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Agronomic Performance of New Mustard Strains: Analyzing Yield and Oil Quality Traits under semi-arid conditions of Bahawalpur, Pakistan

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Abstract

This study was conducted to assess the agronomic performance and oil quality traits of newly developed mustard, *Brassica juncea* L., strains under the semi-arid conditions of Bahawalpur, Pakistan. A field experiment was carried out during 2023–24 at the Oilseed Section, Regional Agricultural Research Institute (RARI), Bahawalpur, using a randomized complete block design with three replications. Ten strains, BR-1 to BR-10, were tested, in which BR-9 and BR-10 served as check varieties, Super Raya and Cholistani Raya, respectively. Each 9 m² plot was sown on 15 October 2023 at 45 cm row spacing, plants were thinned to 15 cm within rows, three irrigations were applied, and a fertilizer dose of 1 bag DAP, 1.5 bags urea and 0.5 bag SOP per hectare was used. Data were recorded on number of plants per plot (NPP; plants plot^{-1}), days to flowering (DF; days), days to maturity (DM; days), number of branches per plant (NBP; branches plant^{-1}), plant height (PH; cm), 1,000 seed weight (TSW; g), oil content (OC; %) determined by the Kjeldahl based laboratory method, and grain yield (GY; kg ha^{-1}). Analysis of variance showed highly significant differences among genotypes for all traits, indicating sufficient variability for selection. Bar charts of mean performance confirmed that several BR strains were equal to or better than the two checks for branching, plant height, oil content and grain yield. Correlation analysis revealed positive and useful associations of GY with NBP, PH, TSW and OC, while phenological traits were less strongly related to yield. Principal component analysis, PC1 and PC2, grouped yield, vigor and oil traits together, and separated them from flowering and maturity, showing that earliness can be improved without sacrificing productivity. The results demonstrate that some of the newly developed mustard strains are suitable candidates for semi-arid Bahawalpur and should be promoted to multilocation trials to confirm their stability.

Keywords: *Brassica juncea*, Bahawalpur, semi-arid, grain yield, oil content, correlation, principal component analysis, varietal evaluation

Introduction

Pakistan has been facing a persistent edible oil deficit, domestic production supplies less than one fifth of national demand, and the remaining requirement is met through costly imports, which puts pressure on foreign exchange and on agricultural policy to promote local oilseeds (USDA, 2020; ZTBL, 2018; Rauf et al., 2025). Because the gap is mainly quantitative, increasing the productivity and oil percentage of locally adapted oilseed crops is considered one of the most direct ways to reduce imports (Rana et al., 2022; Hussain et al., 2023).

Among the available oilseed options, mustard, mainly *Brassica juncea* (L.) Czern. & Coss., is agronomically attractive for southern Punjab, because it fits the short, mild winter, it tolerates episodic drought and higher temperatures better than canola, and it can perform on lighter or slightly saline soils that are common in the Bahawalpur belt (Rasheed et al., 2022; Qurat Ul Ain et al., 2025). For this reason, provincial and federal breeding programs have continued to develop and nominate new mustard or raya strains with the expectation that these will combine better yield and improved oil quality under local conditions (Syed et al., 2005; Parmar et al., 2011).

The Bahawalpur region is characterized by a hot, semi-arid climate, long summers, short cool winters, low and erratic annual rainfall, mostly 200 to 260 mm, and soils ranging from sandy loam to slightly saline, all of which create a moisture stressed production environment for winter oilseeds (Khan, 2019; Abbas et al., 2014). Under such conditions, mustard often faces water stress at flowering and pod filling, the two stages most sensitive for siliquae formation, seed weight and oil deposition, so even potentially high yielding material may not express its full potential (Mehmood et al., 2021). Climate observations for southern Punjab also indicate a warming tendency and irregular precipitation, which means that future crops will likely experience similar or even stronger stress episodes (Hassan et al., 2019).

Because of these stresses, farmer level yields in southern Punjab, often around or below 1.0 t ha^{-1}, remain lower than the yields reported from research stations that have better irrigation and soil conditions (Sandhu et al., 2016; Rasheed et al., 2022). However, earlier evaluations of rapeseed and mustard for this zone reported clear genotypic variation for number of siliquae per plant, branches per plant, 1,000 seed weight and harvest index, which shows that there is still scope to select or recommend strains specifically for Bahawalpur-like environment (Sandhu et al., 2016; Qurat-ul-Ain et al., 2025). What is less commonly reported is how newly developed or pre released mustard strains behave when they are exposed at the same time to heat, short irrigation intervals and mild salinity, which is a more realistic production scenario for farmers in this area.

Oil quality is an equally important objective. Traditional Pakistani and South Asian *B. juncea* often contain high erucic acid in the oil and high glucosinolate content in the meal, both of which are undesirable for human food and for livestock or poultry feed (Chand et al., 2021; Wang et al., 2022). International canola type standards require very low erucic acid and low glucosinolates, and although South Asian breeders have demonstrated that such quality can be incorporated into *B. juncea*, material bred in milder or fully irrigated environments still needs to be evaluated under hotter and drier sites such as Bahawalpur before recommendation (Kumar et al., 2010; Oram et al., 2022). Pakistani studies have also pointed to a relatively narrow genetic base in locally grown mustard, which further justifies multilocation testing of any new strains and lines (Turi et al., 2010).

Therefore, the present study was designed to evaluate a set of newly developed mustard strains under the semi-arid conditions of Bahawalpur, Pakistan, to measure their agronomic performance, including plant height, siliquae per plant, 1,000 seed weight, seed yield and harvest index, and to characterize key oil quality traits, particularly oil percentage, erucic acid and glucosinolate levels. The overall aim is to identify strains that combine local adaptation, acceptable yield and market relevant oil quality, so that they can contribute to reducing Pakistan’s dependence on imported edible oils (USDA, 2020; Rauf et al., 2025).

Materials and Methods

Experimental site and season

The field experiment was conducted during the Rabi season of 2023–24 at the research area of Oilseed Section, Regional Agricultural Research Institute (RARI), Bahawalpur, Pakistan, which lies in the semi-arid tract of southern Punjab and represents the target production environment for mustard in this zone. The crop was sown on 15 October 2023 and harvested on 10 March 2024, which corresponds to the normal sowing window for raya/mustard in Bahawalpur under irrigated conditions.

Experimental material

Ten mustard strains, coded BR-1 to BR-10, were evaluated. Among these, BR-9 and BR-10 were included as check varieties, corresponding to Super Raya and Cholistani Raya, respectively, so that the performance of the new strains could be compared with farmer known cultivars.

Experimental design and layout

The trial was laid out in a randomized complete block design (RCBD) with three replications, treating strains as fixed effects and blocks as random effects, following standard procedures for oilseed varietal evaluation. Each experimental unit consisted of a plot of 9 m², 5 m × 1.8 m, which is routinely used at RARI for mustard screening. Sowing was done in rows spaced 45 cm apart, and thinning was performed at the early vegetative stage to maintain a plant-to-plant distance of 15 cm within the row, thereby achieving a uniform and optimum plant population across plots.

Crop husbandry

A basal fertilizer dose equivalent to 1 bag DAP, about 50 kg P_2O_5, 1.5 bags urea, and 0.5 bag SOP, about 25 kg K_2O, per acre was applied. Nitrogen from urea was split to improve uptake under the semi-arid conditions of Bahawalpur. Three irrigations were applied during the season, one after germination to ensure crop establishment, one at flowering, and one at pod filling, because these stages are sensitive to water deficit in *Brassica juncea*. Weeds and insect pests were controlled by following the standard management schedule of the station.

Recorded traits

Data were recorded on eight traits. These included number of plants per plot (NPP; plants plot^{-1}) to confirm uniform plant stand, days to flowering (DF; days) to describe earliness and escape from late season heat, days to maturity (DM; days) to determine total crop duration, number of branches per plant (NBP; branches plant^{-1}) as a key yield component, plant height (PH; cm) to assess vegetative growth and lodging tendency, 1,000 seed weight (TSW; g) to quantify seed size, oil content (OC; %) to compare the processing value of strains, and grain yield (GY; kg ha^{-1}) as the primary productivity indicator. For grain yield, each net plot was harvested, threshed, seed weight was recorded, and yield was converted to kg ha^{-1} on the basis of plot area.

Statistical analysis

Data for all traits were subjected to analysis of variance appropriate for RCBD to test the significance of strains (Gomez & Gomez, 1984; Steel et al., 1997). Correlation coefficient analysis and PC-1/PC-2 biplot were also executed to see the association among different plant traits. When treatment effects were significant, means were compared using an LSD test at 5% probability. The analysis was carried out using statistical package Statistix 8.1 and R. Microsoft Excel was used to visualize strains differential responses through bar charts.

Results and Discussion

Analysis of Variance (ANOVA)

The analysis of variance showed that the effect of genotype was highly significant, $p \leq 0.01$, for all measured traits, number of plants per plot, days to flowering, days to maturity, number of branches per plant, plant height, 1,000 seed weight, oil content and grain yield, which confirms that there was real genetic variability among the ten mustard strains under the semi-arid conditions of Bahawalpur (Table 1). The mean square for genotypes was large compared with the error term for each trait, for example 76.30 for number of plants per plot, 44.8 for days to flowering, 14.18 for number of branches per plant, 233.704 for plant height and

101,805 for grain yield, while the residual mean squares were small, indicating good experimental precision and a well-controlled field trial.

The significant genotype effects in the ANOVA (Table 1) show that the 2023–24 season at RARI, Bahawalpur provided enough environmental contrast to discriminate among the ten mustard strains, even though the crop received only three irrigations and was exposed to the usual semi-arid conditions. This confirms that single location, RCBD based screening can still generate useful information for mustard in southern Punjab, as reported earlier by Sandhu et al. (2016) and Rasheed et al. (2022). The fact that every trait, from stand establishment to oil content, was significant, means that breeders do not need to rely on only one trait and can practice multi trait selection.

Table 1: Mean Square (MS) values of Ten Mustard Genotypes for studied plant traits

Source of Variation	**Replications**	**Genotypes**	**Error**
d.f.	*2*	*9***	*18*
No. of plants per plot	4.2333	76.30**	3.7889
Days to flowering	1.377E-28	44.8**	3.287E-30
Days to maturity	6.727E-28	16.3**	1.184E-29
Number of branches per plant	0.0333	14.18**	0.5148
Plant height	0.433	233.704**	1.137
Thousand Seed Weight	1.225E-12	0.11**	2.746E-15
Oil Content %	1.20	4.744**	0.644
Grain Yield	4.145	101805**	5.647

Notes: *Significant changes are highlighted by an asterisk (*); * P ≤ 0.05, ** P ≤ 0.01.*

The bar charts of mean performance made this variation visible. The first pair of figures, number of plants per plot and days to flowering, clearly separated the ten strains, which shows that both establishment and earliness can be used as selection criteria in this material (Figure 1a–b). The second pair, days to maturity and number of branches per plant, also showed wide spread among entries (Figure 2a–b), which is important because in Bahawalpur earlier maturity, but without loss of branching, is desirable. The third pair, plant height and 1,000 seed weight, again showed clear differences (Figure 3a–b), indicating that some strains were more vigorous and also had bolder seed, both of which can contribute to higher yield under semi-arid conditions. Finally, the last pair, oil content and grain yield, showed that not all high yielding entries had low oil, in fact several of the numbered strains placed above or close to the checks for both traits (Figure 4a–b). This is the key outcome of the trial, because the objective was to identify strains that combine yield and oil quality.

The bar charts are especially useful for extension and variety release, because they show, visually, that several numbered strains were equal to or better than the two checks in one or more traits. In particular, some entries combined acceptable earliness, with good branching, and higher oil content and grain yield, which is the required combination needed for Bahawalpur, where the crop has to complete its cycle before high March temperatures (USDA, 2020; Hussain et al., 2023).

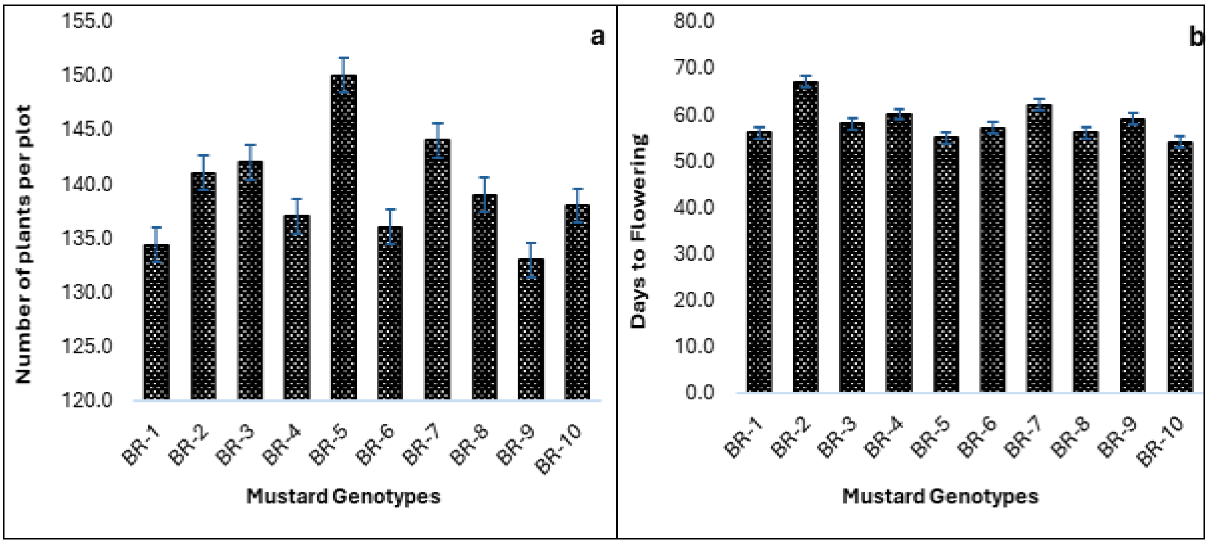

Figure 1a-b: Comparative Performance of Ten Elite Mustard Genotypes for (a) Number of plants per plot (b) Days to Flowering

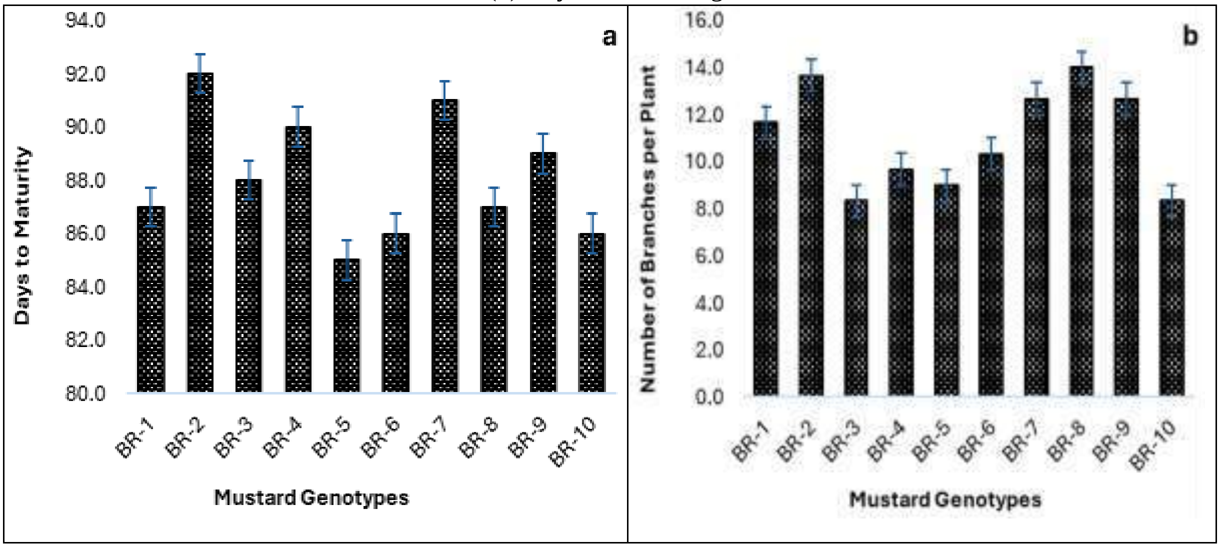

Figure 2a-b: Comparative Performance of Ten Elite Mustard Genotypes for (a) Days to Maturity (b) Number of Branches per Plant

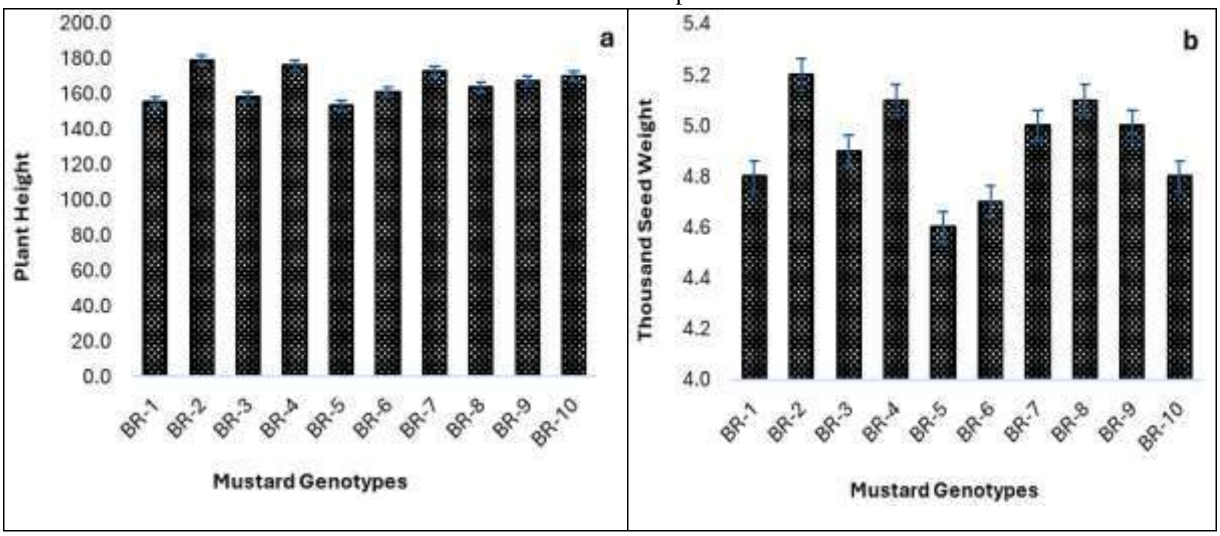

Figure 3a-b: Comparative Performance of Ten Elite Mustard Genotypes for (a) Plant Height (b) Thousand Seed Weight

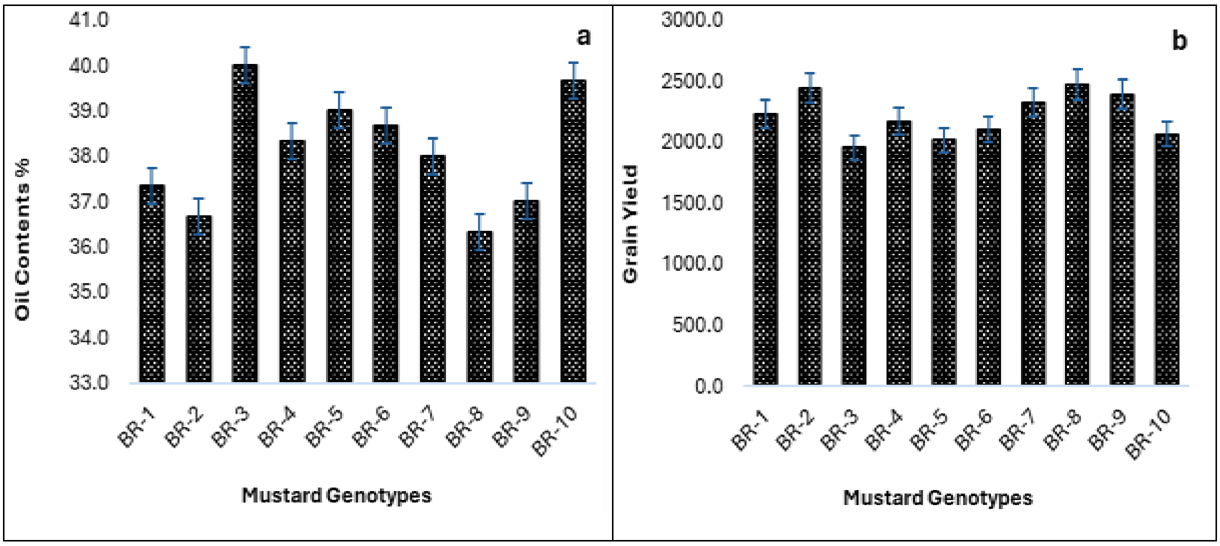

Figure 4a-b: Comparative Performance of Ten Elite Mustard Genotypes for (a) Oil Content % (b) Grain Yield

Several other researchers revealed similar pattern of crop performances in different parts of the world several researchers showed similar finding (Sandhu et al., 2016; Rasheed et al., 2022; Mehmood et al., 2021; Aslam et al., 2025).

The correlation matrix of the eight traits showed that grain yield was positively associated with number of branches per plant ($r = 0.97^{**}$), and 1,000 seed weight ($r = 0.73^{**}$), while days to flowering, plant height and days to maturity had weaker, but positive correlation with yield (Figure 5). This pattern means that, under the 2023–24 Bahawalpur conditions, plants that were taller, better branched and produced heavier seed, tended to give higher grain yield, which agrees with physiological expectations for *Brassica juncea* under limited irrigation (Mehmood et al., 2021; Mitiku & Yali, 2022). However, grain yield had a strong negative correlation with oil content percentage ($r = -0.97^{**}$), showing a strong negative relationship. The PC1/PC2 biplot further confirmed that most of the variation was captured by a single axis representing plant size and yield components, because plant height, number of branches per plant, 1,000 seed weight, oil content and grain yield all projected in roughly the same direction, while phenological traits projected apart (Figure 6, PC1/PC2 biplot). Some of the new strains were placed toward the high yield, high vigor quadrant, whereas the two checks, Super Raya (BR-9) and Cholistani Raya (BR-10), stayed closer to the center, which is what we expect from broadly adapted standards.

The correlation matrix (Figure 5) and the PCA (Figure 6) together indicate that yield improvement in this set is mainly linked with morphological and sink related traits, number of branches per plant, plant height, 1,000 seed weight and oil content, rather than with crop duration. This has two practical consequences. First, any of these traits can be used as an indirect selection criterion in early generations or small plots, because they point in the same direction as grain yield. Second, earliness traits, days to flowering and days to maturity, were partly independent in the multivariate space, so breeders can still adjust phenology without losing yield, which is important for matching mustard to a 15 October sowing and a 10 March harvest, as in this trial.

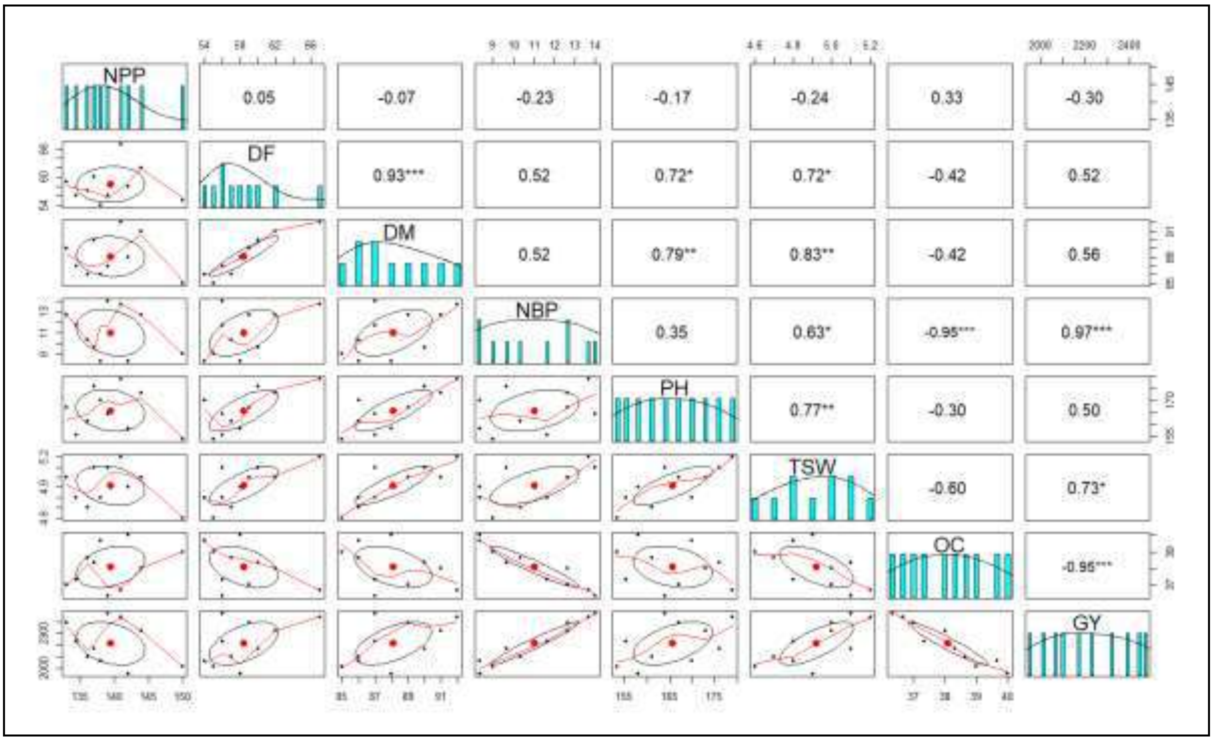

Figure 5: *Correlation Matrix of studied plant traits in Elite Mustard Genotypes*

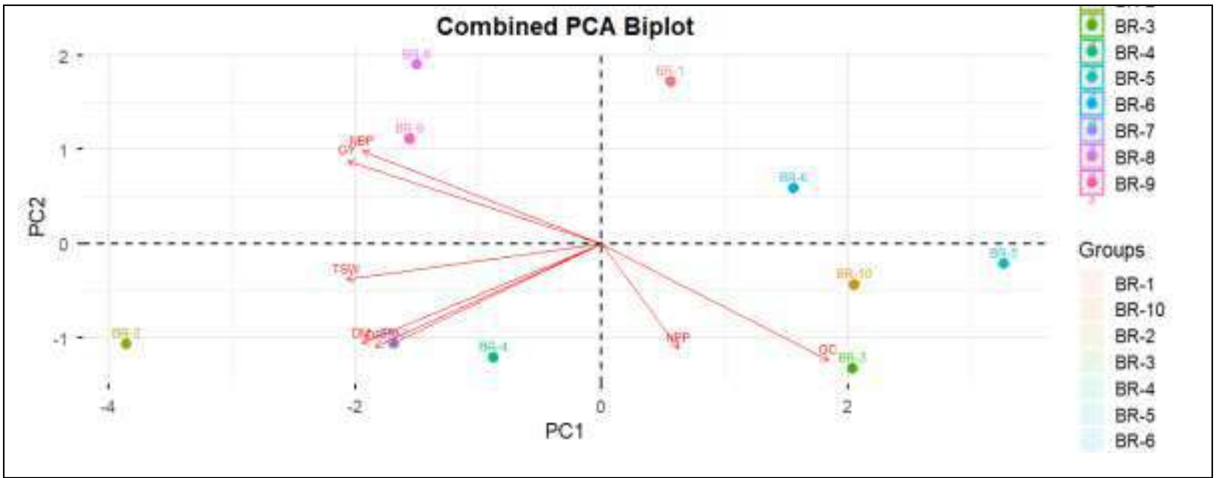

Figure 6: Combined PC1/PC2 Biplot between plant traits and mustard genotypes

When the results from Table 1, the bar charts, Figures 1a–b to 4a–b, the correlation matrix, and the PC1/PC2 biplot, is viewed together, it supports the conclusion that some of the new BR series strains are promising candidates for semi-arid Bahawalpur. They should be advanced to multilocation testing to confirm stability of grain yield (GY; kg ha^{-1}) and oil content (OC; %) under varying irrigation and temperature, as recommended in earlier Pakistani mustard work.

Conclusion

The evaluation of ten mustard strains at the Oilseed Section, RARI, Bahawalpur during 2023–24 showed that genotypic differences were highly significant for all agronomic and oil related traits, as confirmed by the ANOVA. This means that the tested material contains real and exploitable variability for semi-arid conditions. The bar charts for stand establishment, phenology, plant stature, seed size, oil content and grain yield (Figure 1a–b to Figure 4a–b) further showed that several of the newly developed BR lines performed at least at par with, and in some traits better than, the two check varieties, Super Raya (BR-9) and Cholistani Raya (BR-10). The correlation analysis indicated that grain yield (GY; kg ha^{-1}) was positively associated with number of branches per plant (NBP; branches $plant^{-1}$), plant height (PH; cm), 1,000 seed weight (TSW; g) and oil content (OC; %), while days to flowering and days to maturity were relatively independent, which allows simultaneous selection for earliness and productivity under a 15 October to 10 March cropping window. The PC1/PC2 biplot also placed most high yielding and high oil traits on the same side, showing that improvement in yield does not necessarily reduce oil content in this material. Taken together, these results support the advancement of the best performing BR strains to multilocation and multiyear testing in southern Punjab, so that stable, farmer acceptable mustard cultivars can be released for the Bahawalpur belt, where edible oil crops are required to mature early, tolerate episodic water stress and still provide good oil recovery.

Author's Contribution

Conceptualization, Planning, Execution, Data Recording and Supervision; **SH**: *Writing – original draft;* **MIY, SH, NK, AHS, ZH:** *Writing – review & editing;* **HMZUG, ST, AMK, MK, FH:** *Data Retrieval and Analysis;* **IN, NA, FG, ZJ**

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