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Impact of Seed hardening, Varying Fertilizer Levels and Organic Foliar Applications on Nutrient Content and Uptake in Sorghum (*Sorghum bicolor* L. Moench)

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***Abstract*— *A field experiment entitled "Impact of Seed Priming, Varying Fertilizer Levels and Organic Foliar Applications on Nutrient Content and Uptake in Sorghum (Sorghum bicolor L. Moench)" was conducted during the kharif season of 2024 at the Agronomy Instructional Farm, Rajasthan College of Agriculture, MPUAT, Udaipur. The experiment was laid out in a factorial randomized block design comprising three factors: seed hardening (control, 2% KCl and 3% panchagavya), fertilizer levels (control, 75% RDF and 100% RDF) and foliar nutrition (7.5% and 10% vermiwash), replicated three times. The results revealed that application of 100 per cent RDF along with seed hardening using 2 per cent KCl and foliar spray of 10% vermiwash significantly enhanced nitrogen, phosphorus and potassium content and uptake in sorghum grain and stover. The highest nitrogen content in grain (1.626%) and stover (0.524%) and maximum total nitrogen uptake (106.06 kg ha⁻¹) were recorded under 100 per cent RDF. Similarly, foliar application of vermiwash @10% and seed hardening with 2% KCl improved nutrient content and uptake, being statistically superior over respective controls. These results indicate that integrated application of seed hardening, optimal fertilizer dose and foliar nutrition plays a significant role in enhancing nutrient use efficiency and productivity in rainfed sorghum.*

***Keywords*— Sorghum, Seed hardening, RDF, Vermiwash, Nutrient content, Nutrient uptake**

I. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is one of the most important cereal crops cultivated in arid and semi-arid regions of the world, owing to its remarkable adaptability to harsh climatic conditions. It is popularly known as the "king of millets" and is ranked fifth in global cereal production after wheat, rice, maize and barley. Sorghum's ability to withstand drought, tolerate marginal soils and produce reasonable yields under low-input farming systems makes it an ideal crop for dry land agriculture. This resilience has increased its relevance not only as a food and fodder crop but also for industrial applications such as bioethanol production and animal feed. Nutritionally, sorghum grain is gluten-free and contains approximately 10–12% protein, 1.9% fat and 72.6% carbohydrates. It is also a good source of dietary fibre, resistant starch and essential micronutrients including iron, zinc, calcium, magnesium and phosphorus. Moreover, sorghum is rich in bioactive compounds such as polyphenols, flavonoids and antioxidants that offer potential health benefits, including anti-inflammatory and anti-carcinogenic properties. The grain contains important vitamins like thiamine, riboflavin, niacin and folic acid, making it suitable for health-conscious diets and people with gluten intolerance. The nutritional profile of sorghum contributes to its increasing popularity as a functional food crop in both developed and developing countries. Globally, sorghum is grown on approximately 9.96 million hectares, with an estimated production of 62.42 million metric tonnes (USDA, 2025). The United States is the leading producer, followed by Nigeria, Mexico and Sudan. India ranks fourth globally in sorghum production, accounting for around 12.3% of global output. In India, the crop is cultivated on about 4.80 million hectares with a production of 7.29 million metric tonnes. Maharashtra is the leading sorghum-growing state, contributing about 37% of the total production, followed by Karnataka (22%), Tamil Nadu (10%) and Rajasthan (8%). In Rajasthan, sorghum is cultivated across 0.50 million hectares with a total production of 0.52 million tonnes. Districts such as Ajmer, Alwar, Barmer and Sawai Madhopur are the major sorghum-producing areas in the state (APEDA, 2023-24). Despite sorghum's potential, its productivity under rainfed conditions remains low due to several limiting factors. Chief among them is poor soil fertility, which reduces nutrient availability and uptake. The problem is compounded by erratic rainfall distribution and prolonged dry spells during the growing season, which further hinder crop growth and development. Under such challenging environments, integrated nutrient and moisture management strategies become essential to harness the full potential of the crop. Balanced nutrient application, particularly of macronutrients such as nitrogen (N), phosphorus (P) and potassium (K), plays a vital role in enhancing sorghum growth, yield and quality. Nitrogen is essential for vegetative growth and protein synthesis; phosphorus plays a crucial role in energy transfer and root development, while potassium regulates osmotic balance, enzyme activation and disease resistance. However, indiscriminate use of chemical fertilizers has led to nutrient imbalances and declining soil health. Additionally, in coarse-textured soils typical of dryland regions, nutrient leaching and volatilization often reduce the effectiveness of soil-applied fertilizers. Therefore, combining soil application with complementary techniques such as foliar feeding and seed treatments can significantly improve nutrient use efficiency. Foliar nutrition involves the application of essential nutrients directly to the foliage, allowing rapid absorption and immediate availability to plants. This technique is particularly useful under moisture-stressed conditions where root activity is restricted. In sandy loam soils, foliar-applied fertilizers have been reported to be up to 20 times more effective than soil-applied fertilizers in supplying nutrients to the plant. Among organic foliar inputs, vermiwash has gained prominence due to its nutrient richness and plant growth-promoting properties. Vermiwash is a liquid extract obtained from vermicompost systems and contains a variety of beneficial components including enzymes, plant hormones (auxins, cytokinins), micronutrients and beneficial microbes. It has been shown to enhance photosynthesis, chlorophyll content and plant vigor, ultimately leading to improved nutrient uptake and yield (Jandaik *et al*., 2015; Meyyappan and Sivakumar, 2020).

Seed hardening is another low-cost pre-sowing technique that has been proven effective in improving seedling vigor, early establishment and drought tolerance. It involves soaking seeds in specific chemical or organic solutions, followed by drying to restore their original moisture content. Hardening seeds with potassium chloride (KCl) is a common practice that induces osmotic adjustments and enhances resistance to moisture stress. KCl-hardened seeds show improved root development, water absorption and nutrient uptake in the early growth stages, which contributes to better stand establishment and higher yields. Organic seed treatments using panchagavya - a fermented bio-formulation composed of cow dung, cow urine, milk, curd and ghee - have also shown promise. Panchagavya contains growth-regulating substances like gibberellins and cytokinins as well as beneficial microbes such as yeast, lactic acid bacteria and actinomycetes. It promotes seed germination, early root development and nutrient uptake while enhancing soil microbial diversity and health (Raj *et al*., 2021; Jain *et al*., 2022). In this context, a field experiment was conducted to evaluate the effects of seed hardening (with 2% KCl and 3% panchagavya), soil-applied fertilizers (control, 75% RDF, 100% RDF) and foliar nutrition (7.5% and 10% vermiwash) on nutrient content, uptake, growth and yield of sorghum under rainfed conditions.

II. MATERIALS AND METHODS

A field experiment was conducted at Instructional Farm (Agronomy) Rajasthan College of Agriculture, Udaipur. which is located in the South-East of the state at a height of 581.13 m above mean sea level and 24°35′ N latitude and 73°42′ E longitude. This region falls under IV-A (Sub-Humid Southern Plain and Aravalli Hills) agro-climatic zone of Rajasthan.

The experiment consisted of 18 treatment combinations in factorial randomized block design, comprising various fertility levels of control, NPK–75 per cent, NPK–100 per cent and foliar applications of vermiwash 7.5, 10 per cent and seed treatment of control, KCl @ 2 per cent solution, panchgavya @ 3 per cent. In grinding seed and haulm sample, nitrogen was estimated by Nesseler`s reagent colorimeter method (snell and snell,1949). Phosphorus was determined by Ammonium vanadomolybdate yellow colour method (Richards, 1968) and potassium content was determined by (Jacson,1973).

III. RESULTS AND DISCUSSION

Nutrient Content

The data presented in Table 1 revealed that nitrogen, phosphorus and potassium content in sorghum grain and stover were significantly influenced by seed hardening, soil-applied fertilizer levels and foliar nutrition treatments. Among the fertilizer levels, application of 100 per cent RDF recorded the highest nitrogen content in grain (1.626%) and stover (0.524%), which was significantly superior to the control (no fertilizer) and statistically at par with 75 per cent RDF. The enhanced nitrogen content under 100 per cent RDF may be due to the continuous availability of nitrogen during the crop growth period, promoting protein synthesis and biomass accumulation. These results are in accordance with the findings of Patel *et al*. (2018), who reported improved nitrogen content in cereals under balanced fertilization. Foliar application of vermiwash at 10 per cent significantly improved nitrogen content in grain (1.596%) and stover (0.472%) over the 7.5 per cent vermiwash spray, likely due to the presence of readily available nutrients, plant growth regulators and beneficial microbes that enhance absorption and metabolism. Likewise, seed hardening with 2 per cent KCL resulted in significantly higher nitrogen content in grain (1.596%) and stover (0.470%), which was statistically at par with 3 per cent panchagavya and significantly superior to the control treatment (no hardening). Phosphorus content in grain and stover also followed a similar trend. Application of 100 per cent RDF recorded the highest phosphorus content in grain (0.306%) and stover (0.267%), followed by 75 per cent RDF. Among foliar nutrition treatments, vermiwash at 10 per cent significantly increased phosphorus content in grain (0.299%) and stover (0.254%). Seed hardening with 2 per cent KCL also showed maximum phosphorus content in grain (0.302%) and stover (0.256%). The improvement in phosphorus content could be attributed to enhanced root activity and microbial activity that promote phosphorus solubilization and uptake. Potassium content in grain and stover was significantly affected by all treatments. Maximum potassium content in grain (0.513%) and stover (2.712%) was recorded under application of 100 per cent RDF. Foliar application of vermiwash at 10 per cent and seed hardening with 2 per cent KCL also resulted in significantly higher potassium content - grain values of 0.490 per cent and 0.495 per cent and stover values of 2.685 per cent and 2.732 per cent, respectively - over their respective control treatments. The improved potassium content under these treatments may be attributed to enhanced physiological processes and nutrient translocation in plants. These findings are supported by Verma *et al*. (2018), who observed that seed priming and foliar bio-inputs increase the availability and absorption of macronutrients.

Nutrient Uptake

Nutrient uptake by sorghum grain and stover (Table 2) was significantly influenced by seed hardening, fertilizer application and foliar nutrition practices. Among the fertilizer levels, application of 100 per cent RDF recorded the highest nitrogen uptake in grain (53.34 kg ha^{-1}) and stover (52.72 kg ha^{-1}), resulting in a total nitrogen uptake of 106.06 kilograms per hectare, which was significantly superior to both the control and 75 per cent RDF. The improved uptake was mainly due to higher dry matter accumulation and nutrient concentration under adequate fertilization. These results align with Rathva (2021), who also observed higher nitrogen uptake with optimal nutrient supply. Foliar nutrition with vermiwash at 10 per cent significantly increased nitrogen uptake in grain (49.47 kg ha^{-1}), stover (46.75 kg ha^{-1}) and total uptake (96.22 kilograms per hectare), which was 7.13 per cent higher than that observed with 7.5 per cent vermiwash. Seed hardening with 2 per cent KCL resulted in the highest nitrogen uptake among seed treatments, recording 50.63 kg ha^{-1}in grain, 47.18 kg ha^{-1} in stover and total uptake of 97.81 kg ha^{-1}, which was statistically at par with seed hardening using 3 per cent panchagavya. Phosphorus uptake also showed a similar trend. Application of 100 per cent RDF resulted in maximum phosphorus uptake in grain (10.09 kg ha^{-1}), stover (26.83 kg ha^{-1}) and total (36.93 kg ha^{-1}). Foliar application of vermiwash at 10 per cent and seed hardening with 2 per cent KCL recorded significantly higher total phosphorus uptake (34.45 and 35.19 kg ha^{-1}, respectively) over their respective controls. This improvement may be attributed to better root proliferation and phosphorus solubilization promoted by organic inputs and seed priming, as reported by Kumar and Angadi (2016). Potassium uptake in grain and stover was also significantly improved by all three factors. Application of 100 per cent RDF resulted in the highest grain potassium uptake (16.82 kg ha^{-1}) and total uptake. Foliar application of vermiwash at 10 per cent enhanced grain uptake (15.24 kg ha^{-1}) and total potassium uptake (155.25 kg ha^{-1}) compared to 7.5 per cent. Among seed treatments, hardening with 2 per cent KCL showed the highest total potassium uptake (158.70 kg ha^{-1}), outperforming both the control and panchagavya-treated seeds. These results are consistent with those of Ramesh and Neelaveni (2013), who emphasized the beneficial role of foliar and seed-applied treatments in enhancing nutrient uptake and utilization under rainfed conditions.

IV. CONCLUSION

The present investigation clearly demonstrated that the combined application of seed hardening with 2 per cent KCL, soil fertilization with 100 per cent RDF and foliar spray of 10 per cent vermiwash significantly enhanced nitrogen, phosphorus and potassium content and uptake in both grain and stover of sorghum. These integrated practices improved nutrient availability, root growth and physiological efficiency, resulting in higher nutrient assimilation and dry matter production. Thus, a holistic nutrient management approach involving seed physiological conditioning, balanced fertilization and organic foliar nutrition is recommended for enhancing nutrient use efficiency and sustainable productivity of sorghum under rainfed conditions

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Table 1 Effect of seed hardening, soil and foliar nutrition on nutrient content of sorghum

Treatments	Nutrient content (%)					
	Nitrogen		Phosphorus		Potassium	
	Grain	Stover	Grain	Stover	Grain	Stover
Fertility levels						
Control (F_0)	1.555	0.4184	0.267	0.232	0.444	2.577
75 % RDF (F_1)	1.578	0.4443	0.297	0.255	0.493	2.649
3. 100 % RDF (F_2)	1.626	0.5245	0.306	0.267	0.513	2.712
S.Em. ±	0.007	0.0020	0.003	0.001	0.005	0.018
C.D. (P=0.05)	0.021	0.0056	0.009	0.004	0.015	0.051
Foliar application						
Vermiwash 7.5 % (V_1)	1.577	0.4529	0.281	0.249	0.476	2.607
Vermiwash 10 % (V_2)	1.596	0.4719	0.299	0.254	0.490	2.685
SEm±	0.006	0.0016	0.002	0.001	0.004	0.014
C.D. (P=0.05)	0.017	0.0046	0.007	0.003	0.012	0.042
Seed treatments						
Control (S_0)	1.571	0.4475	0.270	0.246	0.468	2.574
KCL @2 % solution (S_1)	1.596	0.4702	0.302	0.256	0.495	2.732
Panchgavya @3 % (S_2)	1.592	0.4695	0.297	0.252	0.486	2.632
SEm±	0.007	0.0020	0.003	0.001	0.005	0.018
C.D. (P=0.05)	0.021	0.0056	0.009	0.004	0.015	0.051

Table 2 Effect of seed hardening, soil and foliar nutrition on nutrient uptake of sorghum

Treatments	Nutrient uptake (kg ha^{-1})								
	Nitrogen			Phosphorus			Potassium		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
Fertility levels									
Control (F_0)	41.66	39.32	80.97	7.15	21.77	28.93	11.90	242.42	254.32
75 % RDF (F_1)	49.32	42.47	91.80	9.30	24.36	33.67	15.42	252.98	268.40
3. 100 % RDF (F_2)	53.34	52.72	106.06	10.09	26.83	36.93	16.82	272.18	289.00
S.Em. ±	0.89	0.75	1.20	0.23	0.39	0.47	0.31	4.10	4.07
C.D. (P=0.05)	2.56	2.14	3.44	0.67	1.11	1.34	0.88	11.79	11.69
Foliar application									
Vermiwash 7.5 % (V_1)	46.74	42.92	89.66	8.36	23.54	31.90	14.19	246.38	260.57
Vermiwash 10 % (V_2)	49.47	46.75	96.22	9.34	25.11	34.45	15.24	265.34	280.58
SEm±	0.73	0.61	0.98	0.19	0.32	0.38	0.25	3.35	3.32
C.D. (P=0.05)	2.09	1.75	2.81	0.55	0.91	1.09	0.72	9.63	9.54
Seed treatments									
Control (S_0)	45.64	41.41	87.05	7.88	22.67	30.55	13.68	237.67	251.35
KCL @2 % solution (S_1)	50.91	46.90	97.81	9.69	25.50	35.19	15.84	271.70	287.54
Panchgavya @3 % (S_2)	47.77	46.20	93.97	8.98	24.80	33.78	14.62	258.21	272.83
SEm±	0.89	0.75	1.20	0.23	0.39	0.47	0.31	4.10	4.07
C.D. (P=0.05)	2.56	2.14	3.44	0.67	1.11	1.34	0.88	11.79	11.69

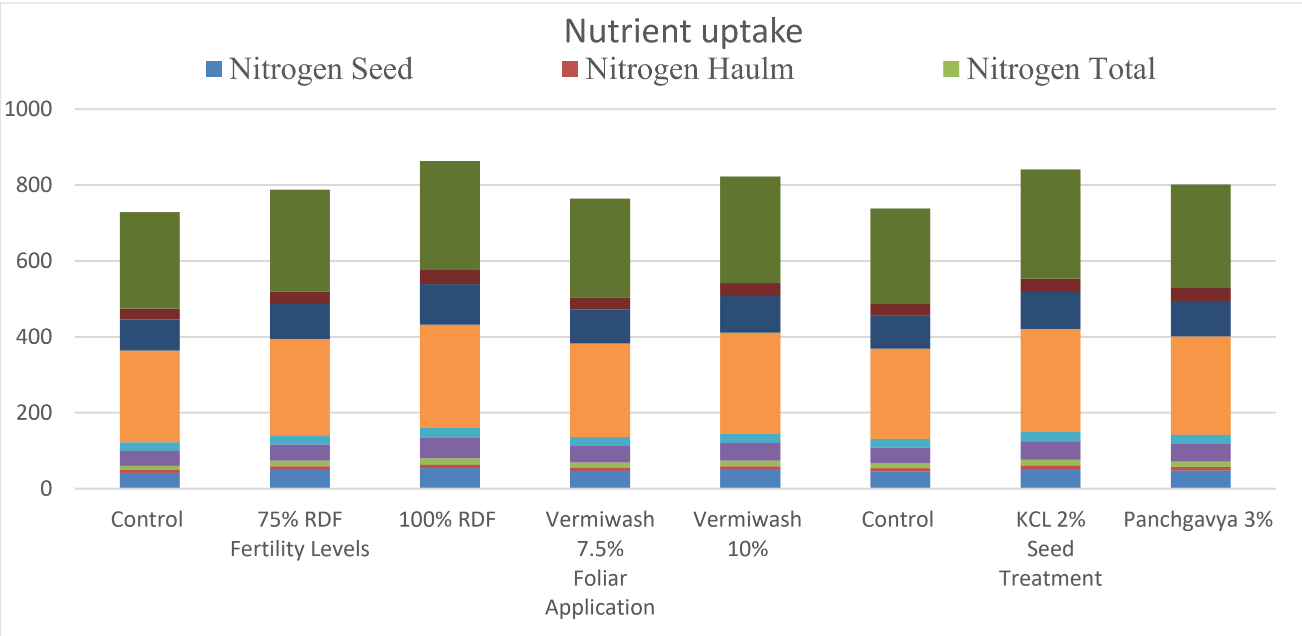

Fig 1: Effect of seed hardening, soil and foliar nutrition on nutrient uptake by sorghum