 days after sowing), respectively. The interaction effects regarding NDF content were found to be non-significant.

zinc application effect on neutral detergent fibre of multi-cut oat cultivars

Treatment	Neutral Detergent Fibre (%)	
	60 DAS	At final cutting
Variety		
JHO-851	50.96	55.99
OL-10	47.18	50.57
SEm (±)	2.47	2.45
Least significant diff.(p = 0.05)	Non significant	Non significant
Nutrient management		
Trt_1	45.90	50.46
Trt_2	47.48	51.78
Trt_3	48.78	52.63
Trt_4	48.53	53.00
Trt_5	49.38	53.42
Trt_6	51.55	54.46
Trt_7	50.25	55.01
Trt_8	50.72	55.51
SEm (±)	5.37	3.77
Least significant diff.(p = 0.05)	NS	NS
Interaction	NS	NS

Acid detergent fibre

The main components of acid detergent fibre (ADF) are cellulose and lignin. The data on ADF, presented below, indicates that there were no significant differences between the multicut forage oat varieties and

the RDF treatments combined with zinc applications at both 60 days after sowing and the final cutting. However, the highest ADF values of 35.10% at 60 days after sowing and 35.68% at the final cutting were observed in Trt6 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 days after sowing) and Trt8 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 and 90 days after sowing), respectively. The interaction effects between varieties and nutrient management were also non-significant in relation to ADF content.

Effect of zinc application on Acid detergent fibre of multi cut oat cultivars

Treatment	Acid Detergent Fiber (%)	
	60 DAS	At final cutting
Variety		
JHO-851	35.16	35.18
OL-10	31.58	33.68
SEm (±)	4.07	2.23
Least significant diff.(p = 0.05)	Non significant	Non significant
Nutrient Management		
Trt_1	31.55	32.87
Trt_2	32.38	33.80
Trt_3	32.99	33.97
Trt_4	32.84	34.14
Trt_5	33.56	34.33
Trt_6	35.10	35.67
Trt_7	34.07	35.05
Trt_8	34.45	35.68
SEm (±)	3.76	4.08
Least significant diff.(p = 0.05)	NS	NS
Interaction	NS	NS

Hemicellulose

Hemicellulose content is calculated by subtracting the acid detergent fibre from the neutral detergent fibre content. The data on hemicellulose, shown in the table below, indicates no significant differences among the multicut forage oat varieties and the RDF treatments combined with zinc applications at both 60 days after sowing and the final cutting. However, the highest hemicellulose values of 16.45% at 60 days after sowing and 19.96% at the final cutting were observed in Trt6 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 45 days after sowing) and Trt7 (RDF + soil application of $ZnSO_4$ at 25 kg/ha + foliar spray of $ZnSO_4$ at 0.5% at 90 days after sowing), respectively. The interaction effect between the oat varieties and zinc fertilization combined with RDF was non-significant for hemicellulose content.

Effect of zinc application on hemicellulose of multicut oat cultivars

Treatment	Hemicellulose (%)	
	60 DAS	At final cutting
Variety		
JHO-851	15.80	20.81
OL-10	15.60	16.89
SEm (±)	3.53	1.69
Least significant diff.(p = 0.05)	NS	NS
Nutrient Management		
Trt_1	14.34	17.58
Trt_2	15.10	17.97
Trt_3	15.78	18.65
Trt_4	15.69	18.85
Trt_5	15.81	19.08
Trt_6	16.45	18.79
Trt_7	16.15	19.96
Trt_8	16.27	19.91
SEm (±)	5.97	6.13
Least significant diff.(p = 0.05)	Non significant	Non significant
Interaction	Non significant	Non significant

Crude protein

This table presents data concerning the crude protein content of forage crops. Crude protein content is an important indicator of a crop's protein content. In the main plots, maximum crude protein was recorded in variety JH0-851 at both intervals of observation (11.89 and 10.80 percent at 60 days after sowing and final cutting, respectively).In sub plot treatments, where zinc was applied with RDF for bio-fortification of Oat fodder, the plants that were fertilized with RDF + soil application of ZnSO4 @ 25 kg/ha + foliar spray of ZnSO4 @ 0.5% at 45 days after sowing (Trt_6) denoted significantly maximum crude protein content (12.05 percent) in comparison to to other treatments at 60 days after sowing. However, statistically at par with treatment Trt_8 (RDF + soil application of ZnSO4 @ 25 kg/ha+ foliar

spray @ 0.5% at 45 days after sowing and 90 days after sowing) and Trt_7 (RDF + soil application ofZnSO4 @ 25 kg/ha + foliar spray of ZnSO4 @0.5% at 90 days after sowing). On the other hand, at final cuttings treatment Trt_8 recorded highest crude protein content (11.07 percent) which was statistically at par with Trt_7 and Trt_6 recording crude protein contents of 10.81 and 10.52 percent, respectively. Minimum crude protein contents (10.71 and 9.67 percent) at 60 days after sowing Gand at final cutting were recorded in treatment Trt_1 (RDR-No Zinc). Interaction effects between multicut forage oat cultivars and RDF supplemented with zinc fertilization were non-significant.

Effect of zinc application on crude protein of multicut oat cultivars

Treatment	**Crude Protein (%)**	
	60 DAS	**At final cutting**
Variety		
JHO-851	11.89	10.80
OL-10	10.81	9.78
SEm (±)	0.19	0.08
Least significant diff.(p = 0.05)	Non-significant	0.24
Nutrient management		
Trt_1	10.71	9.67
Trt_2	10.90	9.95
Trt_3	11.24	10.01
Trt_4	11.04	10.06
Trt_5	11.36	10.26
Trt_6	12.05	10.52
Trt_7	11.59	10.81
Trt_8	11.91	11.07
SEm (±)	0.25	0.27
Least significant diff.(p = 0.05)	0.74	0.79
Interaction	NS	NS

Soil studies

Soil pH

As shown in the table below, after harvest of the crop, multicut forage oat varieties and Zinc application treatments did not significantly affect soil pH.. Similarly, the interaction effects of multicut forage oat varieties and zinc fertilization were non-significant with regard to soil Ph.

Soil EC (ds m^{-1})

A perusal of data pertaining to electrical conductivity given in the below table shows that like soil pH oat cultivars in main plot and Zinc applications in subplot did not have a significant difference in EC after the harvest of the crop. Likewise, interaction effect were also revealed to be non significant with regard to soil EC.

Impact of Zn application on physico-chemical properties of soil after harvest of the crop

Treatment	pH	EC (dS m^{-1})
Variety		
JHO-851	7.47	0.17
OL-10	7.44	0.16
SEm (±)	0.03	0.001
Least significant diff.(p = 0.05)	Non significant	Non significant
Nutrient Management		
Trt_1	7.31	0.15
Trt_2	7.37	0.16
Trt_3	7.39	0.16
Trt_4	7.42	0.16
Trt_5	7.48	0.17
Trt_6	7.54	0.17
Trt_7	7.56	0.18
Trt_8	7.59	0.18
SEm (±)	0.09	0.004
Least significant diff.(p = 0.05)	NS	NS
Interaction	NS	NS

Available N (kg/ha)

Pertaining to available nitrogen data after the harvest of the crop depicted in below table clearly

indicates that both multicut forage oat cultivars and Zinc applications added with RDF have no significant impact on available N in soil. Similarly, interaction effect with regard to available N were also non significant.

Available P (kg/ha)

Available P given in below table again shows non-significant variations due to multicut forage oat cultivars and Zinc applications combined with RDF after final crop harvest. Likewise, non-significant

interactions were observed with regard to available P in soil.

Available potassium (kg/ha)

Potassium available in the soil after final fodder cutting given in below table also shows non-significant variations among multicut forage oat varieties and treatments of Zinc applications added to RDF. In the same manner, non-significant interactions were obtained with regard to available potassium in the soil.

Impact of Zn application on soil fertility after harvest of the crop

Treatment	Nirogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Zinc (mg/ha)
Variety				
JHO-851	230.42	13.77	132.25	0.52
OL-10	229.33	13.63	131.95	0.49
SEm (±)	0.90	0.28	0.48	0.03
Least significant diff.(p = 0.05)	Non significant	Non significant	Non significant	Non significant
Nutrient Management				
Trt_1	221.17	13.17	130.66	0.38
Trt_2	225.67	13.35	131.50	0.51
Trt_3	227.17	13.45	131.51	0.46
Trt_4	228.83	13.70	132.16	0.47
Trt_5	231.50	13.72	131.83	0.48
Trt_6	232.67	13.88	132.16	0.54
Trt_7	234.67	14.00	133.16	0.58
Trt8	237.33	14.35	133.83	0.62
SEm (±)	5.74	0.56	0.70	0.051
Least significant diff.(p = 0.05)	Non significant	Non significant	Non significant	Non significant
Interaction	Non significant	Non significant	Non significant	Non significant

Discussion

Nutrient uptake studies

A significant improvement in the overall uptake of nitrogen and potassium was observed. At 60 days after sowing (DAS), the treatment combining RDF with soil application of $ZnSO_4$ at 25 kg/ha and foliar spray of $ZnSO_4$ at 0.5% at 45 DAS recorded the highest nitrogen and potassium uptake, which was statistically comparable to the treatment where zinc was applied in both soil and foliar forms. At the final cutting, the treatment with RDF, soil application of $ZnSO_4$ at 25 kg/ha, and foliar spray of $ZnSO_4$ at 0.5% at both 45 and 90 DAS showed the maximum nitrogen and potassium uptake, which was statistically

similar to the treatment where zinc was applied as additional foliar sprays along with soil incorporation. No significant differences were observed for phosphorus uptake, as nutrient uptake was influenced by dry matter production and partly due to an increase in nutrient concentration. These results are consistent with the findings of Singh et al. (2016), Kumar (2017), Gaur et al. (2018), Karrimi et al. (2018), and Saha et al. (2020).

A similar trend was observed in zinc uptake, mirroring the patterns seen for nitrogen and potassium uptake. At 60 days after sowing, the treatment with RDF, soil application of $ZnSO_4$ at 25 kg/ha, and foliar spray of $ZnSO_4$ at 0.5% at 45 days after sowing recorded the highest zinc uptake, which was statistically comparable to the treatment where zinc was applied in both soil incorporation and foliar spray forms (1). At the final cutting, the combination of RDF, soil application of $ZnSO_4$ at 25 kg/ha, and foliar spray of $ZnSO_4$ at 0.5% at both 45 and 90 days after sowing resulted in significantly the highest zinc uptake (114.68 g/ha) compared to other treatments. This improvement in zinc uptake could be attributed to the additional foliar zinc spray at the later stage (90 days after sowing), along with the initial foliar spray at 45 days after sowing and soil incorporation, which likely enhanced zinc concentration in the plants. This increase in zinc content may have resulted from improved availability of zinc in the rhizosphere, better absorption via foliar application, efficient translocation to storage organs, and the prevention of fixation losses on leaf surfaces. These findings align with the results reported by Castagnara et al. (2013), Keram et al. (2014), Malik et al. (2015), Ahmad et al. (2018), Dhaliwal et al. (2020), and Kumar and Ram et al. (2021).

Quality parameters

The results about quality parameters show that Zn applications have no significant influence on NDF, ADF and hemicellulose at both 60 days after sowing and final cuttings. NDF values are crucial for livestock ration formulation as they indicate the amount of forage an animal can consume. However, acid detergent fibre values signify the strength of an animal to digest fodder. The increase and/or decrease of NDF and ADF percentage of fodder hampers the digestibility as well as the intake of herbage, its higher values effects the intake, whereas its lower percentages affects the digestibility of forage. The findings of the this study are in concurrence with the results of Ahmad et al. (2018) and Dhaliwal et al (2020) who too reported no change in values of cell wall fractions on Zn application in forage.

Crude protein (CP) is a key indicator of the protein content in forage crops and plays a significant role in classifying fodder, quality assessment, and formulating rations for various animal categories, including those for growth, lactation, and reproduction in ruminants. The results indicate that at 60 days after sowing (DAS), the treatment with RDF, soil application of $ZnSO_4$ at 25 kg/ha, and foliar spray of $ZnSO_4$ at 0.5% at 45 DAS showed the highest crude protein content, which was statistically similar to the treatment where zinc was applied both through soil incorporation and foliar spray, compared to single-mode applications (either soil or foliar). Similarly, at the final cutting, the combination of RDF, soil application of $ZnSO_4$ at 25 kg/ha, and foliar spray at 0.5% at both 45 and 90 DAS resulted in the highest crude protein content, which was statistically comparable to all treatments where zinc was applied in

both soil and foliar forms. This increase in crude protein content is likely due to the positive impact of zinc on nitrogen metabolism, leading to the accumulation of amino acids, enhanced protein synthesis, and consequently, higher crude protein content. The application of zinc in both soil and foliar forms enhanced its concentration in plants, which is associated with RNA and ribosome induction, a probable mechanism for the accelerated protein synthesis. Similar results have been reported by previous studies (Joshi et al., 2007; Deisa et al., 2012; Sutaria et al., 2013; Ahmad et al., 2018; Dhaliwal et al., 2020; Saha et al., 2020).

Soil studies

Concerning changes in soil properties, zinc fertilization did not show any significant variation in soil properties after harvest over initial status. This might be due to the short growing period of oat crop. However minute variations between the treatments through insignificant was observed. These findings are in close conformity with the findings of Sutaria et al. (2013) and Durgude et al. (2019).

CONCLUSIONS

Based on the findings of a one-year study, it can be concluded that the variety JHO-851 exhibited the highest nutrient uptake and quality parameters. The combination of soil application of $ZnSO_4$ at 25 kg/ha with foliar sprays at 0.5% resulted in the maximum zinc enrichment, as well as improved nutrient uptake and quality characteristics. In summary, the effectiveness of soil-applied zinc was significantly enhanced when supplemented with foliar zinc sprays at 0.5%, fulfilling the study's objective of fortifying fodder oats with zinc.

Declarations

Funding

This research received no external funding.

Ethics Approval and Consent to Participate

This study did not involve human participants, human data, or animals, and therefore ethics approval was not required.

Consent for Publication

Not applicable.

Competing Interests

The authors declare no competing interests.

References

Ahmad, M., Zaffar, G., Dar, Z.A., Saleem, N. and Habib, M. 2014. A review on oat (*Avena sativa* L.) as a dual purpose crop. *Scientific and Essays*,9(4):52-59.

DOI:https://doi.org/10.5897/SRE2014.5820

Ahmad, W., Tahir, M., Ahmad, R. and Ahmad, R. 2018. Agronomic biofortification of fodder sorghum with zinc under different levels of nitrogen. *Sains Malaysiana*, **47**(6): 1269-1276.http://dx.doi.org/10.17576/jsm-2018-4706-23.

DOI:https://doi.org/10.17576/jsm-2018-4706-23

Ahmed, A., Anjum, F.M., Rehman, S.U., Randhawa, M and Farooq, U. 2008. Bioavailability of calcium, iron and zinc fortified whole wheat flour chapatti. *Plant Foods for Human Nutrition,* **63(**1**)**: 7–13.

DOI:https://doi.org/10.1007/s11130-007-0062-8

Anonymous, 2019. Food and Agriculture Organization, Statistics .Available at URL http://www.fao.org.Accessed on 27 September, 2021.

Bouis, H. E. 2013. Micronutrient fortification of plants through plant breeding can it improve nutrition in man at low cost. In: *Proceeding of the Nutritional Society*. University of Washington DC, USA .pp 403-411.

DOI:https://doi.org/10.1079/PNS2003262

Castagnara, D.D., Krutzmann, A., Zoz, T., Steiner, F., Conte e Castro, A.M., Neres, M.A. and Oliveira, P.S.R.D. 2012. Effect of boron and zinc fertilization on white oats grown in soil with average content of these nutrients. *Revista Brasileira de Zootecnia*, **41**(7): 1598-1607.

DOI:https://doi.org/10.1590/S1516-35982012000700007

Chaudhary, M., Dwivedi, K.K., Sah, R.P., Gajghate, R., Ahmed, S. and Singh, K.K. 2021. Zinc biofortification of fodder oat (*Avena sativa* L.) through bioinoculant and synthetic fertilizers. *Range Management and Agroforestry*, **42(**1): 181-185.

DOI:*No DOI assigned*

Cochran, W.G. and Cox,G.M. 1963. Experimental Designs. Asia Publishing House, Bombay, India.

DOI:*No DOI assigned (Print Book)*

Das, M.M., K.K. Singh, A.K. Rai and S.K. Mahanta. 2018.Effect of feeding micronutrient fertilized sorghum hay based diet on nutrient utilization and mineral balance in sheep. *Indian Journal of Animal Sciences*,**88**:944-948.

DOI:https://doi.org/10.56093/ijans.v88i8.82956

Deisa, D.C., Alexandre, K., Tiago, Z., Fabio, S., Ana, M., Conte, E.C., Marcelo, A.N., and Paulo, S.R.O. 2012. Effect of boron and zinc fertilization on white oats grown in soils with average content of these nutrients. *Revista Brasileirade Zootecnia*, **41**: 1598-1607.

DOI:https://doi.org/10.1590/S1516-35982012000700007

Dhaliwal, S.S., Sandhu, A.S., Shukla, A.K., Sharma, V., Kumar, B. and Singh, R. 2020. Bio fortification of oats fodder through Zinc enrichment to reduce animal malnutrition. *Journal of Agriculture Science and Technology,* **10**: 98-108.

DOI:https://doi.org/10.17265/2161-6256/2020.02.006

Durgude, A.G., Kadam, S.R., Bagwan, I.R., Kadlag, A.D. and Pharande, A.L. 2019. Response of zinc and iron to rabi sorghum grown on an inceptisol. *International Journal of Chemical Studies*, **7**(3): 90- 94.

DOI:*No DOI assigned*

Gaur, M., Singh, V. and Singh, U.N. 2018. Soil zinc status and response of berseem (*Trifolium alexandrium*) and lentil (*Lens culinaris*) to zinc application. *Annals of Plant and Soil Research*, **20**: 35-38.

DOI:*No DOI assigned*

Joshi, V.P., Verma, S. S. and Bhilare, R. L.2007. Effect of zinc levels on growth and yield of oat (*Avena sativa* L.). *Forage Research*, **32** (4): 238-239.

DOI:*No DOI assigned*

Karrimi, A.S., Reddy, A.P.K., Babazoi, F. and Kohistani, T. 2018. Growth, yield and post- harvest soil available nutrients in sweet corn (*Zea mays* L.) as influenced by zinc and iron nutrition. *Journal of Pharmacognosy and Phytochemistry*, **7**(4): 2372-2374.

DOI:*No DOI assigned*

Keram, K.S. 2014. Response of zinc fertilization to wheat on yield, quality, nutrients uptake and soil fertility grown in a zinc deficient soil. *European Journal of Academic Essays*, **1**(1): 22-26.

DOI:*No DOI assigned*

Kumar, B. and Ram, H., 2021. Biofortification of maize fodder with zinc improves forage productivity and nutritive value for livestock. *Journal of Animal and Feed Sciences*, **30**(2): 149-158.

DOI:https://doi.org/10.22358/jafs/135932/2021

Kumar, R., Singh, M., Meena, B.S., Ram, H., Parihar, C.M., Kumar, S., Yadav, M.R., Meena, R.K., Kumar, U. and Meena, V.K. 2017. Zinc management effects on quality and nutrient yield of fodder maize (*Zea mays*). *Indian Journal of Agricultural Sciences*, **87**(8): 1013-17.

DOI:https://doi.org/10.56093/ijas.v87i8.73070

Makhdoomi, D.M. 2022.Fighting Hunger in Animals: Enhancing Forage Yield. Kashmir Reader, July 24, 2022.

DOI:*No DOI assigned (Newspaper article)*

Malik, P., Duhan, B.S, Midha, L.K., and Sheoran, H.S. 2015. Interactive effect of nitrogen, phosphorus and cutting management on micronutrients uptake by oat. *Forage Research*, **41**: 68-71.

DOI:*No DOI assigned*

Meena, R.L., Meena, M.C., Meena, B.L., Sharma, S.C. and Sahu, A. 2019. Varshakaleen ghas se kamayen munafa. *Kheti magazine published by ICAR*, **75**(5): 41-4.

DOI:*No DOI assigned (Extension publication)*

Mousavi, S.R., Galavi, M. and Rezaei, M. 2013. Zinc (Zn) importance for crop production a review. *International Journal of Agronomy and Plant Production*, **4**(1): 64-68.

DOI:*No DOI assigned*

Prasad, R. 2009. Zinc malnutrition and its alleviation through zinc fortified cereal grains.

Proceeding of the Indian National Science Academy, **75**(2): 89–92.

DOI:*No DOI assigned*

Saha, S., Shankar, T. and Barik, A. K. 2020. Effect of nutrient management on growth, productivity and quality of oats with special emphasis on zinc and boron. *International Journal of Bioresource Science*, **7**(1): 25-31.

DOI:https://doi.org/10.30954/2347-9655.01.2020.6

Shivay, Y.S., Kumar, D. and Prasad, R., 2008. Effect of zinc-enriched urea on productivity, zinc uptake and efficiency of an aromatic rice–wheat cropping system. *Nutrient Cycling in Agroecosystems*, **81**(3): 229-243.

DOI:https://doi.org/10.1007/s10705-007-9159-6

Singh, A.P., Lal, A.K. and Singh, A.P. 2016. Effect of FYM, potassium and zinc on yield, quality and uptake of nutrients in forage oat in alluvial soil. *Annals of Plant and Soil Research*, **18**(4): 338-341.

DOI:*No DOI assigned*

Sutaria, G.S., Ramdevputra, M.V., Ansodaria, S.V. and Akbari, K.N. 2013. Effects of potassium and zinc nutrition on yield and quality of forage sorghum. *Indian Journal of Agricultural Research*, **47**(6): 540-544.

DOI:*No DOI assigned*

Figures

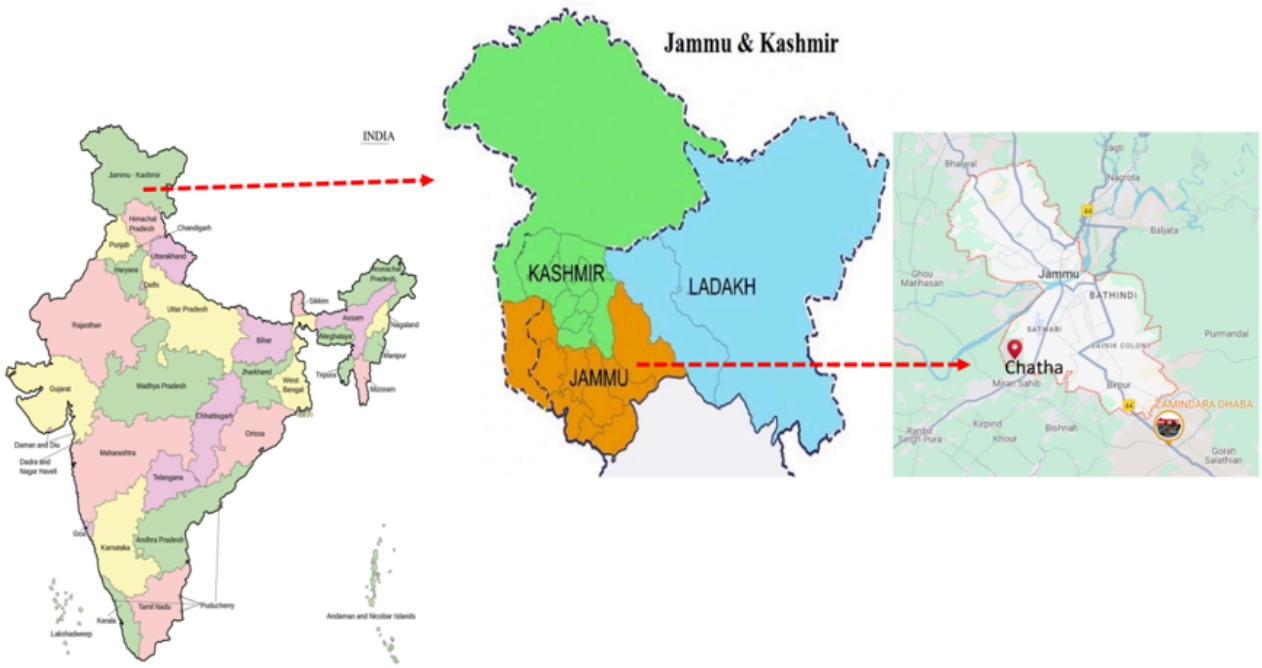


Figure 1

Unnumbered image in the Materials & Methods section.