Gene Action, Combining Ability, Genetic Expression of Heterosis and Characterization of Rice (Oryza sativa L.) Genotypes for Quality Traits

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Abstract Present investigation was conducted to estimate the per se performance, combining ability and heterosis for grain quality traits in rice using line × tester mating design. Analysis of variance with respect to crosses revealed significant differences for all the traits studied. GCA and SCA results revealed the predominance of SCA variance in relation to GCA variance for all the traits. For aroma, twenty one cross combinations were identified having slight to moderate aroma. Among lines, investigation of highest gca effects illustrated that HPR 2858, HPR 2761, HPR 2754, HPR 2668 and HPR 2748 (P) were good general combiners for different quality traits. Among the testers, HPR 2216 exhibited maximum gca effects for protein content, amylose content and gel consistency while Pusa Basmati 1509 was good combiner for gelatinization temperature. Further, cross combinations HPR 2748 (W) × HPR 2216, HPR 2755 × Kasturi, HPR 2761 × Pusa Basmati 1509 and HPR 2748 (P) × Pusa Basmati 1509 were identified as best specific combination for different grain quality traits. Cross combinations HPR 2748 (W) × HPR 2216, HPR 2761 × HPR 2216, HPR 2748 (P) × Pusa Basmati 1509 showed high degree of heterosis over standard check for different quality parameters.

Keywords Rice; Grain quality; per se performance; Gene action; Combining ability; Heterosis

Introduction Rice (Oryza sativa L. 2n = 24) is one of the most vital food crop, belongs to the family poecceae, feeding by more than half of the global population (Khush, 1997). Globally rice provides 21% energy and 14% protein Kennedy and Burlingame (2003). In the Asia and Pacific region, where 90 per cent of total rice is produced and consumed and acts as a lifeline of the people over there. Nowadays, with the continuous strengthening of the economies of different rice-producing countries demand for superior rice grain quality also escalates. The primary components of rice grain quality include grain size and shape, appearance, hulling-milling properties and cooking-eating characteristics. The cooking-eating qualities include amylose content, gelatinization temperature and gel consistency (Sarial, 2014). In addition to that, protein is one of the essential macronutrient present in rice that composess a large portion of human body’s structure. Furthermore, rice having aroma is preferred by almost all the consumers and it fetches a good price. Nowadays, next to yield, grain and nutritional quality has also become the chief consideration. So there is an imperative need to give emphasis on improving rice grain quality in rice breeding programmes, which is feasible by heterosis breeding and by having good knowledge about combining ability and per se performance. Moreover, the estimation of additive and non-additive gene action may be useful in determining the possibility of exploitation of heterosis and isolation of pure line among the progenies of the good hybrids. Heterosis breeding is an important genetic tool that can facilitate yield enhancement and helps enrich many other desirable quantitative and qualitative traits in crops (Srivastava, 2000). One of the main problems faced by plant breeders for improving varieties is to select good parents and crosses. Combining ability analysis helps in recognition of parents with greater general combining (GCA) and parental combinations with high specific combining (SCA) and hence help in selection of the desirable parents (Pradhan et al., 2006).

Breeding strategies based on hybrid production require a high level of heterosis as well as the specific combining ability (SCA) of crosses (Jelodar, 2010) The present study was carried out the objectives to evaluate GCA and
SCA in rice cultivars and heterosis of different traits for identifying desirable cultivars and developing high yielding hybrid rice varieties.

Materials and Methods
The experimental material consisted of ten lines and three testers. The ten lines viz., HPR 2615, HPR 2668, HPR 2720, HPR 2748 (Purple), HPR 2748 (White), HPR 2754, HPR 2755, HPR 2761, HPR 2858 and HPR 2862 were crossed with three testers viz., Kasturi, HPR 2216 (Improved) and Pusa Basmati 1509 for the hybrid development using line × tester mating design during Kharif 2013. All the F₁s (30) materials along with parental lines [lines (10) + testers (3)] were evaluated in randomized block design with three replications during Kharif 2014 at RWRC, Malan. Twenty nine days old seedlings were transplanted in a single row of 2 m length with inter and intra spacing of 20 and 15 cm, respectively. Single seedling was transplanted per hill and all agronomic and plant protection recommended packages of practices were followed throughout the crop growth period in order to get precise evaluations. Data were recorded for grain quality and physico-chemical attributes viz., protein content, amylose content, gelatinization temperature (GT), gel consistency (GC) and presence of aroma. Amylose content of polished rice was estimated by using Juliano (1971) method. Gelatinization temperature was evaluated by the alkali digestion method of Little et al. (1958) using alkali spreading value. The gel consistency was done by applying method of Cagampang et al. (1973). Presence of aroma was evaluated by following method of Rani et al. (2013). Remaining trait was recorded as per standard method. The magnitude of heterosis was calculated over better parent (Hb) and superiority over check variety (Sc). The combining ability analysis and general (GCA) and specific (SCA) effects were estimated following line × tester design proposed by Kempthorne (1957).

Results and Discussion
Analysis of variance for line × tester mating design with respect to crosses, lines and testers revealed significant differences among all traits except protein content in case of lines and testers whereas, the interaction between lines and testers were significant for all the traits indicating the importance of non-additive variance in their expression. GCA and SCA results illustrated the predominance of SCA variance in relation to GCA variance for all the traits studied. Furthermore, the ratio of GCA and SCA variance was less than unity for all the characters which also indicated preponderance of non-additive gene action and suggested good prospects of the exploitation of variation for the studied traits through hybrid breeding (Table 1). As earlier was reported by Malini et al. 2014.

Table 1 Analysis of variance for combining ability analysis in line × tester design for grain quality traits

| Sources of variation | Mean Sum of Square | DF | Replications | Crosses | Lines | Testers | Lines × Testers | Error | gca | sca | gca/sca |
|----------------------|-------------------|----|--------------|---------|-------|---------|----------------|--------|-----|-----|--------|
| Protein              | 0.043             | 2  | 29           | 3.728   | 3.633 | 1.830   | 0.090          | 0.013  | 0.580 | 0.023  |
| Amylose content      | 0.024             | 2  | 29           | 89.384  | 54.857| 2.574   | 0.074          | 0.571  | 0.833 | 0.685  |
| GT                   | 0.178             | 2  | 29           | 4.667   | 56.311| 1.830   | 0.097          | 0.087  | 0.577 | 0.150  |
| Gel consistency      | 3.678             | 2  | 29           | 435.608 | 2833.244| 152.022 | 5.302          | 50.310  | 0.105  |

Note: * Significant at 5% level of significance, GT- Gelatinization temperature

Mean performance of crosses/genotype
Mean performance of thirty crosses and thirteen parents are presented in Table 2. Twelve cross combinations i.e. HPR 2615 × Pusa Basmati 1509, HPR 2668 × Kasturi, HPR 2668 × Pusa Basmati 1509, HPR 2720 × Kasturi, HPR 2720 × HPR 2216, HPR 2720 × Pusa Basmati 1509, HPR 2748 (W) × HPR 2216, HPR 2754 × HPR 2216, HPR 2761 × Pusa Basmati 1509, HPR 2858 × Pusa Basmati 1509, HPR 2862 × Kasturi, HPR 2862 × Pusa Basmati 1509 showed better performance than their respective parents For protein content. For amylose content, the cross HPR 2761 × HPR 2216 illustrated the higher mean than their respective parents. On the other hand, for
Table 2: Mean values of rice crosses/genotypes for grain quality traits

| Sr. No. | Cross combinations/Genotype | Protein content (%) | Amylose content (%) | GT | GC (mm) | Aroma |
|---------|-----------------------------|---------------------|---------------------|----|--------|-------|
| 1       | HPR 2615 × Kasturi          | 7.55                | 17.69               | 2  | 42.33  | 3     |
| 2       | HPR 2615 × HPR 2216         | 7.77                | 20.58               | 2  | 61.67  | 2     |
| 3       | HPR 2615 × Pusa Basmati 1509| 8.44                | 19.5                | 3  | 33.67  | 4     |
| 4       | HPR 2668 × Kasturi          | 8.66                | 18.58               | 3  | 53.67  | 3     |
| 5       | HPR 2668 × HPR 2216         | 8.21                | 21.7                | 2  | 58     | 1     |
| 6       | HPR 2668 × Pusa Basmati 1509| 9.54                | 20.17               | 5.67| 49.33  | 3     |
| 7       | HPR 2720 × Kasturi          | 8.88                | 24.52               | 2  | 44.67  | 2     |
| 8       | HPR 2720 × HPR 2216         | 9.32                | 26.92               | 2  | 62     | 1     |
| 9       | HPR 2720 × Pusa Basmati 1509| 9.32                | 25.94               | 4.67| 35.67  | 3     |
| 10      | HPR 2748 (P) × Kasturi      | 7.33                | 23.6                | 3  | 42     | 2     |
| 11      | HPR 2748 (P) × HPR 2216     | 8.66                | 27.42               | 3.67| 52     | 1     |
| 12      | HPR 2748 (P) × Pusa Basmati 1509| 7.99                | 25.3                | 6  | 57.33  | 2     |
| 13      | HPR 2748 (W) × Kasturi      | 7.77                | 23                  | 2  | 41.33  | 2     |
| 14      | HPR 2748 (W) × HPR 2216     | 10.66               | 27.25               | 2  | 46     | 2     |
| 15      | HPR 2748 (W) × Pusa Basmati 1509| 7.55                | 25.94               | 5  | 34.67  | 1     |
| 16      | HPR 2754 × Kasturi          | 7.77                | 22.27               | 2  | 70     | 3     |
| 17      | HPR 2754 × HPR 2216         | 9.32                | 24.68               | 2  | 74.33  | 2     |
| 18      | HPR 2754 × Pusa Basmati 1509| 7.77                | 24.05               | 2.67| 58     | 2     |
| 19      | HPR 2755 × Kasturi          | 7.11                | 21.56               | 2  | 60     | 2     |
| 20      | HPR 2755 × HPR 2216         | 7.99                | 19.9                | 2  | 65     | 1     |
| 21      | HPR 2755 × Pusa Basmati 1509| 7.11                | 20.51               | 4.67| 44.33  | 3     |
| 22      | HPR 2761 × Kasturi          | 8.66                | 28.63               | 1  | 44     | 2     |
| 23      | HPR 2761 × HPR 2216         | 8.66                | 30.98               | 2  | 75     | 1     |
| 24      | HPR 2761 × Pusa Basmati 1509| 9.1                 | 29.51               | 3  | 35     | 3     |
| 25      | HPR 2858 × Kasturi          | 9.1                 | 21.84               | 3  | 48.33  | 3     |
| 26      | HPR 2858 × HPR 2216         | 9.32                | 26.1                | 3  | 63.67  | 1     |
| 27      | HPR 2858 × Pusa Basmati 1509| 10.21               | 22.71               | 5.67| 37.67  | 4     |
| 28      | HPR 2862 × Kasturi          | 8.66                | 20.58               | 2  | 51     | 1     |
| 29      | HPR 2862 × HPR 2216         | 7.99                | 23.75               | 4  | 67.67  | 1     |
| 30      | HPR 2862 × Pusa Basmati 1509| 9.99                | 23.15               | 4.67| 49     | 3     |

**Lines**

| Sr. No. | Cross combinations/Genotype | Protein content (%) | Amylose content (%) | GT | GC (mm) | Aroma |
|---------|-----------------------------|---------------------|---------------------|----|--------|-------|
| 31      | HPR 2615                    | 7.99                | 18.84               | 2  | 37.67  | 2     |
| 32      | HPR 2668                    | 8.44                | 19.37               | 2  | 46.33  | 1     |
Continued table 2

| Sr. No. | Cross combinations/Genotype | Protein content (%) | Amylose content (%) | GT (mm) | GC (mm) | Aroma |
|---------|-----------------------------|---------------------|---------------------|---------|---------|-------|
| 34      | HPR 2748 (P)                | 7.77                | 25.46               | 6.67    | 46.67   | 1     |
| 35      | HPR 2748 (W)                | 9.32                | 23.77               | 2.67    | 31      | 3     |
| 36      | HPR 2754                    | 7.55                | 23.6                | 2       | 61      | 2     |
| 37      | HPR 2755                    | 7.33                | 21.7                | 2       | 37.33   | 1     |
| 38      | HPR 2761                    | 8.66                | 29.87               | 2       | 31.67   | 1     |
| 39      | HPR 2858                    | 9.32                | 23.76               | 2       | 37      | 3     |
| 40      | HPR 2862                    | 8.21                | 22.71               | 2       | 60      | 2     |

**Testers**

| Sr. No. | Cross combinations | Protein content (%) | Amylose content (%) | GT (mm) | GC (mm) | Aroma |
|---------|--------------------|---------------------|---------------------|---------|---------|-------|
| 41      | Kasturi            | 7.99                | 20.73               | 2       | 46      | 4     |
| 42      | HPR 2216           | 8.66                | 30.81               | 3       | 66      | 1     |
| 43      | Pusa Basmati 1509  | 8.21                | 27.25               | 5.67    | 34      | 4     |

| Sr. No. | Cross combinations | Protein content (%) | Amylose content (%) | GT (mm) | GC (mm) | Aroma |
|---------|--------------------|---------------------|---------------------|---------|---------|-------|
| 44      |                   |                     |                     |         |         |       |
| 45      |                   |                     |                     |         |         |       |
| 46      |                   |                     |                     |         |         |       |
| 47      |                   |                     |                     |         |         |       |
| 48      |                   |                     |                     |         |         |       |
| 49      |                   |                     |                     |         |         |       |
| 50      |                   |                     |                     |         |         |       |

Note: GT= Gelatinization temperature, GC = Gel consistency

gelatinization temperature, the cross combinations HPR 2668 × Kasturi, HPR 2761 × Pusa Basmati 1509, HPR 2858 × Kasturi, HPR 2858 × Pusa Basmati 1509, HPR 2862 × Pusa Basmati 1509, HPR 2748 × Pusa Basmati 1509, HPR 2748 (P) × Pusa Basmati 1509, HPR 2748 (W) × Pusa Basmati 1509, HPR 2754 × Kasturi, HPR 2754 × HPR 2216, HPR 2755 × Kasturi, HPR 2755 × Pusa Basmati 1509, HPR 2761 × HPR 2216, HPR 2761 × Pusa Basmati 1509, HPR 2858 × Kasturi, HPR 2858 × Pusa Basmati 1509, HPR 2862 × HPR 2216 demonstrated the higher mean than their respective parents. For gel consistency, the cross combinations HPR 2668 × Kasturi, HPR 2668 × Pusa Basmati 1509, HPR 2858 × Pusa Basmati 1509, HPR 2748 (P) × Pusa Basmati 1509, HPR 2748 (W) × Pusa Basmati 1509, HPR 2754 × Kasturi, HPR 2754 × HPR 2216, HPR 2755 × Kasturi, HPR 2755 × Pusa Basmati 1509, HPR 2761 × HPR 2216, HPR 2761 × Pusa Basmati 1509, HPR 2858 × Kasturi, HPR 2858 × Pusa Basmati 1509, HPR 2862 × HPR 2216 showed higher mean than their respective parents. Among lines, five genotypes viz., HPR 2615, HPR 2754, HPR 2862, HPR 2748 (W), and HPR 2858 had slight to moderate aroma whereas, in testers Kasturi and Pusa Basmati 1509 had strong aroma. Moreover, slight to moderate aroma was found in twenty one hybrids out of total hybrids. Aroma character is a single recessive gene inherited trait and for the development of heterotic aromatic hybrids both the parents need to be aromatic.

**Proportional contribution of lines, testers and their interactions**

The proportional contribution of lines ranged from 22.39 (Gelatinization temperature) to 83.75 per cent (Amylose content). The proportional contribution of testers ranged from 9.85 (Protein content) to 60.05 per cent (Gelatinization temperature). Similarly, the proportional contribution of line × tester interactions ranged from 4.82 (Amylose content) to 44.66 per cent (Protein content). (Table 3 and Figure 1).

Table 3 Estimation of proportional contribution of lines, testers and their interactions

|                      | Protein content | Amylose content | Gelatinization temp | Gel consistency |
|----------------------|-----------------|-----------------|---------------------|-----------------|
| CONTRIBUTION OF LINES| 45.49           | 83.75           | 22.39               | 33.48           |
| CONTRIBUTION OF TESTERS | 9.85       | 11.42           | 60.05               | 44.86           |
| CONTRIBUTION OF L x T | 44.66         | 4.82            | 17.56               | 21.66           |

The contribution of lines was found to be higher than individual contribution of testers and interactions between line × tester for protein content and amylase content, whereas the contribution due to the testers was higher than the individual contribution of lines and interactions between line × tester for gelatinization temperature and gel consistency. The smaller contribution of interaction of the line × tester than either lines or testers indicating higher
estimates of variances due to general combining ability. Selection of the male and female parents on the basis of gca effects would be effective for all the characters.

**Combining ability:** Higher gca effects could be beneficial for the additive gene effects and is theoretically fixable. Present investigation illustrated that HPR 2858, HPR 2761, HPR 2754 were good general combiners for protein content, amylose content and gel consistency, respectively. Furthermore, HPR 2668 and HPR 2748 (P) were also good combiners for gelatinization temperature and showed high gca effects. In addition to that, among the testers, HPR 2216 had maximum gca effects for protein content, amylose content and gel consistency while Pusa Basmati 1509 was good combiner for gelatinization temperature (Table 4). Therefore, identification of parents carrying candidate genes for quality traits with high gca can be involved in hybrid rice breeding programmes.

Specific combining ability is considered to be the one of the best criterion for the selection of superior hybrids. Among the thirty hybrids, eight cross combinations viz., HPR 2615 × Pusa Basmati 1509, HPR 2668 × Pusa Basmati 1509, HPR 2748 (P) × HPR 2216, HPR 2748 (W) × HPR 2216, HPR 2754 × HPR 2216, HPR 2858 × Pusa Basmati 1509, HPR 2862 × Pusa Basmati 1509 recorded positive significant sca effects for protein content. Further seven cross combinations HPR 2748 (P) × HPR 2216, HPR 2748 (W) × Pusa Basmati 1509, HPR 2754 × Pusa Basmati 1509, HPR 2755 × Kasturi, HPR 2858 × HPR 2216, HPR 2862 × Pusa Basmati 1509 showed positive significant value for amylose content. In addition, seven cross combinations viz., HPR 2615 × Kasturi, HPR 2668 × Kasturi, HPR 2748 (W) × Pusa Basmati 1509, HPR 2754 × Kasturi, HPR 2754 × HPR 2216, HPR 2761 × Pusa Basmati 1509, HPR 2858 × HPR 2216, HPR 2862 × Pusa Basmati 1509, HPR 2862 × HPR 2216 illustrated positive significant sca effects for gelatinization temperature while twelve cross combinations viz., HPR 2615 × HPR 2216, HPR 2668 × Kasturi, HPR 2668 × Pusa Basmati 1509, HPR 2720 × HPR 2216, HPR 2748 (P) × Pusa Basmati 1509, HPR 2748 (W) × Kasturi, HPR 2748 (W) × Pusa Basmati 1509, HPR 2754 × Kasturi, HPR 2755 × Kasturi, HPR 2761 × HPR 2216, HPR 2858 × HPR 2216, HPR 2862 × Pusa Basmati 1509 recorded significant positive sca effects for gel consistency. On the other hand, thecross combinations HPR 2748 (W) × HPR 2216, HPR 2755 × Kasturi, HPR 2761 × Pusa Basmati 1509 and HPR 2748 (P) × Pusa Basmati 1509 were showed high scavor protein content, amylose content, gelatinization temperature and gel consistency, respectively (Table 5).

**Heterosis:** In rice, heterosis was first reported by Jones (1926) and the degree of heterosis depends on the degree to which parental lines are diverse and it a universal phenomenon in the nature although it remains a puzzle. Percent heterosis for quality traits was calculated better parent and standard check. The maximum significant positive heterobeltiosis was observed for HPR 2862 × Pusa Basmati 1509 followed by HPR 2748 (W) × HPR 2216, HPR 2668 × Pusa Basmati 1509 and HPR 2858 × Pusa Basmati 1509and the maximum significantly positive heterosis over standard check was observed for HPR 2748 (W) × HPR 2216followed by HPR 2858 ×
Table 4 List of heterotic crosses over heterobeltiosis (Htb) (%), standard check (%), good specific combinations and good general combiners grain quality traits

| Grain quality traits | Heterobeltiosis (Htb) (%) | Standard check (%) | Good specific combinations | Good general combiners |
|----------------------|---------------------------|--------------------|---------------------------|------------------------|
| Protein content      |                           |                    |                           |                        |
| HPR 2862 × Pusa Basmati 1509 (21.63) | HPR 2748 (W) × HPR 2216 1509 (33.42) | HPR 2748 (W) × HPR 2216 1509 (1.76) | HPR 2858 (1.00) |
| HPR 2748 (W) × HPR 2216 1509 (14.38) | HPR 2858 × Pusa Basmati 1509 (27.83) | HPR 2862 × Pusa Basmati 1509 (0.95) | HPR 2720 (0.63) |
| HPR 2668 × Pusa Basmati 1509 (13.12) | HPR 2862 × Pusa Basmati 1509 (25.03) | HPR 2754 × HPR 2216 1509 (0.79) | HPR 2862 (0.33) |
| HPR 2858 × Pusa Basmati 1509 (9.59) | HPR 2668 × Pusa Basmati 1509 (19.44) | HPR 2668 × Pusa Basmati 1509 (0.58) | HPR 2216 (0.24) |

Amylose content

| HPR 2761 × HPR 2216 1509 (49.46) | HPR 2755 × Kasturi (2.29) | HPR 2761 (6.10) |
| HPR 2761 × Pusa Basmati 1509 (42.35) | HPR 2858 × HPR 2216 1509 (2.13) | HPR 2720 (2.18) |
| HPR 2761 × Kasturi (38.09) | HPR 2748 (P) × HPR 2216 1509 (0.66) | HPR 2724 (P) |
| HPR 2761 (32.27) | HPR 2862 × Pusa Basmati 1509 (0.59) | HPR 2726 (0.59) |

Gelatinization temperature

| HPR 2668 × Kasturi (116.67) | HPR 2748 (P) × Pusa Basmati 1509 (200) | HPR 2761 × Pusa Basmati 1509 (1.42) | HPR 2668 (1.00) |
| HPR 2858 × Kasturi (50.00) | HPR 2761 × Pusa Basmati 1509 (200) | HPR 2862 × HPR 2216 1509 (1.13) | HPR 2724 (P) |
| HPR 2862 × HPR 2216 (33.33) | HPR 2668 (183.33) | HPR 2668 × Kasturi 1509 (1.00) | HPR 2858 (0.67) |

Gel consistency

| HPR 2755 × Kasturi (30.43) | HPR 2761 × HPR 2216 1509 (63.04) | HPR 2748 (P) × HPR 2216 1509 (15.53) | HPR 2754 (15.33) |
| HPR 2748 (P) × Pusa Basmati 1509 (22.86) | HPR 2754 × HPR 2216 1509 (61.59) | HPR 2761 × HPR 2216 1509 (13.04) | HPR 2755 (4.53) |
| HPR 2755 × Pusa Basmati 1509 (18.75) | HPR 2754 × Kasturi 1509 (52.17) | HPR 2755 × Kasturi 1509 (5.73) | HPR 2862 (3.98) |
| HPR 2668 × Kasturi 1509 (15.83) | HPR 2862 × HPR 2216 1509 (47.10) | HPR 2615 × HPR 2216 1509 (10.62) | HPR 2221 (5.16) |

Pusa Basmati 1509, HPR 2862 × Pusa Basmati 1509 and HPR 2668 × Pusa Basmati 1509 for protein content. For amylose content, none of the cross combination showed significant positive heterobeltiosis whereas, cross combinations with higher superiority over standard check were HPR 2761 × Pusa Basmati 1509, HPR 2761 × Kasturi and HPR 2748 (P) × HPR 2216. For gelatinization temperature, maximum significant positive heterobeltiosis was observed for the cross combination viz., HPR 2668 × Kasturi followed by HPR 2858 × Kasturi and HPR 2862 × HPR 2216 and cross combinations which showed higher superiority over standard check were HPR 2748 (P) × Pusa Basmati 1509 and HPR 2761 × Pusa Basmati 1509.
cy can be use in breeding improvement, addition of those parents having soft to medium gel consistency, Now moreover, cooked rice with hard gel consistency takes longer time to cook and expands very little (Juliano, 1965). From consumers’ point of view, rice with intermediate gelatinization temperature is preferred. In general, crosses involving parent Pusa Basmati 1509 had medium gelatinization temperature. Thus, in hybrid breeding programme selection of parents with medium gelatinization temperature is important to develop superior hybrids. Rice varies in gel consistency from soft to hard. Rice with soft gel consistency cook tender and remain soft even upon cooling (Juliano, 1979). Moreover, cooked rice with hard gel consistency hardens faster than those with a medium and soft one. Now-a-days rice with soft to medium gel consistency is preferred by most of the consumers. So in terms of quality improvement, addition of those parents having soft to medium gel consistency can be use in breeding programmes.

| Cross                  | Protein | Amylose content | Gelatinization temperature | Gel consistency |
|------------------------|---------|-----------------|----------------------------|-----------------|
| HPR 2615 × Kasturi     | 0.03    | -0.19           | 0.56                       | -1.38           |
| HPR 2615 × HPR 2216    | -0.39†  | 0.01            | 0.36                       | 5.16†           |
| HPR 2615 × Pusa Basmati 1509 | 0.36†  | 0.18            | -0.91†                      | -3.78†          |
| HPR 2668 × Kasturi     | 0.25    | -0.19           | 1.00†                       | 2.18†           |
| HPR 2668 × HPR 2216    | -0.84†  | 0.23            | -0.87†                      | -6.29†          |
| HPR 2668 × Pusa Basmati 1509 | 0.58†  | -0.05           | -0.13                       | 4.11†           |
| HPR 2720 × Kasturi     | 0.11    | 0.11            | 0.00                       | -0.60           |
| HPR 2720 × HPR 2216    | -0.10   | -0.19           | -0.20                       | 3.93†           |
| HPR 2720 × Pusa Basmati 1509 | -0.01  | 0.08            | 0.20                       | -3.33†          |
| HPR 2748 (P) × Kasturi | -0.27   | -0.46†          | -0.33                       | -6.27†          |
| HPR 2748 (P) × HPR 2216 | 0.42†  | 0.66†           | 0.13                       | -9.07†          |
| HPR 2748 (P) × Pusa Basmati 1509 | -0.16  | -0.21           | 0.20                       | 15.33†          |
| HPR 2748 (W) × Kasturi | -0.49†  | -1.01†          | -0.11                      | 2.84†           |
| HPR 2748 (W) × HPR 2216 | 1.76†  | 0.54†           | -0.31                      | -5.29†          |
| HPR 2748 (W) × Pusa Basmati 1509 | -1.27† | 0.47†           | 0.42†                      | 2.44†           |
| HPR 2754 × Kasturi     | -0.12   | -0.01           | 0.67†                      | 4.73†           |
| HPR 2754 × HPR 2216    | 0.79†   | -0.31           | 0.47†                      | -3.73†          |
| HPR 2754 × Pusa Basmati 1509 | -0.67† | 0.32†           | -1.13†                     | -1.00           |
| HPR 2755 × Kasturi     | 0.10    | 2.29†           | 0.00                       | 5.73†           |
| HPR 2755 × HPR 2216    | 0.35†   | -2.07†          | -0.20                      | -2.07†          |
| HPR 2755 × Pusa Basmati 1509 | -0.45† | -0.22           | 0.20                       | -3.67†          |
| HPR 2761 × Kasturi     | 0.25    | 0.30            | -1.11†                     | -5.16†          |
| HPR 2761 × HPR 2216    | -0.39†  | -0.04           | -0.31                      | 13.04†          |
| HPR 2761 × Pusa Basmati 1509 | 0.14   | -0.26           | 1.42†                      | -7.89†          |
| HPR 2858 × Kasturi     | -0.05   | -0.33†          | -0.00                      | 0.62            |
| HPR 2858 × HPR 2216    | -0.47†  | 1.23†           | -0.20                      | 3.16†           |
| HPR 2858 × Pusa Basmati 1509 | 0.51†  | -0.91†          | 0.20                       | -3.78†          |
| HPR 2862 × Kasturi     | 0.18    | -0.53†          | -0.67†                     | -2.71†          |
| HPR 2862 × HPR 2216    | -1.13†  | -0.06           | 1.13†                      | 1.16            |
| HPR 2862 × Pusa Basmati 1509 | 0.95†  | 0.59†           | -0.47†                     | 1.56*           |
| SE (S_a) ±             | 0.17    | 0.16            | 0.18                       | 0.60            |
| SE (S_a - S_a) ±       | 0.24    | 0.22            | 0.25                       | 0.85            |

Note: * Significant at 5% level of significance

followed by HPR 2668 × Pusa Basmati 1509 and HPR 2858 × Pusa Basmati 1509. For gel consistency, maximum significant positive heterobeltiosis was observed for HPR 2755 × Kasturi followed by HPR 2748 (P) × Pusa Basmati 1509, HPR 2755 × Pusa Basmati 1509 and HPR 2668 × Kasturi and cross combinations with higher superiority over standard check were HPR 2761 × HPR 2216 (63.04 per cent) followed by HPR 2754 × HPR 2216, HPR 2754 × Kasturi and HPR 2862 × HPR 2216 (Table 6). Apart from this, rice with high gelatinization temperature takes longer time to cook and expands very little (Juliano et al., 1965). From consumers’ point of view, rice with intermediate gelatinization temperature is preferred. In general, crosses involving parent Pusa Basmati 1509 had medium gelatinization temperature. Thus, in hybrid breeding programme selection of parents with medium gelatinization temperature is important to develop superior hybrids. Rice varies in gel consistency from soft to hard. Rice with soft gel consistency cook tender and remain soft even upon cooling (Juliano, 1979). Moreover, cooked rice with hard gel consistency hardens faster than those with a medium and soft one. Now-a-days rice with soft to medium gel consistency is preferred by most of the consumers. So in terms of quality improvement, addition of those parents having soft to medium gel consistency can be use in breeding programmes.
### Table 6 Estimates of heterosis (%) over better parent (H₁) and standard check (H₂) for grain quality traits

| Cross combinations | Protein content | Amylose content | Gelatinization temperature | Gel consistency |
|--------------------|-----------------|-----------------|-----------------------------|-----------------|
|                    | H₁              | H₂              | H₁                          | H₂              |
| HPR 2615 × Kasturi | -5.51           | -5.51           | -14.68                      | -14.68          |
| HPR 2615 × HPR 2216| -10.28          | -2.75           | -33.20                      | -0.72           |
| HPR 2615 × Pusa Basmati 1509 | 2.72 | 5.59              | -28.44                      | -5.92           |
| HPR 2668 × Kasturi | 2.65            | 8.39            | -10.37                      | -10.37          |
| HPR 2668 × HPR 2216| -5.16           | 2.80            | -29.56                      | 4.68            |
| HPR 2668 × Pusa Basmati 1509 | 13.12        | 19.44            | -25.99                      | -2.70           |
| HPR 2720 × Kasturi | 2.54            | 11.14           | -2.47                       | 18.28           |
| HPR 2720 × HPR 2216| 7.62            | 16.65           | -12.62                      | 29.86           |
| HPR 2720 × Pusa Basmati 1509 | 7.62        | 16.65           | -4.82                       | 25.13           |
| HPR 2748 (P) × Kasturi | -8.30       | -8.30           | -7.31                       | 13.84           |
| HPR 2748 (P) × HPR 2216| 0.00           | 8.39            | -10.99                      | 32.27           |
| HPR 2748 (P) × Pusa Basmati 1509 | -2.72       | 0.00            | -7.17                       | 22.05           |
| HPR 2748 (W) × Kasturi | -16.63        | -2.75           | -3.24                       | 10.97           |
| HPR 2748 (W) × HPR 2216| 14.38          | 33.42           | -11.53                      | 31.47           |
| HPR 2748 (W) × Pusa Basmati 1509 | -18.99       | -5.51           | -4.82                       | 25.13           |
| HPR 2754 × Kasturi | -2.75           | -2.75           | -5.64                       | 7.43            |
| HPR 2754 × HPR 2216| 7.62            | 16.65           | -19.90                      | 19.04           |
| HPR 2754 × Pusa Basmati 1509 | -5.40       | -2.75           | -11.75                      | 16.02           |
| HPR 2755 × Kasturi | -11.06          | -11.06          | -0.65                       | 4.00            |
| HPR 2755 × HPR 2216| -7.74           | 0.00            | -35.39                      | -3.99           |
| HPR 2755 × Pusa Basmati 1509 | -13.47      | -11.06          | -24.76                      | -1.08           |
| HPR 2761 × Kasturi | 0.00            | 8.39            | -4.16                       | 38.09           |
| HPR 2761 × HPR 2216| 0.00            | 8.39            | 0.57                        | 49.46           |
| HPR 2761 × Pusa Basmati 1509 | 5.08        | 13.89           | -1.21                       | 42.35           |
| HPR 2858 × Kasturi | -2.36           | 13.89           | -8.07                       | 5.35            |
| HPR 2858 × HPR 2216| 0.00            | 16.65           | -15.28                      | 25.90           |
| HPR 2858 × Pusa Basmati 1509 | 9.59        | 27.83           | -16.67                      | 9.55            |
| HPR 2862 × Kasturi | 5.44            | 8.39            | -9.38                       | -0.72           |
| HPR 2862 × HPR 2216| -7.74           | 0.00            | -22.91                      | 14.57           |
| HPR 2862 × Pusa Basmati 2109 | 21.63        | 25.03           | -15.06                      | 11.67           |
| SE ±              | 0.24            | 0.24            | 0.22                        | 0.22            |

Note: * Significant at 5% level of significance

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