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AGRONOMIC PERFORMANCE AND SPROUTING QUALITY OF IMPROVED MUNGBEAN LINES IN MYANMAR

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SUMMARY

Mungbean is a pulse crop of economic importance in Myanmar. The susceptibility of current grown mungbean varieties to the Mungbean Yellow Mosaic Disease (MYMD), utilized in the high premium-sprout market segment, is a major concern. Field-testing of seven improved mungbean lines across six locations in Bago and Yangon regions ensued in the post monsoon season of 2021–2022 and across four locations in Magway, Naypyitaw, and Mandalay regions in the monsoon season of 2022. Two promising lines (AVMU 1688 and AVMU 1690), with known resistance to all known species of the viruses causing MYMD, were further tested during the pre-monsoon season of 2023 and confirmed for resistance to the MYMD. Both lines showed good performance for seed yield per plant (9.70–10.57 g/plant) and were early maturing (62–63 days) during the monsoon season. AVMU 1688 showed with sprouting quality similar to Yezin -1 and the commercial reference standard. The seed color and luster (green and shiny) also meet the market requirements of the grain market segment. Both AVMU 1688 and AVMU 1690 lines may proceed to testing for potential release as a variety or could serve as donor parents for resistance to MYMD in the National Breeding Program.

Keywords: Mungbean, mungbean yellow mosaic disease, GGE biplot, sprouting

Key findings: Among the seven improved mungbean lines with MYMD resistance, two lines, such as AVMU 1688 and AVMU 1690, exhibited good agronomic traits, including high seed yield per plant and early maturity, suitable for the monsoon season. Particularly, the AVMU 1688 is on par with Yezin 1 in meeting the market preference, with its good sprouting quality and shiny green seeds.

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INTRODUCTION

Mungbean (*Vigna radiata* [L.] R. Wilczek var. *radiata*), popularly known as green gram, is one of the important pulse crops and belongs to the Fabaceae family. In Myanmar, the crop cultivation as a cash crop covers about 1.15 million ha, with a total production of 1.45 million tons (Aung and Lee, 2021). Over 90% of the total production serves as overseas export or border trade, with markets extending especially in China, Vietnam, and EU countries, creating many opportunities for smallholder farmers (Department of Planning, 2021; MAOLI, 2019). The crop growing is typically during the pre-monsoon, monsoon, and post-monsoon seasons, depending on the varieties and land types.

Mungbean grains serve as a chief source of dietary protein (20%–30%), rich in iron (40–70 ppm), and other nutrients, thus, contribute to alleviating malnutrition in developing countries (Selvi *et al*., 2006; Vairam *et al*., 2016; Mishra *et al*., 2020; Somta *et al*., 2022). The use of dried seeds also has different versions of *dhal* or bean stew, sprouts, snacks, paste used in noodles, protein isolates, and protein concentrates (ACIAR, 2020; Nair and Schreinemachers, 2020). The mungbean sprout contains high vitamin C and folate serving many relishes in the Asian cuisine (Nair *et al.,* 2013b). Although, the area under mungbean production is increasing, still, the yield is low due to poor soil management and limited options for pest and disease control (Nair and Schreinemachers, 2020).

Mungbean Yellow Mosaic Disease (MYMD) caused by *Mungbean yellow mosaic virus* (MYMV) and *Mungbean yellow mosaic India virus* (MYMIV) is the most important constraint to mungbean production (Nariani, 1960; Qazi *et al*., 2007; Ilyas *et al*., 2010; Mishra *et al*., 2020; Singh *et al.,* 2022; Kohli *et al.*, 2024). The disease causes substantial yield loss and the incidence ranges from 10% to 100% depending on the mungbean genotype and stage of crop infection (Singh, 1980; Marimuthu *et al.,* 1981; Bashir *et al.*, 2006; Mishra *et al.,* 2020; Dasgupta *et al.,* 2021; Singh *et al.,* 2022). The demand for mungbeans and mungbean products is growing among European consumers following trends around healthy, organic, and plant-based foods.

Europe relies on Myanmar and Tanzania for the supply of mungbeans for the sprout market (CBI, 2023). In Myanmar, mungbean farmers are exporting their mungbean grains to high valued European market used for sprouts (ACIAR, 2020). However, two popular mungbean varieties, Yezin 1 and Yezin 9 cultivated in Myanmar suitable for the premium sprout market segment, are susceptible to MYMD, affecting the livelihoods of farmers reliant on mungbean production for export (Khaing *et al.,* 2013). The study sought to evaluate improved mungbean lines for their sprouting qualities and agronomic performance in Myanmar as part of a DANIDA (Danish International Development Agency) supported project on "Accelerating the Competitiveness and Inclusiveness of the Mungbean Value Chain in Myanmar (ACTIOM)."

MATERIALS AND METHODS

Agronomic evaluation

A set of seven mungbean advanced breeding lines along with two checks (Yezin-1 and Yezin-9) underwent evaluation across six locations in Bago and Yangon regions of Myanmar (Table 1). The trials conducted at two locations in the Bago region included the Mu Du Village, Kawa Township (17° 05′ 23″N, 96° 27′ 59″E, and ASL = 6 m) and the Naung Pat Ta Ya Village, Waw Township (17° 30′ 14.62″ N, 96° 44′ 47.4″ E, and ASL = 10 m). Trials occurred at four locations in the Yangon region—Nyaung Pin Kwin Village, Khayan Township (16° 46′ 0″ N, 96° 32′ 0″ E, and ASL = 12.67 m), Kyon Kan Village, Kyauktan Township (16° 38′ 17″N, 96° 19′ 22″E, and ASL = 26 m), Pyin Ma Kan Village, Thongwa Township (16° 41′ 0″N, 96° 32′ 0″E, and ASL = 8.73 m), and Thu Htay Kwin Village, Thanlyin Township (16° 44′ 0″N, 96° 15′ 0″E, and ASL = 21 m). All trials happened during the post-monsoon season (November 2021 to February 2022). The trials

Table 1. Pedigree of the improved mungbean lines utilized in the study.

Mungbean Line	Pedigree
AVMU-1631	NM94 x V04718
AVMU-1632	NM94 x V04718
AVMU-1642	NM94 x V04718
AVMU-1643	NM94 x V04718
AVMU-1659	VR 2012-18 x VR 2012-19
AVMU-1688	NM 94 x ML 1628
AVMU-1690	NM 94 x ML 1628

comprised randomized complete block design (RCBD) with three replications. All the planted lines were in five rows of 5 m length with 45 cm and 10 cm inter-and intra-row spacing, respectively (plot size: 5m × 2.25 m). Pendimethalin 33% EC served as a pre-emergent herbicide (2500 cc/ha), and the applied fertilizers consisted of a basal dose—urea (12 kg/ha); triple super phosphate (125 kg/ha); and muriate of potash (63 kg/ha) and foliar application—10:60:40 (N:P:K – 2500 ml/ha).

During the monsoon season (May to September 2022), the same set of materials gained assessment across four locations: Hlaywunn Village, Sinbaungwe Township, Magway Region (19° 37′ 26″N, 95° 21′ 24″E, and ASL = 48 m), Yae Pyayt Village, Taungdwingyi Township, Magway Region (19° 49′ 15″N, 95° 33′ 55″E, and ASL = 138 m), Thabyebin Village, Zayyarthiri Township, Naypyitaw (19°44′42″N, 96°07′46″E, and ASL = 115 m), Pankhwar Village, Kyaukse, Mandalay Region (21°36′35.39″N, 96°8′2.91″E, and ASL = 88.6 m). The trials continued in RCBD with three replications, with all the lines planted in five rows of 5 m length with 45 cm and 10 cm inter-and intra-row spacing, respectively (plot size: 5 m × 2.25 m). Pendimethalin 33% EC served as a pre-emergent herbicide (2500 cc/ha). Fertilizer application included a basal dose—urea (12 kg/ha); triple super phosphate (125 kg/ha); and muriate of potash (63 kg/ha) and foliar application—10:60:40 (N:P:K – 2500 ml /ha).

Data collection in the above field trials consisted of the following: the number of days to flowering—collected only during the post monsoon season (number of days from planting to when at least 50% of the plants in a plot have at least one unopened flower), plant height (recorded on five randomly sampled plants per plot at physiological maturity), days to maturity (days from sowing to when 90% of pods in a plot changed color to black or brown), pod yield per plant (mean weight for all pods measured from five randomly selected plants), pod number (mean number of pods from five random plants per plot), pod length (mean length measured from five randomly selected pods from each plant up to five plants), number of seeds per pod (mean number of seeds counted from five randomly selected pods from each plant up to five plants), 100 seed weight (weight of 100 randomly selected seeds), and seed yield per plant (mean weight for all seeds measured from five randomly selected plants).

Evaluation for resistance to MYMD

With no incidence of MYMD during the post-monsoon and monsoon trials, the inclusion of two selected mungbean lines (AVMU 1688 and AVMU 1690) and other four check varieties (Yezin 11, Yezin 14, Yezin 15, and Yezin 16) in an evaluation trial during the pre-monsoon (February-May) season during 2023 at Yezin (19° 49.735′N, 96° 15.799′97 E, and ASL = 97 m) helped confirm the resistance to MYMD. Both these lines showed good performance for seed yield per plant and were early maturing during the monsoon season. More importantly, both AVMU 1688 and AVMU 1690 resulted from crosses with ML 1628 as one of the parents. Reports of ML 1628 indicated to have resistance to all known species of viruses causing MYMD (Nair *et al.,* 2017). Disease rating scale used ranged from 0 to 5 (Bashir et al., 1987).

Sprouting quality evaluation

Sprouting quality of the mungbean lines attained testing in 2022 by Evers Specials in the Netherlands. Seed multiplication of nine selected lines ensued in Myanmar and shipped to the Netherlands. A sprouting trial transpired to evaluate the sprout quality. The selected nine lines' testing had a commercial variety from Myanmar used in Evers Specials as reference. Propagating the beans in stainless steel crates occurred for seven days. The growing condition was the same as the normal commercial production (22 °C–28 °C growing temperature, kept at 100% moisture in a dark room). After harvesting the sprouts manually, the expert staff observed the sprout quality.

The sprout quality evaluation relied on six points, as follows: 1. An overall bright white color; 2. Short roots are light brownish; 3. Small leaves are light yellow; 4. Cotyledons have fallen off; 5. Sprouts are crispy with a sweet taste; and 6. Free from rotten or diseased sprouts.

Additionally, the bean size and 100 seed weight testing showed as a reflection of bean quality. For each genotype, the following steps continued: 100 grams of beans randomly taken and sieved with 3, 3.5, 4, and 4.5 mm sieve, with the weight of beans of each size range measured. Regarding the 100 seed weight, having two replicates for each genotype comprised randomly choosing and weighing each replicate of 100 beans.

Statistical analysis

The combined analysis of variance (ANOVA) tested the significance of main and interaction effects of lines and locations using mixed models, considering the genotype, locations, and design factor of replication as fixed (type3) effects. Individual location variances estimation and modelling for error distribution used the Residual Maximum Likelihood (REML) using the SAS mixed procedure (SAS Institute Inc., 2018). Approximates of the Best Linear Unbiased Estimates (BLUEs) for main and interaction effects of genotype and location came from the combined ANOVA.

Broad-sense heritability calculation for the combined data used the below formula:

$$H^2 = \sigma_g{}^2/(\sigma_g{}^2 + \left(\sigma_{gxl}{}^2/l\right) + (\sigma_e{}^2/r * l))$$

Where, *r* and *l* are number of replications and number of locations.

The GGE biplot visualization (VSN International, 2022) is an effective tool for mega-environment analysis, genotype evaluation, and environment assessment (Vemula and Parthasarathy, 2023). The Genotype + Genotype × Environment (GGE) biplot graphically displays G plus GE of a multienvironment trial in a way that it facilitates visual cultivar evaluation and assesses relative stability of test lines (Yan *et al*., 2000). Developing GGE biplots employed the plot wise mean data in R studio. GGE biplot resulted from the following model:

$$Yij - Yi = \lambda 1 \alpha i1 \gamma j1 + \lambda 2 \alpha i2 \gamma j2 + \varepsilon i$$

Where, 'Yij' is the mean grain yield of ith genotype and 'Yi' is the mean grain yield of all the test lines in the jth environment; '$\lambda 1$' and '$\lambda 2$' are the square roots of eigen values of first and second IPC axis, 1 and 2; 'ɑi1' and 'ɑi2' are scores of the first and second IPC, respectively, for ith genotype; and 'γj1' and 'γj2' are the first and second IPC's, respectively, for jth environment.

RESULTS

Post-monsoon season

In the post-monsoon season (November 2021 to February 2022), the combined analysis results across the six locations revealed that, location means were significant at prob < 0.01 for all traits, except pod length (prob < 0.05). The lines' means were significant at prob < 0.01, and interaction effect of location and lines were significant at prob < 0.01 for plant height, days to maturity, pod yield per plant, number of pods per plant, and seed yield per plant. Likewise, it was significant at prob < 0.05 for days to flowering and pod length and

Table 2. Combined analysis of variance (F-statistic) for morphological traits across six locations during 2021–2022 in Myanmar.

Source of Variation	Year 1 (Type-III fixed effects)								
	DFF	PH	DM	PY	NP	PL	NS	HSW	SY
Location	4.22**	37.60**	5.41**	37.00**	55.03**	2.43*	4.86**	10.50**	48.77**
Lines	1218.00**	95.87**	675.10**	42.59**	5.43**	309.90**	16.75**	236.80**	51.64**
Location x Lines	1.79*	4.22**	2.81**	3.19**	2.90**	1.58*	0.96	1.25	3.71**
	Residuals (locations)								
Kawa	0.218	9.836	0.245	7.472	0.200	0.084	0.016	0.072	1.819
Khayan	0.356	9.692	0.620	0.812	0.049	0.061	0.010	0.060	0.397
KyaukTan	0.329	13.134	0.745	3.309	0.190	0.062	0.010	0.097	1.824
Waw	0.236	9.534	0.329	7.424	0.215	0.119	0.010	0.089	3.293
Thanlyin	0.259	6.817	1.093	0.922	0.060	0.090	0.013	0.080	2.116
Thongwa	0.273	15.961	0.417	3.755	0.175	0.103	0.013	0.080	0.460
Heritability (H^2)	99.85	95.63	99.49	86.58	17.03	99.57	93.72	99.45	87.74
CV%	1.27	9.97	1.24	23.69	10.04	3.93	3.83	5.40	21.34

DFF: No. of days to 50% flowering, PH: Plant height, DM: No. of days to 90% pod maturity, PY: Pod yield/plant, NP: No. of pods/plant, PL: Pod length, NS: No. of seeds per pod, HSW-100: Weight of 100 seeds, SY: Seed yield/plant, ns: Non-significant, *, **, significant at 5% and 0.1%, respectively.

for the number of seeds per pod and a hundred seed weight, it was notable at prob ≥ 0.05. This implied that ranks of line means were not changing across the locations and considered as no crossover interaction between the locations, i.e., the performance of lines were alike across all the locations (Table 2). All the advanced breeding lines matured earlier (<62 days) than both Yezin 1 (65 days) and Yezin 9 (70 days) (Table 3). AVMU 1642 (57 days) and AVMU 1643 (56 days) matured earliest among all the advanced breeding lines and standard checks. For seed yield per plant, the check variety Yezin-9 (8.52 g/plant), followed by Yezin 1 (7.18 g/plant) and AVMU 1688 (7.10 g/plant), recorded superior yield compared with all other lines (Table 4).

Broad-sense heritability results revealed all traits have shown above 85%, except for number of pods/plant (17%) (Table 2). Overall, high genetic variation was evident among the lines compared with the environmental variation. From the GGE biplot, first and second principal component axis explained above 90% of the variation in the line x location interaction data for the seed yield per plant. According to the location evaluation from Figure 1, KyaukTan and Waw locations were the farthest locations, and their cosine angle is >90° (obtuse angle), which means line ranks change in between these two locations, with a crossover interaction existing between the locations.

Sectors segregated in all six locations into two mega environments. KyaukTan, Khayan, Thanlyin, Thongwa, and Kawa locations formed one mega environment, which explained that the line ranks are not changing across five locations, and Waw is in another mega environment. Except the Thongwa location, all locations had high discriminating power and explained the diversity among the lines. Thongwa had the shortest vector, which did not explain the variation among the lines and, hence, recommended for discarding in future experiments. According to the line evaluation, Yezin-9 was the most prominent and adaptable check for first mega environment locations. For the second mega environment (Waw location), AVMU- 1690 and AVMU-1688 were the most adaptable lines. AVMU-1632 and AVMU-1659 were high-yielding lines and can be suitable for the KyaukTan location. AVMU-1631 and Yezin-1 showed specific adaptation and were high-yielding lines for Thongwa and Kawa locations. The AVMU-1642 and AVMU-1643 lines are unsuitable for any locations. The lines, AVMUs 1631, 1632, 1659, 1688, and 1690 (5.13 to 5.70 g), recorded a similar 100 seed weight as Yezin 1 (5.42 g), the check variety.

Table 3. Combined analysis of variance (F-statistic) for morphological traits across four locations during 2022 in Myanmar.

Source of Variation	Year 2 (Type-III fixed effects)							
	PH	DM	PY	NP	PL	NS	HSW	SY
Location	1.20**	NA	1.14**	1.15**	0.87	0.01	1.12**	1.13**
Lines	10.18**	46.70**	2.72*	0.72	116.90**	3.96**	84.72*	1.67
Location x Lines	3.05**	2.70**	2.68**	0.25	1.93**	1.98**	1.56	2.83**
Residuals (locations)								
Sinbaungwe	17.623	0.91	13.508	0.514	0.081	0.011	0.046	7.205
Taungdwingyi	49.575	0.33	1.361	0.311	0.054	0.009	0.099	1.872
Zayyarthiri	88.303	0.211	9.763	0.522	0.071	0.006	0.042	1.995
Kyaukse	11.898	0.282	3.035	0.43	0.038	0.002	0.066	1.486
Heritability (H^2)	90.35	97.81	63.77	.	99.13	71.98	98.80	40.97
CV%	8.25	1.06	19.55	14.53	2.93	2.54	5.54	18.47

PH: Plant height, DM: No. of days to 90% pod maturity, PY: Pod yield/plant, NP: No. of pods/plant, PL: Pod length, NS: No. of seeds per pod, HSW-100: Weight of 100 seeds, SY: Seed yield/plant, ns: Non-significant, *, **, significant at 5% and 0.1%, respectively.

Table 4. Mean performance of 11 mungbean lines across the locations for the years 2021–2022 (Y1) and 2022 (Y2).

Lines	DFF	PH		DM		PY		NP		PL		NS		HSW		SY	
	Y1	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
AVMU-1631	38.56	30.96	70.27	59.44	62.50	9.05	17.17	3.61	4.85	8.47	9.39	2.95	3.39	5.46	4.8	6.05	11.54
AVMU-1632	39.00	28.15	66.36	59.33	59.92	7.98	14.54	3.60	4.55	7.77	9.24	2.92	3.42	5.34	5.02	5.55	10.51
AVMU-1642	36.56	22.88	106.49	56.50	65.50	5.07	9.61	3.82	4.54	5.46	6.38	2.84	3.45	3.77	3.04	3.60	7.36
AVMU-1643	36.44	23.45	106.09	56.28	65.41	5.18	8.97	3.85	4.61	5.55	6.53	2.86	3.50	3.81	3.07	3.50	6.81
AVMU-1659	42.72	35.01	70.10	60.33	62.37	8.13	12.40	3.74	4.32	7.77	8.73	2.97	3.32	5.12	4.78	6.14	8.84
AVMU-1688	43.33	34.84	70.30	61.00	62.45	10.27	15.21	4.04	4.73	7.88	9.10	2.84	3.26	5.70	5.12	7.10	10.57
AVMU-1690	43.67	34.70	67.20	61.67	62.97	9.28	14.01	3.97	4.58	7.75	8.92	2.95	3.36	5.26	4.61	6.57	9.70
Yezin-1	46.50	41.81		64.50		8.73		3.96		7.98		3.13		5.41		7.18	
Yezin-9	48.39	45.42		69.61		11.82		3.93		8.81		3.12		7.15		8.52	
Yezin-11			67.19		57.26		14.77		4.74		8.53		3.36		4.83		10.38
Yezin-14			81.63		62.05		14.36		4.39		9.05		3.33		5.64		10.64

DFF: No. of days to 50% flowering, PH: Plant height, DM: No. of days to 90% pod maturity, PY: Pod weight/plant, NP: No. of pods/plant, PL: Pod length, NS: No. of seeds per pod, HSW-100: Weight of 100 seeds, SY: Seed yield/plant.

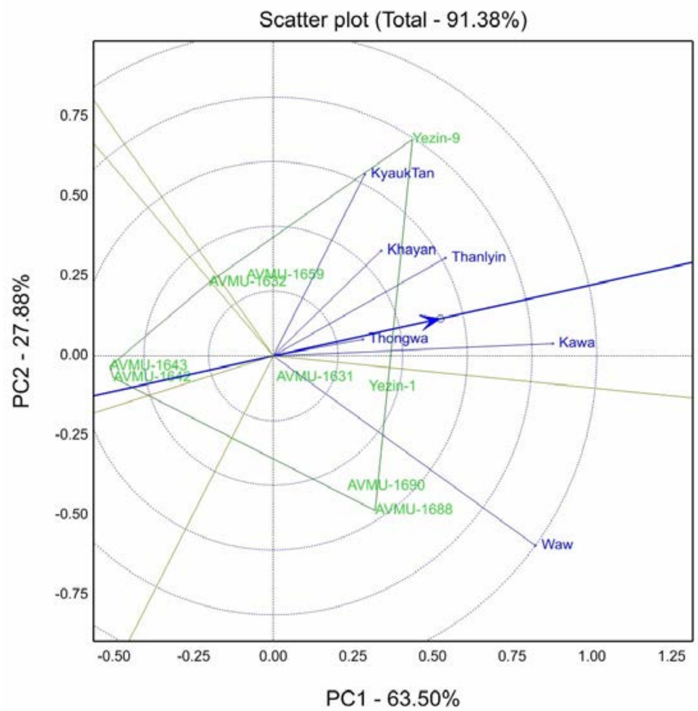

Figure 1. GGE biplot for seed yield per plant (g) representing mean performance and stability of mungbean advanced breeding lines and checks evaluated across six locations in Myanmar during post-monsoon season (November 2021 to February 2022).

Monsoon season

In the monsoon season (May to September 2022), the combined analysis results across the four locations revealed that location means were significant at a prob < 0.01 for all traits, except for days to maturity, pod length, and the number of seeds per pod. Line means were significant at a prob < 0.01, except for the number of pods per plant and seed yield per plant. Meanwhile, the interaction effect of location and line was significant at a prob < 0.01 for all traits, except the number of pods per plant and a hundred seed weight. This suggested that the ranks of line means were not changing across the locations and had no crossover interaction between the locations, i.e., the performance of lines are the same in all four locations (Table 3).

The advanced breeding lines (AVMU1631, AVMU 1659, AVMU 1688, and AVMU 1690) matured around 62–63 days versus the check variety Yezin 14 (62 days). Both Yezin-11 (at 57 days) and AVMU 1632 (at 60 days) were early maturing, while the AVMU 1642 matured at around 65 days (Table 4). The highest seed yield resulted in AVMU 1631 (11.54 g/plant), followed by Yezin 14 (10.64 g/plant), AVMU 1688 (10.57 g/plant), AVMU 1632 (10.51 g/plant), and Yezin 11 (10.38 g/plant). Broad-sense heritability results revealed that all traits have shown above 60%, except seed yield per plant (41%) and the number of pods per plant (Table 3). Overall, the study observed moderate (pod yield and number of seeds per pod) to high (plant height, days to maturity, pod length, and a hundred seed weight) genetic variations among lines compared with environmental variation.

From the GGE biplot (Figure 2), first and second principal component axis explained 78% of the variation in the line x location interaction data for the seed yield per plant. According to location evaluation, Kyaukse location had shown the shortest vector due to less variation among the lines, indicating as not recommendable for future experiments.

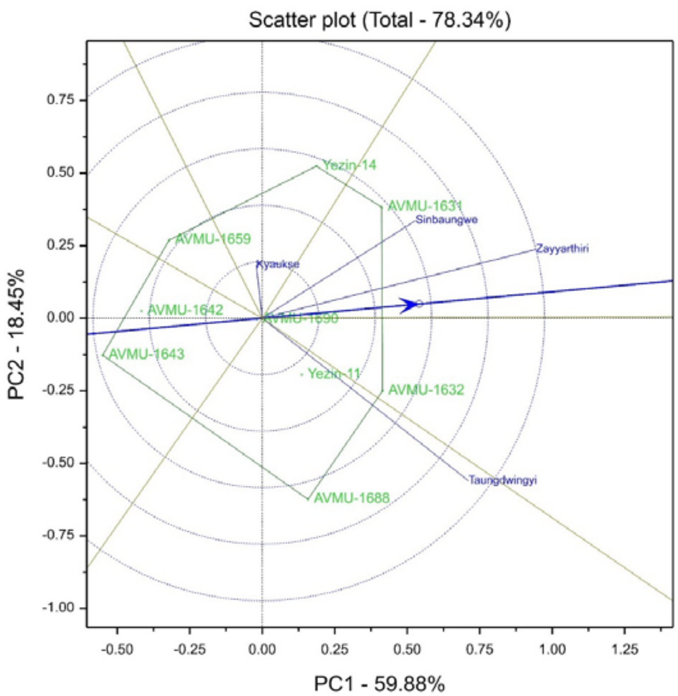

Figure 2. GGE biplot for seed yield per plant (g) representing mean performance and stability of mungbean advanced breeding lines and checks evaluated over four locations in Myanmar during monsoon season (May to September 2022).

The remaining three locations had shown high discriminating power and explained significant variations among the lines. The two locations, Sinbaungwe and Zayyarthiri, formed one mega environment, and Taungdwingyi was in another mega environment. Line AVMU 1631 was specifically adaptable for both Sinbaungwe and Zayyarthiri, while AVMU 1632 and AVMU 1688 were particularly adaptable lines for the Taungdwingyi location. AVMU 1642, AVMU 1643, and AVMU 1659 are unsuitable for any of the locations.

Evaluation for resistance to MYMD during the pre-monsoon season (February–May)

The MYMD disease scores and MYMD square root values, respectively, of the evaluated lines were: AVMU-1688 (1; 1.17), AVMU-1690 (0; 0.88), Yezin-11 [check] (1; 1.34), Yezin-14 [check] (2; 1.68), Yezin-15 [check] (2; 1.68), and Yezin-16 [check] (2; 1.46). Both lines, AVMU 1688 and AVMU 1690, proved resistant to MYMD.

Sprouting quality evaluation

Sprout quality test

The sprout qualities of different lines were: AVMU1631 — around 10 diseased sprouts observed; shorter sprouts compared with the control; AVMU 1632 — healthy; shorter sprouts compared with the control; the color of sprouts and roots is bright; sprouts' appearance generally better than other lines; AVMU 1642 — healthy; shorter sprouts compared with the control; AVMU 1643 — healthy; shorter sprouts compared with the control; AVMU 1659 — healthy, similar to the control; AVMU 1688 — healthy, similar to the control; AVMU 1690 — healthy, longer, and thinner compared with the control; Yezin 1— healthy, similar to the control, and Yezin 9 — healthy, longest hypocotyl. AVMU 1632 and Yezin 9 have the best sprouting qualities, while the sprouting quality of AVMU 1659, AVMU 1643, AVMU 1688, and Yezin 1 were similar to the reference sample.

Table 5. Performance of the lines for the bean size tests.

Seed diameter (mm)	AVMU 1631	AVMU 1632	AVMU 1642	AVMU 1643	AVMU 1659	AVMU 1688	AVMU 1690	Yezin 1	Yezin 9
>4.5	1.82*	2.7	0	0	2.83	3.8	1.34	3.8	2.18
4–4.5	5.86	3.42	1.3	0.76	10.34	14.02	7.48	15.51	17.81
3.5–4	28.41	21.17	11.18	9.97	18.79	33.96	23.16	43.68	64.79
3–3.5	59.98	67.78	35.76	42.55	60.32	46.53	61.25	34.01	14.84
<3	3.84	5	51.69	46.81	7.68	2.18	6.67	2.42	0.62

* Percentage in a sample of 100 g seed.

Bean size test

The bean size range normally used for sprouting is 3.5–4 mm. The table below (Table 5) shows that seeds of AVMU 1642 and AVMU 1643 are too small, with half of the seeds smaller than 3.5 mm. Yezin 9 performed the best, which had the most seeds of 3.5–4 mm.

100-seed weight

The 100-seed weight (g) of the evaluated lines were: AVMU 1631: 5.125; AVMU 1632: 5.085; AVMU 1642: 4.315; AVMU1643: 4.235; AVMU 1659: 5.175; AVMU 1688: 5.445; AVMU 1690: 5.08; Yezin 1 [check] 4:.835, and Yezin 9 [check]: 6.445. The preferred 100-seed weight for the European sprout market segment is more than 6.4 g. The check variety Yezin 9 is the only one that met the criteria, followed by AVMU 1688.

DISCUSSION

The Mungbean Yellow Mosaic Disease (MYMD) poses a significant challenge to mungbean cultivation as it could lead to complete crop loss (Mishra *et al*., 2020; Dasgupta *et al*., 2021). With the increasing demand for mungbean sprouts, Myanmar farmers are intensifying efforts to export mungbean grains to high valued European market used for bean shoots (ACIAR, 2020). However, current cultivated mungbean varieties, such as, Yezin 1 and Yezin 9 suitable to the high-premium sprout market segment, are susceptible to MYMD (Khaing *et al*., 2013; Nair *et al*., 2013a; Mahmoud *et al*., 2023).

The broad-sense heritability helped assess the performance of trials across environments, the high heritability (>60%) explains the trait's performance is consistent and reliable. High heritability suggests that the trait expression is stable, resulting in more efficient selection, whereas low heritability indicates unpredictability in the trait performance. In the current study, the trait the number of pods per plant has shown low heritability due to a high environmental variation. Singh *et al.* (2018) also reported a low heritability value for the number of pods per plant (21.9%) in mungbeans.

From the GGE biplot for seed yield/plant, in the post-monsoon season, Yezin-9 was the high yielding and most adaptable line for KyaukTan, Khayan, and Thaniyin locations. Meanwhile, the high yielding and adaptable for the Waw location are the AVMU1688 and AVMU-1690. In the monsoon season, AVMU 1631 was the high yielding and most adaptable for Sinbaungwe and Zayyarthiri locations, whereas Yezin-11, AVMU 1632, and AVMU 1688 were best in the Taungdwingyi location. AVMU 1643 was poorly performing consistently across all locations and will not be beneficial for further evaluations. In the field evaluation of improved mungbean lines, AVMU 1688 and AVMU 1690 emerged as forerunners due to their impressive agronomic performance and excellent sprouting qualities. The resistance of these lines to MYMD enhances their value and also safeguards against potential yield losses. Notably, both lines, derived from ML 1628, as one of the parental lines, have exhibited resistance to all known species of viruses causing MYMD (Nair *et al.,* 2017). These lines had shown high level of resistance to MYMD in a hotspot in North

India (Ludhiana, Punjab (R. M. Nair, Personal Communication, 2023).

Analysis of MYMD samples from South Asia revealed the prevalence of the Mungbean yellow mosaic India virus (MYMIV) and the Mungbean yellow mosaic virus (MYMV) (Mishra *et al*., 2020; Nair *et al*., 2022). Currently in Myanmar, only the MYMIV has been reported (Nair *et al.,* 2022). The available varieties of mungbean in Myanmar are resistant only to the MYMIV. The introduction of lines, such as, AVMU 1688 and AVMU 1690 to Myanmar is a preemptive move in anticipating possible entry of other viral species into the country. These lines demonstrated high seed yield per plant and exhibited early maturity, particularly favorable during the monsoon season. Moreover, the AVMU 1688 matches the check variety, Yezin 1, for sprouting quality, meeting the requirement of the market segment with its shiny green color grains. These lines may continue for further testing for potential release as a variety or could serve as donor parents for resistance to MYMD in the National Breeding Program.

CONCLUSIONS

From the seven improved mungbean lines field-tested across different locations in Myanmar, AVMU 1688 and AVMU 1690 were the most promising. These lines may proceed testing for potential release as varieties or utilizing as donors for resistance to MYMD in the National Breeding Program.

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