Article AR2438

DOI: HTTPS://DOI.ORG/10.23910/1.2021.2438

International Journal of Bio-resource and Stress Management

Crossref

October 2021

Print ISSN 0976-3988
Online ISSN 0976-4038

IJBSM 2021, 12(5):416-425

Research Article *Natural Resource Management*

Micronutrient Fortification of Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Hybrids using Customized Fertilizer Formulation

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Citation: Kumar et al., 2021. Micronutrient Fortification of Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Hybrids using Customized Fertilizer Formulation. International Journal of Bio-resource and Stress Management 2021, 12(5), 416-425. HTTPS://DOI.ORG/10.23910/1.2021.2438.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Acknowledgement: The authors duly acknowledge the support received from the ICAR-All India Coordinated Research Project on Pearl Millet, Agricultural Research Station, Mandor, Jodhpur (Agriculture University, Jodhpur). Our sincere thanks are also due to the College of Agriculture, Agriculture University, Jodhpur for providing facilities for accomplishing the research work.

Abstract

The studies were undertaken at ICAR-AICRP on Pearl Millet, Research Farm, ARS, Mandor, Jodhpur (Agriculture University, Jodhpur), Rajasthan, India during July to October of both the 2019 and 2020. The experiment was consisted of three fertilizers (Control, Nutrient supply through straight fertilizers and Nutrient supply through customized fertilizer) and seven pearl millet hybrids ('MPMH 21', 'MPMH 17', 'RHB 177', 'RHB 173', 'HHB 67 (Improved)', 'HHB 197' and 'HHB 272') in FRBD and replicated thrice. Findings revealed, application of customized fertilizer of the grade 6:6:2:1 ($N:P_2O_5:K_2O:Zn$) to pearl millet substantially enhanced Zn concentration in the roots, shoots, and leaves at panicle initiation (47.30, 54.31, 52.33 mg kg^{-1}), 50% flowering (40.30, 50.96, 50.10 mg kg^{-1}) and at harvest (45.27, 46.54, 47.29 mg kg^{-1}), respectively, over control. Similarly, Fe concentration in the roots, shoots and leaves were also increased markedly due to the application of customized fertilizer. Substantially higher Zn (56.42 mg kg^{-1}), Fe (39.50 mg kg^{-1}), Mn (15.13 mg kg^{-1}) and Cu (18.31 mg kg^{-1}) concentrations in the pearl millet grain was also fetched by applying customized fertilizer. Moreover, customized fertilizer application statistically enhanced grain (2,010 kg) and straw (3,417 kg) yields over control. Among pearl millet hybrids, 'HHB 67 Improved' recorded substantially higher Zn (61.97 mg kg^{-1}), Fe (43.98 mg kg^{-1}) and Mn (15.46 mg kg^{-1}) concentration in grain and Cu (25.09 mg kg^{-1}) concentration in straw. Albeit, 'HHB 173' noticed significantly higher Cu (19.60 mg kg^{-1}) concentration in grain. Further, among hybrids, 'MPMH 17' out yielded (1,958 kg ha^{-1}) followed by 'RHB 173' (1,795 kg ha^{-1}).

Keywords: Biofortification, customized fertilizer, micronutrients, pearl millet, zinc

1. Introduction

Micronutrient malnutrition or '*Hidden Hunger*' is known to affect more than half of the world's population and is considered to be among the most serious global challenges to humankind (Singh et al., 2016). The distressingly increasing population growth would likely lead towards a remarkably enhanced proportion of people that suffer from nutrient scarcity, more particularly the micronutrient deficiencies. The minerals that are indispensable to human health include a wide range of macro [sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S),

Article History
RECEIVED on 18th June 2021 RECEIVED in revised form on 15th September 2021 ACCEPTED in final form on 03rd October 2021

phosphorus (P) and chlorine (Cl)] and micro-nutrients or trace elements [iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), iodine (I), fluorine (F), selenium (Se), molybdenum (Mo), cobalt (Co) and boron (B)] (Bouis and Welch, 2010). Currently, more than half of the world population encounters the critical problem of micronutrient malnutrition. Among micronutrients, zinc is an important nutrient for the growth and development of plants which requires a proper balance of all the essential nutrients for normal growth and optimum yield. It is required as a structural component of a large number of proteins, such as transcription factors and metallo enzymes and plays a very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome (Dev and Singh, 2020). Plant enzymes activated by Zn are involved in carbohydrate metabolism, maintenance of the integrity of cellular membranes, protein synthesis, and regulation of auxin synthesis and pollen formation (Marschner, 1995; Hafeez et al., 2013; Shahzad et al., 2014; Singh et al., 2015). The regulation and maintenance of the gene expression required for the tolerance of environmental stresses in plants are Zn dependent (Cakmak and Kutman, 2017). Its deficiency results in the development of abnormalities in plants which become visible as deficiency symptoms such as stunted growth, chlorosis and smaller leaves, spikelet sterility. Zn deficiency can also adversely affect the quality of harvested products; plants susceptible to injury by high light or temperature intensity (Marschner, 1995; Cakmak and Kutman, 2017). Likewise, iron is also acentral component of electron chains and a co-factor of several vital enzymes. In plants, iron is also required for photosynthesis and chlorophyll synthesis. The availability of iron in soils dictates the distribution of plant species in natural ecosystems and limits yield and nutritional quality of crops (Morrissey and Guerinot, 2009). Roots of plant species take up Zn, Fe, Mn and Cu in their cationic forms. Of the 17 essential plant nutroents, Mn in plants is required for growth and reproduction. Although its requirement is trace by plants, but is ultimately as critical to growth as are the other nutrients. Manganese is essential element of the metalloenzyme cluster of the oxygen-evolving complex (OEC) in photosystem II (PSII) in photosynthetic plants (Alejandro et al., 2020). Copper is also a large number of enzymes related to respiration and photosynthesis (Marschner, 1995) and acts as structural element in regulatory proteins and participates in photosynthetic electron transport, oxidative stress responses and hormone signalling.

Farmers have applied mineral fertilizers to the soil for hundreds of years in order to improve plants health, albeit within certain limits similar strategy can also be advocated to enhance mineral accumulation within cereal grains for nutritional purposes (Rengel et al., 1999). Such a strategy of agronomic biofortification only works if the mineral deficiency in the grain reflects the absence of that mineral in the soil and if the mineral fertilizer contains minerals that are rapidly and easily mobilizable. Also, even if plants can absorb minerals efficiently from the soil, and may store the mineral in leaves but fails to translocate it to the fruits or seeds, or they may accumulate the mineral in a form that is not bioavailable, consequently having no substantial impact on nutrition (Frossard et al., 2000). Like supplements and fortification, agronomic intervention is probably best applied in niche situations or combination with other strategies (Cakmak, 2008). Agronomic strategies to increase the concentrations of mineral elements in edible tissues generally rely on the application of mineral fertilizers and/or improvement of the solubilization and mobilization of mineral elements in the soil (White and Broadley, 2009; Singh et al., 2015a). When crops are grown where mineral elements become immediately unavailable in the soil, targeted application of soluble inorganic fertilizers to roots or leaves is practiced. Therefore, customized fertilizer having a slow matrix to release the plant nutrient to the plants and capable to enhance nutrient concentration in the economic plant part i.e. grain (Singh et al., 2016a; Singh et al., 2020). As identified, customized fertilizer is a multi-nutrient carrier designed to contain macro and/or micronutrient forms, both from inorganic and/or organic sources, manufactured through a systematic process of granulation, satisfying the crop's nutritional needs, specific to its site, soil and stage, validated by a scientific crop model capability developed by an accredited fertiliser manufacturing/marketing company is a mixed fertilizer formulated according to individual specifications furnished by the consumers before mixing. The customized fertilizers are a combination of micro and macro plant nutrients and are made up through a process of granulation under strictly controlled conditions (Singh et al., 2017). These fertilizers are capable to increase nutrient use efficiency, grain nutritional quality and are helpful in soil fertility status improvement.

In India, pearl millet is the fourth most widely cultivated food crop after rice, wheat and maize. Currently, pearl millet covers an acreage of 7.54 million hectares with a production of 10.36 million tonnes and 1374 kg ha^{-1} productivity (Anonymous, 2020). Presently, Farmers' in drier parts of the country are not well acquainted with hybrids and fertilizer sources for grain enrichment. To answer the questions of efficient fertilizer source and high yielding pearl millet hybrid and is nutritionally responsive, the present investigation was undertaken.

2. Materials and Methods

2.1. Description of the study area

The field experiments were conducted at ICAR-All India Coordinated Research Project on Pearl Millet, Research Farm, Agricultural Research Station, Mandor, Jodhpur (Agriculture University, Jodhpur), Rajasthan, India during July to October months of 2019 and 2020. The geographically experimental site was located between 26°15′ N to 26°45′ North latitude and 73°00′ E to 73°29′ East longitude at an altitude of 231 meters above mean sea level. This region falls under agro-climatic zone Ia (Arid Western Plain Zone) of Rajasthan.

During the cropping period of pearl millet, the mean weekly maximum and minimum temperature fluctuated between 25.6°C to 35.2°C during 2019 and 28.1°C to 35.4°C during 2020. The experimental crop received 537.7 and 223.3 mm of rainfall with 24 and 15 rainy days during 2019 and 2020, respectively. The average weekly relative humidity fluctuated between 48.5 to 76.1% and 46.2 to 71.0% during 2019 and 2020, respectively. The soil of the experimental field was sandy loam in texture, well drained with a low level of organic carbon, available nitrogen and diethylene tri-amine penta acetic acid (DTPA) extractable zinc. However, it was medium in available phosphorus and high in available potassium. The experimental soil was non-saline with slightly alkaline in reaction. The details of the physico-chemical properties of the experimental soil for both years are presented in Table 1.

Table 1: Physico-chemical characteristics of the experimental field (0-15 cm)

Soil parameters	Value	
	2019	2020
pH	8.20	8.20
EC (dS m^{-1})	0.13	0.12
Organic carbon (g kg^{-1})	1.13	1.13
Bulk density (Mg m^{-3})	1.54	1.55
Available N (kg ha^{-1})	158.2	159.3
Available P2O5 (kg ha^{-1})	15.8	16.0
Available K2O (kg ha^{-1})	284.7	283.4
DTPA extractable Zn (mg kg^{-1})	0.43	0.44
DTPA extractable Fe (mg kg^{-1})	3.91	3.13
DTPA extractable Mn (mg kg^{-1})	7.62	7.48
DTPA extractable Cu (mg kg^{-1})	0.46	0.51
Soil texture	Sandy loam	Sandy loam

2.2. Experimental design and procedure

The field experiments were laid out in Factorial Randomized Block Design (FRBD) and replicated thrice. The treatments were randomly allotted to different plots, using the random number table of Fisher and Yates (1963). The experiment consisted of three fertility levels (Control, Nutrient supply through straight fertilizers and Nutrient supply through customized fertilizer) and seven different pearl millet hybrids ('MPMH 21', 'MPMH 17', 'RHB 177', 'RHB 173', 'HHB 67 (Improved)', 'HHB 197' and 'HHB 272'). In pearl millet, customized fertilizer of the grade 6:6:2:1 (N:P_2O_5:K_2O:Zn) was prepared in the Agronomy Lab, College of Agriculture, Jodhpur and applied as per treatments in the form of basal dose at the time of sowing. The recommended dose of fertilizers to the experimental crop of pearl millet at 60 kg N, 30 kg P_2O_5, 10 kg K_2O and 5 kg Zn ha^{-1} was applied through straight fertilizers viz; urea, diammonium phosphate (DAP), muriate of potash (MOP) and zinc oxide, respectively. Complete dose of phosphorus, potassium and zinc and half dose of nitrogen (30 kg) were applied to the crop as basal dose at the time of sowing. Whereas, the remaining 30 kg dose of N for both the treatments i.e. customized fertilizer and RDF through straight fertilizers was applied through neem coated urea in the form of top dressing at 30 DAS. Treatments were applied as per standard methods. The crop of pearl millet was sown on July 21, 2019 and July 7, 2020. Sowing of seeds was done in rows through *kera/pora* methods during both seasons. Pearl millet was sown at a row to row spacing of 45 cm and 15 cm plant to plant using 4 kg seeds ha^{-1}.

The representative samples of pearl millet plant parts viz; root, shoot and leaf at panicle initiation, 50% flowering and at harvest were collected carefully avoiding any external contamination. The collected samples were washed in the double distilled water, dried and grounded for analyzing zinc and iron content (Singh and Praharaj, 2017). At harvest, samples of grain and straw were drawn from each plot of the experiment for the chemical analysis of Zn, Fe, Mn and Cu concentration. Zinc and iron in root, shoot, leaves and zinc, iron, manganese and copper concentration in grain and straw samples were digested using di-acid ($HClO_4$+HNO_3 in 4:9 ratio) mixture. Mineral concentrations (Zn, Fe, Mn and Cu) of the filtrates were measured using Atomic Absorption Spectrophotometer (Singh and Praharaj, 2017).

These experimental data recorded under observations were statistically analyzed in accordance with the 'Analysis of Variance' technique as described by Fisher (1950). Wherever variance ratio (F value) was found significant, critical difference (CD) values at 5% level of probability were computed for making a comparison between treatments. To elucidate the nature and magnitude of treatments effects, standard errors of means (SEm±) and CD (p=0.05) were computed. The data recorded on different parameters were pooled, as the differences between the years were not significant.

3. Results and Discussion

3.1. Zinc partitioning in plant parts

Application of customized fertilizer to pearl millet substantially enhanced zinc concentration in the root, shoot and leaf at varying growth stages viz; panicle initiation, 50% flowering and at harvest stage (Table 2). Application of customized fertilizer enhanced zinc concentration in the root by 6.22, 5.99 and 6.07 percent at panicle initiation, 50% flowering and at harvest stage, respectively, over control. Likewise, zinc concentration improvement in the shoot at varying growth stages viz; panicle initiation, 50% flowering and at harvest stage was to the extent of 5.33, 6.12 and 5.70% higher, respectively, over control or no fertilizer application. Similarly, the enhancement in terms of zinc concentration the leaves of pearl millet was also recorded higher by 5.16, 4.96 and 5.53% at panicle

Table 2: Effect of fertilizers and hybrids on zinc concentration in different plant parts of pearl millet (Pooled data)

Treatments	Zinc concentration (mg kg^{-1})								
	Panicle initiation			50% flowering			At harvest		
	Root	Shoot	Leaf	Root	Shoot	Leaf	Root	Shoot	Leaf
Fertilizers									
Control	44.53	51.56	49.76	38.02	48.02	47.73	42.68	44.03	44.81
Straight fertilizer	44.98	53.51	51.60	38.66	50.12	49.50	44.70	45.81	46.69
Customized fertilizer	47.30	54.31	52.33	40.30	50.96	50.10	45.27	46.54	47.29
SEm±	0.05	0.05	0.04	0.07	0.06	0.06	0.06	0.05	0.09
CD (*p*=0.05)	0.14	0.13	0.12	0.20	0.17	0.18	0.16	0.15	0.25
Hybrids									
MPMH 21	45.81	52.24	51.51	38.22	50.70	48.02	44.53	43.46	43.10
MPMH 17	41.41	54.13	49.45	33.24	50.63	44.09	42.24	46.26	41.64
RHB 177	46.12	54.19	49.45	40.87	51.44	49.49	43.00	47.42	47.91
RHB 173	42.22	53.79	50.15	37.57	48.58	48.51	45.85	46.10	45.71
HHB 67 Improved	46.97	53.17	51.47	37.34	50.32	52.08	43.64	46.07	50.42
HHB 197	48.54	52.17	53.13	41.20	47.68	52.28	42.13	43.32	49.36
HHB 272	48.17	52.20	53.43	44.51	48.54	49.28	48.14	45.59	45.71
SEm±	0.08	0.07	0.07	0.11	0.09	0.10	0.09	0.08	0.13
CD (*p*=0.05)	0.22	0.20	0.19	0.30	0.26	0.27	0.25	0.22	0.37
Interaction									
SEm±	0.13	0.12	0.12	0.18	0.16	0.17	0.15	0.14	0.23
CD (*p*=0.05)	0.37	0.34	NS	0.52	NS	NS	NS	NS	NS

initiation, 50% flowering and at harvest stage, respectively, over control. The major reason for higher concentration Zn due to application of customized fertilizer which contains N, P and K along with micronutrients in formulation enhanced the efficiency of micronutrient as compared over straight application of nutrient (Beuerlein et al., 1992). Therefore, an appropriate combination of NPK and Zn nutrients provided through formulation might enhance the Zn concentration at all the growth stages of pearl millet. The concentration of Zn is also ascribed to an improved nutritional environment in soil rhizosphere, slow release matrix and consequently higher absorption in plant system by varying plant parts (Singh et al., 2017). Further, the order of zinc concentration in pearl millet plant parts at varying phonological events was in the order: shoot (54.31 mg kg^{-1})>leaf (52.33 mg kg^{-1})>root (47.30 mg kg^{-1}) at panicle initiation; shoot (50.96 mg kg^{-1})>leaf (50.10 mg kg^{-1})>root (40.30 mg kg^{-1}) at 50% flowering and leaf (47.29 mg kg^{-1})>shoot (46.54 mg kg^{-1})>root (45.27 mg kg^{-1}). The reason for the higher concentration in leaves at harvest may be due to the fact that at adequate nutrient supply, the leaves of the pearl millet were a major reserve of zinc at maturity. These observations are consistent with the results of Jakhar et al. (2006); Singh et al. (2015) and Karmakar et al. (2021)

Marked variations in terms of zinc concentration in different plant parts of pearl millet were recorded due to various hybrids tested under the study (Table 2). The trend of zinc concentration increment was different for different plant parts among the pearl millet hybrids. Pearl millet hybrid 'RHB 177' recorded substantially higher zinc concentration in shoots at panicle initiation (54.19 mg kg^{-1}), at 50% flowering (51.44 mg kg^{-1}) and harvest (47.42 mg kg^{-1}). However, pearl millet hybrid 'HHB 197' fetched markedly higher zinc concentration in root at panicle initiation (48.54 mg kg^{-1}) and in leaves at 50% flowering (52.28 mg kg^{-1}). Increased supply of zinc favoured increased zinc accumulation in the entire plant. The increase in zinc concentration showed adequate zinc supply treatments may also be due to increased availability of zinc to the crop through xylem transport from root to shoot in the transpiration stream. The results are supported by the findings of Samreen et al. (2017). These results also corroborate the findings of Fageria (2013). Graham and Rengel (1993) suggested that more than one mechanism could be responsible for establishing zinc efficiency in a genotype and are likely that different genotypes subjected to zinc deficiency under different climatic conditions will respond by, one or more, different crop management practices. Hafeez et al. (2013) reported that efficient genotypes are those with a high capacity to absorb the nutrients from the root zone and store relatively little nutrients. The mechanisms responsible for this tolerance of genotypes in low zinc availability conditions include multifarious reasons and one of the major causes being the increased zinc bioavailability in the root zone due to release of root exudates, higher uptake of zinc by roots, and efficient utilization and re-translocation of zinc (Sadeghzadeh, 2013).

3.2. Iron partitioning in plant parts

Application of customized fertilizer to pearl millet markedly influenced iron concentration in different plant parts (root, shoot, leaves) at varying growth stages viz; panicle initiation, 50% flowering and at harvest (Table 3). Application of customized fertilizer to pearl millet at panicle initiation enhanced iron concentration in shoots and leaves by 2.65 and 2.64%, respectively, over control. Likewise, at 50% flowering stage, iron concentration increased by 4.70, 2.21 and 2.19%, respectively, by root, shoot and leaves over control. Similarly, at the harvest stage also, customized fertilized improved iron concentration in root and shoot by 6.96 and 2.99%, respectively, over control or no fertilizer treatment. Improvement in iron content by the crop might ascribe to enhanced immobilization of iron due to the addition of customized fertilizer supplying N, P, K and Zn. Fageria (2001) find out that sufficient P-inputs in the soil enhance Fe immobilization. Similarly, Bolle-Jones (1955) studied potato fertilization in pot sand culture and found that added K reduced mild Fe deficiency symptoms thereby increasing Fe content in plant roots and other parts.

It is revealed from the data presented in Table 3 that varying pearl millet hybrids tested under the experimentation had a substantial influence on iron concentration in different plant parts viz; root, shoot and leaves of pearl millet. Pearl millet hybrid 'RHB 173' fetched markedly higher Fe concentration in shoots (60.72 mg kg^{-1}) and leaves (56.13 mg kg^{-1}) at panicle initiation, in shoots (57.87 mg^{-} kg^{-1}) and leaves (53.27 mg kg^{-1}) at 50% flowering and in shoots (67.63 mg kg^{-1}) and leaves (45.92 mg kg^{-1}) at harvest stage. Albeit, 'HHB 67 Improved' recorded statistically higher iron concentration in roots at panicle initiation (38.77 mg kg^{-1}), 50% flowering (38.06 mg kg^{-1}) and at harvest stage (33.627 mg kg^{-1}). Variations in Fe concentrations among pearl millet hybrids might be due to large variations in morphological characters between crop species. In a research paper White et al. (2013) discussed root ideotypes for improving the acquisition of essential mineral elements and identified root growth vigor as globally important traits affecting the uptake of most essential nutrients. Bruck et al. (2003) and Palta and Watt (2009) have

Table 3: Effect of fertilizers and hybrids on iron concentration in different plant parts of pearl millet

Treatments	Iron concentration (mg kg^{-1})								
	Panicle initiation			50% flowering			At harvest		
	Root	Shoot	Leaf	Root	Shoot	Leaf	Root	Shoot	Leaf
Fertilizers									
Control	34.96	57.38	53.73	33.53	54.64	50.99	28.45	64.08	44.01
Straight fertilizer	35.58	58.09	54.10	34.53	55.31	51.32	29.48	65.01	43.94
Customized fertilizer	35.68	58.90	55.15	35.20	55.85	52.11	30.43	66.00	44.18
SEm±	0.43	0.05	0.05	0.05	0.06	0.05	0.04	0.07	0.14
CD (*p*=0.05)	NS	0.14	0.13	0.15	0.18	0.13	0.13	0.21	NS
Hybrids									
MPMH 21	32.80	56.61	54.42	32.29	53.76	51.57	25.57	63.52	44.24
MPMH 17	34.38	57.91	53.16	33.23	55.06	50.31	26.59	64.82	42.81
RHB 177	36.62	58.55	54.18	35.32	55.70	51.33	29.35	65.46	44.24
RHB 173	35.03	60.72	56.13	35.93	57.87	53.27	31.81	67.63	45.92
HHB 67 Improved	38.77	60.51	54.01	38.06	57.66	51.15	33.62	67.42	43.55
HHB 197	38.34	57.95	53.38	33.04	55.09	50.53	28.47	64.86	42.95
HHB 272	31.93	54.60	55.02	33.07	51.75	52.17	30.75	61.51	44.58
SEm±	0.65	0.08	0.07	0.08	0.10	0.07	0.07	0.11	0.21
CD (*p*=0.05)	1.83	0.22	0.20	0.23	0.27	0.20	0.19	0.31	0.58
Interaction									
SEm±	1.13	0.13	0.12	0.14	0.17	0.12	0.12	0.19	0.36
CD (*p*=0.05)	NS	0.37	0.34	0.40	0.47	0.35	NS	0.54	NS

also shown a positive relationship between vigorous shoot and root growth, coupled with an efficient uptake of soil nutrients. Thus, it is relevant to assess the variability of morphological traits viz; root, shoot and leaves and the associated uptake of nutrients in existing cultivars to be used for a low input production system.

3.3. Nutritional enrichment of pearl millet grain and straw

To mitigate the multi-nutrient malnutrition or hidden hunger, enrichment of grain for human health and straw for animals health through the novel approaches of Agronomic biofortification advocating customized fertilizer, is crucial and important. Application of customized fertilizer to pearl millet significantly enriched its grain and straw in terms of micronutrients (Zn, Fe, Mn and Cu) over control (Table 4). Substantially higher Zn (56.42 mg kg^{-1}), Fe (39.50 mg kg^{-1}) Mn (15.13 mg kg^{-1}) and Cu (18.31 mg kg^{-1}) in grain were noticed due to the application of customized fertilizer. Likewise, the addition of pearl millet with customized fertilizer also had a marked influence on the concentration of Zn (30.03 mg kg^{-1}), Fe (69.07 mg kg^{-1}), Mn (39.93 mg kg^{-1}) and Cu (24.90 mg kg^{-1}) improvement in straw, an important source of fodder for milch animals in the arid region of India. Balanced macronutrient concentrations along with micronutrient zinc in the soil supplied through customized fertilizer were related to a higher ratio of root length to shoot dry matter, indicating that vigorous roots enable plants to absorb higher amounts of macro-and micronutrients from soil, and thereby supply higher micronutrient concentration to the straw and grain. The advantages of compound NPK fertilizers containing Zn had also been reported by Cakmak (2008) and Rietra et al. (2017). Positive interactions among applied soil nutrients add nutritional concentrations in plants (Graham and Rengel, 1993; Robson and Pitman, 1983)

Marked variation in micronutrient concentrations viz; Zn, Fe, Mn and Cu in pearl millet grain and straw have been recorded under varying pearl millet hybrids. A large variability for micronutrient content in germplasm and breeding lines has been indicated, suggesting the feasibility of genetic enhancement for micronutrients in pearl millet (Yadav and Rai, 2013; Yadav et al., 2021). The pearl millet hybrid 'HHB 67 Improved' recorded substantially higher Zn (61.97 mg kg^{-1}), Fe (43.98 mg kg^{-1}) and Mn (15.46 mg kg^{-1}) in grain and Cu (25.09 mg kg^{-1}) in straw. However, 'HHB 173' noticed a significantly higher Cu (19.60 mg kg^{-1}) concentration in grain. Albeit, in straw, significant improvement of Zn (31.36 mg kg^{-1}), Fe (68.97 mg kg^{-1}), Mn (41.70 mg kg^{-1}) and Cu (25.09 mg kg^{-1}) was fetched by 'HHB 197', 'MPMH 17', 'MPMH 21' and 'HHB 67 Improved' pearl millet hybrids, respectively.

Table 4: Effect of fertilizers and hybrids on nutrient concentration in pearl millet (Pooled data)

Treatments	Nutrient concentration in grain (mg kg^{-1})				Nutrient concentration in straw (mg kg^{-1})			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
Fertilizers								
Control	53.69	36.68	12.02	16.14	27.49	68.31	39.24	22.16
Straight fertilizer	55.83	39.00	14.44	17.87	29.53	68.80	39.25	22.12
Customized fertilizer	56.42	39.50	15.13	18.31	30.03	69.07	39.93	24.90
SEm±	0.09	0.06	0.05	0.08	0.06	0.06	0.08	0.06
CD (*p*=0.05)	0.26	0.18	0.14	0.24	0.18	0.18	0.24	0.18
Hybrids								
MPMH 21	55.29	37.86	13.18	18.92	28.33	68.65	41.70	24.08
MPMH 17	61.25	39.59	13.42	16.35	29.31	68.97	41.19	23.31
RHB 177	55.96	37.50	13.39	18.64	28.52	68.65	40.55	23.51
RHB 173	53.88	37.78	14.47	19.60	28.44	68.63	41.15	22.79
HHB 67 Improved	61.97	43.98	15.46	15.36	28.81	68.93	37.50	25.09
HHB 197	48.89	33.52	13.10	18.54	31.36	68.64	40.11	22.51
HHB 272	49.93	38.52	14.03	14.67	28.35	68.62	34.12	20.13
SEm±	0.14	0.10	0.07	0.13	0.10	0.10	0.13	0.10
CD (*p*=0.05)	0.39	0.28	0.21	0.36	0.28	0.28	0.36	0.27
Interaction								
SEm±	0.24	0.17	0.13	0.22	0.17	0.17	0.22	0.17
CD (*p*=0.05)	NS	0.48	0.36	NS	NS	NS	0.62	0.47

3.4. Nutrient acquisition and zinc use indices

Application of customized fertilizer to pearl millet improved substantially uptake of Zn, Fe, Mn and Cu by grain and straw both (Figure 1 to 4). Application of customized fertilizer enhanced uptake of Zn, Fe, Mn and Cu by grain which was significantly higher by 12.3, 12.4, 16.4 and 14.0%, respectively. Likewise, customized fertilizer also substantially improved uptake of Zn, Fe, Mn and Cu by straw to the tune of 8.3, 5.5, 8.4 and 19.2% higher, respectively over straight fertilizers. The increment in micronutrient uptake reveal synergism with macronutrients. The addition of Zn and primary nutrients (N, P and K) resulted in a higher yield of pearl millet and thereby enhanced uptake of micronutrients (Rietra et al., 2017).

Significant differences in uptake of micronutrients viz; Zn, Fe, Mn and Cu of pearl millet grain and straw have also been recorded due to varying hybrids undertaken in the experimentation (Figure 1 to 4). Among hybrids, 'MPMH 17' fetched highest acquisition of Zn (120.20 mg kg^{-1}), Fe (77.86 mg kg^{-1}), Mn (26.62 mg kg^{-1}) and 'RHB 173' of Cu (35.54 mg kg^{-1}) by grain which were markedly higher over rest of the hybrids. Similarly by straw, 'MPMH 17' fetched highest acquisition of Zn (96.04 mg kg^{-1}), Fe (222.53 mg kg^{-1}), Mn (143.05 mg kg^{-1}) and Cu (81.25 mg kg^{-1}) which were noticeably higher over rest of the hybrids. Enhanced content and supply favoured increased micronutrients accumulation in the entire plant. Additionalyy, efficient genotypes have high capacity to absorb the nutrients from root zone and store relatively little nutrients (Graham and Rengel, 1993; Fageria, 2013; Hafeez et al., 2013).

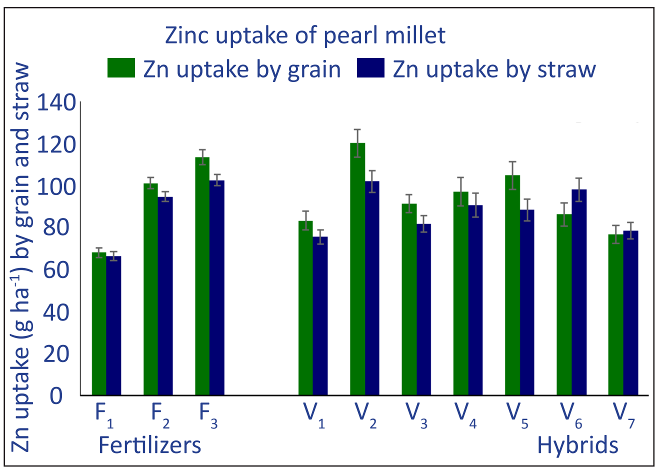

Figure 1: Effect of fertilizers and hybrids on zinc uptake (g ha^{-1}) of pearl millet grain and straw. Bar show standard error of mean with LSD value at p=0.05 to determine the significance differences among the treatment mean

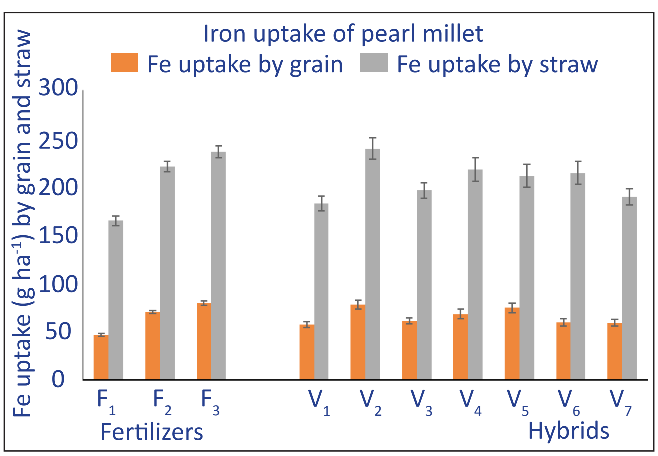

Figure 2: Effect of fertilizers and hybrids on iron uptake (g ha^{-1}) of pearl millet grain and straw. Bar show standard error of mean with LSD value at p=0.05 to determine the significance differences among the treatment mean

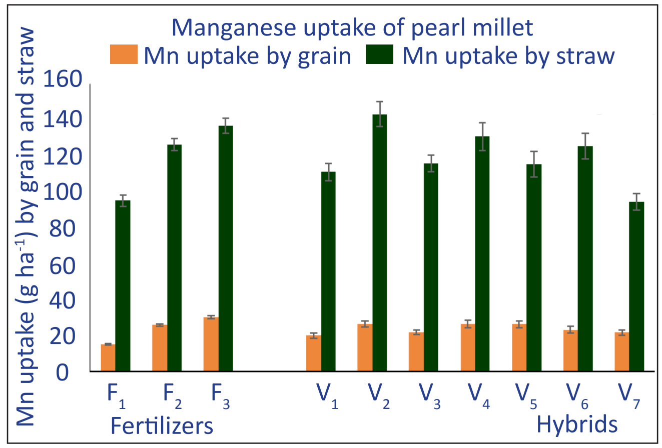

Figure 3: Effect of fertilizers and hybrids on manganese uptake (g ha^{-1}) of pearl millet grain and straw. Bar show standard error of mean with LSD value at p=0.05 to determine the significance differences among the treatment mean

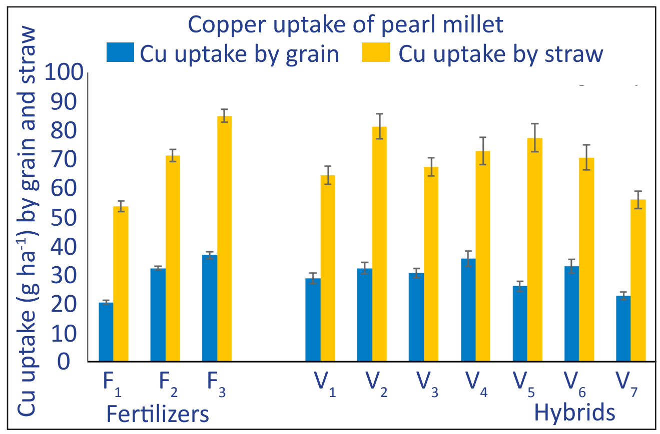

Figure 4: Effect of fertilizers and hybrids on copper uptake (g ha^{-1}) of pearl millet grain and straw. Bar show standard error of mean with LSD value at p=0.05 to determine the significance differences among the treatment mean

In addition to nutrient acquisition, zinc use indices in terms of agronomic zinc use efficiency and zinc recovery efficiency (Table 5) influenced substantially due to application of customized fertilizers and hybrids. Application of customized fertilizer recorded significantly higher agronomic zinc use efficiency (149.3 kg grain kg^{-1} Zn applied) and zinc recovery

Table 5: Effect of fertilizers and hybrids on zinc use indices of pearl millet (pooled data)

Treatments	Agronomic Zn use efficiency (kg grain kg^{-1} Zn applied)	Recovery efficiency (%)
Fertilizers		
Control	-	-
Straight fertilizer	109.6	1.23
Customized fertilizer	149.3	1.64
SEm±	7.3	0.08
CD (*p*=0.05)	20.6	0.22
Hybrids		
MPMH 21	66.4	0.72
MPMH 17	100.0	1.16
RHB 177	58.7	0.63
RHB 173	106.1	1.16
HHB 67 Improved	90.5	1.08
HHB 197	101.8	1.08
HHB 272	80.6	0.85
SEm±	11.2	0.12
CD (*p*=0.05)	31.5	0.34
Interaction		
SEm±	19.4	0.21
CD (*p*=0.05)	NS	NS

efficiency (1.64%). On the other hand, among pearl millet hybrids, 'RHB 173' highest agronomic zinc use efficiency (106.1 kg grain kg^{-1} Zn applied) and zinc recovery efficiency (1.16%).

3.5. Yield

Data pertaining to grain and straw yield are presented in Table 6. Applying customized fertilizers to pearl millet gave significantly more yield (grain and straw yield) over no fertilizer. The addition of customized fertilizer recorded significantly higher grain (2,010 kg ha^{-1}) and straw (3,417 kg ha^{-1}) yield, which was higher by 59.14 and 41.67% respectively, over control. Achieving higher yield due to customized fertilizer ascribed to the balanced supply of the nutrients to the plants as per the demand and slow release matrix (Kumar and Singh, 2017; Singh et al., 2016a; Singh et al., 2017; Singh et al., 2020).

Substantial variations in grain and straw yield of pearl millet have also been recorded due to different hybrids undertaken in the experimentation. Among pearl millet hybrids, 'MPMH 17' out yielded (1,958 kg ha^{-1}) followed by 'RHB 173' (1,795 kg ha^{-1}). In terms of straw yield, 'MPMH 17' recorded 3,466 kg straw ha^{-1} followed by 'RHB 173' (3,170 kg ha^{-1}), which was significantly superior over the rest of the hybrids. The differences in dry matter production and nutrient use

Table 6: Yield of pearl millet as influenced by fertilizers and hybrids (pooled data)

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Fertilizers		
Control	1,263	2,412
Straight fertilizer	1,811	3,208
Customized fertilizer	2,010	3,417
SEm±	30	54
CD (*p*=0.05)	86	153
Hybrids		
MPMH 21	1,502	2,661
MPMH 17	1,958	3,466
RHB 177	1,628	2,858
RHB 173	1,795	3,170
HHB 67 Improved	1,687	3,057
HHB 197	1,760	3,117
HHB 272	1,531	2,757
SEm±	47	83
CD (*p*=0.05)	131	234
Interaction		
SEm±	81	144
CD (*p*=0.05)	NS	NS

acquisition efficiencies between the hybrids of pearl millet might be attributed to the effect of the genetic makeup of the hybrids. These findings are closely correlated by Arshewar et al. (2018), Lagat et al. (2018) and Bijarnia et al. (2020).

4. Conclusion

Application of customized fertilizer (6:6:2:1) to pearl millet gave substantially higher grain yield (2010 kg ha^{-1}) and straw yield (3417 kg ha^{-1}). Micronutrient fortification (Zn, Fe, Mn and Cu) of grain and straw has been achieved with the application of customized fertilizer. Moreover, pearl millet hybrid 'MPMH 17' recorded significantly higher grain (1,958 kg ha^{-1}) and straw (3,466 kg ha^{-1}). Among hybrids, 'HHB 67 Improved' fetched the greatest concentration of Zn, Fe and Mn in the grain.

5. Further Research

The slow release matrix of the developed customized fertilizer grade (6:6:2:1) should be tested under different soil types for all the individual elements viz; N, P, K and Zn.

6. Acknowledgement

The authors duly acknowledge the support received from the ICAR-All India Coordinated Research Project on Pearl Millet, Agricultural Research Station, Mandor, Jodhpur (Agriculture

University, Jodhpur). Our sincere thanks are also due to the College of Agriculture, Agriculture University, Jodhpur for providing facilities for accomplishing the research work.

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