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RESEARCH ARTICLE

Unveiling hard seededness and enhancing seedling vigor: Genotypic response and priming strategies in mung bean (*Vigna radiata* L.) under temperate conditions

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Abstract

A comprehensive study was conducted at the Faculty of Agriculture, Wadura, SKUAST-Kashmir, to evaluate hard seededness and the effect of seed priming in mung bean (*Vigna radiata* L.) genotypes over two consecutive years (2021 and 2022). Genotypic variation for hard seededness was evident. In 2021, 80 of the total genotypes evaluated showed full germination, 36 had 1-5 hard seeds and 7 had more than 10 hard seeds, with hard seed counts ranging from 0 to 12. In 2022, only 52 genotypes achieved complete germination, while 60 genotypes had 1-10 hard seeds and 10 genotypes had more than 10, for a total range of 0 to 22 hard seeds. Notably, genotype PKV-AKM-4 consistently produced the highest number of hard seeds in both years (12 in 2021 and 22 in 2022). Furthermore, a seed priming experiment indicated substantial differences between mung bean genotypes and priming regimens. *Rhizobium*-treated seeds had the greatest average root depth (9.1 cm), root weight (0.099 g) and shoot weight (0.133 g). *Trichoderma* treatment produced the longest shoot length (7.3 cm), followed by *Pseudomonas* treatment, which produced a shoot length of 6.4 cm and a root weight of 0.064 g. These data show the effectiveness of microbial seed priming, particularly with *Rhizobium* and *Trichoderma*, in improving early seedling vigor in mung bean genotypes. The observed variance in hard seededness highlights the possibility for developing mung bean cultivars with lower dormancy to enable uniform field emergence. Microbial seed priming, notably with *Rhizobium* and *Trichoderma*, has been shown to significantly improve root and shoot development, as well as early seedling vigor. Adoption of these priming approaches can improve crop establishment and production stability under a variety of agroclimatic conditions.

Keywords: hard seededness; mung bean; *Rhizobium*; seed priming; *Trichoderma*

Introduction

Green gram, or mung bean (*Vigna radiata* L.), is a significant legume crop in South and Southeast Asia that supplies plant protein to people all around the region (1). It is a nutritious food that is high in minerals, protein, pro-vitamin A and vitamin B complex. Green grams are produced on 7.3 mha worldwide, with an average yield of 721 kg/ha. 30 % of the 5.3 million tons of green grams produced are produced jointly by India and Myanmar. During the kharif season, it is mostly grown in the Indian states of Rajasthan (69.3 %), Karnataka (6.4 %) and Maharashtra (5.7 %); the leading states for rabi green gram cultivation are Odisha (82.4 %) Andhra Pradesh (8.1 %) and Tamil Nadu (4 %), respectively (2).

Legumes are primarily impacted by physical dormancy, often known as hard seededness (3). It is distinguished by an impenetrable seed coat due to the presence of phenolics and palisade cells with suberin layers. The presence of hard seeds is a serious issue, especially when taken as cooked seeds. Hard seededness causes inconsistent germination, poor stand establishment, weed concerns and issues with good cooking and digestion. However, it has been demonstrated that legume cultivars with semipermeable seed coats are more resistant to environmental conditions and of higher quality (4, 5). Seed hardness peaks shortly after harvest and somewhat diminishes with storage. However, it has been demonstrated that legume cultivars with semipermeable seed coats are more resistant to environmental conditions and of higher quality (3). Hard seeds are resistant to water and stay hard even after cooking (4). Seed quality is an essential factor in determining consumer acceptance of mung bean. Consumers favor varieties with fewer hard seeds and larger, green seeds with shine. Furthermore, seed hardness is determined by more than one element. The existence of hard seeds is a physiological and genetically established characteristic, according to Rodriguez & Mendoza (6). In addition to greater establishment (higher plant population), primed crops grew faster (higher growth rate), bloomed sooner (early flowering) and produced more (higher productivity). Seed priming improves allometry, emergence, stand establishment, tillering, grain and straw yields and harvest index (7). *Rhizobium* seed priming greatly improved nodulation and nitrogenase activity while having no influence on yield (8). Seed priming techniques such as hydro priming, hormo priming and nutrient priming have been shown to improve the rate, speed, uniformity and percentage of seed germination, as well as seedling vigour, resulting in greater growth and yield than unprimed seed (9), whereas poor seed germination and seedling growth affect subsequent crop growth and yield (10). This approach prevents seed cell membrane damage by slowing and controlling water intake throughout the imbibition phase (the most essential time of germination), resulting in the seed retaining the maximum amount of stored conserved nutrients while preventing leakage. Seed priming strategies boost seed tolerance to abiotic stress in the field (11). Keeping in view the above facts, a study was carried to evaluate mung bean germplasm for hard seededness and effect of various seed priming and seed treatment agents under controlled conditions.

Materials and Methods

Variation for hard-seededness

The germination of seeds and hard seed shall be recorded on the basis of number of normal seedlings and number of hard seeds only at final count and expressed in percentage. The seeds identified as hard seeds (those failed to imbibe any moisture) were collected. The hard seededness was recorded for two consecutive years (2021 and 2022). The seeds harvested in year-2021 were studied for hard seededness in the same year and stored for the next year also to check the reduction in germination percentage with time. Same seed harvested in year-2021 was tested for seed hardiness in year 2022.

Seed priming and seed treatments

The seeds of mung bean (*Vigna radiata*) genotypes were first hydroprimed for 6 hrs in distilled water, dried under shade and then treated with biological strains viz, *Rhizobium leguminosarum*, *Pseudomonas fluorescens*, *Trichoderma viride* and chemical fungicides viz, Thirum/Vitavax/Carbendazim and also untreated seeds as Control. The treated seeds were sown in germination cups and after reaching three leaf stage, the seedlings were analyzed for various traits *viz.,* root depth (cm), root weight (g), shoot length (cm) and shoot weight (g).

Statistical analysis

The data was analyzed by using R-software.

Results

Hard seededness in mung bean (*Vigna radiata*) germplasm

The various genotypes were categorized into different groups based on the presence of hard seeds, as outlined in (Table 1, Fig. 1). In the year 2021, out of the total genotypes evaluated, 80 genotypes exhibited complete germination, while 36 genotypes contained hard seeds in the range of 1-5. Furthermore, 7 genotypes were found to have more than 10 seeds. The overall range of hard seed counts for the year 2021 spanned from 0-12. In the subsequent year, 2022, 52 genotypes achieved full germination. In contrast, 60 genotypes displayed hard seeds, with counts ranging from 1-10 and among all, 10 genotypes were identified as having more than 10 hard seeds. The overall range for the year 2022 encompassed 0-22 hard seeds. The genotype PKV-AKM-4 consistently recorded the highest number of hard seeds in both years, with counts of 12 and 22 for the years 2021

Table 1. Variation for hard-seededness in mung bean (*Vigna radiata*) genotypes

YEAR-1	YEAR-2
0 (80)	0 (52)
1-5 (36)	1-5 (32)
6-10 (1)	6-10 (30)
>10 (7)	>10 (10)
Range= 0-12	Range= 0-22
Highest No. of hard seeds= **PKV-AKM-4 (12)**	Highest No. of hard seeds= **PKV-AKM-4 (22)**
Total number of hard seeds= 161	**Total number of hard seeds= 484**

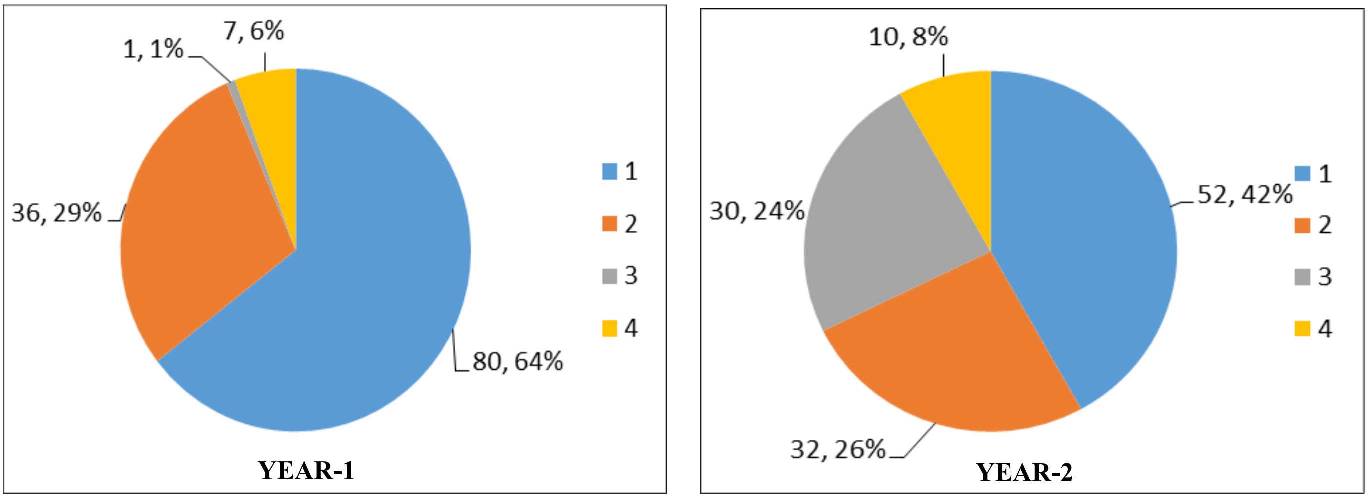

Fig. 1. Year wise variation of hard seededness in mung bean genotypes.

and 2022, respectively.

Effect of seed priming in mung bean (*Vigna radiata*) genotypes

Analysis of variance

The analysis of variance for seed priming is presented in (Table 2). The results suggested that there was significant variability observed among all the genotypes when different seed priming agents were applied and likewise, all the seed priming agents themselves exhibited statistical significance.

Mean performance of mung bean genotypes for various seed priming agents on root traits

(Table 3, Fig. 2) demonstrates the mean performance of mung bean (*Vigna radiata*) genotypes with various seed priming agents on root traits. *Rhizobium* treatment resulted in the highest root depth (9.1 cm) and root weight (0.099 g), whereas *Trichoderma* produced the second-most root depth (7.3 cm). *Pseudomonas* treatment resulted in a root weight of 0.064 g.

Seed priming has emerged as an effective approach to enhance seedling vigor and root development, which are critical determinants of plant establishment and yield potential. The present investigation evaluated the root traits of mung bean genotypes under different priming agents, namely carbendazim (Cb), *Pseudomonas* sp. (P), *Rhizobium* sp. (R) and *Trichoderma* sp. (T), compared with an untreated control (C).

The pooled mean values across 94 genotypes indicated significant improvements in both root length and root weight due to biological priming agents compared with control. Among the treatments, *Rhizobium* priming recorded the highest mean root length (9.1 cm) and root weight (0.099 g), followed by *Trichoderma* (7.3 cm and 0.058 g, respectively). In contrast, unprimed control seeds showed the lowest root length (5.0 cm) and root weight (0.037 g).

Genotype-wise performance highlighted substantial variation in priming response. Genotypes such as KDMB-12 (11.0 cm, 0.155 g), IC-305249 (11.5 cm, 0.155 g) and SM1 (11.4 cm, 0.176 g) exhibited superior root growth under *Rhizobium* priming, indicating a strong symbiotic advantage. Similarly, LGG-460 and SML-668 showed consistently higher root biomass under biological priming treatments. Conversely, susceptible genotypes such as IPM-99-125 and KDMB-4 expressed poor root development across treatments, suggesting genotype-dependent priming efficiency.

Table 2. ANOVA for mung bean (*Vigna radiata*) genotypes for different traits on application of various priming agents

Source of variation	Mean sum of squares (MSS)				
	Df	RL	RW	SL	SW
Genotypes (G)	123	16.22**	0.009**	17.77**	0.008**
Priming Agents (P)	4	850.20**	0.212**	471.12**	0.243**
G:P	492	0.14	0.00001	0.02	0.00001
Error	**1240**	**1.11**	**0.00009**	**0.79**	**0.00009**

Rl= Root depth (cm), **RW**= Root weight (g), **SL**= Shoot length (cm), **SW**= Shoot weight (g)

Mean performance of mung bean genotypes for various seed priming agents on shoot traits

Table 4, Fig. 3 demonstrates the mean performance of mung bean (*Vigna radiata*) genotypes with various seed priming agents on shoot traits. *Trichoderma* had the longest shoots (7.3 cm), followed by *Pseudomonas* with 6.4 cm. *Rhizobium* treatment also had the highest shoot weight (0.133 g), followed by *Pseudomonas* (0.09 g).

For shoot length, the overall mean values ranged from 4.6 cm in control (C) to 7.3 cm in *Trichoderma* (T) priming. Among the treatments, *Trichoderma* (7.3 cm) recorded the maximum mean shoot length, followed by *Pseudomonas* (6.4 cm) and *Rhizobium* (6.1

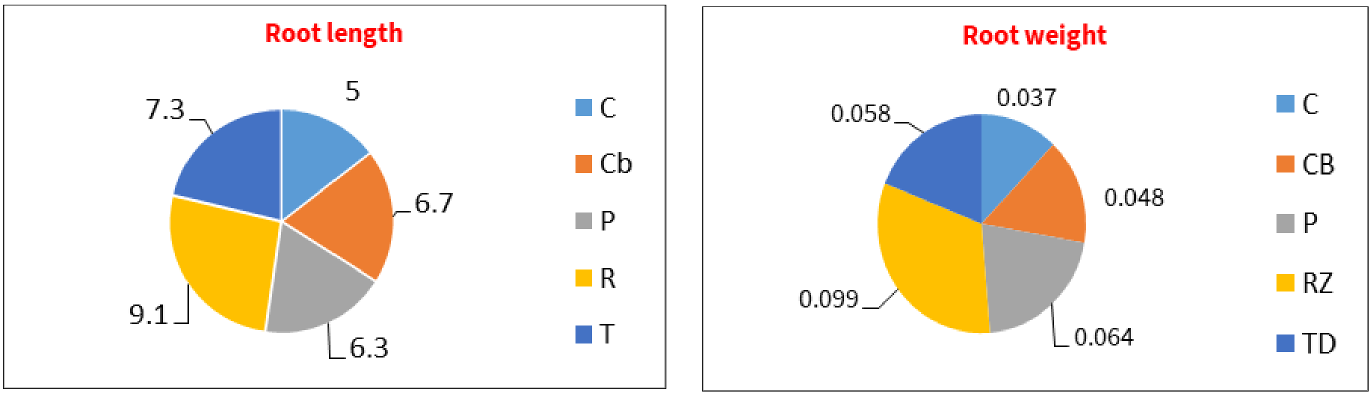

Fig. 2. Mean performance of mung bean genotypes for various seed priming agent on root traits.

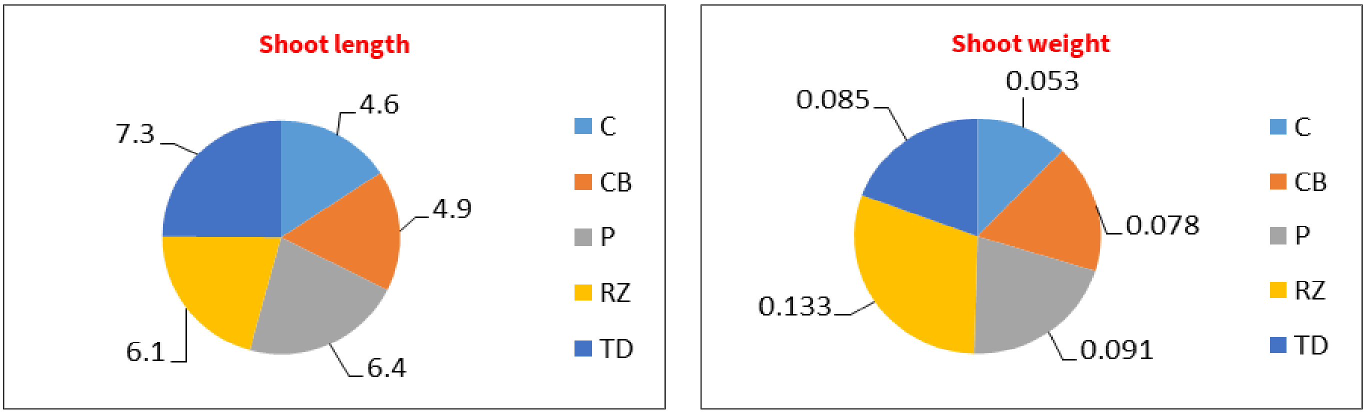

Fig. 3. Mean performance of mung bean genotypes for various seed priming agent on shoot traits.

Table 3. Mean performance of mung bean (*Vigna radiata*) genotypes for various seed priming agents on root traits

Genotype	Root length						Root weight					
	C	Cb	P	R	T	GT	C	Cb	P	R	T	GT
BARAMATI	3	4.8	4.2	7	5.2	4.8	0.019	0.028	0.032	0.073	0.041	0.039
COGG-8	5.1	6.8	6.5	9.3	7.4	7	0.058	0.063	0.072	0.124	0.083	0.08
EC-2511552	5.6	7.3	7.3	10.1	8.3	7.7	0.054	0.094	0.089	0.155	0.114	0.101
EC-30400	5.1	6.8	6.2	9	7.1	6.8	0.021	0.031	0.007	0.072	0.031	0.032
EC-393410	4.3	6.1	6.7	9.5	7.6	6.9	0.054	0.063	0.058	0.124	0.083	0.076
EC-399223	4.5	6.3	5.6	8.4	6.5	6.3	0.027	0.035	0.031	0.083	0.041	0.043
EC-470095	4.7	6.4	5.7	8.5	6.6	6.4	0.021	0.032	0.027	0.093	0.052	0.045
EC-5815	5	6.7	7.9	10.6	8.8	7.8	0.069	0.094	0.112	0.155	0.114	0.109
EC-581523-B	4.9	6.6	4.8	7.5	5.7	5.9	0.021	0.036	0.017	0.083	0.04	0.039
GM-11-02	5.1	6.8	6.2	9	7.1	6.8	0.014	0.02	0.035	0.073	0.041	0.037
HUM-16	4.5	6.3	5.9	8.7	6.8	6.4	0.028	0.032	0.034	0.083	0.041	0.044
IC-10187	4.9	6.6	6	8.8	6.9	6.6	0.021	0.041	0.036	0.072	0.031	0.04
IC-102913	5.3	7	6.6	9.4	7.5	7.2	0.03	0.042	0.052	0.103	0.062	0.058
IC-10503	6.7	8.5	8.3	11.1	9.2	8.7	0.032	0.053	0.048	0.114	0.072	0.064
IC-1082	6.1	7.9	7.4	10.2	8.4	8	0.026	0.073	0.069	0.134	0.093	0.079
IC-148446	4.4	6.2	5.6	8.4	6.5	6.2	0.022	0.048	0.029	0.067	0.032	0.04
IC-252008	5	6.7	6.3	9.1	7.2	6.9	0.021	0.033	0.021	0.072	0.031	0.036
IC-252012	3.9	5.7	5.1	7.9	6	5.7	0.01	0.027	0.014	0.062	0.021	0.027
IC-272613	4.9	6.6	6.1	8.9	7	6.7	0.021	0.032	0.031	0.072	0.031	0.037
IC-282082	5.2	6.9	6.4	9.2	7.3	7	0.031	0.052	0.034	0.083	0.041	0.048
IC-285532	3.8	5.6	5.3	8.1	6.2	5.8	0.01	0.022	0.023	0.062	0.021	0.028
IC-305241	5	6.7	6.3	9.1	7.2	6.9	0.031	0.044	0.031	0.083	0.041	0.046
IC-305249	7.1	8.9	8.7	11.5	9.6	9.2	0.033	0.075	0.053	0.155	0.114	0.086
IC-305284	5.6	7.3	6.6	9.4	7.5	7.3	0.021	0.032	0.044	0.093	0.042	0.046
IC-305291	6.4	8.2	7.9	10.6	8.8	8.4	0.025	0.032	0.041	0.083	0.052	0.047
IC-314970	5.1	6.8	6.5	9.3	7.4	7	0.021	0.038	0.031	0.083	0.041	0.043
IC-325853	5	6.7	6	8.8	6.9	6.7	0.016	0.031	0.041	0.093	0.052	0.047
IC-343935	5.5	7.2	6.6	9.4	7.5	7.3	0.028	0.038	0.041	0.093	0.052	0.05
IC-397142	6.4	8.2	7.8	10.5	8.7	8.3	0.024	0.035	0.041	0.093	0.052	0.049
IC-398746	5.6	7.3	6.9	9.7	7.9	7.5	0.036	0.042	0.052	0.103	0.062	0.059
IC-420310	4.8	6.5	6.3	9.1	7.2	6.8	0.015	0.024	0.021	0.072	0.031	0.033
IC-420329	6	7.8	7.2	10	8.2	7.8	0.026	0.053	0.062	0.114	0.072	0.065
IC-436932	4.1	5.9	5.5	8.3	6.4	6	0.011	0.023	0.01	0.062	0.021	0.025
IC-451184	6.2	8	7.6	10.4	8.6	8.2	0.026	0.069	0.072	0.124	0.083	0.075
IC-541822	4	5.8	5.4	8.2	6.3	5.9	0.012	0.03	0.032	0.062	0.021	0.031
IC-541824	5.5	7.2	7	9.8	8	7.5	0.035	0.052	0.051	0.093	0.052	0.057
IC-541825	5	6.7	6.3	9.1	7.2	6.9	0.015	0.021	0.021	0.072	0.031	0.032
IC-541828	5.7	7.4	7	9.8	8	7.6	0.022	0.043	0.052	0.103	0.062	0.056
IC-546476	6.1	7.9	7.5	10.3	8.5	8.1	0.025	0.052	0.052	0.103	0.062	0.059
IC-55494	5.8	7.5	7.2	10	8.2	7.8	0.031	0.046	0.052	0.103	0.062	0.059
IC-555219	4.9	6.6	6.3	9.1	7.2	6.8	0.035	0.046	0.031	0.083	0.041	0.047
IC-76322	6.6	8.4	8.1	10.9	9	8.6	0.026	0.059	0.062	0.114	0.072	0.067
IC-76338	5.5	7.2	6.6	9.4	7.5	7.3	0.042	0.061	0.084	0.093	0.052	0.066
IC-763502	5.5	7.2	7	9.8	8	7.5	0.053	0.062	0.085	0.114	0.072	0.077
IC-76361	6.3	8.1	7.4	10.2	8.4	8.1	0.073	0.083	0.106	0.134	0.093	0.098
IC-76366	3.9	5.7	5.1	7.9	6	5.7	0.011	0.033	0.044	0.072	0.031	0.036
IC-76370	6.2	8	7.6	10.4	8.6	8.2	0.042	0.052	0.075	0.103	0.062	0.067
IC-76377	5.7	7.4	7.1	9.9	8.1	7.6	0.042	0.052	0.075	0.103	0.062	0.067
IC-76378	5.6	7.3	7.1	9.9	8.1	7.6	0.042	0.052	0.075	0.103	0.062	0.067
IC-76414	5.5	7.2	6.6	9.4	7.5	7.3	0.032	0.041	0.064	0.093	0.052	0.056
IC-76418	5.5	7.2	6.8	9.6	7.8	7.4	0.042	0.052	0.075	0.103	0.062	0.067
IC-76444	4	5.8	5.4	8.2	6.3	5.9	0.021	0.046	0.069	0.062	0.021	0.044
IC-76448	4.7	6.4	6.1	8.9	7	6.6	0.032	0.041	0.064	0.093	0.052	0.056
IC-76453	5.6	7.3	6.9	9.7	7.9	7.5	0.042	0.052	0.075	0.103	0.062	0.067
IC-76463	6.5	8.3	7.9	10.6	8.8	8.4	0.063	0.072	0.095	0.124	0.083	0.087
IC-76464	4.7	6.4	5.8	8.6	6.7	6.4	0.011	0.021	0.044	0.072	0.031	0.036
IC-76474	5.8	7.5	7.2	10	8.2	7.8	0.042	0.052	0.075	0.103	0.062	0.067
IC-76476	6.6	8.4	8.4	11.2	9.3	8.8	0.073	0.083	0.106	0.134	0.093	0.098
IC-8422	6.6	8.4	8.1	10.9	9	8.6	0.063	0.072	0.095	0.124	0.083	0.087

IC-8915	4.4	6.2	5.6	8.4	6.5	6.2	0.022	0.031	0.054	0.083	0.041	0.046
IC-8925	6.6	8.4	8.3	11.1	9.2	8.7	0.053	0.062	0.085	0.114	0.072	0.077
IMB-13	3.7	5.5	3.8	7.6	5.8	5.3	0.031	0.021	0.044	0.078	0.081	0.051
IMB-131	4.1	5.9	5.2	8	6.1	5.8	0.036	0.024	0.047	0.072	0.061	0.048
IMB-37	4.7	6.4	6	8.8	6.9	6.6	0.032	0.041	0.064	0.093	0.052	0.056
IPM-0203	5.6	7.3	7	9.8	8	7.5	0.073	0.083	0.106	0.134	0.093	0.098
IPM-205	5.5	7.2	6.7	9.5	7.6	7.3	0.073	0.083	0.106	0.134	0.093	0.098
IPM-99-125	2.7	4.4	3.9	6.7	4.9	4.5	0.017	0.033	0.044	0.072	0.031	0.036
KDMB-1	5.6	7.3	6.9	9.7	7.9	7.5	0.042	0.052	0.075	0.103	0.062	0.067
KDMB-10	5.5	7.2	6.7	9.5	7.6	7.3	0.042	0.052	0.075	0.103	0.062	0.067
KDMB-11	4.5	6.3	6	8.8	6.9	6.5	0.032	0.041	0.064	0.093	0.052	0.056
KDMB-12	6.7	8.5	8.2	11	9.1	8.7	0.094	0.103	0.126	0.155	0.114	0.118
KDMB-13	3.1	4.9	4.3	7.1	5.3	4.9	0.011	0.021	0.044	0.072	0.031	0.036
KDMB-14	5.5	7.2	6.8	9.6	7.8	7.4	0.063	0.072	0.095	0.124	0.083	0.087
KDMB-15	4.8	6.5	6	8.8	6.9	6.6	0.032	0.041	0.064	0.093	0.052	0.056
KDMB-16	5.8	7.5	7.1	9.9	8.1	7.7	0.053	0.062	0.085	0.114	0.072	0.077
KDMB-17	4.1	5.9	5.4	8.2	6.3	6	0.022	0.031	0.054	0.083	0.041	0.046
KDMB-18	4.2	6	5.4	8.2	6.3	6	0.022	0.031	0.054	0.083	0.041	0.046
KDMB-19	5.7	7.4	6.8	9.6	7.8	7.5	0.063	0.072	0.095	0.124	0.083	0.087
KDMB-2	5.7	7.4	7	9.8	8	7.6	0.042	0.052	0.075	0.103	0.062	0.067
KDMB-20	4	5.8	5.2	8	6.1	5.8	0.022	0.031	0.054	0.083	0.041	0.046
KDMB-21	4.7	6.4	6	8.8	6.9	6.6	0.022	0.031	0.054	0.083	0.041	0.046
KDMB-22	6.6	8.4	8.3	11.1	9.2	8.7	0.076	0.103	0.126	0.155	0.114	0.118
KDMB-23	5	6.7	6.1	8.9	7	6.7	0.032	0.041	0.064	0.093	0.052	0.056
KDMB-25	6	7.8	7.2	10	8.2	7.8	0.073	0.083	0.106	0.134	0.093	0.098
KDMB-26	3.8	5.6	5.1	7.9	6	5.7	0.032	0.041	0.064	0.093	0.052	0.056
KDMB-27	5.4	7.1	6.7	9.5	7.6	7.3	0.042	0.052	0.067	0.103	0.062	0.065
KDMB-28	4.8	6.5	5.9	8.7	6.8	6.5	0.032	0.041	0.057	0.093	0.052	0.055
KDMB-29	4.2	6	5.4	8.2	6.3	6	0.022	0.031	0.078	0.083	0.041	0.051
KDMB-3	5.2	6.9	6.5	9.3	7.4	7.1	0.042	0.052	0.057	0.103	0.062	0.063
KDMB-30	4.7	6.4	5.8	8.6	6.7	6.4	0.022	0.031	0.119	0.083	0.041	0.059
KDMB-35	6.7	8.5	8.1	10.9	9	8.6	0.084	0.093	0.036	0.145	0.103	0.092
KDMB-4	2.9	4.7	3.8	6.6	4.8	4.5	0.023	0.044	0.036	0.062	0.021	0.028
KDMB-5	3	4.8	4.2	7	5.2	4.8	0.031	0.043	0.036	0.062	0.021	0.028
KDMB-6	3.8	5.6	5.1	7.9	6	5.7	0.027	0.051	0.119	0.062	0.021	0.044
KDMB-7	6.3	8.1	7.9	10.6	8.8	8.3	0.064	0.093	0.078	0.145	0.103	0.101
KDMB-8	5.4	7.1	6.6	9.4	7.5	7.2	0.042	0.052	0.088	0.103	0.062	0.069
KDMB-9	5	6.7	6.4	9.2	7.3	6.9	0.053	0.062	0.098	0.114	0.072	0.08
KM-2241	4.4	6.2	7.1	9.9	8.1	7.2	0.063	0.072	0.129	0.124	0.083	0.094
LGG-460	4.8	6.5	7.6	10.4	8.6	7.6	0.084	0.103	0.098	0.155	0.114	0.113
M-365	4.7	6.4	6	8.8	6.9	6.6	0.063	0.072	0.067	0.124	0.083	0.082
MH-1010	4.2	6	5.7	8.5	6.6	6.2	0.032	0.041	0.057	0.093	0.052	0.055
MH-421	5	6.7	6.2	9	7.1	6.8	0.022	0.031	0.067	0.083	0.041	0.049
MH-534	4.9	6.6	6	8.8	6.9	6.6	0.032	0.041	0.036	0.093	0.052	0.051
MH-539	2.9	4.7	4.1	6.9	5.1	4.7	0.023	0.04	0.047	0.062	0.021	0.033
MH-560	4.9	6.6	5.2	8	6.1	6.1	0.011	0.028	0.067	0.072	0.031	0.041
MH-919	3.6	5.4	4.9	7.6	5.8	5.5	0.032	0.041	0.036	0.093	0.052	0.051
MH-925	3	4.8	4	6.8	5	4.7	0.023	0.044	0.119	0.062	0.021	0.044
ML-2037	5.4	7.1	7.6	10.4	8.6	7.8	0.084	0.093	0.057	0.145	0.103	0.096
P-0672	3.4	5.2	4.9	7.6	5.8	5.4	0.022	0.031	0.047	0.083	0.041	0.045
Pant moong-5	3.4	5.2	4.5	7.3	5.5	5.2	0.011	0.021	0.036	0.072	0.031	0.034
PKV-AKM-4	3.6	5.4	4.7	7.4	5.6	5.3	0.026	0.048	0.036	0.062	0.021	0.028
PM-14-3	4.8	6.5	6.2	9	7.1	6.7	0.022	0.057	0.098	0.062	0.021	0.04
Pusa Mishal	6	7.8	7.1	9.9	8.1	7.8	0.063	0.072	0.047	0.124	0.083	0.078
Pusa Ratna	3.7	5.5	5.1	7.9	6	5.6	0.011	0.031	0.098	0.072	0.031	0.047
Pusa-95	4.2	6	6.8	9.6	7.8	6.9	0.063	0.072	0.078	0.124	0.083	0.084
RMG-268	5.9	7.6	7	9.8	8	7.7	0.042	0.052	0.098	0.103	0.062	0.071
SAMRAT	4.8	6.5	6.7	9.5	7.6	7	0.063	0.072	0.047	0.124	0.083	0.078
Satya-MH2-15	4.9	6.6	6	8.8	6.9	6.6	0.041	0.021	0.15	0.072	0.031	0.057
SM1	6.1	7.9	8.6	11.4	9.5	8.7	0.083	0.124	0.098	0.176	0.134	0.123
SM2	4.4	6.2	5.9	8.7	6.8	6.4	0.063	0.072	0.057	0.124	0.083	0.08
SML-1018	4.5	6.3	5.8	8.6	6.7	6.4	0.022	0.031	0.088	0.083	0.041	0.053
SML-1817	4.9	6.6	6.1	8.9	7	6.7	0.053	0.062	0.109	0.114	0.072	0.082
SML-668	5.6	7.3	6.8	9.6	7.8	7.4	0.073	0.083	0.088	0.134	0.093	0.094
SML-832	6.5	8.3	7.6	10.4	8.6	8.3	0.053	0.062	0.067	0.114	0.072	0.074
Mean	**5.0^{a}**	**6.7^{b}**	**6.3^{c}**	**9.1^{d}**	**7.3^{e}**		**0.037^{a}**	**0.048^{b}**	**0.064^{c}**	**0.099^{d}**	**0.058^{e}**	

C= Control, Cb= *Carbendazium,* P= *Pseudomonas,* R= *Rhizobium,* T= *Trichoderma,* GT= Grand total

For both traits, all five treatments (a-e) differed significantly from each other at the chosen significance level ($P \leq 0.05$)

Table 4. Mean performance of mung bean (*Vigna radiata*) genotypes for various seed priming agents on shoot traits

Genotype	Shoot length						Shoot weight					
	C	Cb	P	R	T	GT	C	Cb	P	R	T	GT
BARAMATI	2.6	2.9	4.2	4.1	5.2	3.8	0.041	0.055	0.082	0.114	0.072	0.073
C0GG-8	4.9	5.2	6.5	6.4	7.4	6.1	0.083	0.097	0.124	0.155	0.093	0.11
EC-2511552	5.7	6	7.3	7.2	8.3	6.9	0.114	0.128	0.155	0.186	0.114	0.139
EC-30400	4.4	4.8	6.2	6	7.1	5.7	0.031	0.045	0.072	0.103	0.062	0.063
EC-393410	5	5.3	6.7	6.5	7.6	6.2	0.083	0.097	0.124	0.155	0.093	0.11
EC-399223	3.8	4.1	5.6	5.4	6.5	5.1	0.041	0.055	0.082	0.114	0.062	0.071
EC-470095	4	4.3	5.7	5.6	6.6	5.2	0.052	0.066	0.093	0.124	0.072	0.081
EC-5815	6.1	6.4	7.9	7.6	8.8	7.4	0.114	0.128	0.155	0.186	0.124	0.141
EC-581523-B	3	3.3	4.8	4.5	5.7	4.3	0.041	0.055	0.082	0.114	0.072	0.073
GM-11-02	4.4	4.8	6.2	6	7.1	5.7	0.041	0.055	0.082	0.114	0.072	0.073
HUM-16	4.1	4.4	5.9	5.7	6.8	5.4	0.041	0.055	0.082	0.114	0.072	0.073
IC-10187	4	4.3	6	5.6	6.9	5.4	0.041	0.055	0.082	0.114	0.072	0.073
IC-102913	4.7	5	6.6	6.2	7.5	6	0.072	0.086	0.113	0.145	0.093	0.102
IC-10503	6.3	6.6	8.3	7.9	9.2	7.6	0.083	0.097	0.124	0.155	0.103	0.112
IC-1082	5.7	6	7.4	7.2	8.4	6.9	0.093	0.107	0.134	0.165	0.103	0.12
IC-148446	3.6	3.9	5.6	5.2	6.5	5	0.041	0.055	0.082	0.114	0.072	0.073
IC-252008	4.3	4.7	6.3	5.9	7.2	5.7	0.041	0.055	0.082	0.114	0.072	0.073
IC-252012	3.1	3.4	5.1	4.7	6	4.4	0.031	0.045	0.072	0.103	0.062	0.063
IC-272613	4.1	4.4	6.1	5.7	7	5.5	0.041	0.055	0.082	0.114	0.072	0.073
IC-282082	4.4	4.8	6.4	6	7.3	5.8	0.052	0.066	0.093	0.124	0.083	0.084
IC-285532	3.3	3.6	5.3	4.9	6.2	4.7	0.031	0.045	0.072	0.103	0.062	0.063
IC-305241	4.3	4.7	6.3	5.9	7.2	5.7	0.052	0.066	0.093	0.124	0.083	0.084
IC-305249	6.7	7	8.7	8.3	9.6	8.1	0.124	0.138	0.165	0.196	0.134	0.151
IC-305284	4.7	5	6.6	6.2	7.5	6	0.062	0.076	0.103	0.134	0.093	0.094
IC-305291	5.9	6.2	7.9	7.4	8.8	7.2	0.062	0.076	0.103	0.134	0.093	0.094
IC-314970	4.5	4.9	6.5	6.1	7.4	5.9	0.052	0.066	0.093	0.124	0.083	0.084
IC-325853	4.2	4.5	6	5.8	6.9	5.5	0.052	0.066	0.093	0.124	0.083	0.084
IC-343935	4.7	5	6.6	6.2	7.5	6	0.062	0.076	0.103	0.134	0.093	0.094
IC-397142	5.8	6.1	7.8	7.3	8.7	7.1	0.062	0.076	0.103	0.134	0.083	0.092
IC-398746	5	5.3	6.9	6.5	7.9	6.3	0.072	0.086	0.113	0.145	0.103	0.104
IC-420310	4.3	4.7	6.3	5.9	7.2	5.7	0.041	0.055	0.082	0.114	0.072	0.073
IC-420329	5.3	5.6	7.2	6.8	8.2	6.6	0.083	0.097	0.124	0.155	0.103	0.112
IC-436932	3.5	3.8	5.5	5.1	6.4	4.9	0.031	0.045	0.072	0.103	0.062	0.063
IC-451184	5.7	6	7.6	7.2	8.6	7	0.093	0.107	0.134	0.165	0.114	0.123
IC-541822	3.4	3.7	5.4	5	6.3	4.8	0.031	0.045	0.072	0.103	0.062	0.063
IC-541824	5.1	5.4	7	6.6	8	6.4	0.062	0.076	0.103	0.134	0.093	0.094
IC-541825	4.3	4.7	6.3	5.9	7.2	5.7	0.041	0.055	0.082	0.114	0.072	0.073
IC-541828	5.1	5.4	7	6.6	8	6.4	0.072	0.086	0.113	0.145	0.103	0.104
IC-546476	5.6	5.9	7.5	7.1	8.5	6.9	0.072	0.086	0.113	0.145	0.093	0.102
IC-55494	5.3	5.6	7.2	6.8	8.2	6.6	0.072	0.086	0.113	0.145	0.103	0.104
IC-555219	4.3	4.7	6.3	5.9	7.2	5.7	0.052	0.066	0.093	0.124	0.083	0.084
IC-76322	6.1	6.4	8.1	7.6	9	7.4	0.083	0.097	0.124	0.155	0.093	0.11
IC-76338	4.7	5	6.6	6.2	7.5	6	0.062	0.097	0.103	0.134	0.093	0.098
IC-763502	5.3	5.6	7	6.8	8	6.5	0.042	0.076	0.113	0.145	0.093	0.094
IC-76361	5.7	6	7.4	7.2	8.4	6.9	0.053	0.086	0.134	0.165	0.114	0.11
IC-76366	3.3	3.6	5.1	4.9	6	4.6	0.031	0.055	0.072	0.103	0.062	0.065
IC-76370	5.7	6	7.6	7.2	8.6	7	0.034	0.065	0.113	0.145	0.083	0.088
IC-76377	5.4	5.7	7.1	6.9	8.1	6.6	0.062	0.086	0.103	0.134	0.083	0.094
IC-76378	5.4	5.7	7.1	6.9	8.1	6.6	0.062	0.076	0.103	0.134	0.093	0.094
IC-76414	4.7	5	6.6	6.2	7.5	6	0.062	0.076	0.103	0.134	0.083	0.092
IC-76418	4.9	5.2	6.8	6.4	7.8	6.2	0.072	0.076	0.113	0.145	0.103	0.102
IC-76444	3.4	3.7	5.4	5	6.3	4.8	0.031	0.086	0.072	0.103	0.062	0.071
IC-76448	4.3	4.7	6.1	5.9	7	5.6	0.052	0.045	0.093	0.124	0.083	0.079
IC-76453	5	5.3	6.9	6.5	7.9	6.3	0.032	0.066	0.113	0.145	0.103	0.092
IC-76463	5.9	6.2	7.9	7.4	8.8	7.2	0.053	0.086	0.134	0.165	0.114	0.11
IC-76464	3.8	4.1	5.8	5.4	6.7	5.2	0.041	0.107	0.082	0.114	0.072	0.083
IC-76474	5.3	5.6	7.2	6.8	8.2	6.6	0.072	0.055	0.113	0.145	0.093	0.096
IC-76476	6.4	6.7	8.4	8	9.3	7.8	0.067	0.086	0.144	0.176	0.114	0.117
IC-8422	6.1	6.4	8.1	7.6	9	7.4	0.093	0.117	0.134	0.165	0.103	0.122
IC-8915	3.6	3.9	5.6	5.2	6.5	5	0.052	0.107	0.093	0.124	0.083	0.092
IC-8925	6.3	6.6	8.3	7.9	9.2	7.6	0.033	0.066	0.124	0.155	0.093	0.094
IMB-13	3.1	3.4	3.8	4.7	5.8	4.2	0.031	0.057	0.072	0.103	0.062	0.065
IMB-131	3.4	3.7	5.2	5	6.1	4.7	0.031	0.045	0.072	0.103	0.062	0.063

IMB-37	4.2	4.5	6	5.8	6.9	5.5	0.042	0.065	0.093	0.124	0.083	0.081
IPM-0203	5.4	5.7	7	6.9	8	6.6	0.093	0.066	0.134	0.165	0.093	0.11
IPM-205	5.1	5.4	6.7	6.6	7.6	6.3	0.093	0.107	0.134	0.165	0.103	0.12
IPM-99-125	2.3	2.6	3.9	3.8	4.9	3.5	0.031	0.056	0.072	0.103	0.072	0.067
KDMB-1	5.2	5.5	6.9	6.7	7.9	6.4	0.045	0.063	0.103	0.134	0.083	0.086
KDMB-10	5	5.3	6.7	6.5	7.6	6.2	0.051	0.076	0.103	0.134	0.093	0.091
KDMB-11	4.2	4.5	6	5.8	6.9	5.5	0.052	0.076	0.093	0.124	0.083	0.086
KDMB-12	6.4	6.7	8.2	8	9.1	7.7	0.024	0.066	0.155	0.186	0.124	0.111
KDMB-13	2.6	2.9	4.3	4.1	5.3	3.8	0.031	0.068	0.072	0.103	0.062	0.067
KDMB-14	5.1	5.4	6.8	6.6	7.8	6.3	0.043	0.085	0.124	0.155	0.093	0.1
KDMB-15	4.2	4.5	6	5.8	6.9	5.5	0.052	0.097	0.093	0.124	0.083	0.09
KDMB-16	5.4	5.7	7.1	6.9	8.1	6.6	0.046	0.066	0.113	0.145	0.093	0.093
KDMB-17	3.6	3.9	5.4	5.2	6.3	4.9	0.041	0.086	0.082	0.114	0.072	0.079
KDMB-18	3.6	3.9	5.4	5.2	6.3	4.9	0.041	0.055	0.082	0.114	0.072	0.073
KDMB-19	5.1	5.4	6.8	6.6	7.8	6.3	0.083	0.115	0.124	0.155	0.093	0.114
KDMB-2	5.3	5.6	7	6.8	8	6.5	0.062	0.097	0.103	0.134	0.072	0.094
KDMB-20	3.4	3.7	5.2	5	6.1	4.7	0.041	0.076	0.082	0.114	0.072	0.077
KDMB-21	4.2	4.5	6	5.8	6.9	5.5	0.041	0.055	0.082	0.114	0.072	0.073
KDMB-22	6.5	6.8	8.3	8.1	9.2	7.8	0.114	0.055	0.155	0.186	0.124	0.127
KDMB-23	4.3	4.7	6.1	5.9	7	5.6	0.052	0.064	0.093	0.124	0.083	0.083
KDMB-25	5.5	5.8	7.2	7	8.2	6.7	0.093	0.066	0.134	0.165	0.103	0.112
KDMB-26	3.3	3.6	5.1	4.9	6	4.6	0.052	0.077	0.093	0.124	0.083	0.086
KDMB-27	5	5.3	6.7	6.5	7.6	6.2	0.062	0.083	0.062	0.134	0.083	0.085
KDMB-28	4.1	4.4	5.9	5.7	6.8	5.4	0.052	0.072	0.052	0.124	0.072	0.074
KDMB-29	3.6	3.9	5.4	5.2	6.3	4.9	0.041	0.062	0.052	0.114	0.072	0.068
KDMB-3	4.8	5.1	6.5	6.3	7.4	6	0.062	0.083	0.062	0.134	0.083	0.085
KDMB-30	4	4.3	5.8	5.6	6.7	5.3	0.041	0.062	0.052	0.114	0.072	0.068
KDMB-35	6.3	6.6	8.1	7.9	9	7.6	0.103	0.124	0.093	0.176	0.114	0.122
KDMB-4	2.1	2.4	3.8	3.6	4.8	3.3	0.021	0.041	0.031	0.093	0.052	0.048
KDMB-5	2.5	2.8	4.2	4	5.2	3.7	0.023	0.041	0.031	0.093	0.052	0.048
KDMB-6	3.3	3.6	5.1	4.9	6	4.6	0.026	0.041	0.031	0.093	0.052	0.049
KDMB-7	6.1	6.4	7.9	7.6	8.8	7.4	0.067	0.088	0.103	0.176	0.124	0.112
KDMB-8	4.9	5.2	6.6	6.4	7.5	6.1	0.062	0.083	0.062	0.134	0.083	0.085
KDMB-9	4.7	5	6.4	6.2	7.3	5.9	0.072	0.093	0.072	0.145	0.093	0.095
KM-2241	5.4	5.7	7.1	6.9	8.1	6.6	0.083	0.076	0.092	0.155	0.093	0.1
LGG-460	5.9	6.2	7.6	7.4	8.6	7.2	0.068	0.088	0.103	0.186	0.124	0.114
M-365	4.3	4.7	6	5.9	6.9	5.6	0.066	0.78	0.122	0.155	0.093	0.243
MH-1010	4	4.3	5.7	5.6	6.6	5.2	0.052	0.072	0.052	0.124	0.072	0.074
MH-421	4.4	4.8	6.2	6	7.1	5.7	0.041	0.062	0.062	0.114	0.083	0.072
MH-534	4.2	4.5	6	5.8	6.9	5.5	0.052	0.072	0.052	0.124	0.072	0.074
MH-539	2.4	2.7	4.1	3.9	5.1	3.6	0.021	0.041	0.031	0.093	0.052	0.048
MH-560	3.4	3.7	5.2	5	6.1	4.7	0.031	0.052	0.041	0.103	0.062	0.058
MH-919	3.2	3.5	4.9	4.8	5.8	4.4	0.052	0.072	0.062	0.124	0.083	0.079
MH-925	2.3	2.6	4	3.8	5	3.5	0.021	0.041	0.031	0.093	0.052	0.048
ML-2037	6	6.3	7.6	7.5	8.6	7.2	0.045	0.077	0.093	0.176	0.114	0.101
P-0672	3.2	3.5	4.9	4.8	5.8	4.4	0.041	0.062	0.041	0.114	0.062	0.064
Pant moong-5	2.9	3.2	4.5	4.4	5.5	4.1	0.031	0.052	0.041	0.103	0.062	0.058
PKV-AKM-4	2.9	3.2	4.7	4.4	5.6	4.2	0.021	0.041	0.067	0.09	0.052	0.054
PM-14-3	4.4	4.8	6.2	6	7.1	5.7	0.033	0.049	0.072	0.083	0.052	0.058
Pusa Mishal	5.4	5.7	7.1	6.9	8.1	6.6	0.053	0.077	0.083	0.155	0.103	0.094
Pusa Ratna	3.3	3.6	5.1	4.9	6	4.6	0.031	0.052	0.041	0.103	0.062	0.058
Pusa-95	5.1	5.4	6.8	6.6	7.8	6.3	0.054	0.066	0.072	0.155	0.093	0.088
RMG-268	5.3	5.6	7	6.8	8	6.5	0.042	0.057	0.072	0.134	0.093	0.08
SAMRAT	5	5.3	6.7	6.5	7.6	6.2	0.034	0.054	0.072	0.155	0.093	0.082
Satya-MH2-15	4.2	4.5	6	5.8	6.9	5.5	0.021	0.041	0.061	0.103	0.062	0.058
SM1	6.9	7.2	8.6	8.5	9.5	8.1	0.045	0.065	0.087	0.207	0.134	0.108
SM2	4.2	4.5	5.9	5.8	6.8	5.5	0.026	0.053	0.062	0.155	0.083	0.076
SML-1018	4	4.3	5.8	5.6	6.7	5.3	0.041	0.052	0.065	0.114	0.072	0.069
SML-1817	4.4	4.8	6.1	6	7	5.7	0.044	0.063	0.082	0.145	0.083	0.083
SML-668	5.2	5.5	6.8	6.7	7.8	6.4	0.041	0.065	0.083	0.165	0.103	0.091
SML-832	5.9	6.2	7.6	7.4	8.6	7.2	0.052	0.077	0.092	0.145	0.093	0.092
Mean	**4.6**^{a}	**4.9**^{b}	**6.4**^{c}	**6.1**^{d}	**7.3**^{e}		**0.053**^{a}	**0.078**^{b}	**0.091**^{c}	**0.133**^{d}	**0.085**^{e}	

C= Control, Cb= *Carbendazium,* P= *Pseudomonas,* R= *Rhizobium,* T= *Trichoderma,* GT= Grand total

For both traits, all five treatments (a-e) differed significantly from each other at the chosen significance level (P≤ 0.05) cm), whereas the lowest shoot length was consistently observed in the untreated control (4.6 cm). Genotype SM1 (8.6 cm under *Pseudomonas*, 8.5 cm under *Rhizobium* and 9.5 cm under *Trichoderma*), IC-305249 (9.6 cm under *Trichoderma*) and IC-76476 (9.3 cm under *Trichoderma*) were among the best performers. Conversely, genotypes such as KDMB-4 (2.1-4.8 cm across treatments), MH-539 (2.4-5.1 cm) and IPM-99-125 (2.3-4.9 cm) remained at the lower end of shoot length expression across treatments.

For shoot weight, the mean performance showed a similar trend, with values ranging from 0.053 g in control to 0.133 g in *Rhizobium* priming. The *Rhizobium* treatment (0.133 g) resulted in the highest average shoot biomass, followed by *Pseudomonas* (0.091 g) and *Trichoderma* (0.085 g). Superior genotypic responses were noted in IC-305249 (0.196 g under *Rhizobium*), IC-5815 (0.186 g under *Rhizobium*) and SM1 (0.207 g under *Rhizobium*), which substantially surpassed the grand mean (0.091 g). In contrast, genotypes like KDMB-4, MH-539 and MH-925 recorded minimal shoot weight (<0.05 g under control conditions).

Discussion

The assessment of hard seeds in mung bean (*Vigna radiata*) genotypes and the evaluation of seed priming effects are essential aspects of mung bean breeding and seed quality improvement (12). The presence of hard seeds is a critical factor in determining seed quality and germination potential (13). In this study, a standard germination test was conducted on mung bean seeds harvested in 2021 to assess the incidence of hard seeds. The results revealed that a certain percentage of seeds did not absorb water during the germination period, indicating the presence of hard seeds. This observation is consistent with previous studies on mung bean (14). The percentage of hard seeds was calculated for each genotype, providing valuable information about the variation in hard seededness among different mung bean genotypes. These findings are crucial for breeders and seed producers as they help identify genotypes with reduced hard seed content, which can enhance seed quality and germination rates (15). Storing seeds for extended periods while maintaining their viability is a common challenge in seed conservation and agriculture (16). Hard seed count increases with time due to gradual dehydration and structural hardening of the seed coat during storage. These changes reduce seed coat permeability and enhancing physical dormancy (17). This assessment provides awareness into seed longevity and the impact of storage conditions on seed quality. The results of this evaluation can guide seed storage practices to ensure seed viability over extended periods, which is particularly important for crop preservation and maintaining genetic resources (18).

Seed priming is a technique that involves pre-soaking seeds in various solutions to enhance germination and seedling growth (19). In this study, different priming agents, including hydro priming, *Rhizobium*, *Pseudomonas*, *Trichoderma* and *carbendazim*, were used to evaluate their impact on mung bean genotypes. The recorded traits, including root depth (cm), root weight (g), shoot length (cm) and shoot weight (g), provide valuable perceptions into the response of different genotypes to seed priming treatments. These findings can aid in optimizing seed priming protocols for specific genotypes and environmental conditions (20). The results presented in (Table 1, Fig. 1) and (Table 3 & Table 4, Fig. 2 and Fig. 3) provide comprehensive data on hard seededness and seed priming effects for different mung bean genotypes. This information is of great importance for mung bean breeders, seed producers and farmers. Future research in this field may focus on the molecular mechanisms underlying hard seed formation and the development of efficient priming protocols for mung bean genotypes under diverse environmental conditions. Additionally, studies on the genetic basis of seed quality traits can aid in marker-assisted breeding efforts to develop superior mung bean varieties with improved seed quality and germination characteristics (21).

In conclusion, the assessment of hard seeds and the evaluation of seed priming effects in mung bean genotypes are crucial steps in improving seed quality and crop performance. The results of these experiments provide valuable understandings into seed quality management and breeding strategies for mung bean production.

The significant variability observed among mung bean genotypes when subjected to various seed priming agents underscores the potential for optimizing seed priming protocols to enhance crop performance. Seed priming is a valuable technique for improving germination, seedling growth and overall crop productivity (22). Among the seed priming agents investigated, *Rhizobium* stands out as an effective agent in terms of root-related traits. It recorded the highest mean root depth at 9.1 cm, indicating that it promotes substantial root growth. Additionally, *Rhizobium* resulted in the maximum mean root weight of 0.099 g, further emphasizing its positive impact on root development. These findings are in line with previous research on *Rhizobium*'s role in enhancing root growth and nutrient uptake (23). *Trichoderma*, another seed priming agent, exhibited a notable effect on both root and shoot length. It recorded a mean root depth of 7.3 cm and a mean shoot length of 7.3 cm. This suggests that *Trichoderma* not only promotes root development but also enhances shoot growth, which is essential for crop establishment and yield potential (24). *Pseudomonas*, while not surpassing *Rhizobium* and *Trichoderma* in any single trait, displayed a beneficial impact on both root and shoot development. It recorded a mean root weight of 0.064 g and a mean shoot length of 6.4 centimeters. These results indicate that *Pseudomonas* can contribute to overall seedling vigor, which is crucial for early crop growth and stress tolerance (25). In terms of shoot weight, *Rhizobium* emerged as the most effective priming agent, with a recorded mean shoot weight of 0.133 g. This suggests that *Rhizobium* not only promotes root development but also leads to a substantial increase in shoot biomass (26). Increased shoot weight is often associated with improved photosynthesis and potential for higher crop yield (27). These findings have significant implications for mung bean cultivation and agriculture in general. Seed priming can be tailored to specific genotypes and environmental conditions to maximize crop performance (28). The selection of appropriate priming agents, such as *Rhizobium*, *Trichoderma*, or *Pseudomonas*, can contribute to enhanced root and shoot growth, ultimately leading to improved mung bean yields. Future research in this field may delve deeper into the molecular mechanisms underlying the positive effects of specific priming agents on mung bean genotypes. Additionally, studies on the long-term impact of seed priming on crop growth and yield under various environmental conditions could acknowledge for sustainable agriculture practices.

Conclusion

Significant variation was found across genotypes and treatments in the study on hard seededness and the impact of seed priming in mung beans (*Vigna radiata* L.). The genotype PKV-AKM-4 consistently had the highest hard seed count in both years, while there were notable differences in the number of hard seeds for two years. All priming agents showed statistically significant effects on plant features when it came to seed priming, although *Rhizobium* treatment performed better in terms of increasing root depth, root weight and shoot weight. While *Pseudomonas* also had a favorable influence on both shoot and root attributes, *Trichoderma* was more successful at increasing shoot length. These results demonstrate how seed priming, especially with *Rhizobium* and *Trichoderma*, can enhance the early growth traits of mung beans.

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Authors' contributions

AG helped with the design of the study, the analysis of the data and the manuscript's critical editing. The study was conceived and designed by AAL, PAS and MAW. ZAD and MAB gave their final approval for submission after thoroughly evaluating the final paper for intellectual content. FFW and LA, RK helped with the manuscript's formatting, data tabulation and literature review. MR helped with the creation of the figures and tables and laboratory analysis. FJW assisted with the composition of the findings and discussion sections and helped with statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

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

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