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RESEARCH ARTICLE

Nano urea reduces chemical fertilizer footprints amidst enhancing productivity and quality of fodder maize

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Abstract

The experiment was carried out at Dryland Agricultural Research Station, Rangreth of SKUAST-K, Srinagar (Jammu & Kashmir) during the Kharif season of 2022 and 2023. The experiment comprised ten treatment combinations of nano-urea and conventional chemical fertilizers were applied in fodder specialty corn Shalimar fodder maize 1 (SFM-1) over two years and was conducted using Randomized Complete Block Design. The various parameters that were recorded during the study include plant height (cm), leaf stem ratio, green fodder yield (qha^{-1}), dry fodder yield (qha^{-1}), crude protein content (%) and dry matter content (%). The relative economics of the experiment was also evaluated during the study. The results of the experiment revealed that plant height and leaf stem ratio was recorded higher than the treatment of the recommended dose of fertilizers RDF (N:P:K@120:60:40 kg/ha), however this treatment was comparable with 75 % recommended dose of N+Nano@2 mL/litre of water, 75 % recommended dose of N+Nano@4mL/litre of water and 75 % recommended dose of N+Nano@6mL/litre of water treatments during both the years of study. The maximum yields of dry, green fodder, crude protein content and green fodder content were also obtained higher by applying the recommended nitrogen dose (RDF) and this was comparable to applying 75 % of the recommended nitrogen dose with nano-urea spray at concentrations of 2 mL L^{-1}, 4 mL L^{-1} and 6 mL L^{-1} of water, as well as applying 50 % of the recommended nitrogen dose with nano-urea spray at 6 mL L^{-1}of water for green fodder yield. In the second year, the highest green fodder yield and dry fodder yield were observed with the application of RDF, which was at par with the application of 75 % of the RDF with nano-urea for both green and dry fodder yield. These findings suggest that of 25 % of the recommended nitrogen dose could be saved by using two sprays of nano-urea at concentrations of 2 mL L^{-1}, 4 mL L^{-1}, or 6 mL L^{-1} during the first year of experimentation. The results also show that soil application of 25 % - 50 % of chemical nitrogen fertilizer can be skipped thus reducing the negative impacts of chemical fertilizers on the soil environment.

Keywords: environment; fodder; maize; nano urea; yield

Introduction

Among the cultivated forage crops, maize is an ideal crop for fodder and silage because of its high yield potential and nutritional profile. It has the highest production potential, per day productivity, wider adaptability, succulent nature and excellent fodder quality with high digestibility and palatability. Hence, it can be fed at any growth stage without any risk to animals as it is free from antimetabolites. It is one of the most adaptable emerging crops, having wider adaptability under varied agro-climatic conditions (1). Nitrogen is the most important limiting factor for plant growth. Its application increases the nitrogen, crude protein content and metabolizable energy, besides improving the succulency, palatability and digestibility of fodder maize (2). Ideal forage crops and optimum management practices might produce high-quality fodder for sustainability in a limited amount of time and area, helping to fulfil the growing need for a supply of high-quality fodder due to increasing pressure on agricultural land for food and cash crops. Therefore, nitrogen management with increased use efficiency is required. Foliar application of Nano urea (liquid) at critical crop growth stages effectively fulfills the nitrogen requirement and reflects higher crop productivity and quality than conventional urea.

Agriculture and animal husbandry are deeply interconnected, with the livestock sector playing a vital role in supporting rural economies, contributing 6.2 % to the total Gross Value Added (GVA) in 2020-21 (3). India holds the top position globally regarding livestock population, with

536.76 million animals, and leads in milk production as well (4). Sustaining such a vast livestock population necessitates a consistent supply of green and dry fodder. Maize (*Zea mays* L.) is renowned for thriving in diverse climatic conditions and producing high-quality fodder in large quantities. Its rapid growth, succulence, palatability, and absence of anti-nutritional substances make it a preferred fodder crop. Maize cultivation requires effective nutrient management to optimize growth and yield as it is a crop that depletes nutrients quickly (5). Providing adequate nutrients at the right time and through appropriate sources is considered an optimal strategy for bridging the gap between actual and potential yields. Nitrogen (N), which makes up 1 % of the plant's dry mass, is the primary nutrient that controls the amount and quality of herbage. Nitrogen deficiency diminishes chlorophyll, amino acid, and energy production, directly impacting growth and yield. Research has shown that fertilizing with nitrogen enhances the quality and yield of fodder maize. However, nitrogen fertilizers such as urea typically have an efficiency of 30 to 40 percent. Despite ample nitrogen supply, its availability is hindered by significant losses through leaching, volatilization, and denitrification (6). Unused urea contaminates soil, air and water as I t enters the environment through various pathways. Urea that leaches into the soil as nitrate negatively affects the quality of drinking water. Nano urea production is an energy-efficient and environmentally friendly process, which involves the conversion of bulk urea into nano-sized particles. This process results in reduced carbon footprints and lower energy requirements than conventional urea production methods. The production process of nano-urea is nearly zero-discharge and does not require additional control measures, making it a clean and eco-friendly alternative to traditional urea manufacturing. Conventional urea production is a highly energy-intensive process, involving the production of solid urea particles, which can lead to significant emissions and pollution. In contrast, nano-urea production requires less energy and fewer emissions, making it a more sustainable option for agricultural input. Furthermore, compared to traditional urea production techniques, nano-urea synthesis produces fewer particles and does not contribute to air pollution. Particle size, coating composition, and nutrient encapsulating methods vary throughout nano-urea formulations. These formulations seek to prolong nitrogen availability for plant uptake, regulate solubility and maximize nutrient release. One popular method is to encapsulate urea nanoparticles in polymer coatings or matrices, which allows for the slow release of nutrients in response to environmental conditions. According to a study that computed the GHG emissions from N100PK and N75PK + nano-urea treatments, N100PK treatments had significantly greater GHG emissions than N75PK + nano-urea treatments (7). Nano urea is an attractive option for sustainable agriculture due to its many qualities, including improved water solubility, increased fertilizer usage efficiency, and fewer environmental effects (8). Thus, there is a critical need for an alternative nitrogen source that minimizes environmental harm. Additionally, the nitrogen use efficiency of urea fertilizer is only 30-35 % (9). Consequently, an urgent need is to embrace slow-release nitrogen fertilizers with higher efficiency to promote agricultural sustainability. Utilizing nanotechnology for nitrogen fertilization, which allows for a controlled and gradual release of nitrogen, could be a suitable alternative to conventional fertilizers (10). The experiment aimed to evaluate the efficiency of nano urea fertilizer in the growth and productivity of fodder maize compared to mineral nitrogen fertilizer.

Materials and Methods

The experiment was carried out at Dryland Agricultural Research Station, Rangreth of SKUAST-K, Srinagar (Jammu & Kashmir) during the Kharif season of 2022 and 2023. The experiment site is situated in the valley between 34° 05′ N latitude and 74° 50′ E longitude at 1640 m above mean sea level (AMSL). The soil at the experimental site is characterized as silty clay, with 9.4 % sand, 27.9 % clay, and 62.6 % silt content. With respect to the chemical properties, the soil of the experimental site was having pH of 7.2, the electrical conductivity of 0.15 dsm^{-1} and organic carbon 0.38 %, medium in available nitrogen (480.2 kg/ha), phosphorus (9.5 kg/ha) and potash (202.4 kg/ha) (Table S1, S2).

The experiment comprised of ten treatments viz; T1: Control (without N), T2: RDF (150:60:40 kg N, P_2O_5 and K_2O ha^{-1}), T3: 75 % recommended dose of N + Nano-urea at 2 ml $litre^{-1}$ of water, T4: 50 % recommended dose of N + Nano-urea at 2 mL $litre^{-1}$ of water, T5: 75 % recommended dose of N + Nano-urea at 4 mL $litre^{-1}$ of water, T6: 50 % recommended dose of N + Nano-urea at 4 mL $litre^{-1}$ of water, T7: 75 % recommended dose of N + Nano-urea at 6 mL $litre^{-1}$ of water, T8: 50 % recommended dose of N + Nano-urea at 6 ml $litre^{-1}$ of water, T9-75 % recommended dose of N+ Urea (2 % spray) and T10- 50 % recommended dose of N+ Urea (2 % spray). The experiment was replicated three times using a Randomized Complete Block Design. A standard set of agricultural practices was followed to cultivate the crop, with each plot measuring $12m^2$ (4m ×3m). Two splits of nitrogen were applied using urea granules: 50 % was applied at the time of sowing, and the other 50 % was applied as a top dressing 30 days later. Nano-urea and urea were sprayed onto the crops at 20 and 40 days after sowing, respectively. The recommended doses of phosphorus and potassium were applied as basal fertilizer for all treatments. The crop was harvested manually when the crop reached the grain milking stage, corresponding to approximately 50 % flowering. During harvesting, a sample plant was collected from each plot to determine the percentage of dry matter and nutrient content. Nitrogen content was assessed using a modified Micro-Kjeldhal method, phosphorus content was determined through the vanado-molybdate phosphoric yellow color method in a nitric acid medium, and potassium content was analyzed using a flame photometer as outlined by Jackson (11). Data regarding growth and yield parameters, including plant height, leaf-to-stem ratio, green fodder yield, and dry fodder yield, were collected at the time of harvesting and subjected to statistical analysis. The economic aspects of each treatment were evaluated by considering the current market prices of inputs and outputs for production, which were then expressed in terms of cultivation costs, gross returns, net returns, and the benefit-cost ratio.

Results and Discussion

Morphological characters

Statistical analysis was conducted on morphological parameters, specifically plant height (in centimeters) and dry matter accumulation of fodder maize, and the results are presented in Table 1 and depicted in Fig. 1. The findings revealed that all treatments significantly influenced both parameters compared to the control group where no nitrogen was applied. Maximum plant height was observed in treatment T_2, where the recommended dose of fertilizers was applied, measuring 230.0 cm in 2022 and 198.2 cm in 2023. This height was statistically at par (216.0 cm) with the treatment where 75 % of the recommended dose of fertilizers was applied in conjunction with nano-urea at a concentration of 6 mL L^{-1} during 2022A significantly higher dry matter content was evident with the application of the recommended dose of fertilizers, which was at par with the treatment involving 75 % of the recommended dose of fertilizers combined with nano-urea at a concentration of 6 mL L^{-1} indicating that nano urea at 6 mL L^{-1}can reduce 25 % of solid N requirement in the maize when it comes to plant height and dry matter accumulation These values were notably higher compared to other treatments. Conversely, the control group exhibited the lowest plant height and dry matter content throughout both years of experimentation. This observation could be attributed to the ample supply of nitrogen, which stimulates shoot development by enhancing cell division and elongation, thereby improving light interception for photosynthesis. Additionally, the increased synthesis of tryptophan, an amino acid, may contribute to cell elongation and consequently, an increase in leaf area, influencing various growth parameters.

The application of 75 % of the recommended nitrogen dose along with nano-urea at a concentration of 6 ml $L^{-1}$of water resulted in notably superior growth and yield characteristics among the various nano-urea concentrations tested. This could be attributed to the swift absorption and translocation of nano-fertilizers by the plant, enhancing the

Table 1. Effect of different levels of nano urea on morphological parameters, yield attributes and yield of fodder maize (SFM-1)

Treatments	**Plant height (cm)**		**Leaf: Stem ratio**		**Green fodder yield (qha^{-1})**		**Dry fodder yield (qha^{-1})**		**CP content (%)**		**Dry matter content (%)**
	2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**
Control(without N)	180.7	153.6	0.33	0.3	404.0	343.4	115.0	94.4	8.50	8.2	28.47
RDF(N:P:K@120:60:40kg/ha)	230.0	198.2	0.48	0.4	474.0	402.9	140.0	110.8	8.95	9.0	29.54
75 % recommended dose of N+Nano@2ml/ litre of water	200.3	176.5	0.41	0.3	454.0	385.9	129.0	106.1	8.78	8.8	28.41
50 % recommended dose of N+Nano@2ml/ litre of water	188.0	159.8	0.37	0.3	434.0	368.9	122.0	101.4	8.6	8.6	28.11
75 % recommended dose of N+Nano@4ml/ litre of water	211.3	189.7	0.42	0.36	458.0	389.3	132.0	107.0	8.82	8.8	28.82
50 % recommended dose of N+Nano@4ml/ litre of water	190.3	161.7	0.38	0.3	440.0	374.0	122.0	102.9	8.64	8.6	27.73
75 % recommended dose of N+Nano@6ml/ litre of water	216.0	193.8	0.45	0.4	463.0	393.5	135.0	108.2	8.87	8.9	29.16
50 % recommended dose of N+Nano@6ml/ litre of water	193.0	166.0	0.39	0.3	446.0	379.1	124.0	104.2	8.75	8.7	27.80
75 % recommended dose of N+ Urea(2 % spray)	186.3	158.1	0.36	0.3	427.0	362.9	119.0	99.8	8.56	8.6	27.87
50 % recommended dose of N+ Urea(2 % spray)	184.7	156.3	0.35	0.3	417.0	354.4	118.0	97.4	8.54	8.5	28.30
SE(m)±	**6.9**	**10.3**	**0.02**	**0.08**	**9.8**	**8.34**	**4.5**	**2.3**	**0.10**	**0.15**	**-**
C.D.(P=0.05)	**20.8**	**34.0**	**0.06**	**NS**	**29.4**	**24.8**	**13.5**	**6.8**	**0.21**	**NS**	**-**

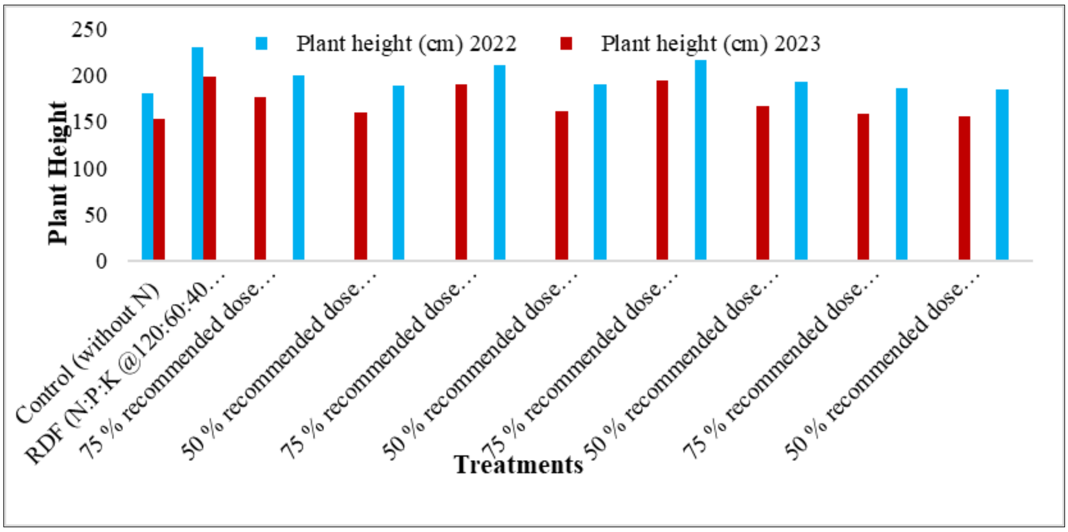

Fig. 1. Effect of different levels of nano urea on plant height of fodder maize (SFM-1).

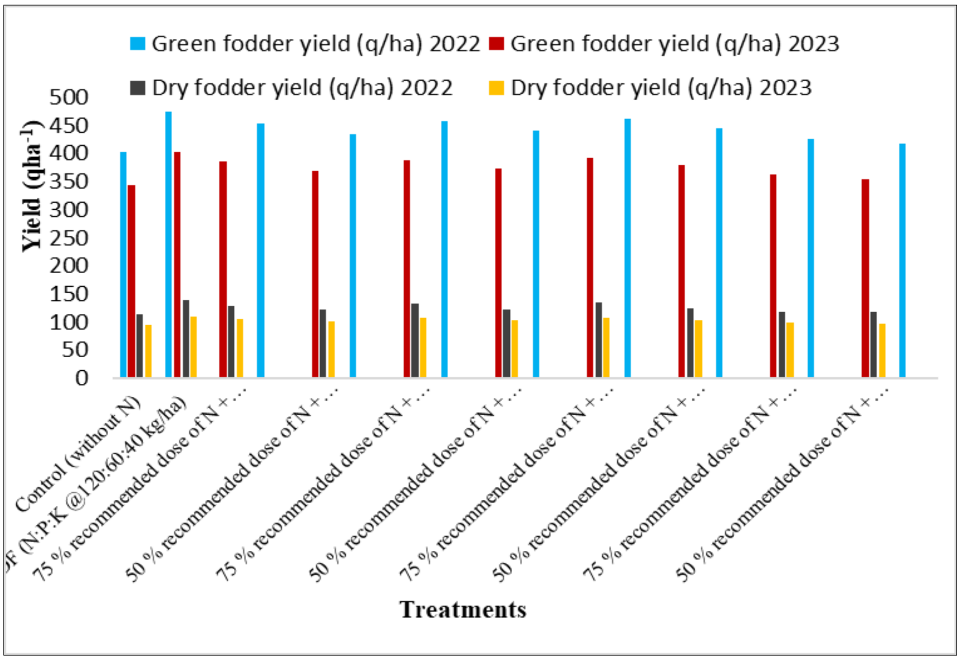

Fig. 2. Effect of different levels of nano urea on yield of fodder maize (SFM-1).

rate of photosynthesis, particularly at higher concentrations. These findings align with some previous studies (9, 12). The findings revealed that significantly higher leaf-to-stem ratio, green fodder yield, and dry fodder yield were achieved with treatment T_2, involving the application of the recommended dose of fertilizers (150:60:40 kg N, P_2O_5 and K_2O ha^{-1}). Applying the full nitrogen dose as urea proved to be significantly superior over control. The results presented in Table 1 and depicted in Fig. 2 revealed that applying 75 % of the recommended dose of fertilizers along with 6 mL L^{-1}of nano-urea was statistically at par with treatment including recommended dose of fertilizers alone. However, the lowest yields and yield attributes were observed in the control, which received no nitrogen. Nitrogen stands out as one of the crucial nutrients for fodder cereals, playing a vital role in photosynthesis and various biological processes such as xylem movement, vacuole storage, and absorption of water and minerals. Therefore, ensuring an efficient supply of nitrogenous fertilizer is paramount for achieving optimal crop growth and yield. The results indicated that both the 100 % recommended dose of fertilizers (RDF) and 75 % RDF with 6 mL L^{-1} of nano-urea yielded equally in terms of green fodder and dry fodder. This productivity parity is attributed to the high efficiency and assimilation of nano-urea within the plant system, facilitated by its large surface area and small particle size. These characteristics promote increased biomass production, consequently enhancing both green and dry fodder yields. The nano-sized urea facilitates efficient uptake and utilization, as well as penetration into the plant from the applied leaf surface, leading to robust vegetative growth of additional fodder maize (13–15). These findings might help in increasing nitrogen use efficiency and consequently reduce the leaching of urea residues in the environment. Also, nano urea increases the availability of N per se for a longer time due to it being slow to release in nature (8). In rainfed ecologies such as Kashmir valley, the availability of moisture needs to be in sync with the availability of nutrients in the soil. Urea-based N can get wasted very quickly as it is available for shorter periods of time. Therefore, nano urea-based N application can bridge the gap between water availability and vital ion availability for the plants. The primary goal for a farmer is to maximize returns on investment. The economic viability of combining urea with liquid nano-urea in fodder maize is presented in Table 2. The highest net returns, amounting to Rs. 98765 ha^{-1} and Rs. 92956 ha^{-1} were achieved with the application of the recommended dose of fertilizers (RDF) and the application of 75 % of the recommended nitrogen dose along with nano-urea spray at a concentration of 6 mL L^{-1} of water, respectively. Similarly, the benefit-to-cost ratio (B:C ratio) reached 2.27 and 2.10 with RDF application and the application of 75 % of the recommended nitrogen dose along with nano-urea spray at a concentration of 2 mL L^{-1}of water, respectively. These results align with the findings of previous studies conducted by (13, 16). The minor difference between the BC ratio here can be reduced by efficiently managing other factors and the overall economy of the system can be improved by efficient utilization of by-products and combining farm household system such as

Table 2. Relative economics of fodder maize (SFM-1) influenced by different levels of nano urea

Treatments	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
Control (without N)	43418	121200	77782	1.79
RDF(N:P:K@120:60:40kg/ha)	43435	142200	98765	2.27
75 % recommendeddoseofN+Nano@2mL/litre of water	43944	136200	92256	2.10
50 % recommended doseofN+Nano@2mL/litre of water	43435	130200	86765	2.00
75 % recommended doseofN+Nano@4mL/litre of water	44944	137400	92456	2.06
50 % recommendeddoseofN+Nano@4mL/litre of water	44435	132000	87565	1.97
75 % recommended doseofN+Nano@6mL/litre of water	45944	138900	92956	2.02
50 % recommended doseofN+Nano@6mL/litre of water	45434	133800	88366	1.94
75 % recommended doseofN+ Urea (2 % spray)	43935	128100	84165	1.92
50 % recommended doseofN+ Urea (2 % spray)	43935	125100	81165	1.85

Table M1. Meteorological data of DARS Rangreth during the crop growth period of Kharif in 2022

SMW	Temperature (C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	RH1	RH2	
26	32.6	17.5	76	44	0.0
27	31.3	20.3	77	58	1.3
28	26.2	17.3	89	68	13.8
29	29.3	18.4	83	61	0.9
30	28.1	18.9	86	62	9.0
31	28.4	17.2	84	63	3.2
32	29.9	18.6	86	59	0.9
33	29.3	18.4	85	59	6.5
34	28.1	17.0	82	67	1.5
35	30.0	15.5	80	53	0.0
36	30.0	15.4	78	46	1.0
37	28.6	13.1	78	52	1.1
38	28.4	11.7	74	46	0.7
39	26.9	11.9	85	47	0.1
40	26.6	7.9	85	41	0.0
41	24.7	7.3	75	48	0.0
42	20.1	4.6	93	54	5.7
43	20.0	2.4	91	70	0.0
44	18.9	3.5	90	62	0.6
Mean/ Total	**27.2**	**13.5**	**83.0**	**55.8**	**46.3**

Table M2. Meteorological data of DARS Rangreth during the crop growth period of Kharif in 2023

SMW	Temperature (C)		Humidity (%)		Rainfall (mm)
	Max.	Min.	RH1	RH2	
26	28.6	15.2	88	61	1.0
27	28.5	15.1	7	7	28.4
28	26.9	19.3	91	68	63.0
29	27.1	17.3	92	66	83.0
30	30.4	16.6	91	54	38.2
31	31.6	17.1	89	56	0.0
32	32.1	16.5	84	49	5.8
33	32.6	17.3	79	49	0.0
34	29.2	13.2	91	49	0.0
35	31.6	13.0	85	42	9.4
36	32.7	15.7	88	36	0.0
37	24.9	9.4	90	49	21.4
38	25.2	7.4	91	61	16.4
39	18.0	6.6	90	73	43.0
40	20.4	2.7	90	71	0.0
41	21.0	2.4	92	74	1.0
42	16.5	1.1	91	76	21.0
43	14.7	0.7	91	81	8.0
44	14.2	-1.3	94	74	0.0
Mean/Total	**25.6**	**10.8**	**84.9**	**57.6**	**339.6**

dairy and poultry.

Conclusion

From the present experiment, it was concluded that by utilizing two sprays of nano-urea at concentrations of 2 mL L^{-1}, 4 mL L^{-1}, or 6 mL L^{-1} of water, approximately 25 % of the recommended nitrogen dose could be saved. Also the environmental impact of chemical fertilizers can be minimized. This suggests that utilizing Nano-urea in combination with reduced nitrogen doses can be an effective strategy for optimizing fodder maize production while reducing input costs. Overall, these findings underscore the potential of Nano-urea as a viable alternative to conventional urea fertilizers for improving fodder maize productivity and quality, especially when integrated with appropriate nutrient management practices. This research provides valuable insights for farmers and agricultural practitioners seeking to enhance fodder crop yields sustainably while minimizing resource inputs.

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Authors' contributions

ZR conceptualized the study and formulated the initial idea. NSK, SN, ZAD and SM designed the experiment and theoretical framework. ZR, TAA and RAB carried out data analysis. ZR, RKA and SB drafted the manuscript. ZR and SN performed data collection. ZR, NSK, TAA, SN, ZAD, SM, RAB, RKA, SB and MR reviewed and edited the manuscript. ZR supervised the research. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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