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BOX PLOT VISUALIZATION OF AGRO-MORPHOLOGICAL CHARACTERS IN *Brassica juncea* UNDER NORMAL AND SODIC CONDITIONS

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ABSTRACT

Brassica juncea (Indian mustard), a major oilseed crop of global and national importance, exhibits considerable phenotypic plasticity across diverse agro-ecological environments. This study evaluated 176 diverse genotypes over two years (2023–24 and 2024–25) at two contrasting locations in Uttar Pradesh, India—Kumarganj (L1; normal soil) and Masaudha (L2; sodic soil). Using an alpha lattice design, phenological, morphological, and yield-related traits were assessed under open field conditions. Descriptive statistics and box plot analyses were employed to explore genotype performance and environment-induced variation. Results revealed that L1 favored early and uniform flowering (DFI, DFF, DHF), greater plant height variability, and higher productivity (biological yield, seed yield, harvest index), indicating suitability for high-input systems. In contrast, L2 exhibited wider flowering intervals and delayed maturity under stress conditions but showed more stable plant architecture and higher thousand-seed weight, suggesting better adaptation to resource-limited environments. The findings emphasize the significance of genotype × environment interaction in *B. juncea* and recommend exploiting complementary traits through targeted hybridization between high-yielding and stress-resilient genotypes to enhance breeding efficiency and adaptability.

INTRODUCTION

Brassicas, particularly rapeseed and mustard, are among the principal oilseed crops cultivated globally (McVetty, *et al.*, 2015), contributing to nearly one-third of the world's vegetable oil production behind soybean and palm oil (Bryxová *et al.*, 2025; Vessar *et al.*, 2025). These crops are a significant source of edible oil in India, second only to groundnuts. Rapeseed-mustard group contributes over 30% of India's oilseed production, making it a crucial crop for food and nutritional security (https://www.drmr.res.in). Having great economic significance, the genus Brassica is an important member of the family Brassicaceae. In order to provide oilseeds, vegetables, or condiments, mankind have domesticated a large number of crop species. Crop Brassicas: these comprise three allotetraploid species (*B. napus*, AACC; *B. juncea*, AABB; *B. carinata*, BBCC) that naturally resulted from pairwise hybridizations between three diploid species (*B. rapa*, AA; *B. oleracea*, CC; and *B. nigra*, BB) (Morinaga 1934, Nagahara 1935). Collaboratively, these species are referred to as crop Brassicas.

Materials and Methods

For two years, two sites assessed a fixed diversity stock of diverse germplasm that included 176 genotypes. The panel included indigenous varieties, advanced breeding lines or cultivars, germplasm from east Europe, Australia, Canada, Germany, derived resynthesized *B. juncea*, and introgression lines. The two locations selected for phenotypic observation were:

a) Location 1 (L1)- SIF ANDUAT, Kumarganj (representing normal soil conditions)

b) Location 2 (L2)- CRS ANDUAT, Masaudha (representing sodic soil conditions)

During the *Rabi* season 2023-24 (Y1) and 2024-25 (Y2), two locations mentioned were used to assess the germplasm stock. These sites were selected based on their distinct soil pH profiles (Table 1), allowing assessment of phenological traits under contrasting edaphic conditions. The experimental layout followed an Alpha Lattice Design (Piepho *et al.*, 2016) with two replications per genotype per environment (i.e., per year and location). The 176 genotypes were randomized within incomplete blocks to account for field heterogeneity. Each genotype was sown in paired 2-meter-long rows, with a row-to-row spacing of 30 cm and a plant-to-plant spacing of 10 cm. All field trials were conducted under open-air, irrigated field plot conditions.

The observations included-Days to flowering initiation (DTF), Days to 50% flowering (DFF), Days to 100% flowering (DHF), Days to flowering completion (DFC), Days to maturity (DM), Plant height at 1st primary branch (PHPB, cm), Plant height at flowering initiation (PHFI, cm), Plant height at maturity (PHM, cm), Number of primary branches (PB), Number of secondary branches (SB), Main shoot length (MSL, cm), Number of pods per main shoot (P.MS), Number of seeds per pod (S.P), Pod length (PL, cm), Biological yield of 5 plants (BY.5P, g), Seed yield of 5 plants (SY.5P, g), Seed yield per plant (SY. P, g), Harvest index (HI, %), Total seed yield (TSY, g), Thousand seed weight (TSW, g). Additionally, using standard methods implemented in META-R, descriptive statistics (mean, range, heritability, genetic advance, expected mean for next generation and CV- Coefficient of Variation) were created. Minitab 16 was used to display the range and mean graphically through boxplots (Mathews, 2004).

Results and Discussion

The box plot analysis revealed distinct patterns across locations (Figure 1). At Kumarganj, DFI (Days to Flowering Initiation) exhibited low variability (IQR: 45–55 days; median: 50 days) with a near-normal distribution, contrasting with Masaudha's wider IQR (55–65 days) and upper outliers, suggesting stress-induced delays—a phenomenon also observed by Saroj *et al.* (2021) and Kang *et al.* (2021) in heat-sensitive genotypes. For DFF (Days to 50% Flowering), Kumarganj's uniform IQR (58–62 days) indicated genetic stability, while Masaudha's broader range (65–75 days) aligned with Akhatar *et al.* (2015) on genotype-environment interactions. DHF (Days to 100% Flowering) showed high precision at Kumarganj (IQR: 68–72 days; heritability: 93%), whereas Masaudha's variability (75–85 days) supported Kang *et al.* (2021) on delayed flowering under abiotic stress. DFC (Days to Flower Completion) was consistent at Kumarganj (IQR: 103–110 days) but right-skewed at Masaudha, echoing Saroj *et al.* (2021) on prolonged flowering under suboptimal conditions. Finally, DM (Days to Maturity) displayed fixed timing at Kumarganj (IQR: 132–136 days; GCV: 1.3%) versus Masaudha's wider range (148–158 days), consistent with Akhatar *et al.* (2015) and Kang *et al.* (2021) on maturity plasticity in stress environments. These findings highlight location-specific trait expression, emphasizing the need for environment-tailored breeding, as discussed across these studies.

At Kumarganj, a wide interquartile range (50–150 cm) and a 25% increase in median height from Year-1 to Year-2 suggest improved management or adaptive responses—findings supported by Saroj *et al.* (2021) and Kang *et al.* (2021), who emphasized genotype-by-environment interactions in similar conditions. Masaudha showed consistent PHPB values (75–125 cm) with <10% interannual variation, indicating genetic stability or uniform environmental conditions, as also noted by Akhatar *et al.* (2015). The Year-1 skew at Kumarganj (Q3–Q1 = 40 cm) vs. Year-2 (30 cm) points to the elimination of stress-sensitive genotypes. PHFI distributions reinforce these observations: Kumarganj's Year-2 bimodal peaks (125 cm, 175 cm) imply divergent genotype responses to soil stress, while Masaudha's tight normal distribution (125–175 cm) reflects uniformity. PHM plots further highlight genotype-environment effects. Kumarganj's Year-1 showed extreme dispersion (150–250 cm) and 15% outliers, possibly representing stress casualties or highly tolerant lines. The narrower Year-2 range (175–225 cm) suggests either selection or improved field conditions. In contrast, Masaudha's consistent PHM range (175–225 cm) positions it as a stability benchmark. MSL trends revealed differing growth strategies between locations. Kumarganj's median MSL increased by 50% in Year-2 (75 cm vs. 50 cm), indicating positive selection or favorable conditions. Meanwhile, Masaudha remained stable (50–75 cm) with <15% variation, underscoring stronger genetic control. Notably, Kumarganj's 25th percentile jumped from 35 cm to 60 cm, while Masaudha's stayed steady at 55 cm ± 2 cm, suggesting location-specific height regulation mechanisms.

Kumarganj (L1) exhibited superior performance in primary branches (PB: ~25 vs. ~15 in L2), secondary branches (SB: ~20 vs. ~10), and pods per main shoot (P.MS: ~30 vs. ~20), reflecting stronger vegetative growth and pod production. However, Masaudha (L2) surpassed L1 in thousand-seed weight (TSW: ~6g vs. ~4g), indicating better seed quality. Yield traits like biological yield (BY.5P: ~400g vs. ~300g) and seed yield (SY.5P: ~200g vs. ~150g) were higher in L1 but with greater variability, suggesting environmental sensitivity. In contrast, L2 showed stable but moderate yields (SY.P: ~15g vs. ~20g in L1), likely due to its resilience. Harvest index (HI: ~0.05 in L1 vs. ~0.03 in L2) further confirmed L1's efficiency in converting biomass to yield. Year-2 outperformed Year-1 across locations, possibly due to improved climatic conditions. In alignment with the observations reported by Akhtar *et al.* (2015), the present findings indicate that L1 may be more suitable for high-input production systems, whereas L2 demonstrates greater adaptability under resource-constrained or low-input conditions. Hybridizing L1's yield potential with L2's stability could optimize productivity.

CONCLUSION

The comparative box plot analysis across Kumarganj (L1) and Masaudha (L2) revealed substantial location-specific differences in the expression of phenological, morphological, and yield-related traits in *Brassica juncea*. Flowering traits such as DFI, DFF, and DHF exhibited more uniform and stable distributions at Kumarganj, while Masaudha showed broader variability and delayed flowering patterns—likely attributed to environmental stress, aligning with prior studies. Traits like DFC and DM followed similar trends, highlighting the plasticity and stress responsiveness of genotypes under differing environmental conditions. These variations underscore the importance of site-specific trait selection in breeding programs.

Plant height components, including PHPB, PHFI, PHM, and MSL, also demonstrated distinct patterns. Kumarganj displayed greater interannual changes, bimodal height distributions, and evidence of genotype selection or improved agronomic management, whereas Masaudha maintained a consistent and narrow phenotypic range, reflecting stronger environmental uniformity or genetic stability. Such patterns point to a pronounced genotype × environment interaction, necessitating environment-specific selection strategies.

In terms of yield-related attributes, Kumarganj outperformed Masaudha in traits like the number of branches, pod count, biological and seed yield, and harvest index—though often with greater variability. Conversely, Masaudha consistently recorded higher seed quality (TSW) and yield stability. These findings suggest that while Kumarganj holds promise for high-input, yield-maximizing systems, Masaudha offers a reliable performance under stress or low-input conditions. Therefore, integrating the high-yield potential of L1 with the stability of L2 through targeted hybridization may serve as an effective approach to enhance both productivity and adaptability in Indian mustard breeding programs.

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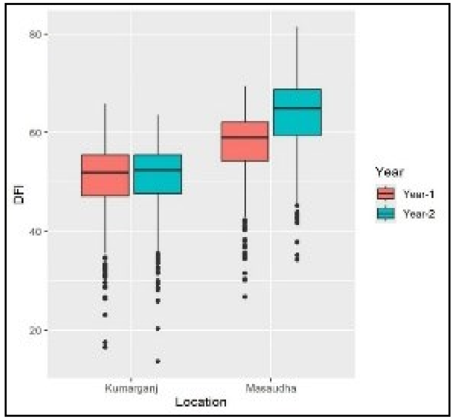
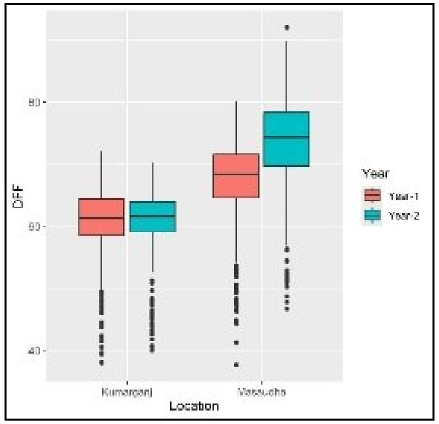
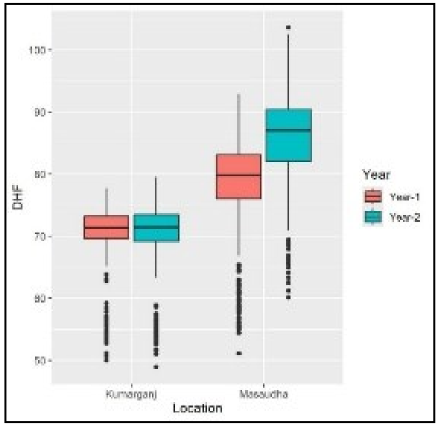
Figure 1: Comparative Analysis of Phenotypic Traits through Boxplots



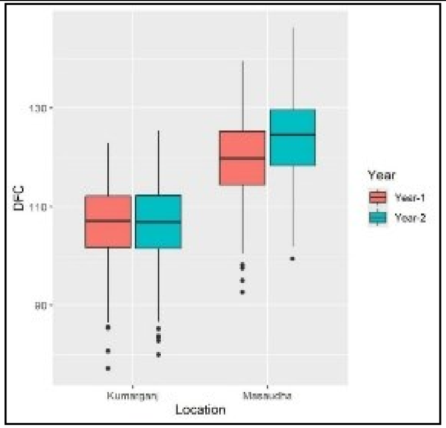
Box Plot- DFI



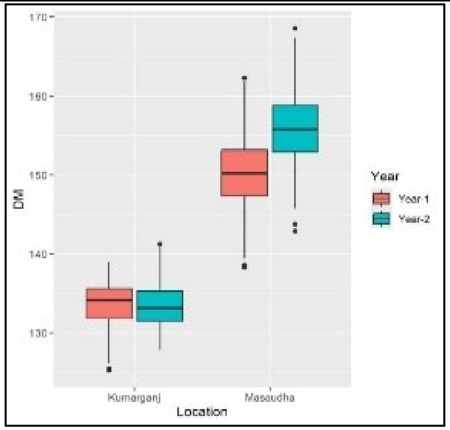
Box Plot- DFF



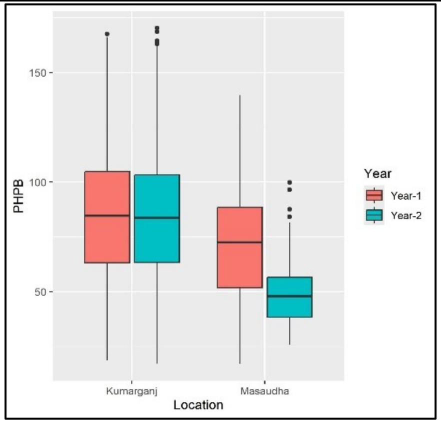
Box Plot- DHF



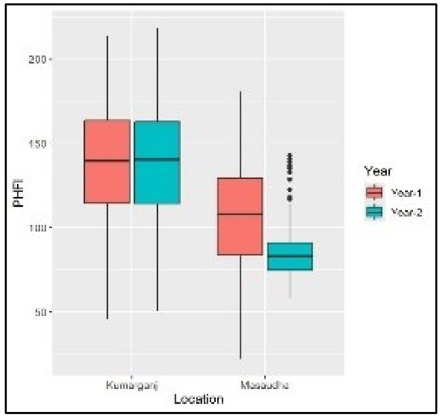
Box Plot- DFC



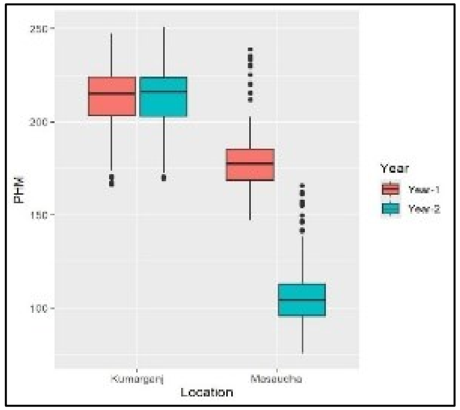
Box Plot- DM



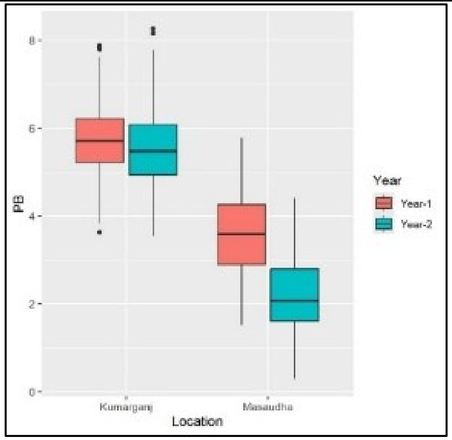
Box Plot- PHPB



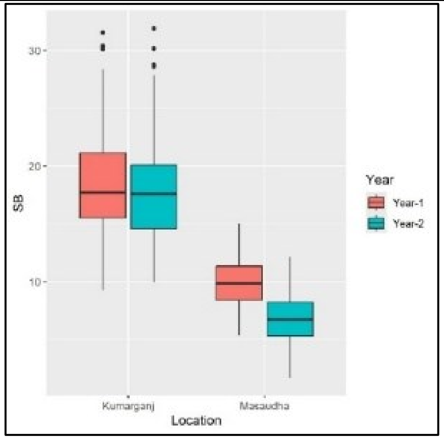
Box Plot- PHFI



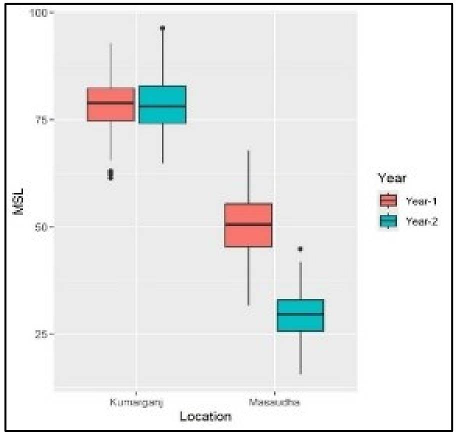
Box Plot- PHM



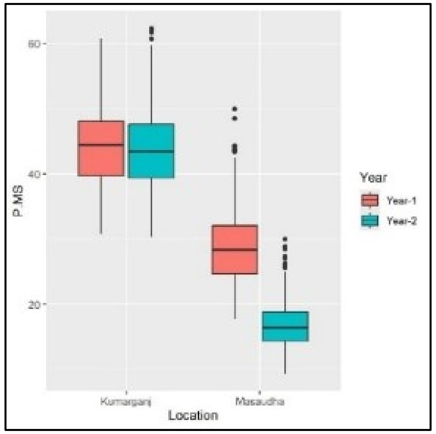
Box Plot- PB



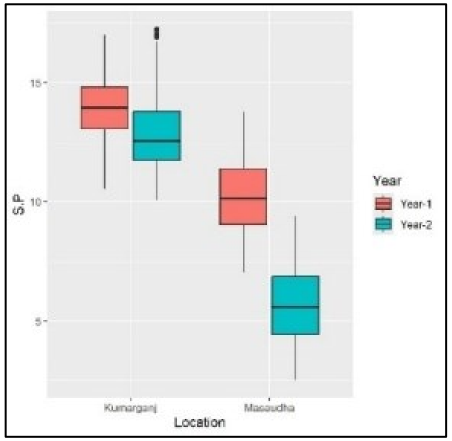
Box Plot- SB



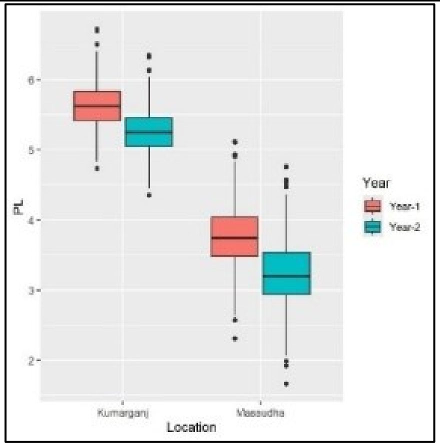
Box Plot- MSL



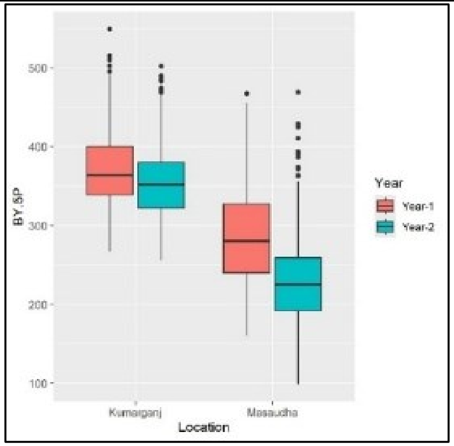
Box Plot- P.MS



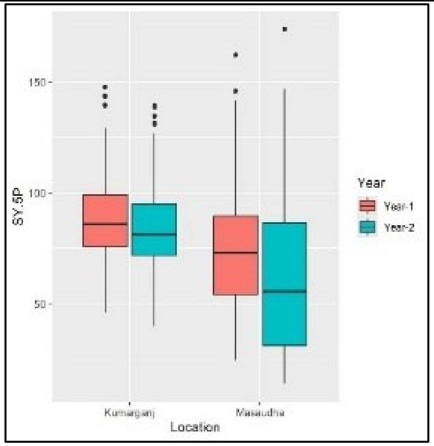
Box Plot- S.P



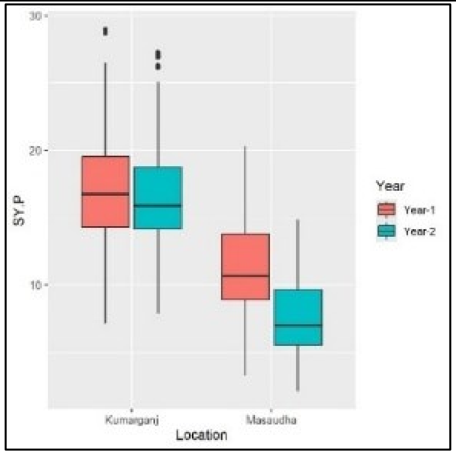
Box Plot- PL



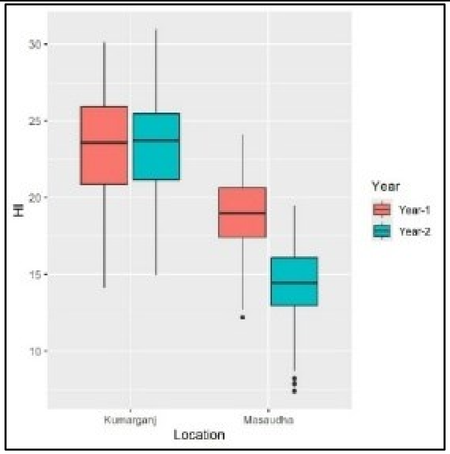
Box Plot- BY.5P



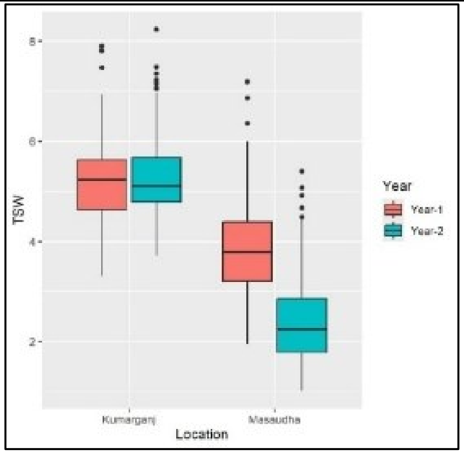
Box Plot- SY.5P



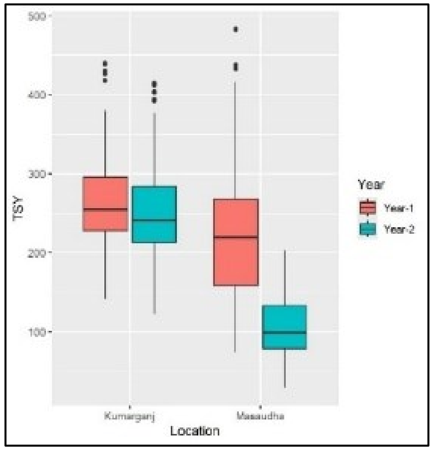
Box Plot- SY.P



Box Plot- HI



Box Plot- TSW



Box Plot- TSY