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# Wide hybridisation and introgression of anthracnose resistance in the background of local landraces of rajmash (*Phaseolus vulgaris*)

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## ABSTRACT

The present study was aimed to broaden the genetic base of rajmash (*Phaseolus vulgaris* L.) by conducting a wide hybridisation programme under controlled conditions. The study involved crosses between cultivated and wild *Phaseolus vulgaris* and inter-specific crosses of *P. vulgaris* with *P. coccineus, P. acutifolius* and *P. lunatus*. The success of hybrid establishment and their comprehensive development was up to 18.28% in intra-specific hybrids, with accessions of secondary gene pool 3.94–9.04%, with tertiary gene pool and with quarterly gene pool only 0.5%. However with mentor pollinated, the achievement rate of intra-specific hybrids was 16.84%. On the basis of pooled mean performance, RIL (Recombinant inbred line) 14 of Bhaderwah Local (BL) × Poonch Local (PL) in $F_4$ and $F_5$ generations showed maximum seed yield (15.56 g/plant) along with moderately resistance against anthracnose. Similarly, RIL11of mentor pollinated inter-specific hybrid in $F_4$ and $F_5$ generations showed higher seed yield (29.79 g/plant) along with resistance against anthracnose. The application of wild species of rajmash i.e. *P. coccineus, P. acutifolius* and *P. lunatus* for the improvement of rajmash was just initiated and success rate is very less in India and remains limited. Promising RILs of both intra and inter-specific hybrids may be further evaluated for stability in performance for varietal development programme in the background of local land races of rajmash of Union Territory of Jammu and Kashmir.

**Keywords**: Common bean, *Phaseolus vulgaris*, *Phaseolus coccineus*, *Phaseolus acutifolius,* Inter-specific hybridisation

Among diseases, bean anthracnose caused by the fungus *Colletotrichum lindemuthianum* (Sacc and Magn) is the most destructive disease of common beans. A universal weakening in the part under cultivation and production of pulses in overall and rajmash (*Phaseolus vulgaris* L.) in specific has been noted in the north western region for the last three decades. Among the five domesticated species, *P. vulgaris* accounts for more than 90% of the cultivated crop worldwide and is by far the most widely consumed grain legume in the world (Singh 2001). Wild progenitors are the foundation for landraces and landraces are the foundation for modern cultivars. The cultivated species of secondary and tertiary gene pools have been used for the improvement of common bean. While partial resistance is existing in the cultivated *P. vulgaris* for anthracnose, the wild rajmash species of the gene pool one ($GP_1$) and the species in the secondary and tertiary gene pools that comprises of several annuals and perennials are important sources of resistance to anthracnose (Blair *et al.* 2006). One of the types in the $2^{nd}$ gene pool i.e. *P. coccineus* is a promising source for resistance against anthracnose.

In addition to the diversity available within the species, inter-specific hybrids are very difficult to produce between the common bean and *P. coccineus* besides the recovery of useful progenies from such crosses is low due to reduced viability and fertility. *P. acutifolius* has been used as a source of resistance to anthracnose (Singh and Munoz 1999), and it is well known for its tolerance to drought and high temperatures as well. The wild relatives are a potential source of novel alleles that can be exploited for the improvement of yield and other quantitative traits in domesticated bean (Kumar *et al.* 2022). Hence, the present investigation was planned to develop wide hybrids for the development of improved varieties and broadening the inherent base of rajmash.

## MATERIALS AND METHODS

*Germplasm*: Twenty-three accessions of primary gene pool (*P. vulgaris*), four from secondary gene pool (*P. coccineus*) and three each from tertiary (*P. acutifolius*)

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and 4th gene pool (*P. lunatus*) were attained from the ICAR-National Bureau of Plant Genetic Resources, New Delhi (Table 1). These accessions were screened under both phytotron and field conditions against bean anthracnose.

*Hybridisation*: Crosses for generation of segregating population required for this study were carried out during 2021 and 2022 in the glasshouse at School of Biotechnology, Sher-e-Kashmir University of Agriculture Sciences and Technology, Jammu (32°39′N, 74°48′E; at an elevation of 293 m amsl), Jammu and Kashmir. Crossing was made by emasculation of the female flowers followed by transfer of pollen grains from just opened flowers to the stigma of emasculated flower.

Intra-specific hybrids i.e. between 'Bhaderwah Local' (BL), 'Poonch Local' (PL) (land races) and 'Shalimar' as females with IC258276, IC202274 and IC341928 as donor parents and inter-specific hybrids between local land races and accessions from secondary gene pool (IC361884 and IC423433) and 3rd gene pool (EC755281, EC755282 and EC755283) and 4th gene pool (IC328272) were attempted (Table 1). Mentor pollinated hybrids between 'Bhaderwah Local' as female and mixtures of pollens from IC361584 IC423433 and IC328372 were also attempted in a glasshouse at School of Biotechnology, Chatha and Regional Horticulture Research Station, Bhaderwah, Sher-e-Kashmir University of Agriculture Sciences and Technology, Jammu, Jammu and Kashmir during 2021 and 2022. Fresh distant hybrid as well as back crosses (BC1F1S) between [Bhaderwah Local × (BL × IC361884)], [Bhaderwah Local × (BL × IC423433)], [Bhaderwah Local × (BL × IC341928)], [Bhaderwah Local × (BL × IC202274)] and [Bhaderwah Local × (BL × IC202271)] were also attempted both *in vitro* and under field conditions in 2022. RILs (Recombinant inbred lines) of both inter/intra specific hybrids in $F_4$ and $F_5$ generations were evaluated at the experimental farm of Regional Horticulture Research Station, Bhaderwah, Sher-e-Kashmir University of Agriculture Sciences and Technology, Jammu, Jammu and Kashmir during *kharif* 2023 and 2024. Screening against anthracnose disease was done based on a 1–9 scale (Schoohoven and Pastor 1987). Rajmash genotypes and accessions with scores of 1–3 as resistant; those with scores of 4–6 were intermediate and 7–9 as susceptible.

## RESULTS AND DISCUSSION

*Response of primary gene pool to* C. lindemuthianum: Twenty-three accessions of $GP_1$ along with two landraces and one released variety of rajmash were screened for resistance against anthracnose under glasshouse conditions after treating with artificial inoculum. The data were recorded as per Schoohoven and Pastor (1987) after three weeks of inoculation. Accessions from primary gene pool ($GP_1$), 13.04% were found resistant to *C. lindemuthianum.* Of these concurrences, 82.60% were moderately resistant to *C. lindemuthianum*, 4.35% accessions of $GP_1$ were susceptible against anthracnose (Table 1). Sofi *et al.* (2023) reported that western Himalayan region is a rich repository

Table 1 Screening of indigenous and exotic accessions of common bean for anthracnose resistance in the greenhouse

| S. no. | Accessions | Anthracnose score | Disease reaction to *C. lindemuthianum* |
|---|---|---|---|
| Primary gene pool ($GP_1$) | | | |
| 1 | Shalimar | 3.5 | Resistant |
| 2 | Bhaderwah Local | 5.6 | Moderate resistant |
| 3 | Poonch Local | 5.5 | Moderate resistant |
| 4 | IC260312 | 3.8 | Moderate resistant |
| 5 | IC258365 | 3.75 | Moderate resistant |
| 6 | IC260336 | 4.02 | Moderate resistant |
| 7 | IC243198 | 5.5 | Moderate resistant |
| 8 | IC202271 | 5.78 | Moderate resistant |
| 9 | IC202274 | 3.5 | Moderate resistant |
| 10 | IC341807 | 6.5 | Susceptible |
| 11 | IC258276 | 3.02 | Resistant |
| 12 | IC47838 | 4.5 | Moderate resistant |
| 13 | IC341765 | 4.2 | Moderate resistant |
| 14 | IC341884 | 3.5 | Moderate resistant |
| 15 | IC341905 | 3.78 | Moderate resistant |
| 16 | IC341922 | 3.22 | Moderate resistant |
| 17 | IC313322 | 3.5 | Moderate resistant |
| 18 | IC341807 | 4.5 | Moderate resistant |
| 19 | IC341928 | 3.41 | Moderate resistant |
| 20 | IC243197 | 4.58 | Moderate resistant |
| 21 | EC500362 | 3.00 | Resistant |
| 22 | EC500308 | 3.2 | Moderate resistant |
| 23 | IC43576 | 4.01 | Moderate resistant |
| Secondary gene pool ($GP_2$) | | | |
| 1 | IC361884 | 2.14 | Resistant |
| 2 | IC47839 | 2.0 | Resistant |
| 3 | IC423433 | 1.10 | Resistant |
| 4 | IC361584 | 1.58 | Resistant |
| Tertiary gene pool ($GP_3$) | | | |
| 1 | EC755281 | 2.5 | Resistant |
| 2 | EC755282 | 2.0 | Resistant |
| 3 | EC755283 | 1.50 | Resistant |
| Quarternary gene pool ($GP_4$) | | | |
| 1 | IC328372 | 1.00 | Resistant |
| 2 | EC755285 | 1.10 | Resistant |
| 3 | EC755286 | 1.5 | Resistant |

of common bean genetic resources evolved over generations of farmer selection; and genotype WB-1634 was resistant to multiple diseases including anthracnose.

*Response of secondary gene pool accessions to anthracnose*: All the accessions of $GP_2$ (IC361884, IC47839, IC423433 and IC361584) were extremely resistant to *C. lindemuthianum* with no symptoms of anthracnose. The maximum rating verified for the accessions of *P. coccineus* were 1.10. Scores varied from 1.10–2.14 (Table 1).

*Response of $GP_3$ and $GP_4$ to anthracnose*: All three accessions each from $GP_3$ and $GP_4$ were exceedingly resistant to anthracnose (Table 1). The vulnerable genotypes of *P. vulgaris* included as controls (BL and PL) were all vulnerable to anthracnose, and established large lesions with sunken cankers on stems and the apex of plants was often dead. The moderately unaffected genotypes comprised as controls (Shalimar) were resistant to anthracnose. The consistency and durability of resistant cultivars is incompletely reliant on the variation showed by the pathogen. For diseases produced by extremely mutable pathogens, such as *C. lindemuthianum*, it is obligatory to differentiate the causes of infection or resistance to successfully manage the disease. Identification of genotypes with resistance to anthracnose within the $GP_2$, $GP_3$ and $GP_4$ could subsidise to this management approach.

*Wide hybridisation*: Hybridisation of *Phaseolus* spp. (domesticated) with wild types were carried out in glasshouse throughout the year with number of sowings in plastic pots for getting enough number of fruitful crosses with lines of $GP_1$, $GP_2$, $GP_3$ and $GP_4$ during 2021 and 2022. All *P. vulgaris* landraces (BL and PL) and genotypes (Shalimar) flowered along with donor parents from *P. coccineus*, *P. acutifolius and P. lunatus* accessions, although staggered sowings were done in an attempt to obtain synchronous flowering with the applications of $GA_3$. Though number of concentration were ranging from 50–150 ppm but 150 ppm concentrations was the most successful (Table 1). As a consequence, *P. coccineus*, *P. acutifolius* and *P. lunatus* were mainly used as male parent in crosses with *P. vulgaris*.

Crosses were attempted during 2021 and 2022 on 252 flowers of landrace i.e. Bhaderwah Local with pollens from IC258276, 140 crosses were primarily established with the applications of 150 ppm of $GA_3$ but 0.50% successfully developed into normal pod and remaining crosses were degenerated between 5–14 days. In many cases, pods began to advance but within 5 and 14 days after pollination (DAP), they turned yellow and dried. Hybrids between Bhaderwah Local × Poonch Local showed 18.28% success rate for the progress of normal fertile plant with shriveled seeds (Table 2, Fig. A–C). However, 180 crosses were primarily established and majority of them were degenerated within two weeks after pollination (Table 2). Success rate of 20–46.42% observed with the pollens from IC341928, IC202274 and IC258276 but within 3–15 DAP, turned yellow and dried. None of the embryos developed but for only outer pericarp.


Fig. 1 Pictorial depiction of wide hybrids of rajmash (A–I) developed with $GP_1$, $GP_3$, $GP_4$ in different generations.
MP, Mentor pollinated; IC, Indigenous collection; EC, Exotic collections; BL, Bhaderwah Local; PL, Poonch Local; $GP_1$, Gene pool one; $GP_2$, Gene pool two; $GP_3$, Gene pool three and $GP_4$, Gene pool four.

Table 2 List of intra and inter-specific hybrids generated by using wild, $GP_1$, $GP_2$ $GP_3$ and $GP_4$ under controlled conditions

| Hybrids | No. of attempted crosses | No. of established crosses | Days to degenerated hybrids | $GA_3$ (ppm) | Per cent of $F_1$ obtained |
|---|---|---|---|---|---|
| Primary gene pool ($GP_1$) (*Phaseolus vulgaris*) | | | | | |
| BL × IC258276 | 252 | 140 | 5–14 | 150 | 0.50 |
| BL × PL | 272 | 180 | 7–12 | 150 | 18.28 |
| BL × IC202274 | 225 | 160 | 8–12 | 150 | 0.80 |
| Shalimar × IC341928 | 125 | 25 | 10–15 | 150 | NIL |
| PL × IC 202274 | 168 | 78 | 3–7 | 150 | NIL |
| PL × IC258276 | 195 | 62 | 3–10 | 150 | NIL |
| Total | 1227 | 465 | 3–15 | - | |
| Secondary gene pool ($GP_2$) (*Phaseolus coccineus*) | | | | | |
| BL × IC361884 | 188 | 40 | 3–23 | 150 | 9.04 |
| PL × IC361884 | 148 | 25 | 7–10 | 150 | NIL |
| Shalimar × IC361884 | 76 | 22 | 5–12 | 150 | NIL |
| BL × IC423433 | 152 | 72 | 3–10 | 150 | 3.94 |
| PL × IC423433 | 32 | 7 | 2–5 | 150 | NIL |
| Shalimar × IC423433 | 12 | 05 | 3–4 | 150 | NIL |
| Total | 608 | 171 | 2–12 | - | - |
| Tertiary gene pool ($GP_3$) (*Phaseolus acutifolius*) | | | | | |
| BL × EC755281 | 87 | 32 | 3–5 | 150 | 0 |
| BL × EC755282 | 32 | 10 | 3–5 | 150 | 0 |
| BL × EC755283 | 92 | 52 | 3–4 | 150 | 0 |
| Total | 211 | 94 | 3–5 | - | NIL |
| Quaternary gene pool ($GP_4$) (*Phaseolus lunatus*) | | | | | |
| BL × IC328372 | 462 | 78 | 3–25 | 150 | 0.5 |
| PL × IC328372 | 105 | 35 | 3–7 | 150 | NIL |
| Total | 567 | 113 | 3–25 | - | - |
| Backcrosses (BCs) | | | | | |
| BL × (BL × IC202271) | 54 | 12 | 2–3 | 150 | 11.11 |
| BL × (BL × IC361884) | 55 | 15 | 3–5 | 150 | 5.45 |
| BL (BL × IC423433) | 35 | 15 | 3–5 | 150 | - |
| BL × (BL × IC341928) | 12 | 03 | 4–5 | 150 | - |
| BL × (BL × IC202274) | 42 | 20 | 3–5 | 150 | - |
| Total | 198 | 65 | – | - | - |
| Mentor pollinated hybrids | | | | | |
| BL × (BL × IC423433, IC361584, IC328372) | 95 | 42 | 3–7 | 150 | 16 .84 |
| PL × IC423433, IC361884, IC341765 | 13 | 4 | 2–5 | 150 | - |
| BL × EC755283, IC328372, IC361884 | 6 | 02 | 3–8 | 150 | - |
| PL × IC423433, IC361884, IC328372 | 15 | 5 | 2–5 | 150 | - |
| PL × IC423433, IC361884 | 23 | 5 | 2–5 | 150 | - |
| Total | 180 | 58 | – | | 16 |

BL, Bhaderwah Local; PL, Poonch Local.

Overall, 19.58% crosses were completely developed.

These results indicated that it is potentially useful germplasm (Poonch Local, IC258276 and IC202274) for intra-specific hybridisation programmes. These findings were in conformity with the findings of Kumar *et al.* (2021).

*Hybridisation with secondary gene pool ($GP_2$)* Phaseolus coccineus: It showed 28.13% success rate with the accessions (IC361584, IC423433) with BL, PL and Shalimar as female parent and 12.98% were successfully developed into normal plant but majority of seeds were abnormal, and they were usually small, shrunken, shriveled and had a broken and incomplete testa (Table 2). Crosses between *P. vulgaris* and *P. coccineus* accessions indicated that both cytoplasmic and nuclear incompatibility factors exist between the species (Smartt 1970). Mahuku *et al.* (2002) exhibited that use of heritable resistance is the most applied and monetary way to control anthracnose of rajmash. Accessions from secondary gene pool established an appreciated cause of resistance and might aid in the expansion of resistance to anthracnose. These genetic barriers are not integral to every rajmash line.

*Hybridisation with tertiary ($GP_3$) and quarternary gene pool ($GP_4$)*: It revealed that inter-specific hybrids developed by with females as BL and PL with donor parents from tertiary gene pool (EC755281, EC755282, and EC755283) and quarternary gene pool (IC328372) initially resulted 26% hybrids but none of them were fully developed into normal fertile seeds (Table 2, Fig. 1 D and F). Maximum number of fertile embryos were dried and degenerated between 3–5 DAP, ovules were so small and were very difficult to isolate, and ovule culture showed a very low success rate in developing tissue culture regenerated plant. These observations indicated that the success or failure of inter-specific crosses depends on the genetic barriers between the bean germplasm of interest. Therefore, the identification of inter-specific barriers in common bean lines will make the selection of cross compatible parents possible. Crosses of *P. vulgaris* with *P. acutifolius* and *P. lunatus* have shown that both cytoplasmic and nuclear incompatibility factors exist between the species (Smartt 1970).

*Back crosses with* Phaseolus vulgaris: The study showed that five unlike hybrids $F_1$S were back crossed with *Phaseolus vulgaris* (Bhaderwah Local). One hundred ninety-eight back crosses were attempted to increase the quantum of targeted traits out of which only sixty-five were established but majority of them were degenerated between 3–5 DAP. 11.11% of back crosses of *P. vulgaris* accession IC202271 with F1S of (BL× IC202271) were developed into normal fertile plants and 5.45% of back cross between BL and F1 of BL × IC361884 produced normal fertile plant (Table 2). However, the success rate was very low in the recovery of normal fertile back crosses of secondary gene pool as reported by Munoz *et al.* (2004).

*Mentor pollinated hybrids*: Mentor pollinated technique used to overcome incompatibility barriers by making use of the 'fertilising ability' of compatible pollen. In the early experiments of Steltler and Ager (1984), compatible mentor pollen was mixed with incompatible pollen of another species, and a few of the many progeny proved to be hybrids. One hundred eighty mentor pollinated hybrids were developed by mixing the pollens of compatible (IC361584, IC423433 and IC 3611884) and non-compatible (IC328372 and EC755283) and their dusting on the stigma of local land races i.e. BL and PL which were used as recipient a parent. 32.22% crosses were initially established and degenerated between 2–8 DAP. In these crosses, no embryos/ovules were developed between 2–8 days and can be used in embryo/ovule techniques (Table 2, Fig. G–I). About 16–84% crosses were successfully developed into normal pod with shrinked/small in size seeds. $F_1$S inter-specific hybrids were intermediate between the parents for leaf size and shape. The flower size of the hybrids was similar to that of the female parent whereas, the growth habit was indeterminate prostrate and similar to that of the male parent. These findings were also confirmed by Richard and Sheerens (2006).

*Mean performance of intra and inter-specific hybrids of rajmash*

*Intra-specific hybrids*: Twenty-four RILs of intra-specific hybrids of two local landraces of rajmash were also evaluated for anthracnose resistance and agronomical traits (Table 3, Fig. 1A). On the basis of pooled mean data of two years, RIL14 exhibited the highest seed yield (15.56 g/plant) with superiority of 131.14% over pooled mean performance of both the controls (BL and PL) in $F_5$ and 145.91% ($F_4$) along with moderately resistance against anthracnose. However, RIL12 also showed seed yield (13.97 g/plant) at par with RIL 14 but showed fully resistance against anthracnose (Table 3). These findings were also in accordance with the findings of Kumar *et al.* (2021), Singh *et al.* (2022) and Padha *et al.* (2025). On the basis of pooled mean seed yield /plant and resistant reaction against anthracnose, intra and inter specific hybrids are recommended for their further evaluation and their utilisation in development of improved varieties of rajmash in Jammu and Kashmir. Similar results were also supported by Kumar *et al.* (2021), Bhagat *et al.* (2023) and Bhagat *et al.* (2024).

*Inter-specific hybrids*: Twenty-four RILs of [Bhaderwah Local × (BL × IC361884)] along with controls (BL and PL) were evaluated during *kharif* 2023 and 2024 for days to 50% flowering, number of pods/plant, pod length, seed yield/plant and anthracnose resistance. RILs showed wide range for days to 50% flowering (32–89 days) and seed yield/ plant (4.0–18.90 g/plant) along with reaction from resistant to susceptibility (Table 4, Fig. 1H) in $BC_2F_4$S generation and 39.9–95.67 days to 50% flowering, 609–22.67 g/plant seed yield in $BC_2F_5$S generation (Fig. 1I). On the basis of pooled mean performance, RIL11 exhibited higher number of pods/plant and highest seed yield/plant (20.79 g/plant) among all the RILs along with resistance reaction against anthracnose. These results were in consance with the findings of Kumar *et al.* (2021), Bhagat *et al.* (2023) and Bhagat *et al.* (2024).

Hence, from the present study, it was observed that

Table 3 Mean performance of intra hybrid BL × PL ($F_4$S): BL × PL ($F_5$S) for targeted traits of rajmash during *kharif* 2023 and 2024

| RILs | *Kharif 2023* ($F_4$) | | | | | *Kharif* 2024 ($F_5$) | | | | | Pooled mean of seed yield (g/plant) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of pods/ plant | No. of seeds/ pod | Seed yield/ plant (g) | Superiority % over control | Anthracnose reaction | No. of pods/ plant | No. of seeds/ pod | Seed yield/ plant (g) | Superiority % over control | Anthracnose reaction | |
| RIL 1 | 21.86 | 10.90 | 8.56 | 59.11 | MR | 28.76 | 10.76 | 9.24 | 19.38 | MR | 8.90 |
| RIL 2 | 15.70 | 8.90 | 6.76 | 25.65 | MR | 20.67 | 9.06 | 7.89 | 1.94 | MR | 7.33 |
| RIL 3 | 15.25 | 8.90 | 7.74 | 43.87 | MR | 12.89 | 9.45 | 8.67 | 12.02 | MR | 8.21 |
| RIL 4 | 35.75 | 10.00 | 6.52 | 21.19 | R | 42.89 | 8.76 | 7.56 | -2.33 | MR | 7.04 |
| RIL 5 | 16.00 | 10.56 | 6.63 | 23.23 | R | 21.98 | 10.67 | 7.73 | -0.13 | R | 7.18 |
| RIL 6 | 9.08 | 6.45 | 7.84 | 45.72 | MR | 15.67 | 8.45 | 7.45 | -3.75 | MR | 7.65 |
| RIL 7 | 9.99 | 10.34 | 6.54 | 21.56 | S | 29.09 | 7.78 | 7.00 | -9.56 | MR | 6.77 |
| RIL 8 | 5.25 | 6.56 | 7.86 | 46.10 | S | 10.87 | 7.79 | 8.89 | 14.86 | S | 8.38 |
| RIL 9 | 5.00 | 6.45 | 10.46 | 94.42 | S | 8.08 | 7.23 | 12.89 | 66.54 | S | 11.68 |
| RIL 10 | 5.37 | 6.34 | 9.71 | 80.48 | R | 17.98 | 6.75 | 10.89 | 40.70 | R | 10.30 |
| RIL 11 | 8.98 | 7.67 | 8.02 | 49.07 | R | 18.98 | 8.65 | 8.05 | 4.01 | R | 8.04 |
| RIL 12 | 9.90 | 7.23 | 12.37 | 129.93 | R | 21.24 | 7.77 | 15.56 | 101.03 | R | 13.97 |
| RIL 13 | 8.27 | 6.00 | 13.5 | 150.93 | MR | 10.98 | 6.53 | 16.89 | 118.22 | MR | 15.20 |
| RIL 14 | 8.00 | 5.34 | 13.23 | 145.91 | MR | 18.09 | 6.34 | 17.89 | 131.14 | MR | 15.56 |
| RIL 15 | 8.78 | 7.35 | 6.77 | 25.84 | MR | 14.56 | 7.55 | 7.90 | 2.07 | MR | 7.34 |
| RIL 16 | 8.50 | 9.45 | 5.77 | 7.25 | MR | 18.98 | 10.25 | 6.45 | -16.67 | MR | 6.11 |
| RIL 17 | 7.00 | 8.56 | 8.48 | 57.62 | MR | 12.90 | 9.34 | 9.56 | 23.51 | R | 9.02 |
| RIL 18 | 12.00 | 8.64 | 5.56 | 3.35 | R | 23.09 | 9.65 | 8.09 | 4.52 | R | 6.83 |
| RIL 19 | 7.76 | 7.34 | 5.59 | 3.90 | R | 17.76 | 7.56 | 8.65 | 11.76 | R | 7.12 |
| RIL 20 | 6.34 | 8.00 | 5.89 | 9.48 | R | 16.89 | 8.45 | 7.34 | -5.17 | R | 6.62 |
| RIL 21 | 9.90 | 8.29 | 5.05 | -6.13 | R | 19.90 | 8.55 | 7.90 | 2.07 | R | 6.48 |
| RIL 22 | 28.90 | 7.9 | 5.48 | 1.86 | MR | 28.90 | 8.56 | 8.90 | 14.99 | MR | 7.19 |
| RIL 23 | 14.90 | 8.45 | 6.00 | 11.52 | MR | 24.56 | 9.56 | 7.90 | 2.07 | MR | 6.95 |
| RIL 24 | 7.00 | 6.7 | 5.46 | 1.49 | MR | 12.78 | 10.26 | 8.65 | 11.76 | R | 7.06 |
| Mean of RILs | 11.90 | 8.01 | 7.74 | - | - | 19.52 | 8.57 | 9.50 | - | - | - |
| Control BL | 12.29 | 6.50 | 6.25 | - | MR | 15.60 | 7.50 | 8.05 | - | MR | - |
| PL | 8.56 | 5.25 | 4.50 | - | S | 18.25 | 6.96 | 7.42 | - | S | - |
| Mean of Controls | 10.43 | 5.88 | 5.38 | - | - | 16.93 | 7.23 | 7.74 | - | - | - |

BL, Bhaderwah Local; PL, Poonch Local; RIL, Recombinant inbred lines; MR, Moderate resistant; R, Resistant; S, Susceptible.

Table 4 Mean performance of ($BC_2F_4S$): ($BC_2F_5S$) of (BL × IC361884)] for targeted traits of rajmash during *kharif* 2023 and 2024

| RILs | | *Kharif* 2023 ($BC_2F_4S$) | | | | | *Kharif* 2024 ($BC_2F_5S$) | | | | | Pooled mean seed yield/ plant (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days to 50% flowering | No. of pods | Pod length (cm) | Seed yield/ plant | Anthracnose reaction | Days to 50% flowering | No. of pods/ plant | Pod length (cm) | Seed yield/ plant | Anthracnose reaction | |
| RIL 1 | | 89.00 | 8.76 | 12.00 | 10.00 | MR | 95.67 | 15.90 | 12.67 | 12.89 | MR | 11.45 |
| RIL 2 | | 80.00 | 8.98 | 9.56 | 10.24 | MR | 85.56 | 12.90 | 10.90 | 15.90 | MR | 13.07 |
| RIL 3 | | 71.00 | 8.50 | 9.00 | 11.78 | MR | 72.45 | 15.89 | 9.89 | 14.89 | MR | 13.34 |
| RIL 4 | | 34.00 | 8.35 | 9.67 | 10.67 | R | 50.90 | 21.90 | 9.76 | 12.56 | R | 11.62 |
| RIL 5 | | 62.00 | 12.67 | 6.50 | 8.65 | R | 65.89 | 21.90 | 6.56 | 10.89 | R | 9.77 |
| RIL 6 | | 32.00 | 7.00 | 8.60 | 8.00 | MR | 45.90 | 12.89 | 8.76 | 11.89 | MR | 9.95 |
| RIL 7 | | 73.00 | 8.32 | 7.76 | 7.90 | S | 77.78 | 14.56 | 8.00 | 8.78 | S | 8.34 |
| RIL 8 | | 33.00 | 4.00 | 8.56 | 8.56 | S | 38.90 | 7.67 | 9.00 | 10.67 | S | 9.62 |
| RIL 9 | | 32.00 | 8.00 | 8.43 | 8.45 | S | 34.56 | 18.90 | 8.45 | 9.56 | S | 9.01 |
| RIL 10 | | 32.00 | 9.00 | 8.32 | 8.34 | R | 39.90 | 19.09 | 8.90 | 10.67 | R | 9.51 |
| RIL 11 | | 35.00 | 18.45 | 9.89 | 18.90 | R | 42.90 | 25.67 | 10.89 | 22.67 | R | 20.79 |
| RIL 12 | | 39.00 | 13.34 | 8.43 | 16.25 | R | 41.90 | 21.90 | 8.90 | 18.67 | R | 17.46 |
| RIL 13 | | 36.00 | 8.26 | 6.32 | 6.89 | MR | 42.23 | 7.90 | 6.98 | 10.23 | MR | 8.56 |
| RIL 14 | | 39.00 | 9.67 | 9.65 | 12.89 | MR | 42.34 | 8.89 | 9.77 | 18.90 | MR | 15.90 |
| RIL 15 | | 40.00 | 3.34 | 6.56 | 7.89 | MR | 45.67 | 23.90 | 7.56 | 10.34 | MR | 9.12 |
| RIL 16 | | 45.00 | 8.67 | 9.67 | 10.00 | MR | 49.90 | 18.67 | 9.87 | 12.33 | MR | 11.17 |
| RIL 17 | | 37.00 | 12.26 | 13.23 | 14.89 | MR | 42.23 | 18.90 | 13.67 | 18.38 | MR | 16.64 |
| RIL 18 | | 53.00 | 2.00 | 15.54 | 5.78 | R | 55.87 | 8.00 | 15.87 | 7.90 | R | 6.84 |
| RIL 19 | | 53.00 | 2.00 | 7.98 | 4.00 | R | 56.89 | 10.90 | 8.89 | 10.89 | R | 7.45 |
| RIL 20 | | 82.00 | 8.00 | 8.86 | 4.00 | R | 84.67 | 18.90 | 9.45 | 8.90 | R | 6.45 |
| RIL 21 | | 53.00 | 3.90 | 6.56 | 5.56 | R | 62.89 | 13.90 | 6.43 | 6.90 | R | 6.23 |
| RIL 22 | | 51.00 | 7.67 | 7.20 | 8.00 | R | 55.89 | 15.90 | 7.68 | 10.67 | R | 9.34 |
| RIL 23 | | 54.00 | 4.90 | 9.67 | 6.00 | R | 60.89 | 21.36 | 10.56 | 14.90 | R | 10.45 |
| RIL 24 | | 46.00 | 7.09 | 22.00 | 12.90 | R | 52.34 | 10.89 | 20.56 | 17.09 | R | 15.00 |
| Mean of RILs | | 50.04 | 8.05 | 9.58 | 9.44 | - | 56.01 | 16.14 | 10.00 | 12.81 | - | - |
| Control | BL | 45.09 | 12.00 | 8.98 | 6.25 | MR | 55.87 | 15.67 | 12.09 | 8.50 | MR | 7.38 |
| | PL | 55.65 | 10.00 | 6.25 | 4.50 | S | 58.90 | 12.46 | 10.50 | 7.71 | S | 6.11 |
| Mean of control | | 50.07 | 8.27 | 9.43 | 9.13 | - | 56.11 | 15.98 | 10.10 | 12.45 | - | 11.45 |

BL, Bhaderwah Local; PL, Poonch Local; RIL, Recombinant inbred lines; MR, Moderate resistant; R, Resistant; S, Susceptible.

hybridisation between domesticated land races of *P. vulgaris* exhibited success rate of 18.24%, partially successful with wild accessions of cultivated *P. vulgaris* (0.5–0.8%). It was also found that intra-specific hybrids reasonably successful with the accessions of secondary gene pool. However, limited success has been obtained in developing RILs of intra-specific hybrids (RIL 14 and RIL 12) while inter-specific hybrids (RIL11) showed promising results in terms of higher seed yield (g/plant) and resistance reaction against anthracnose and shall be used in future rajmash varietal development programme.

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