

Research Article

Effect of bio-seed priming and nano zinc oxide foliar application on quality and productivity of finger millet + greengram intercropping system

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Abstract

A critical stage of the plant's life cycle is germination and insufficient seedling emergence contributes to the lower productivity of finger millet. Priming improves seedling emergence, reduces stand establishment time, and improves seedling germination. There is a need to develop a new technology like Nanotechnology that can precisely detect and deliver the right amount of nutrients or other inputs to safe crops for the environment and maximising productivity. A field experiment was conducted during *Kharif* season to evaluate the response of effective farming practice for sole finger millet + greengram intercropping system under rainfed conditions to varied levels of bio-seed priming and foliar application of nanoparticles on crop growth and productivity. The results of the experiment revealed that finger millet (*Eleusine coracana*) intercropped with greengram (*Vigna radiata*) (2:1) had a significant level (≤ 0.05) increase in growth and yield parameter of finger millet compared to sole finger millet. Application of *Prosopis juliflora* leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm showed a significant level (≤ 0.05) increase in growth and yield parameter like grain yield ($3238.84 \text{ kg ha}^{-1}$), finger millet equivalent yield (FMEY) ($3483.84 \text{ kg ha}^{-1}$) and straw yield ($7393.83 \text{ kg ha}^{-1}$) compared to *Pogonia pinnata* leaf extract 1% alone + Foliar ZnO nanoparticle @ 500 ppm. The present study mainly focussed on cropping system, bio seed priming, and foliar application of nano zinc oxide utilized during rainfed conditions to increase uniform germination, drought resistance and improve crop yield along with nutrient content in seeds.

Keywords: Finger millet, Intercropping, Nanoparticles, Productivity, Seed priming

INTRODUCTION

Finger millet (*Eleusine coracana* L.) is one of the pre-dominant millet crops generally known as ragi belongs to the *Poaceae* family and is enormously cultivated in India, next to sorghum and pearl millet (Dass *et al.*,

2013). India is the world's leading producer of finger millet, accounting for approximately 85 percent of worldwide production (Divya *et al.*, 2013; Sakamma *et al.*, 2018). Finger millet contains 9.2 percent protein, 76.3 percent carbohydrate, 2.2 percent minerals, 1.3 percent fat and 3.9 percent ash, and vitamin A and B.

The grains are rich in phosphorus, potassium and amino acid and have the richest source of energy calcium (410 mg/100g grain), which is especially important supplement for growing children and aged people (Tomar *et al.*, 2011). Approximately 1.02 million ha of finger millet are planted in India, with annual production of 1.38 million tonnes and an average yield of 1.4 tonnes per hectare. Finger millet occupies a significant portion of the land in Tamil Nadu, covering 0.61 lakh ha, producing 0.11 million tonnes and yielding 1.9 tons per hectare for marginal farmers (Indiastat, 2017).

As per Manjunath *et al.* (2018), intercropping is a beneficial crop production technique that aims to maximize productivity and profitability over area and time. Intercropping is a strategy that relies on greater exploitation of sunlight, effective usage of nutrients and water, risk reduction, and increased research of environmental growth parameters (Mobasser *et al.*, 2014; Ajibola and Kolawole, 2019). Other benefits of intercropping include higher profitability and lower fixed costs for land as a benefit of growing a second crop in the same field (Thobatsi, 2009). Intercropping millets with other pulses leads to more efficient use of land and other resources. The system's profitability may be increased by selecting appropriate intercrops that vary in length and development in a range of environments (Sadashiv, 2004).

Crops with different growth characteristics are planted together to complement one another, leading to increased resource use efficiency. Because of their capacity to fix and transmit nitrogen, legumes are essential in intercropping systems involving cereals and millets. Finger millet's initially slow growth phase can be used to generate short-duration pulses. Additionally, intercropping with fast-growing pulses will benefit in controlling weeds (Reddy *et al.*, 2021). Priming enhances germination, speeds up seedling emergence time, and increases stand establishment. The overall goal of seed priming is to slightly hydrate the seed to the point where germination processes commence, although they would indicate fast germination were re-imbibed under normal or stress situations (Singh *et al.*, 2015). Seed priming enhances metabolic processes, preventing seed deterioration, breaking dormancy, and inducing systemic resistance to biotic and abiotic stresses (Pawar and Laware, 2018). Seed priming, owing to its efficiency and lack of the need for expensive equipment and chemicals, could be used as a simple method for overcoming problems associated with poor germination and seedling establishment, thereby assisting in the sustainability of agriculture and cost effective, economical, non-toxic and eco-friendly sources (Mishra *et al.*, 2017).

Nutrients have a key function in enhancing pulse seed production (Chandrasekhar and Bangarusamy, 2003). Foliar application is associated with the advantages of rapid and effective nutrient use, reduction of losses due

to leaching and fixation and aids in controlling nutrient uptake by plants (Manonmani and Srimathi, 2009). Micronutrient deficiencies in humans and crop plants are hard to detect. Therefore, the problem is referred to as "hidden hunger" (Stein *et al.*, 2008). The zinc (Zn) deficiency is the most prevalent nutritional deficiency after iron and iodine. According to the world health organization, Zn deficiency is the fifth major cause of illness among juveniles and old age people in developing countries. The majority of the Indian soils are reported to be Zn deficient. Consequently, food crops cultivated in those soils contain a minimum level of Zn nutrient. Crop species have shown significant genetic variability in sustaining growth and yield in Zn deficient conditions.

"The art and science of altering materials at the nanoscale level is known as nanotechnology." Nanoparticles are metal particles that are spherical or faceted and are generally 100nm in size. These nanoparticles have a high surface area (30-50 m²/g), high activity, a better catalytic surface, a quick chemical reaction, are rapidly dispersible, and absorb a large amount of water. As a result, nano fertilizers may improve nutrient absorption efficiency, boost yield and nutrient content in edible portions, and reduce nutrient buildup in the soil (Saraswathi, 2019). Nanotechnology has been regarded as the "next great frontier of agricultural research" and it plays an important role in revolutionizing agriculture and food production through effective soil nutrient management (Subramanian and Tarafdar, 2011).

In this context, the aim of the present study was to develop cropping system along with bio seed priming of plant leaf extracts and foliar nanoparticles of zinc oxide nanoparticle which can be an effective and eco-friendly technique that could improve the faster emergence, more uniform plant population and increasing yield with improved seed nutrient content.

MATERIALS AND METHODS

The laboratory analysis was conducted at the Agronomy Department, Tamil Nadu Agricultural University (TNAU), Coimbatore, with the foremost aim to prepare botanical leaf extracts for seed priming using Neem (*Azadirachta indica*), Prosopis (*Prosopis juliflora*) and Pungam (*Pogamia pinnata*) leaves and synthesis of zinc oxide nanoparticles for foliar spray using chemical method. Thus, synthesized zinc oxide nanoparticles were characterized by using zeta potential. The average-sized zinc oxide nanoparticles were tested using Particle Size Analyzer (PSA), UV-Visible Spectroscopy (UV-Vis), Fourier Transform Infrared Spectroscopy (FT-IR), X-Ray Diffraction (XRD), Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM) for shape and size and Stability of suspension and Energy Dispersive X-Ray Spectroscopy.

py (EDAX) available at Department of Nano Science & Technology, Tamil Nadu Agricultural University, Coimbatore.

Standardization of soaking duration and concentration of leaf extracts as priming agent for seed priming

Fresh leaves of Neem (*A. indica*), Prosopis (*P. juliflora*), and Pungam (*P. pinnata*) were picked and dried individually in the shade. Using a mortar and pestle, the dried leaves were crushed. Then, using a weighing scale, precisely weigh one gramme of leaf powder and dissolve it in 100 ml of distilled water that was originally measured in the beaker to generate a 1 percent extract. To eliminate undesired material and leaf debris, the leaf extract was filtered through muslin cloth (Gunasekar et al., 2017).

The seeds of finger millet and greengram were primed by adopting the following Seed to solution ratio and seed soaking duration of finger millet (1:1 and 6 hours) and greengram (1:0.3 and 3 hours) already standardized as per Crop Production Guide (CPG, 2012), Department of Agriculture, Government of Tamil Nadu. The seeds were indeed air-dried in the shade to return to their normal moisture content before being tested for seed quality characteristics.

Synthesis of ZnO nanoparticles

ZnO nanoparticles (NPs) were synthesized by dissolving 0.02M aqueous Zinc acetate dihydrate in 50 ml distilled water under vigorous stirring. At room temperature, aqueous 2.0M NaOH was added drop by drop to reach pH 12 and which was then placed in a magnetic stirrer for 2hr. After completion of the reaction, the white precipitate formed was washed thoroughly with distilled water followed by ethanol to remove the impurities. The precipitate was dried overnight in a hot air oven at 60°C. This drying procedure completely converted Zn (OH)₂ into ZnO nanoparticles.

The farm is geographically situated in the North-Western part of Tamil Nadu at 11°N latitude and 77°E longitude with an altitude of 426.72 m above mean sea level (MSL). Coimbatore is located in the Western Argo Climatic Zones of Tamil Nadu. The field experiments were carried out at field number '36 F' of Eastern Block Farm, Central farm unit, Tamil Nadu Agricultural University, Coimbatore during *Kharif* (June to August) seasons of 2020 to study the response of effective farming practice for sole finger millet and with greengram intercropping system under rainfed conditions to varying levels of bio-seed priming and nano zinc.

Finger millet variety CO 15 was taken as the main crop in this study. This variety was released by the Centre of Excellence on Millets, Athiyandal, TNAU in 2013. It is a popular high yielding and long duration variety rich in protein (11.8 percent) and non-lodging strain with a

duration of 125 days. Greengram variety CO 8 was taken as the intercrop in this study. This variety was released by the Department of Pulses, TNAU, Coimbatore during 2013.

The following treatments schedules were used for conducting the field trail in *kharif* season of finger millet intercropping system to optimizing the suitable treatment combinations of bio seed priming and nano zinc oxide nanoparticles application for finger millet intercropping system. The field experiment was laid out in a factorial randomized block design (FRBD) with three replications. All the treatments and replications were randomized to reduce the experimental error. FACTOR – I (cropping system): M₁ – Sole finger millet and M₂ – Finger millet + Greengram (2:1) in main plot and FACTOR – II (Bio seed priming and Foliar ZnO nanoparticle): S₁ – Neem leaf extract 1 per cent alone, S₂ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₃ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₄ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₅ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₆ – Prosopis leaf extract 1 per cent alone, S₇ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₈ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₉ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₁₀ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₁₁ – Pungam leaf extract 1 per cent alone, S₁₂ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₁₃ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₁₄ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm and S₁₅ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm. The treatments were randomly allotted to the plots as per the experimental design. *Foliar spray was done twice on 30 and 60 DAS.

RESULTS AND DISCUSSION

Growth components

The experiments with treatments showed (≤ 0.05) a significant level of difference in main as well as in sub-plot treatments of observations presented in Tables 1 to 3. All the growth components viz., plant height at harvest, LAI at harvest, number of tiller m⁻², DMP (Kg ha⁻¹) at harvest, days to 50 per cent panicle initiation, days to 50 per cent flowering, days to physiological maturity, chlorophyll index (SPAD) at harvest, number of productive tillers m⁻² and tiller conversion efficiency per cent showed superior performance with finger millet intercropped with greengram as compared to sole crop of finger millet.

Table 1. Effect of bio-seed priming and nano zinc foliar spray on plant height (cm), leaf area index (LAI) and number of tillers per m² of finger millet at harvest

Treatments	Plant height at harvest			LAI at harvest			No. of tillers per m ² at harvest		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	129.45	133.72	131.59	3.35	3.46	3.40	114	120	117
S ₂	131.53	136.74	134.14	3.56	3.85	3.70	138	147	143
S ₃	145.62	148.94	147.28	5.40	5.67	5.53	199	212	205
S ₄	142.84	144.97	143.91	4.80	5.04	4.92	175	189	182
S ₅	136.64	141.07	138.86	4.06	4.53	4.30	154	164	159
S ₆	130.02	135.24	132.63	3.49	3.74	3.62	126	134	130
S ₇	135.76	139.49	137.63	3.90	4.21	4.06	150	159	155
S ₈	146.34	149.75	148.05	5.77	5.92	5.84	218	230	224
S ₉	144.21	147.28	145.75	5.21	5.52	5.36	194	205	200
S ₁₀	138.04	143.64	140.84	4.59	4.85	4.72	163	174	168
S ₁₁	129.93	134.95	132.44	3.42	3.62	3.52	122	131	127
S ₁₂	133.59	138.56	136.08	3.66	3.95	3.81	148	153	150
S ₁₃	146.34	148.94	147.64	5.59	5.81	5.70	211	223	217
S ₁₄	143.36	146.40	144.88	5.01	5.33	5.17	187	196	191
S ₁₅	137.93	142.95	140.44	4.40	4.71	4.56	159	170	164
Mean	138.11	142.18		4.41	4.68		164	174	
	SEd	CD (0.05)		Sed	CD		SEd	CD (0.05)	
M	1.879	3.761		0.055	0.110		2.146	4.296	
S	5.145	10.299		0.151	0.302		5.877	11.764	
M X S	7.276	NS		0.213	NS		8.311	NS	

Note: M₁ – Sole finger millet and M₂ – Finger millet + Greengram (2:1) in main plot and S₁ – Neem leaf extract 1 per cent alone, S₂ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₃ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₄ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₅ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₆ – Prosopis leaf extract 1 per cent alone, S₇ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₈ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₉ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₁₀ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₁₁ – Pungam leaf extract 1 per cent alone, S₁₂ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₁₃ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₁₄ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm and S₁₅ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm.

Among the two-cropping system, finger millet + greengram (2:1) (M₂) recorded the highest mean of plant height at harvest of (142.18 cm), LAI at harvest (4.68), number of tiller m⁻² (174), DMP (9404 kg ha⁻¹) at harvest, days to 50 per cent panicle initiation (71.99 DAS), days to 50 per cent flowering (79.21 DAS), days to physiological maturity (105.77 DAS), chlorophyll index (SPAD) at harvest (35.67), number of productive tiller m⁻² (174.34), tiller conversion efficiency (100.68 per cent) followed by sole finger millet (M₁) 138.11 cm, 4.41, 164, 9008 kg ha⁻¹, 73.0 DAS, 80.17 DAS, 107.26 DAS, 34.30, 162.47, 99.18 % at Plant height at harvest, LAI at harvest, number of tiller m⁻², DMP (kg ha⁻¹) at harvest, days to 50 per cent panicle initiation, days to 50 per cent flowering, days to physiological maturity, chlorophyll index (SPAD) at harvest, number of productive tiller m⁻², tiller conversion efficiency percent given in Tables 2, 3 and 4, respectively.

Concerning bio seed priming and foliar zinc oxide nanoparticle spray, priming of Prosopis leaf extract of 1 per cent along with 500 ppm of foliar ZnO nanoparticle (S₈) recorded higher plant height at harvest of (148.05 cm), LAI at harvest (5.84), number of tiller m⁻² (224), DMP (11350 kg ha⁻¹) at harvest, days to 50 per cent panicle initiation (75.20 DAS), days to 50 per cent flowering (83.85 DAS), days to physiological maturity (110.50 DAS), chlorophyll index (SPAD) at harvest (39.27), number of productive tiller m⁻² (222.40), tiller conversion efficiency (99.34 per cent). This was on par with Pungam leaf extract 1 per cent alone + foliar ZnO nanoparticle @ 500 ppm (S₁₃) at all the stages of observation. The least growth components were obtained with Neem leaf extract 1 per cent alone (S₁), the plant height at harvest, LAI at harvest, number of tiller m⁻², DMP (kg ha⁻¹) at harvest, days to 50 per cent panicle initiation, days to 50 per cent flowering, days to physiological maturity,

Table 2. Effect of bio-seed priming and nano zinc foliar spray on DMP (Kg ha⁻¹) at harvest, days to 50% panicle initiation, days to 50% flowering and physiological maturity of finger millet

Treatments	DMP (Kg ha ⁻¹) at harvest			Days to 50% panicle initiation			Days to 50% flowering			Days to physiological maturity		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	7474	7712	7593	69.80	67.80	68.80	75.80	74.70	75.25	103.60	102.40	103.00
S ₂	7996	8296	8146	71.50	70.50	71.00	77.90	77.20	77.55	104.70	103.30	104.00
S ₃	10272	10715	10493	74.80	74.30	74.55	83.10	81.70	82.40	110.20	108.50	109.35
S ₄	9271	9827	9549	73.50	73.20	73.35	81.50	80.30	80.90	108.50	106.10	107.30
S ₅	8687	9105	8896	72.80	72.30	72.55	79.70	78.90	79.30	106.90	105.10	106.00
S ₆	7839	8022	7930	71.10	69.80	70.45	77.40	76.10	76.75	104.70	103.20	103.95
S ₇	8471	8806	8638	72.70	71.20	71.95	78.90	78.50	78.70	106.10	104.30	105.20
S ₈	11138	11563	11350	75.50	74.90	75.20	84.80	82.90	83.85	111.10	109.90	110.50
S ₉	9898	10372	10135	74.60	73.60	74.10	82.30	81.60	81.95	109.80	107.80	108.80
S ₁₀	9092	9567	9330	73.20	72.80	73.00	80.90	79.90	80.40	107.50	106.10	106.80
S ₁₁	7781	7984	7883	70.60	68.00	69.30	76.10	75.80	75.95	103.80	102.90	103.35
S ₁₂	8148	8585	8367	72.30	71.10	71.70	78.50	77.40	77.95	105.80	104.20	105.00
S ₁₃	10593	11159	10876	75.20	74.50	74.85	83.50	82.30	82.90	110.20	109.50	109.85
S ₁₄	9572	9996	9784	74.30	73.40	73.85	81.50	81.50	81.50	108.70	107.70	108.20
S ₁₅	8887	9354	9121	73.10	72.50	72.80	80.60	79.30	79.95	107.30	105.60	106.45
Mean	9008	9404		73.00	71.99		80.17	79.21		107.26	105.77	
	SEd	CD (0.05)		SEd	CD (0.05)		SEd	CD (0.05)		SEd	CD (0.05)	
M	120.550	241.306		1.111	NS		1.125	NS		1.402	NS	
S	330.139	660.844		3.044	NS		3.080	NS		3.841	NS	
M X S	466.887	NS		4.304	NS		4.356	NS		5.431	NS	

Note: M₁ – Sole finger millet and M₂ – Finger millet + Greengram (2:1) in main plot and S₁ – Neem leaf extract 1 per cent alone, S₂ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₃ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₄– Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₅– Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₆ – Prosopis leaf extract 1 per cent alone, S₇ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₈ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₉– Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₁₀ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₁₁ – Pungam leaf extract 1 per cent alone, S₁₂ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₁₃ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₁₄ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm and S₁₅ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm.

chlorophyll index (SPAD) at harvest, number of productive tiller m⁻², tiller conversion efficiency per cent being 131.59 cm, 3.40, 117, 7593 kg ha⁻¹, 68.80 DAS, 75.25 DAS, 103.0 DAS, 31.30, 115.36, 98.62 per cent, respectively. The interaction effect of cropping system and bio seed priming and foliar zinc nanoparticle spray was non-significant (at 0.05 level) irrespective of the growth stages stated in Tables 2-4, respectively.

The increased growth of finger millet with greengram may be due to the compensating impact of greengram, which provided nitrogen to finger millet and the greater usage of natural resources by the finger millet + greengram intercropping system. (Tripathi and Kushwaha, 2013) also reported that plant height and number of leaves per plant of pearl millet under intercropping system were either higher or statistically similar to sole pearl millet, which could be attributed to effective utili-

sation of space and light interception as nutrient contribution of leguminous crop to cereal crop.

Finger millet intercropped with greengram had a beneficial influence on LAI at all stages of crop growth. This might be due to a larger tiller number, which led in a greater number of leaves, resulting in a greater LAI value. (Fawusi *et al.*, 1982) also indicated that maize-based intercropping systems had a greater leaf area index than solo crops. (Kumar *et al.*, 2008) observed that both little millet and pigeonpea sole crops produced greater total dry matter. They also found that a 6:2 row ratio led to an increased total dry matter production of little millet and pigeonpea. This might be attributed to the increased dry matter accumulation in the leaf, stem, and reproductive sections. Kaushik and Sharma (2017) reported similar findings in a wheat-based intercropping system noticed higher leaf area

Table 3. Effect of bio-seed priming and nano zinc foliar spray on chlorophyll index (SPAD value) at harvest, number of productive tillers per hill, number of productive tillers per m² and tiller conversion efficiency (%) of finger millet

Treatments	Chlorophyll index at harvest			No. of productive tillers per m ²			Tiller conversion efficiency (%)		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	30.26	32.34	31.30	112.32	118.40	115.36	98.32	98.93	98.62
S ₂	31.36	33.01	32.19	136.96	146.56	141.76	99.12	99.57	99.34
S ₃	36.60	39.55	38.07	198.40	210.88	204.64	99.68	99.55	99.61
S ₄	36.10	36.79	36.44	173.12	188.16	180.64	99.16	99.32	99.24
S ₅	33.76	33.82	33.79	152.96	162.24	157.60	99.42	99.22	99.32
S ₆	31.02	32.75	31.89	124.48	132.80	128.64	98.98	99.28	99.13
S ₇	33.48	33.61	33.55	148.80	157.76	153.28	99.15	99.20	99.17
S ₈	38.15	40.38	39.27	215.36	229.44	222.40	98.83	99.86	99.34
S ₉	36.28	37.62	36.95	192.32	203.84	198.08	99.17	99.38	99.28
S ₁₀	35.76	36.45	36.10	160.96	172.16	166.56	98.90	99.08	98.99
S ₁₁	30.76	32.51	31.64	121.28	156.80	139.04	99.21	119.51	109.36
S ₁₂	33.06	33.25	33.16	147.20	152.00	149.60	99.39	99.58	99.49
S ₁₃	37.58	39.94	38.76	208.64	221.12	214.88	99.09	99.14	99.11
S ₁₄	36.25	37.16	36.71	186.24	193.92	190.08	99.83	99.18	99.51
S ₁₅	34.12	35.82	34.97	158.08	168.96	163.52	99.48	99.44	99.46
Mean	34.30	35.67		162.47	174.34		99.18	100.68	
	SEd	CD (0.05)		Sed	CD (0.05)		SEd	CD (0.05)	
M	0.422	0.886		2.152	4.308		1.803	NS	
S	1.212	2.425		5.894	11.798		4.938	NS	
M X S	1.714	NS		8.336	NS		6.984	NS	

Note: M₁ – Sole finger millet and M₂ – Finger millet + Greengram (2:1) in main plot and S₁ – Neem leaf extract 1 per cent alone, S₂ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₃ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₄ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₅ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₆ – Prosopis leaf extract 1 per cent alone, S₇ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₈ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₉ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₁₀ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₁₁ – Pungam leaf extract 1 per cent alone, S₁₂ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₁₃ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₁₄ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm and S₁₅ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm.

index compare to sole wheat cropping system.

Prosopis leaf extract of 1 percent alone with 500 ppm of foliar ZnO nanoparticle (S₈) in sorghum recorded higher growth parameters compared to higher concentration (1000 ppm) due to enhance in plant height and photosynthetically active leaf area due to nano ZnO might have been the reason for increased dry matter accumulation and could be due to the complementary effect of other innate nutrients like magnesium, iron, and sulphur with zinc (Koti *et al.*, 2009; Poornima and Koti, 2019).

Zinc acts as an enzyme activator in plants and is directly involved in the biosynthesis of auxin, which generates more cells and dry matter that could be stored in seeds, as stated in various crop experiments by (Slaton *et al.*, 2001; Rehman *et al.*, 2002) in rice, (Genc *et al.*,

2006; Ozkutlu *et al.*, 2006) in bread wheat and (Anand R, 2008) in rabi season sorghum crop. Prasad *et al.* (2012) demonstrated that nano ZnO increased seed germination, seedling vigour, early flowering, and leaf chlorophyll content. They also found beneficial effects of NPs in enhancing plant growth, development, and yield in peanuts at low concentrations, but at larger concentrations, ZnO NPs were negative, exactly like the bulk nutrients.

Yield attributes

The present investigation showed that significant difference in main as well as sub treatments of observations given in Tables 4 and 5. All the yield attributes *viz.*, earhead weight (g), earhead length (cm), number of fingers per earhead, finger length (cm), number of

Table 4. Effect of bio-seed priming and nano zinc foliar spray on earhead weight (g), earhead length (cm), number of fingers per earhead and finger length (cm) of finger millet

Treatments	Earhead weight (g)			Earhead length (cm)			No. of fingers per earhead			Finger length (cm)		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	5.15	5.47	5.31	7.14	7.62	7.38	6.42	6.96	6.69	6.63	7.12	6.88
S ₂	5.49	5.94	5.72	7.81	7.97	7.89	7.03	7.61	7.32	7.36	7.62	7.49
S ₃	6.52	6.74	6.63	10.59	11.37	10.98	8.39	8.44	8.42	9.13	9.57	9.35
S ₄	6.29	6.46	6.38	9.32	10.06	9.69	8.12	8.26	8.19	8.29	8.36	8.32
S ₅	5.82	6.21	6.02	8.55	8.85	8.70	7.62	7.90	7.76	7.83	7.96	7.90
S ₆	5.36	5.85	5.61	7.71	7.94	7.82	6.87	7.32	7.10	7.33	7.58	7.46
S ₇	5.65	6.18	5.92	8.19	8.66	8.42	7.59	7.77	7.68	7.61	7.78	7.69
S ₈	6.73	6.89	6.81	11.45	11.72	11.59	8.46	8.73	8.60	9.68	9.94	9.81
S ₉	6.48	6.69	6.59	10.44	10.87	10.66	8.31	8.42	8.37	8.72	8.88	8.80
S ₁₀	6.04	6.35	6.20	9.18	9.23	9.20	7.96	8.20	8.08	8.16	8.25	8.21
S ₁₁	5.24	5.73	5.49	7.36	7.88	7.62	6.62	7.11	6.87	6.89	7.31	7.10
S ₁₂	5.53	6.03	5.78	8.04	8.51	8.27	7.20	7.69	7.45	7.57	7.74	7.65
S ₁₃	6.64	6.81	6.73	11.15	11.44	11.30	8.40	8.52	8.46	9.43	9.72	9.58
S ₁₄	6.37	6.55	6.46	9.65	10.58	10.12	8.27	8.34	8.31	8.45	8.64	8.55
S ₁₅	5.99	6.27	6.13	8.87	8.94	8.91	7.81	8.06	7.94	8.04	8.14	8.09
Mean	5.95	6.28		9.03	9.44		7.67	7.96		8.07	8.31	
	SEd	CD (0.05)		SEd	CD (0.05)		SEd	CD (0.05)		SEd	CD (0.05)	
M	0.064	0.128		0.129	0.258		0.101	0.203		0.113	0.226	
S	0.175	0.350		0.353	0.706		0.278	0.556		0.309	0.619	
M X S	0.248	NS		0.499	NS		0.393	NS		0.437	NS	

grains per earhead and thousand grain weight (g) showed superior performance with finger millet intercropped with greengram as compared to sole crop of finger millet cultivation.

Among the two-cropping system, finger millet + greengram (2:1) (M₂) gave the highest mean of 6.28 g, 9.44 cm, 7.96, 8.31cm, 2552.79 and 2.51 g at earhead weight, earhead length, number of fingers per earhead, finger length, number of grains per earhead and thousand grain weight followed by sole finger millet of earhead weight (5.95 g), earhead length (9.03 cm), number of fingers per earhead (7.67) and finger length (8.07 cm), number of grains per earhead (2366.96) and thousand grain weight (2.46 g) specified in Tables 5 and 6 respectively.

With respect to bio seed priming and foliar zinc oxide nanoparticle spray, priming of Prosopis leaf extract 1 per cent alone along with 500 ppm of foliar ZnO nanoparticle (S₈) recorded higher earhead weight (6.81 g), earhead length (11.59 cm), number of fingers per ear-

head (8.60) and finger length (9.81 cm), number of grains per earhead (2464.11) and thousand grain weight (2.85 g). This was on par with Pungam leaf extract 1 per cent alone + foliar ZnO nanoparticle @ 500 ppm (S₁₃) at all the stages of observation. The least yield components and yield were obtained with Neem leaf extract 1% alone (S₁), the earhead weight (g), earhead length (cm), number of fingers per earhead, finger length (cm), number of grains per earhead and thousand grain weight (g) being 5.31 g, 7.38 cm, 6.69, 6.88 cm, 2277.45 and 2.14 g respectively. The interaction effect of cropping system with bio seed priming and foliar zinc nanoparticle spray was non-significant at all the growth stages given in Tables 5 and 6, respectively.

The highest dry matter weight was recorded when Prosopis leaf extract was primed with 1 per cent with 500 ppm of foliar ZnO nanoparticles (S₈). A foliar application of nano ZnO resulted in increased dry matter accumulation due to increased plant height, leaves, and leaf area per plant.

Table 5. Effect of bio-seed priming and nano zinc foliar spray on number of grains per earhead and thousand grain weight (g) of finger millet

Treatments	Number of grains per earhead			Thousand grain weight (g)		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁ – Neem leaf extract 1% alone	2148.52	2406.39	2277.45	2.12	2.15	2.14
S ₂ – Neem leaf extract 1% + Foliar Nano ZnO @ 250 ppm	2278.28	2523.63	2400.95	2.26	2.28	2.27
S ₃ – Neem leaf extract 1% + Foliar Nano ZnO @ 500 ppm	2477.52	2652.91	2565.22	2.71	2.80	2.76
S ₄ – Neem leaf extract 1% + Foliar Nano ZnO @ 750 ppm	2419.19	2593.75	2506.47	2.58	2.64	2.61
S ₅ – Neem leaf extract 1% + Foliar Nano ZnO @ 1000 ppm	2384.23	2553.30	2468.77	2.38	2.41	2.39
S ₆ – Prosopis leaf extract 1% alone	2227.59	2476.01	2351.80	2.20	2.24	2.22
S ₇ – Prosopis leaf extract 1% + Foliar Nano ZnO @ 250 ppm	2320.45	2551.13	2435.79	2.32	2.35	2.34
S ₈ – Prosopis leaf extract 1% + Foliar Nano ZnO @ 500 ppm	2537.53	2390.70	2464.11	2.80	2.89	2.85
S ₉ – Prosopis leaf extract 1% + Foliar Nano ZnO @ 750 ppm	2461.24	2648.52	2554.88	2.69	2.75	2.72
S ₁₀ – Prosopis leaf extract 1% + Foliar Nano ZnO @ 1000 ppm	2408.09	2588.86	2498.48	2.51	2.59	2.55
S ₁₁ – Pongamia leaf 1% alone	2204.53	2474.83	2339.68	2.17	2.19	2.18
S ₁₂ – Pongamia leaf extract 1% + Foliar Nano ZnO @ 250 ppm	2286.89	2542.86	2414.87	2.27	2.30	2.29
S ₁₃ – Pongamia leaf extract 1% + Foliar Nano ZnO @ 500 ppm	2494.00	2727.37	2610.69	2.76	2.84	2.80
S ₁₄ – Pongamia leaf extract 1% + Foliar Nano ZnO @ 750 ppm	2454.84	2607.97	2531.40	2.65	2.72	2.69
S ₁₅ – Pongamia leaf extract 1% + Foliar Nano ZnO @ 1000 ppm	2401.49	2553.63	2477.56	2.44	2.53	2.48
Mean	2366.96	2552.79		2.46	2.51	
	SEd	CD (0.05)		SEd	CD (0.05)	
Cropping systems (M)	34.380	68.820		0.044	NS	
Bio seed priming & Foliar Nano ZnO Spray (S)	94.155	188.471		0.121	0.243	
M X S	133.155	NS		0.172	NS	

Note: M₁ – Sole finger millet and M₂ – Finger millet + Greengram (2:1) in main plot and S₁ – Neem leaf extract 1 per cent alone, S₂ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₃ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₄ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₅ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle

Yield

Grain yield, finger millet equivalent yield and straw yield

The present investigation showed a significant difference in main as well as sub treatments of observations given in Table 6 and Fig. 1. Accordingly, the grain yield, finger millet equivalent yield and straw yield showed superior performance with finger millet intercropped greengram as compared to sole crop of finger millet alone. Among the two-cropping system, sole finger millet (M₁) gave the highest mean finger millet grain and straw yield of 3040.23 kg ha⁻¹ and 6854.12 kg ha⁻¹ as compared to finger millet intercropping with greengram. Finger millet intercropping yield (M₂) is converted into finger millet equivalent yield (3200.88 kg ha⁻¹) obtain highest grain yield compared to sole finger millet (3040.23 kg ha⁻¹), respectively.

With respect to bio seed priming and foliar zinc oxide nanoparticle spray, Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm (S₈) recorded higher grain yield (3238.84 kg ha⁻¹), finger millet

equivalent yield (3483.28 kg ha⁻¹), straw yield (7393.83 kg ha⁻¹). This was on par with Pungam leaf extract 1% alone + foliar ZnO nanoparticle @ 500 ppm (S₁₃). The least yield components were obtained with Neem leaf

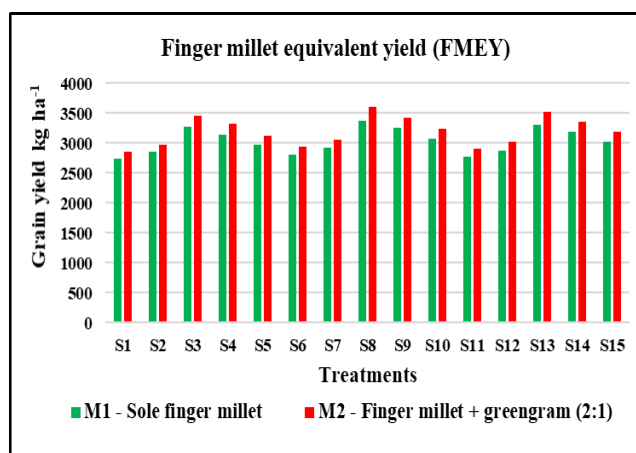


Fig. 1. Effect of bio seed priming and nano zinc foliar spray on FMEY of solo finger millet and intercropping of Finger millet + greengram

Table 6. Effect of bio-seed priming and nano zinc foliar spray on grain yield, finger millet equivalent yield (FMEY) and straw yield (kg ha^{-1}) of finger millet

Treatments	Grain yield (kg ha^{-1})			Finger millet equivalent yield			Straw yield (kg ha^{-1})		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	2746.73	2504.28	2625.51	2746.73	2862.99	2804.86	5795.61	4657.96	5226.78
S ₂	2850.61	2580.54	2715.57	2850.61	2970.11	2910.36	6157.31	4903.02	5530.17
S ₃	3280.86	2995.17	3138.01	3280.86	3462.56	3371.71	7710.02	6312.98	7011.50
S ₄	3141.10	2876.65	3008.87	3141.10	3327.05	3234.07	7193.11	5855.17	6524.14
S ₅	2970.62	2692.81	2831.72	2970.62	3119.96	3045.29	6654.19	5304.84	5979.52
S ₆	2812.39	2562.31	2687.35	2812.39	2946.51	2879.45	6001.64	4791.51	5396.58
S ₇	2928.20	2647.69	2787.94	2928.20	3061.86	2995.03	6471.33	5162.99	5817.16
S ₈	3367.15	3110.53	3238.84	3367.15	3599.40	3483.28	8100.02	6687.65	7393.83
S ₉	3258.57	2961.15	3109.86	3258.57	3424.53	3341.55	7559.89	6176.68	6868.28
S ₁₀	3066.14	2802.41	2934.27	3066.14	3242.52	3154.33	6960.14	5688.89	6324.52
S ₁₁	2781.48	2532.47	2656.97	2781.48	2907.28	2844.38	5924.55	4786.36	5355.45
S ₁₂	2874.82	2614.31	2744.56	2874.82	3024.45	2949.64	6267.11	5019.47	5643.29
S ₁₃	3309.06	3050.96	3180.01	3309.06	3528.64	3418.85	7809.39	6501.02	7155.21
S ₁₄	3196.46	2900.28	3048.37	3196.46	3352.91	3274.69	7383.83	6006.47	6695.15
S ₁₅	3019.30	2749.01	2884.15	3019.30	3182.41	3100.85	6823.61	5498.01	6160.81
Mean	3040.23	2772.04		3040.23	3200.88		6854.12	5556.87	
	SEd	CD (0.05)		Sed	CD (0.05)		SEd	CD (0.05)	
M	33.963	67.984		39.503	79.074		96.629	193.423	
S	93.011	186.183		108.184	216.553		264.629	529.712	
M X S	131.538	NS		152.995	NS		374.241	NS	

Note: M₁ – Sole finger millet and M₂ – Finger millet + Greengram (2:1) in main plot and S₁ – Neem leaf extract 1 per cent alone, S₂ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₃ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₄ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₅ – Neem leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₆ – Prosopis leaf extract 1 per cent alone, S₇ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₈ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₉ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm, S₁₀ – Prosopis leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm, S₁₁ – Pungam leaf extract 1 per cent alone, S₁₂ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 250 ppm, S₁₃ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 500 ppm, S₁₄ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 750 ppm and S₁₅ – Pungam leaf extract 1 per cent alone + Foliar ZnO nanoparticle @ 1000 ppm.

extract 1% alone (S₁). The interaction effect of cropping system and bio seed priming and foliar zinc nanoparticle spray was non-significant irrespective of all the growth stages.

Finger millet intercropped with greengram yielded comparable yields to finger millet grown as a sole crop. (Tripathi and Kushwaha, 2013) reported that yield attributes of pearl millet with intercrop *viz.*, seed per panicle and 100 seed weight were significantly higher than that of sole pearl (Dass and Sudhishri, 2010) recorded

higher system yield of finger millet in intercropped stand with pulses due to efficient use of nutrients, moisture, light and space in intercropped situation. An experimental study suggests that nano zinc oxide in a foliar spray can result in higher grain yields than normal fertilizer. Nanoparticles with a large surface area and small size (Mazaherinia *et al.*, 2010) are expected to be the best material for use as zinc fertilizer in plants. As a result, when materials are transformed to a nanoscale, they change their physical, chemical, and biological

properties, as well as catalytic properties and even become more active chemically and biologically (Prasad et al., 2012) investigated the impacts of nanoscale zinc oxide on peanut germination, growth, and yield and found dramatically increased growth and yield. (Reynolds, 2002) proved that micronutrients in the form of nanoparticles may be utilized to boost output in agricultural production.

Because of its nano size, high surface-to-volume ratio, and high reactivity, ZnO is rapidly absorbed by the leaf surface and metabolised faster than bulk form. Similar to our findings, nano ZnO showed significantly higher crop improvement by improving initial crop establishment, chlorophyll content, and ultimately crop growth and yield in the studies of Pandey et al. (2010) in *Cicer arietinum*, Boonyanitipong et al. (2011) in rice, Prasad et al., (2012) in peanuts, Sedghi et al. (2013) in soybean, Jayarambabu et al. (2014) in mungbean, Yang et al. (2015) in maize and rice and Poornima and Koti (2019) in sorghum. Prasad et al. (2012) stated that foliar application of zinc oxide nano particle is more effective than soil application and that zinc oxide foliar treatment improved pod yield and zinc content in peanut.

Conclusion

The study found that finger millet intercropped with greengram (2:1) performed better when combined with priming of Prosopis leaf extract of 1% alone together along with 500 ppm of foliar ZnO nanoparticle recorded greater growth parameters, resulting in an increase in finger millet crop yield. As a result, utilizing a small amount of fertiliser may minimise fertiliser application dosages, fertiliser waste, environmental dangers, and boost nutrient usage efficiency. As a result, the above treatment might be advised to rainfed millets farmers in order to boost productivity and obtain significant economic benefits from enhanced soil fertility. There is a need to explore the standardizing of nano fertiliser dosages for different crops and the ideal stage of crop development in order to produce improved crop output. There is also a need to understand the cellular mechanisms involved in nanoparticle absorption and translocation.

Conflict of interest

The authors declare that they have no conflict of interest.

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