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RESEARCH ARTICLE

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Zinc Biofortification and Nutrient Management Effect on Growth, Yield and Yield Efficiency Index of Garden Pea under Himalayan Conditions

Stuti Pathak[1,2], H.R. Sharma[1], Aman Ranga[1], Mohd Asif Shah[3,4], Y.R. Shukla[1]

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ABSTRACT

Background: Biofortification, an evolving research strategy, aims to enhance the bioavailability of essential micronutrients in staple food crops. The most efficient approach, agronomic biofortification, involves the challenging task of simultaneously increasing grain zinc content and yield through breeding and biotechnology. In pursuit of biofortifying garden peas in the Himalayan region and optimizing their yield, this study was devised with a focus on foliar zinc fertilization application.

Methods: The experiment was laid out in a randomized complete block design with three replications. The observations were recorded on growth and yield characters and yield efficiency was calculated. The data recorded was analysed as per design of the experiment for working out the following values.

Result: The results revealed that application of 100 % RDF + 0.5 % $ZnSO_4$+ *Rhizobium* produced best results in most of the yield and yield contributing characters likepod length, pod weight, number of grains per pod, yield and yield efficiency index which can be recommended for increasing the yield ad well as zinc content in pea.

Key words: Azad pea 3, Biofertilizer, Biofortification, Yield efficiency, $ZnSO_4$.

INTRODUCTION

Garden Pea (*Pisum sativum* L.) an important crop of Leguminosae family, a native of Fertile Crescent, was among the first crops cultivated by primitive man for food, forage and vegetable (Zohary and Hopf, 2000). Himachal Pradesh is the fifth largest producer of pea in the country and accounts for 5.08% of India's production (Anonymous, 2017). The challenge of micronutrient insufficiency presents a significant issue for more than half of the global population, with developing nations bearing a particularly heavy burden (Ortiz-Monasterio *et al*., 2007). Zinc deficiency, in particular, can result in various physiological complications, including hindered brain development, impaired growth, heightened susceptibility to infectious diseases like diarrhea and pneumonia, as well as reduced work productivity and physical performance (Cakmak, 2010). This deficiency affects up to 2 billion individuals worldwide (Prasad, 2013). The cultivation of zinc-enriched vegetables offers a food-based solution to tackle the widespread problem of global micronutrient malnutrition. The introduction of biofortified crops will provide a sustainable and low-cost way of reaching people with poor access to formal markets or healthcare systems (Jena *et al*., 2018). Nutrient management is described as the technique of using minimum effective dose of sufficient and balanced quantities of organic and inorganic fertilizers in combination with specific microorganisms to make nutrients more available and most effective for maintaining high yields without exposing soil native nutrients and polluting the environment. Today, microbial-based biofertilizers are considered to be among key agricultural components that improve crop productivity and contribute to sustainable agro-ecosystems. It is a component that aggregates a variety of microbial-based bio-products whose bioactivities are essential to stimulate and improve biological processes of the intricate plant–microbe–soil continuum (Singh *et al*., 2016). In intensive agriculture, integrated nutrient management takes care of both crop nutritional needs as well as soil fertility considerations leading to increased yield through judicious consumption of inorganic nutrients in the system while being a legume crop pea has the inherent ability to obtain much of its nitrogen requirement

[1]Department of Vegetable Science, College of Horticulture, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan-173 230, Himachal Pradesh, India.
[2]Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Jalandhar-144 411, Punjab, India.
[3]Department of Economics, Kabridahar University, Somali, 250, Ethiopia.
[4]Division of Research and Development, Lovely Professional University, Phagwara, Jalandhar-144 411, Punjab, India.

Corresponding Author: Stuti Pathak, Department of Vegetable Science, College of Horticulture, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan-173 230, Himachal Pradesh, India. Email: stutipathak94@gmail.com

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from the atmosphere by forming a symbiotic relationship with *Rhizobium* bacteria in the soil (Schatz and Endres, 2009). Rare work on the present study is available in Himachal Pradesh and to fill up the gap it was planned for studying zinc biofortification which is a cost effective and sustainable solution to combat zinc deficiency and malnutrition and how this agronomic zinc biofortification is effecting yield, yield contributing characters and yield efficiency of garden pea under Himalayan conditions. Considering all these facts, the present investigation was carried out.

MATERIALS AND METHODS

The present investigationwas carried out at the Experimental Farm, Department of Vegetable Science, Dr Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India (35°51′N latitude and 77°11′E longitude at an elevation of 1270 m amsl) during *rabi* seasons of 2019-20 and 2020-21. Cultivar 'Azad Pea 3'was taken which is developed by pedigree method from the cross of Azad Pea-1 × Arkel. The biofertilizer used was *Rhizobium* which is an aerobic bacterium forming a symbiotic relationship with legumes, fixing nitrogen from the air into the ammonia, which acts as a natural fertilizer for plants. Nitrogen (N), phosphorus (P) and potassium (K) were used as inorganic fertilizers in the form of urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. $ZnSO_4$ was used as a source of zinc for biofortification. The use of various nutrients is given in the Table 1 with the treatment details and the zinc uptake in different treatments. For inoculation of seeds with bio-fertilizers *viz. Rhizobium* 200 g/10 kg seed was used. *Rhizobium* was also applied as soil application @ 4 kg/ha, by thoroughly mixing with FYM. Soil testing for the initial nutrient status of the soil was done and accordingly the nutrients were applied as per the recommended doses of fertilizers (RDF) for pea crop grown in the present investigation were; 25: 60: 60 kg/ha NPK + FYM 20 t/ha. Nitrogen, phosphorus as per the treatments and full dose of potash were given to all the treatment plots as basal dressing. However, N was applied in split doses; halfof it was given as basal dressing while rest of it was top dressed at 1st and 2nd earthing up, (Anonymous, 2014). Recommended uniform dose of FYM to all the plots as per treatments were incorporated at the time of preparation of plots manually.Bio-inoculated/un-inoculated seeds as per treatment were sown directly into the main field plots at a spacing of 60 cm × 7.5 cm. The experiment was carried out in randomized block (RBD) design replicated thrice and the data recorded was analysed using MS-Excel as per design of the experiment for working out the following values. Meteorological data (rainfall, maximum and minimum temperature, relative humidity) as recorded by the Meteorological Observatory of the Department of Environmental Science, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during cropping periods (October, 2019 to April, 2020 and November 2020 to April, 2021) has been presented graphically through Fig 1, 2, 3 and 4. During first year, the maximum temperature was ranged from 9.00°C (January, 2020) to 27.00°C (April, 2020) while minimum ranged from -1.6°C (January, 2020) to 10.5°C (November, 2019) and during the second year (Fig 3) the maximum temperature ranged from 7.5°C (February, 2021) to 33.00°C (March, 2021) while minimum ranged from -1.6°C (December, 2020) to 14.2°C (March, 2021). Maximum relative humidity (morning) during the first year (Fig 3) was recorded in the range from 45 (December, 2019) to 100 per cent (January, 2020) while minimum was recorded in the range from 26.00 per cent (December, 2019) to 88 per cent (January, 2020) and during the second year, maximum relative humidity ranged from 32.00 per cent (March, 2021) to 100 per cent (January, 2021) while minimum ranged from 14.00 per cent (April, 2021) to 89.00 per cent (February, 2021). The precipitation during the course of study ranged from 0.00 to 60 cm.

The observations for growth of pea plant for the characters like plant height (cm), pod length (cm), pod diameter (cm), pod weight (g), number of grains per pod and number of pods per plant were recorded over two years on ten randomly selected plants in each plot and the mean was worked out for statistical analysis. The plants with outer rows were excluded from random selection to avoid the border effect. While yield parameters were taken for green pod yield per plant (g), pod yield per plot (kg) and projected yield per hectare (q), harvest duration (days) and yield efficiency index. Yield per plant was calculated by pooling the weight of all the pods harvested from ten randomly selected plants over all the pickings in a given plot/treatment and averages were worked out.Total yield of marketable pods of each harvest in each plot was summed up to get pod yield per plot and then multiplied with a suitable factor to get yield per hectare.Days were calculated from the date of first picking to the last picking of pods in each plot of all the replicates. Yield efficiency index was calculated based on the yield of the control plot which was subtracted from the yield of the treated plots and this value is then divided by the yield of the control plot (Graham, 1992).

$$\frac{\text{Yield of treated plot - Yield of control plot}}{\text{Yield of control plot}}$$

RESULTS AND DISCUSSION

Plant height (cm)

Data on effect of treatments (Table 2) revealed that there was no effect of different treatments on height of the plant. Years of study exhibited significant influence on plant height, where 90.96 cm height (Table 2) was recorded during the first year of cropping season *i.e.* 2019-2020 whereas, it was 88.85 cm during the second year (Table 2). In the present findings, the interaction effect of treatment and year was also significant (Table 2). Maximum plant height (95.73 cm) was recorded in the treatment T_5 *i.e.* 100% RDF + 1.0% $ZnSO_4$ during first cropping season which was at par with T_1, T_2, T_3, T_4, T_6, T_7 and T_9 during first cropping season whereas, during cropping season two, it was at par with T_2, T_5, T_8, T_9 and T_{10}. All these treatment combinations were superior over rest of the combinations while, minimum plant height was recorded in T_{14} (84.78) during second cropping season.

Pod length (cm)

The data on pod length in treatments revealed that T_2 (Table 2) *i.e.* 100% RDF + 0.5% $ZnSO_4$+ *Rhizobium* showed maximum pod length of 8.89 cm which was statistically at

Table 1: Details of the treatment and zinc uptake in plant.

Treatment code	Treatment details	Zinc uptake in plant (kg ha^{-1})		
		2019-2020	2020-2021	Mean
T_1	100% RDF (N 25: P 60: K 60 + FYM 20 t/ha)	3.29	3.23	3.26
T_2	100% RDF + 0.5% $ZnSO_4$* + *Rhizobium***	4.63	4.80	4.71
T_3	100% RDF + 0.5% $ZnSO_4$*	3.54	3.40	3.47
T_4	100% RDF + 1.0% $ZnSO_4$*+ *Rhizobium***	4.56	4.68	4.62
T_5	100% RDF + 1.0% $ZnSO_4$*	3.45	3.27	3.36
T_6	90% RDF + 0.5% $ZnSO_4$*+ *Rhizobium***	4.25	4.72	4.49
T_7	90% RDF + 0.5% $ZnSO_4$*	3.81	4.31	4.06
T_8	90% RDF + 1.0% $ZnSO_4$*+ *Rhizobium***	3.46	3.40	3.43
T_9	90% RDF + 1.0% $ZnSO_4$*	3.99	4.24	4.11
T_{10}	80% RDF + 0.5% $ZnSO_4$*+ *Rhizobium***	4.19	4.33	4.26
T_{11}	80% RDF + 0.5% $ZnSO_4$*	3.32	3.24	3.28
T_{12}	80% RDF + 1.0% $ZnSO_4$*+ *Rhizobium***	3.57	3.71	3.64
T_{13}	80% RDF + 1.0% $ZnSO_4$*	4.06	3.80	3.93
T_{14}	Absolute control	3.38	3.05	3.21
Mean		3.82	3.87	3.85
$CD_{0.05(Y)}$		0.65	0.69	
CV		10.15	7.90	
$CD_{0.05(P)}$		Year: NS		0.40
			Treatment × Year: NS	

*Foliar spray.

**Seed Treatment and soil application.

RDF: Recommended dose of fertilizer.

FYM: Farm yard manure.

NPK: Nitrogen, phosphorus, potassium.

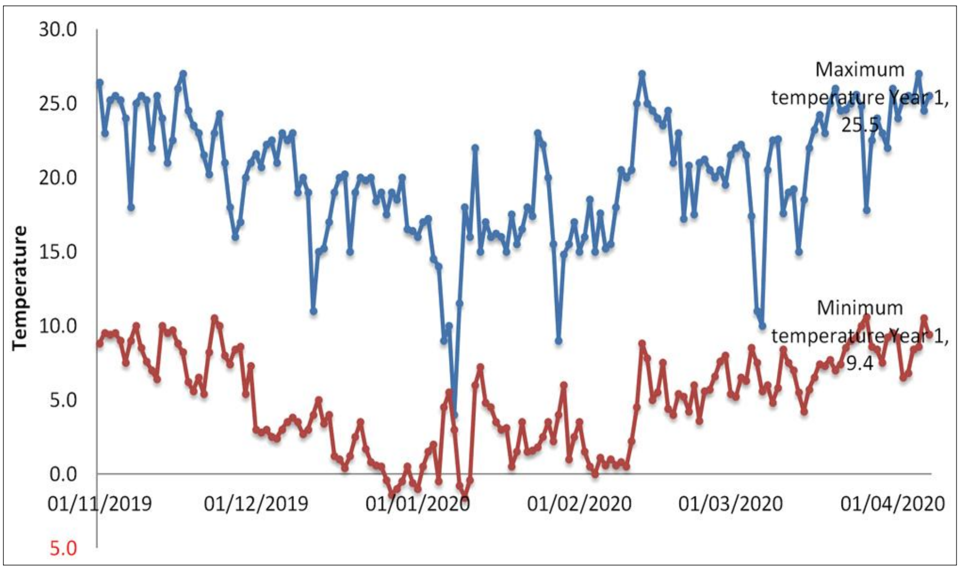

Fig 1: Daily variation of temperature (maximum and minimum) during growing period of first year *i.e.* November, 2019-April 8, 2020.

Table 2: Effect of zinc biofortification and nutrient management on growth parameters in garden pea under Himalayan conditions.

Treatment	Plant height (cm)			Pod length (cm)		Pod diameter (cm)			Pod weight (g)			Number of grains per pod			Number of pods per plant		
code	2019-2020	2020-2021	2019-Mean	2020-2020	2021	2019-Mean	2020-2020	2021	2019-Mean	2020-2020	2021	2019-Mean	2020-2020	2021	2019-Mean	2020-2020	2021	Mean
T_1	94.7	85.22	89.96	8.6	8.79	8.7	1.37	1.38	1.38	5.8	5.92	5.86	7.3	7.7	7.5	14.1	14.44	14.27
T_2	90.93	91.6	91.27	8.86	8.92	8.89	1.37	1.38	1.38	6.72	6.55	6.64	7.61	7.51	7.56	14.21	15.04	14.63
T_3	92.87	87	89.93	8.77	8.57	8.67	1.37	1.37	1.37	5.68	5.76	5.72	7.33	7.28	7.31	14.11	14.78	14.45
T_4	91.1	81.75	86.43	8.7	8.69	8.7	1.39	1.42	1.4	5.74	6.38	6.06	7.53	7.48	7.51	14.78	14.66	14.72
T_5	95.73	94.33	95.03	8.64	8.73	8.69	1.35	1.4	1.38	5.7	5.91	5.81	7.53	7.44	7.49	14.44	16	15.22
T_6	94.73	86.38	90.56	8.7	8.61	8.66	1.32	1.33	1.33	5.71	5.68	5.7	7.17	7.19	7.18	14.44	13.89	14.17
T_7	90.9	89.89	90.4	8.47	8.71	8.59	1.31	1.33	1.32	5.54	5.6	5.57	7.17	6.87	7.02	13.16	15.11	14.14
T_8	89.37	90.93	90.15	8.68	8.51	8.6	1.32	1.33	1.33	5.51	5.66	5.57	7.03	7.06	7.05	13.75	14.78	14.26
T_9	90.77	94.44	92.61	8.42	8.64	8.53	1.3	1.34	1.32	5.47	5.58	5.52	6.93	7.04	6.99	13.44	14.27	13.86
T_{10}	90	92.25	91.13	8.33	8.67	8.5	1.31	1.32	1.32	5.57	5.42	5.49	7.07	6.89	6.98	12.7	14.89	13.8
T_{11}	88.3	90.04	89.17	8.43	8.54	8.48	1.32	1.29	1.3	5.46	5.45	5.46	6.93	6.89	6.91	13.45	13.78	13.61
T_{12}	87.77	89.11	88.44	8.43	8.52	8.47	1.31	1.31	1.31	5.36	5.59	5.48	6.98	6.81	6.9	12.3	13.91	13.1
T_{13}	89.1	86.22	87.66	8.38	8.47	8.42	1.28	1.31	1.29	5.54	5.25	5.39	6.8	6.97	6.88	13.22	13.44	13.38
T_{14}	87.17	84.78	85.97	8.57	8.31	8.44	1.28	1.29	1.28	4.96	5.07	5.02	6.39	6.57	6.48	12.12	12.8	12.46
Mean	90.96	88.85	89.91	8.57	8.62	8.6	1.33	1.34	1.33	5.63	5.7	5.66	7.13	7.12	7.12	13.59	14.41	14
$CD_{0.05(Y)}$	3.83	3.89		NS	NS		0.57	0.65		0.27	0.29		0.34	0.24		0.5	0.68	
CV	2.51	2.61		2.45	2.72		2.54	2.88		2.87	3.03		2.81	1.98		2.2	2.8	
$CD_{0.05(P)}$	Year: 1.01 Treatment × Year:3.77		NS	Year: NS Treatment × Year: NS		0.26	Year: NS Treatment × Year: NS		0.04	Year: 0.07 Treatment × Year: 0.27		0.34	Year: NS Treatment × Year:NS		0.2	Year: 0.16 Treatment × Year: 0.58		1.2

par with T_1, T_4 and T_5 while the minimum pod length was recorded in T_{13} (8.42 cm). The results (Table 2) are in close conformity with Bunker *et al.* (2018) who reported that pod length significantly varied under different nutrient levels and in combination with bio-fertilizers compared to control.The different conditions of two years (Table 2) had no significant effect on the length of the pod length. The results (Table 2) indicated that interaction of treatment and year had no significant effect on the length of the pod.

Pod diameter (cm)

The data on treatments revealed that T_4 *i.e.* 100% RDF + 1.0% ZnSO4 + *Rhizobium* showed maximum pod diameter of 1.40 cm which was statistically at par with T_1, T_2, T_3 and T_5 while the minimum pod length was recorded in T_{14} (1.28 cm) with absolute control (Table 2). The results for *Rhizobium*, NPK and FYM are in line with Negi *et al.* (2004). The results (Table 2) revealed that cropping years had no effect on the pod diameter of pea. The data (Table 2) revealed that interactions of treatment and year had no effect on the pod diameter.

Pod weight (g)

In the present studies, the data on treatmentsrevealed that T_2 *i.e.* (Table 2) 100% RDF + 0.5% $ZnSO_4$ + *Rhizobium* showed maximum pod weight of 6.64 g which was

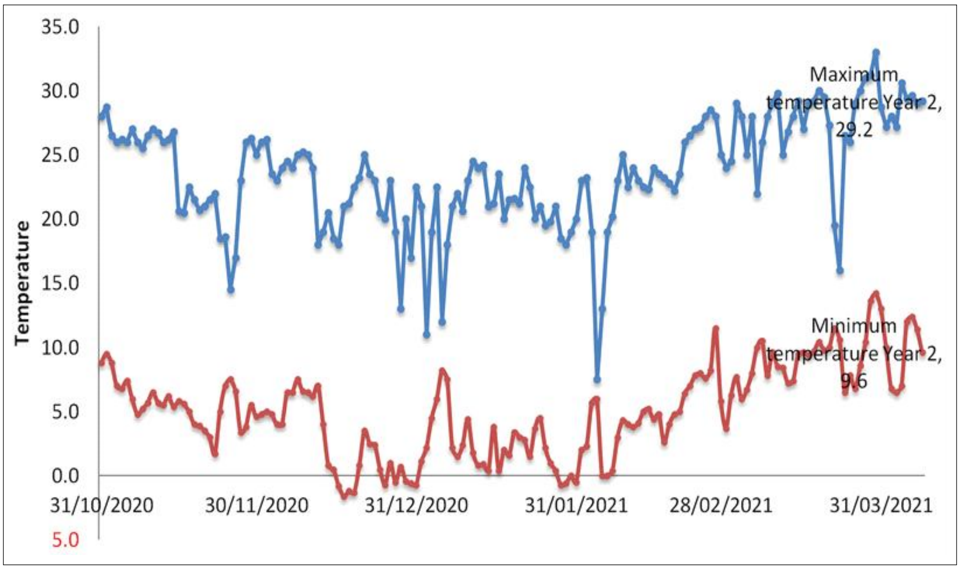

Fig 2: Daily variation of temperature (maximum and minimum) during growing period of second year i.e. October 31, 2020- April 8, 2021.

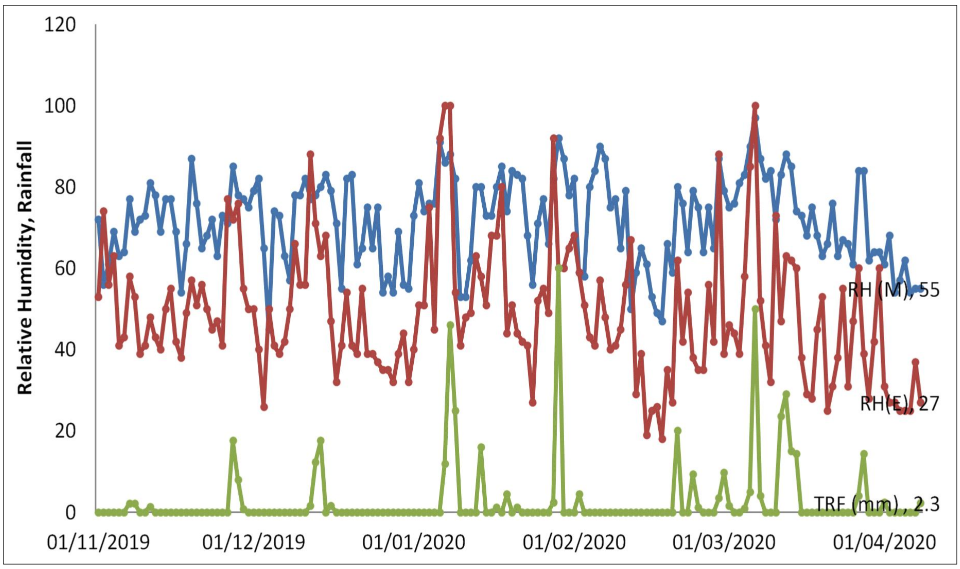

Fig 3: Daily data pertaining to the rainfall (maximum/minimum) and relative humidity during 1st year of growing season *i.e.* November, 2019-April, 2020.

statistically better over rest of the treatments while the minimum pod weight was recorded in the absolute control (5.02 g). The results (Table 2) on weight of pod reveals that different environment of two years had no significant effect on the weight of the pod.The data (Table 2) revealed that interactions of treatment and year had no significant effect on the weight of the pod.

Number of grains per pod

The data on treatments revealed that (Table 2) T_2 *i.e.* 100% RDF + 0.5% $ZnSO_4$ + *Rhizobium* showed maximum number of grains per pods of counting 7.56 which was statistically at par with T_1, T_3, T_4, T_5 and T_6 while the minimum number of grains per pod were recorded in absolute control (6.48). The data (Table 2) revealed that different years had no significant effect on the number of grains per pods. The results (Table 2) revealed that interaction of treatment and year had no significant effect on the number of grains per pod.

Number of pods per plant

The data on treatments revealed that (Table 2) T_5 *i.e.* 100 % RDF + 1.0% $ZnSO_4$ showed maximum number of pods per plant of counting 15.22 which was statistically at par with T_1, T_2 T_3, T_4, T_6,T_7,T_8 and T_9 while the minimum number of pod per plant were recorded in absolute control (12.46). The number of pods per plant was significantly affected by the changing environment of both the years and it was found that the second year of crop *i.e.* 2020-2021 (Table 2) had more number of pods per plant in comparison to the first cropping season averaging 14.41 number of pods per plant in the first picking in second year while, 13.59 number of pods per plant in the first season. The results (Table 2) revealed that the interaction of treatment and year had no significant effect on number of pods per plant.

Yield parameters

Green pod yield per plant (g)

The data on treatments revealed that (Table 3) T_2 *i.e.* 100% RDF + 0.5% $ZnSO_4$ + *Rhizobium* showed maximum green pods yield per plant of 91.25 grams which was statistically at par with T_1, T_3, T_4 and T_5 while the minimum green pod yield per plant was recorded in T_{14} (46.90 g) absolute control. The data (Table 3) revealed that yield per plot had significant effect of the years and it was more in the cropping season two (73.2 g) whereas, than in cropping season one (65.3 g). The results (Table 3) revealed that interaction of treatment and year had no significant effect on yield per plant.

Pod yield per plot (Kg)

The data on treatments revealed that (Table 3) T_2 *i.e.* 100% RDF + 0.5% $ZnSO_4$ + *Rhizobium* showed maximum green pods yield per plot of 10.95 kg which was statistically at par with T_1, T_3, T_4 and T_5 while the minimum green pod yield per plot was recorded in T_{14} (5.63 kg) absolute control. The data (Table 3) revealed that yield per plot had significant effect of the years and it was more in the cropping season two (8.79 kg) whereas, than in cropping season one (7.84 kg). The results (Table 3) revealed that interaction of treatment and year had no significant effect on yield per plot.

Projected pod yield per hectare (q)

The data on treatments revealed that (Table 3) T_2 *i.e.* 100% RDF + 0.5% $ZnSO_4$ + *Rhizobium* showed maximum green pods yield per plot of 10.95 kg which was statistically at par with T_1 and T_4 while the minimum green pod yield per plot was recorded in T_{14} (83.41q) absolute control. The data (Table 3) revealed that yield per hectare had significant effect of the years and it was more in the cropping season two (163.26 q) whereas, than in cropping season one (110.67 q). The data (Table 3) revealed that interaction of treatment and year had no significant effect on yield per hectare.

Harvest duration

Number of days to harvest is also an important character as it indicates the earliness of the crop. Early maturity is a desirable trait since it fetches good returns to the growers, while more duration of harvesting may be needed to increase the yield of the crop by increasing the physiological activity and continuation of photosynthesis. Statistically no variation was seen in the harvest duration due to application of different fertilizers in pea (Table 3). The environment of two years affected harvest duration of the crop, which was found to be more in year two (136.21 days) as shown in Table 3. The interaction of treatment and year revealed that harvest duration was seen to be statistically non significant.

Yield efficiency index

The data (Table 3) pertaining to the yield efficiency index revealed that the treatment had no significant effect on it. The data for the yield efficiency index (Table 3) revealed that the yield efficiency was found to be higher in first year of cropping in comparison to second year of cropping. This could also be due to the low yield in the year one in comparison to year two (Table 3) and very less yield in the absolute control in the first year of cropping season which acted as the denominator to compute the yield efficiency index (Table 3) while, it was more in the second cropping season that lead to more values of yield efficiency index in the year one. The interaction of treatment and year had significant effect on the yield efficiency index which was found to be highest in season one in T_2(1.12) as shown in table 3 and least in T_{10} and T_{13} *i.e.* 0.10 in second season.

Effect of weather conditions

The study found that weather conditions, particularly temperature, did not have a significant impact on plant growth and yield because the temperature remained within the optimal range (below 32°C) for both years of the study.

The integration of nitrogen (N), phosphorus (P) and potassium (K) plays a crucial role in promoting vegetative growth. These nutrients influence chlorophyll production, enzyme activity and protein synthesis, with each nutrient contributing to specific aspects of plant development. The results are in close conformity with (Augustine and Kalyanasundaram, 2020). While, the application of zinc

Table 3: Effect of zinc biofortification and nutrient management on yield and yield efficiency index in garden pea under Himalayan conditions.

Treatment code	Green pod yield per plant (g)			Pod yield per plot (kg)			Yield per hectare (q)			Total harvest duration			Yield efficiency index		
	2019-2020	2020-2021	Mean	2019-2020	2020-2021	Mean	2019-2020	2020-2021	Mean	2019-2020	2020-2021	Mean	2019-2020	2020-2021	Mean
T_1	62.22	91.82	77	7.47	11.02	9.24	110.67	163.26	136.89	129.67	136	132.83	0.49	0.76	0.62
T_2	88.33	94.17	91.25	10.6	11.3	10.95	157.04	167.41	162.22	132.33	135	133.67	1.12	0.8	0.96
T_3	70.56	79.55	75.05	8.47	9.55	9.01	125.48	141.48	133.48	130.33	138	134.17	0.7	0.52	0.61
T_4	83.33	73.4	78.37	10	8.81	9.4	148.15	130.52	139.26	129.33	141.33	135.33	1	0.4	0.7
T_5	73.33	77.03	75.18	8.8	9.24	9.02	130.37	136.89	133.63	131.67	134	132.83	0.76	0.47	0.62
T_6	61.67	81.1	71.4	7.4	9.74	8.57	109.63	144.3	126.96	129.67	135.33	132.5	0.48	0.55	0.52
T_7	60	79.46	69.73	7.2	9.54	8.37	106.67	141.33	124	132.33	134.33	133.33	0.44	0.52	0.48
T_8	55	86.3	70.68	6.6	10.36	8.48	97.78	153.48	125.63	130.33	135.33	132.83	0.32	0.65	0.49
T_9	68.33	67.13	67.73	8.2	8.06	8.13	121.48	119.41	120.44	131.33	135.67	133.5	0.64	0.29	0.46
T_{10}	77.78	57.2	67.49	9.33	6.86	8.1	138.22	101.63	120	128.67	135.33	132	0.87	0.1	0.48
T_{11}	62.78	59.35	61.06	7.53	7.12	7.33	111.56	105.48	108.59	131.33	136.33	133.83	0.51	0.14	0.32
T_{12}	56.67	69.57	63.12	6.8	8.35	7.57	100.74	123.7	112.15	128	136.67	132.33	0.36	0.33	0.35
T_{13}	53.33	57.13	55.23	6.4	6.86	6.63	94.81	101.63	98.22	129.67	136.67	133.17	0.28	0.1	0.19
T_{14}	41.67	52.13	46.9	5	6.26	5.63	74.07	92.74	83.41	129.33	137	133.17	0	0	0
Mean	65.36	73.25	69.3	7.84	8.79	8.32	110.67	163.26	136.89	130.29	136.21	133.25	0.57	0.4	0.49
$CD_{0.05(Y)}$	2.76	3.34		0.37	0.44		5.56	NS		NS	NS		0.02	0.02	
CV	2.51	2.71		2.79	2.96		2.85	30.56		2.28	2.36		2.22	3.22	
$CD_{0.05(P)}$	Year: 6.50		17.19	Year: 0.78		2.06	Year: 11.55		30.56	Year: 1.36		NS	Year: 0.01		NS
	Treatment × Year: NS			Treatment × Year: NS			Treatment × Year: NS			Treatment × Year: NS			Treatment × Year: 0.02		

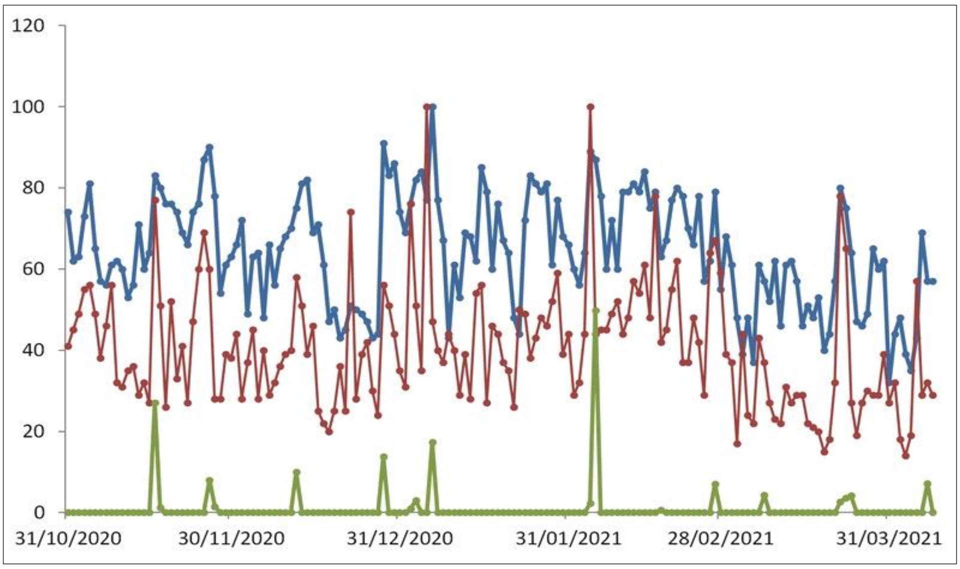

Fig 4: Daily data pertaining to the rainfall and relative humidity during (maximum/minimum) 2nd year of growing season *i.e.* October 31, 2020 to April 8, 2021.

nutrient leads to increased vegetative growth by activating enzymes responsible for cell division and elongation. Zinc also improves the availability of other macro and micro nutrients, creating favorable conditions for plant growth Alam *et al*. (2020) besides zinc accumulation in plant tissues causes alterations in essential growth processes like photosynthesis and chlorophyll biosynthesis, ultimately resulting in improved vegetative growth. Zinc actively participates in auxin production, increasing cell size and number, which leads to increased plant height and overall yield components. It also enhances the interaction between pollen and stigma, leading to proper germination of pollen grains and increased yield parameters. Zinc also stimulates gametogenesis, increases the number of flowers per plant, enhances pollen production, improves pollen-stigma interactions and leads to an increase in yield parameters like the number, size and weight of pods and seeds. Ismail (2016) and Badr and Fayed (2020) reported, fertilization with a combination of N, P and K at different percentages has a positive impact on pod quality traits such as pod length, diameter, weight and seeds per pod. Where, phosphorus promotes reproductive growth, leading to higher pod yield, longer pods, more grains and more pods per plant Husain *et al*. (2019) and potassium is crucial for plant energy status, assimilate translocation and maintenance of tissue water relations. The results are in conformity with Akter *et al.* (2020). When combined with nitrogen, phosphorus and potassium (NPK), these nutrients promote overall plant growth characteristics. On the other hand, nitrogen and phosphorus are essential constituents of proteins and chlorophyll, have important roles in plant metabolism. Their application, either through organic manure, fertilizer, or bio-fertilizer, contributes to the synthesis of plant growth hormones, root system development and efficient nutrient utilization as shown by Meena and Sharma (2010). While, higher levels of nitrogen can delay the maturity of garden pea plants by prolonging canopy senescence, extending physiological activity and allowing for continued photosynthesis. All these nutrients influence a wide range of physiological processes, ultimately affecting plant growth and development. Additionally, the passage addresses the impact of temperature and weather conditions on plant development and discusses the potential delay in maturity associated with higher nitrogen levels. The results are in harmony with the studies of Sayed and Ouis (2022).

CONCLUSION

Based on two years study, the present investigation on Zinc biofortification and nutrient management effect on growth, yield and yield efficiency index of garden pea under Himalayan Conditions on different growth-yield and yield efficiency shows significant variations for all traits. Among all the treatment combinations, T_2 which comprises of 100 % RDF + 0.5 %ZnSO4 + *Rhizobium* was rated as the best treatment for most of the characters under study. It is concluded that balanced application of macro and micro nutrient reveals most effective for yield enhancement. The pod yield reduction was managed to some extent by high management practices. Crop was fortified by zinc properly and a high amount of zinc gave a good yield in both the years.

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Conflict of interest

All authors declared that there is no conflict of interest.

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