Understanding Gene Action, Combining Ability, and Heterosis to Identify Superior Aromatic Rice Hybrids Using Artificial Neural Network

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The aromatic rice represents a smaller but independent rice collection, the quality of which is considered to be highly acceptable. Farmers are interested in growing aromatic rice due to high premium market price. The prime objective of this study was to enhance genetic improvement of aromatic rice. Combining ability analysis (GCA and SCA) and gene action are studied in a set of 7 × 7 half-diallel crosses. Twenty-one hybrids along with their seven parents were assessed in randomized complete block design. Different quantitative characters were used to estimate the magnitude of heterosis. GCA and SCA significance for all traits revealed the importance of both additive and nonadditive genetic components. Several genes determine quantitative traits, with each gene having very little impacts and being easily influenced by environmental factors. Pusa Basmati-1 and Govindobhog were the best combiners among the seven parents. In terms of per se performance, heterosis, and SCA effects on seed yield per plant and important yield qualities, the crosses BM-24 Deharadun Pahari, Baskota × Tulaipanj, and Pusa Basmati-1 × Tulaipanj may be of interest. Because of its interconnected processing properties, ANN can play a critical role in this experiment. As a result, the current study was carried out to collect data and validate it using an artificial neural network (ANN) on the combining ability, gene action, and heterosis involved in the expression of diverse fragrant rice features. Using ANN, the validation of the result was done and it was found that the overall efficiency was approximately 99%.

1. Introduction

Aromatic rice varieties are a lesser but distinct collection of rice that have grown in popularity around the world. Aromatic rice is commonly known as Basmati rice in India, and it is typically grown in northwestern Indian states, such as Jammu and Kashmir, Haryana, Himachal Pradesh, Punjab, and parts of Uttar Pradesh [1]. In India, almost each state has its unique fragrant rice variety. Moreover, much has already been lost as a result of the green revolution, which prioritised production over quality [2]. Cultivation and production of aromatic rice are limited due to specific ecogeographic conditions and also are impeded by poor yield, late maturity, and lodging susceptibility. Furthermore, its agricultural
adaption in eastern India is inadequate owing to the disintegration of its unique scent, grain quality, difficulties in milling due to extremely low head rice recovery, and high vulnerability to insects-pests [3]. According to research, the majority of aromatic rice genotypes are indigenous to the Indian subcontinent. Basmati farming has historically been restricted to the Himalayan foothills and a few places of the Indo-Gangetic Plain (IGP) [4–6]. Aromatic landraces and genotypes exhibit a wide range of genetic variation. Grain quality (both before and after cooking), scent, and flavour all consumer’s decisions [7, 8]; therefore, increasing and genetically upgrading production is a primary priority. To design effective breeding methodology, knowledge about genotype genetic makeup is essential. Most agronomically essential features are driven by polygenes and are affected by environment to a higher extent, resulting in low heritability and making selection challenging. In complicated trait dissection and prediction, accounting for environmental variation has long been a challenge. Finding trends in environmental indices and linking them to changes in underlying genetic factors have huge significance for understanding complex characteristics in plants and forecasting future climates [9]. Although empirical breeding approaches have produced significant results, new tools and resources must be implemented in order to achieve the paradigm shift made appropriate to add significance to feeding the world’s rapidly growing population in the face of climate change, dwindling resources, and changing lifestyles [10]. The success of crop variety development is based on the correct parent selection in addition to the environment and magnitude of gene activity involved in quantitative trait expression. Such information is provided by combining ability studies in order to successfully outline the breeding plan. This method assists in identifying parents with high general combining (GCA) and parental combinations with high particular combining (PC) (SCA). Combining ability analysis can help you find parents with good trait combining ability in the desired direction for a wide range of attributes. Combining ability analysis can be used to assess the relative importance and amount of additive and nonadditive forms of gene activity in the production of features [11, 12]. Selecting parents only based on their phenotypic performance is not always a good idea. Hybridization is the greatest effective method for flouting the produce maximum and developing high-yielding varieties. The success of any hybridization breeding programme is determined by the parents chosen. As a result, it is critical that parents be chosen based on their hereditary worth [13]. This technique for estimating additive and nonadditive gene action may be beneficial in determining the possibility of commercialising heterosis and isolating pure lines among the progenies of good hybrids. Increasing agricultural production in an environmentally sustainable way is heavily reliant on technological advancements and innovation research [14, 15]. This role is referred to as the “Digital Agricultural Revolution” by the United Nations Food and Agriculture Organization (FAO) [16]. Presently, the environment computer deals with a variety of services and allows users to address issues such as regulation, control, and orders. At this point, research in this field begins, including the modelling of an intelligent controller using fuzzy logic [17]. As a consequence, the present research used an artificial neural network to gather information on the inextricable connection, gene activity, and heterosis involved in the development of diverse fragrant rice traits.

The bulk of fragrant rice genotypes are indigenous to the Indian subcontinent, according to the study. Historically, Basmati growing was limited to the Himalayan foothills. Aromatic landraces and genotypes have a vast genetic variability. Most of the agronomically important traits are governed by environment, resulting in low heritability and making selection difficult. In order to describe the breeding plan, such information is offered by merging ability studies. As a result, the current study employed an artificial neural network to collect data on the inextricable link, gene activity, and heterosis involved in the development of several fragrant rice features.

### 2. Materials and Methods

Two improved Basmati rice populations (Pusa Basmati-1 and BM-24) and five traditional cultivars of non-Basmati aromatic rice (Baskota, Govindobhog, Dehradunpahari, Gopalbhog, and Tulaipanji) (Table 1) were chosen as parents considering performance per se, grain type, panicle traits, phenotypic differences, and complementary characteristics.

#### 2.1. Field Techniques

During the Kharif season of 2018, crosses were conducted utilising a $7 \times 7$ half-diallel mating strategy to produce 21 F$_1$ families. To synchronise flowering, parents were planted at 5-day intervals. For emasculation, the clipping process was used. Panicle which emerged 50–60% or halfway from the flag leaf was chosen for crossing. Leaf sheath from the panicle was removed. Care was taken not to break the culm. Spikelets from upper and lower portion of the panicle were removed and the remaining spikelets likely to open in the following day were chosen for emasculation. Pollination took place between 10:00 a.m. and 12:00 p.m. Panicle flowers were picked 25 to 30 days after pollination and stored separately with suitable documentation.

The twenty-one hybrids (Table 2) and their seven parents were evaluated in RCB (randomized complete block design), with three replications, during the Kharif season 2019 at the Agricultural Farm, Institute of Agriculture, Visva-Bharati, Srimketan, which is located at 23°19′N latitude and 87°42′E longitude and at an altitude of 58.9 m above sea level. Twenty-five-day-old seedlings were transplanted as one plant per hill, with a 25 25 cm gap between rows and plants. The crop was grown using the specified agronomic procedures. To evaluate genotypes and F1s based on the ten characters, observations are made on five plants chosen from the middle of each row in each replication.

#### 2.2. Statistical Methods

In computing the ANOVA for combining ability effects, parents and crosses were treated as fixed variables, whereas replication was treated as a random
The GCA and SCA effects were estimated using Griffing’s [18] diallel technique 2, model 1.

The statistical model is as follows:

\[ Y_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc} \sum_{k=1}^{p} \sum_{l=1}^{c} e_{ijkl}, \]  

where \( k = 1, i = 1, \ldots, p, j = 1, \ldots, p, b = \) number of blocks, \( c = \) number of plants, \( Y_{ij} = \) mean of the \( i \times j \)th genotype, \( \mu = \) general mean, \( g_i = \) general combining ability effect of the \( i \)th parent, \( g_j = \) general combining ability effect of the \( j \)th parent, \( s_{ij} = \) specific combining ability effect of the \( i \times j \)th cross combination, \( e_{ijkl} = \) mean error effect, \( i = \) male parent involved in \( i \times j \) cross combination, \( j = \) female parent involved in \( i \times j \) cross combination, \( p = \) number of parental lines, and \( r = \) number of replications.

The restrictions imposed for this model are \( \sum g_i = 0 \) and, \( (\sum s_{ij} + s_{ii}) = 0 \) (for each \( i \)), where \( i = \) number of parents.

The orthogonal partitioning of the genotype sum of squares into its combining ability components, as well as the mean square expectations, is shown as follows:

\[
\text{sum of squares due to GCA (SSg)} = \frac{1}{(p + 2)} \left[ \sum (Y_i + Y_{ii})^2 - \frac{4}{n} \sum Y_i^2 \right],
\]  

\[
\text{sum of squares due to SCA (SSs)} = \frac{1}{(p + 2)} \left[ \sum (Y_j + Y_{jj})^2 \right] + \frac{2}{(p + 1)(p + 2)} Y. \]  

2.3. Artificial Neural Network (ANN) Validation. ANN has gained in popularity and now plays a key part in technological advancement. With the growth of industrial automation and the Internet of Things, it is now simpler than ever to gather data and monitor food dryness,
extrusion, and sterilization [19, 20]. Throughout the industrial revolution, ANN has proven to be useful in food processing operations such as food classification, safety, and quality control. Shallow learning techniques (i.e., the use of already generated ANNs) in food processing have gained increasing attention in recent years, since researchers have demonstrated that they can tackle a variety of complex real-world problems [21, 22]. Food producers are increasingly employing artificial neural networks in all aspects of agricultural production and farm management. Artificial intelligence approaches help agricultural decision-making systems, optimise storage and transportation processes, and estimate expenditures based on management direction. Incorporating machine learning approaches into a farm’s “life cycle” demands the ability to manage massive amounts of data created throughout the growing season, as well as the requisite software. More and more farms are turning to artificial intelligence-based tools as precision farming and digital agriculture become more prominent. The architecture of ANN is shown in Figure 1 and as stated below.

In order to learn and make conclusions, the model receives inputs/information from the outside world via the input layer. The data from the input nodes is directed to the hidden layer, which follows. The hidden layer is made up of a network of neurons that process all of the input data. There can be any number of hidden layers in a neural network. The most fundamental network contains only one hidden layer. The output layer’s computations are utilised to derive the model’s output/conclusions. The output layer may contain one or more nodes.

With the advancement of industrial automation and the Internet of Things, gathering data and monitoring food dryness, extrusion, and sterilization is now easier than ever. Food categorization, safety, and quality control have all been demonstrated to benefit from ANN techniques for shallow learning. Agricultural decision-making systems benefit from artificial intelligence technologies, which optimise storage and transportation operations and anticipate expenses depending on management direction. Incorporating machine learning methodologies into the “life cycle” of a farm necessitates the capacity to manage large volumes of data generated throughout the growing season, as well as the necessary tools. As precision farming and digital agriculture grow more popular, more farmers are turning to artificial intelligence-based systems.

3. Results and Discussion

The analysis of variance explained substantial differences here between parents (P), F1, and the P vs. F1 interaction (Table 3). This revealed that the treatments had a lot of genetic variability amongst them. For almost all of the characteristics, significant differences due to the P vs. F1 interaction revealed significant differences in SCA among hybrids. The findings highlighted the relevance of combining aptitude studies and suggested that selecting acceptable parents and crosses for the generation of appropriate varieties and hybrids had a decent chance.

3.1. Nature of Gene Action. Estimates of extremely significant GCA and SCA variance (Table 3) for all of the traits demonstrated the involvement of both additive and non-additive genes in the manifestation of the characters. The inheritance of several quantitative aspects in rice, including additive and nonadditive gene effects, confirmed prior findings by Kargbo et al. [23], Fels et al. [24], and Mazal et al. [25]. The ratio of $\sigma^2_{GCA}/\sigma^2_{SCA}$ was less than unity for all the characters that also indicated predominance of nonadditive genetic variance. The results were in accordance with the earlier findings of Mallikarjuna et al. [26] for culm length; and Mallikarjuna et al. [26] for panicle number plant$^{-1}$, spikelet fertility and panicle length; Patil et al. [27] and for grain yield plant$^{-1}$ Bano and Singh [28] grain yield plant$^{-1}$ in rice. Therefore, heterosis breeding may be helpful for this trait. In contrast, spikelet fertility and seed yield/plant were controlled principally by additive gene action, and therefore, transgressive breeding is a superior option for these traits. Furthermore, other breeding methodologies such as biparental mating, reciprocal recurrent selection, or diallel selective mating [29] may be reconstituted than conventional pedigree method which would leave the unfixable components of genetic variances untapped for grain yield and its associated traits which were controlled mainly by additive along with non-additive gene action.

3.2. GCA Effects and Performance Per Se of Parents. The information about the parents for hybridization comes from the combining ability analysis. Parental line phenotypic selection can be done based on GCA or parental line performance in general. The GCA is commonly attributed to genetic additive effects and fixable factors [30]. As a result, in plant breeding, selecting parents based on GCA impacts is critical.

The GCA effect and mean performance (Table 4) can both be used to evaluate parents for a breeding programme. In light of this, those parents who performed well in terms of both mean performance and GCA effect were considered good general combiners in the current study. According to
Table 3: Combined analysis of variance for diallel crosses and analysis of variance for combining ability for 10 quantitative traits in the F1 generation.

| Trait                  | df | Plant height | Main panicle length | Exsertion length | Leaf area | Total effective tillers | Spikelet number/panicle | Filled grains per panicle | Fertility (%) | Test weight 250 seeds | Seed yield per plant |
|------------------------|----|--------------|---------------------|------------------|-----------|------------------------|-------------------------|---------------------------|---------------|-----------------------|---------------------|
| Parents                | 6  | 906.98***    | 17.69***            | 29.55**          | 132.59*** | 19.45                  | 12110.97***             | 5553.08***                | 428.08***     | 1.92**                | 273.14*             |
| F1                     | 20 | 484.28***    | 10.73***            | 29.27***         | 175.54*** | 59.41***               | 11301.01***             | 5558.83***                | 402.1***      | 1.9**                 | 258.55**            |
| P v F1                 | 1  | 1294.15***   | 0.002               | 9.45             | 117.95*   | 11.08                  | 31600.18***             | 1780.49*                  | 1657.73***   | 1.56**                | 287.68              |
| Replication            | 1  | 6.94         | 0.037               | 5.54             | 2.82      | 35.55                  | 134.63                  | 339.87                    | 19.25         | 0.016                 | 141.32              |
| Error                  | 27 | 40.36        | 1.02                | 5.81             | 20.27     | 12.99                  | 381.51                  | 250.51                    | 7.16          | 0.030                 | 97.61               |
| GCA                    | 6  | 290.54***    | 6.19***             | 10.44**          | 114.33*** | 20.78*                 | 9072.78***              | 1804.75***                | 477.5***      | 1.18**                | 218.56**            |
| SCA                    | 21 | 307.98***    | 5.87***             | 15.40***         | 72.68***  | 25.4***                | 5271.74***              | 2967.11***                | 155.67***     | 0.879**               | 106.54*             |
| Var GCA                |    | 30.04        | 0.631               | 0.837            | 11.58     | 1.59                   | 986.89                  | 186.61                    | 52.66         | 0.129                 | 18.86               |
| Var SCA                |    | 287.8        | 5.35                | 12.5             | 62.54     | 18.9                   | 5080.98                 | 2841.86                   | 152.1         | 0.864                 | 57.74               |
| Predictability factor  | 0.17| 0.191 | 0.118 | 0.270 | 0.144 | 0.280 | 0.116 | 0.409 | 0.230 | 0.395 |

*, **, ***Significant at p = 0.05, 0.01, and 0.001, respectively. Var GCA: variance due to GCA and Var SCA: variance due to SCA.
Table 4: GCA effect and per se performance of parents in the F1 generation for 10 quantitative characteristics.

| Parents   | Plant height | Main panicle length | Exsertion | Leaf area | Total effective tillers | Spikelet number/panicle | Filled grains per panicle | Fertility (%) | Seed yield per plant | Test weight |
|-----------|--------------|---------------------|-----------|-----------|-------------------------|-------------------------|--------------------------|---------------|----------------------|-------------|
|           | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  | Per se | GCA  |
| Baskota   | 119.53 | −3.37** | 28.9 | 0.215 | 6.19 | −0.260 | 28.68 | −0.228 | 10.21 | −2.19** | 179.34 | 4.17 | 109.84 | 1.54 | 61.27 | −2.02** | 22.22 | −0.152 | 5.62 | 0.529** |
| Pusa Basmati-1 | 178 | 11.67*** | 33.92 | 1.76*** | 11.34 | 1.24* | 31.37 | 4.24*** | 11 | 0.709 | 297.83 | 43.77*** | 190 | 19.27*** | 63.8 | −5.09*** | 29.79 | 9.26*** | 3.99 | 0.039 |
| BM-24    | 149.38 | −3.8* | 24.75 | −0.329 | 2.25 | −0.191 | 28.04 | −4.1*** | 11.75 | 1.35 | 191.5 | 39.4*** | 113.75 | 1.13 | 59.42 | −11.04*** | 19.91 | −1.65 | 5.66 | −0.351*** |
| Govindobhog | 161.75 | 1.32 | 27.69 | −0.039 | 5.69 | −0.1 | 46.25 | 4.53*** | 13.88 | −1.23 | 276.75 | −4.2 | 221.75 | 3.06 | 79.68 | −0.235 | 45.18 | 3.53 | 6.02 | 0.359** |
| Dehradun Pahari | 125.2 | −5.34*** | 31.2 | −0.412 | 5.3 | 0.18 | 23.7 | −4.3*** | 8.5 | −0.653 | 104.23 | −27.83*** | 74.2 | −19.12*** | 71.22 | 1.19 | 10.14 | −4.26 | 5.64 | −0.069 |
| Gopalbhog | 130.8 | 0.603 | 27.05 | −0.597* | 4.8 | −1.45* | 39.95 | 1.02 | 14.3 | 2.18** | 131.4 | −38.66*** | 125.84 | −17.71*** | 95.8 | 5.67*** | 27.49 | −1.96 | 5.47 | −0.010 |
| Tulipanji | 154.6 | −1.07 | 29.65 | −0.596* | 13.1 | 1.48** | 26.05 | −1.15 | 17.9 | −0.175 | 109.4 | −16.65*** | 99.54 | 11.83 | 91.12 | 11.53*** | 13.36 | −4.44* | 3.47 | −0.495** |

*, **, ***Significant at p = 0.05, 0.01, and 0.001, respectively.
Abd El-Aty et al. [31] and Rajan et al. [32], the average performance of the parents together with the nature of combining abilities gives the criteria for selecting parents for hybridization.

This characteristic may benefit from heterosis breeding. Transgressive breeding is a better choice for these variables since spikelet fertility and seed yield/plant were mostly controlled by additive gene activity. The combining ability analysis provides information about the parents for hybridization. GCA or parental line performance in general can be used to choose parental lines for phenotypic selection. In the current study, parents who did well in terms of both mean performance and GCA impact were regarded good general combiners. The criteria for selecting parents for hybridization are based on the average performance of the parents as well as the type of merging skills.

In the F1 generation among the seven parents, Baskota had significant negative GCA effects and high performance per se for plant height, total effective tillers, and fertility percentage, whereas Pusa Basmati-1 had significant positive GCA effects and high performance per se for plant height, main panicle length, exsertion length, leaf area, total grains per panicle, filled grains per panicle, and seed yield per plant. Other cultivars also have either significant positive or negative GCA effects for different traits. The significant and positive GCA effects for grain yield plant−1 were exhibited by Pusa Basmati 1, and it also showed positive and significant GCA effects for other important traits, viz., as a result, simultaneous improvements in yield, yield characteristics, and other associated qualities are attainable and critical for increasing rice yield potential. Grain yield and most other yield component qualities have additive gene effects that can be fixed. Traditional breeding strategies, such as the combination of compatible donor with outstanding restorer parents in autogamous crops like rice, can still result in significant improvements in grain production and critical yield qualities in rice, leading to the development of high yielding varieties.

Due to the trait of complementation of characters, which is dominant among component characters, none of the parents had high general combining ability for all the characters based on GCA impacts. Therefore, to assess overall good general combiner for all the characters separately, individual parent was given a score for singly trait as per their GCA effect. A score “+1” was assigned for any significant GCA effects in desirable direction, while “−1” was assigned for any significant GCA effect in undesirable direction. A score of “0” was assigned for any nonsignificant GCA effect in any direction. After completing this process, Pusa Basmati-1 and, for the most part, Govindobhog have shown the finest overall general combiner (Table 5). More heterosis can be harnessed by using these parents in the hybridization programme. Pahari of Dehradun appeared to be a poor combiner.

3.3. SCA Effects and Performance Per Se of Crosses. SCA effects, which are hypothesized to be expressions of non-additive components of genetic variation, are particularly valuable for judging the genetic merit of crosses as breeding material. They have been linked to the presence of linkage during the repulsion phase or the combination of positive favourable genes from separate parents [33].

Generally, the crosses showing significant and desirable SCA effects were accompanied by better performance per se for respective traits (Table 6), but sometimes this relationship did not show a beneficial direction. Thus, the development of superior hybrid crosses will be evaluated with performance per se along with SCA effects. Baskota × Tulaipanji had significant and positive SCA effects for grain yield plant−1 along with filled grain, spikelet number test weight, and panicle weight. In contrast, it showed negative and significant SCA effect for exsertion length. Among five good specific combining crosses (Table 7), Pusa Basmati-1 × BM-24 showed great performance per se and significant and positive SCA effect for leaf area. BM-24 × Gopalbhog displayed great presentation per se and significant and positive SCA effect for total effective tiller. BM-24 × Dehradun Pahari had great presentation per se along with the positive SCA-effect for spikelet number panicle−1, filled grain per panicle, and seed yield per plant. Baskota × Tulaipanji had high performance per se along with positive and significant SCA effect for seed yield per plant. Pusa Basmati-1 × Tulaipanji had high performance per se along with positive and significant SCA effect for test weight. Hence, these crosses may be utilised for the exploitation of heterosis for yield and yield-related traits in rice. Therefore, the acceptable breeding strategy for attaining high yield would be the full or partial utilization of hybrid vigour by developing hybrid, synthetic, or composite cultivars. Several crossings had substantial and desirable SCA effects for one or more examined variables, but none emerged as a suitable specific combiner for all traits in F1 generations. In general, crossings with significant and desired SCA effects were related with superior performance for the corresponding characteristics, but this connection did not always show up in the F1 generations.

3.4. Heterosis. Generally, positive heterosis is preferred in the selection for yield and its components, whereas negative heterosis is impulsive for short plant height [34, 35] and panicle exertion.

Three crosses Pusa Basmati-1 × BM-24, Pusa Basmati-1 × Tulaipanji, and Govindobhog × Tulaipanji exhibited negative and significant midparent heterosis, while only one cross (Govindobhog × Tulaipanji) showed negative and significant heterosis over both mid- and better-parent for plant height. Mostly breeders are focused in short stature rice plants to bypass the lodging trouble. Therefore, negative heterosis is useful to avoid the tall plant height. Significant negative heterosis for culm length in rice has been reported by Devi et al. [36] and Gaballah et al. [37]. BM-24 × Gopalbhog (23.55%) and Dehradun pahari × Tulaipanji (19.13%) showed maximum midparent, respectively, for main panicle length. Less exertion length are required for better plant type to skip lodging. Seven crosses including Baskota × Dehradun Pahari (70.27%) exhibited positive and
| Parents      | Plant height | Main panicle length | Exsertion length | Leaf area | Total effective tillers | Spikelet number/panicle | Filled grains per panicle | Fertility (%) | Test weight | Seed yield per plant | Total | Category |
|--------------|--------------|---------------------|------------------|-----------|------------------------|-------------------------|--------------------------|----------------|-------------|----------------------|-------|----------|
| Baskota      | −1           | 0                   | 0                | 0         | −1                     | 0                       | 0                        | −1            | 1           | 0                    | −2    | Low      |
| Pusa Basmati-1 | 1            | 1                   | 1                | 1         | 0                      | 1                       | 1                        | −1            | 1           | 1                    | 6     | High     |
| BM-24        | −1           | 0                   | 0                | −1        | 0                      | 1                       | 0                        | −1            | −1          | 0                    | −3    | Low      |
| Govindobhog  | 0            | 0                   | 0                | 1         | 0                      | 0                       | 0                        | 1             | 0           | 0                    | 2     | High     |
| Dehradun     | −1           | 0                   | 0                | −1        | 0                      | −1                      | −1                       | 0             | 0           | 0                    | −4    | Low      |
| Gopalbhog    | 0            | −1                  | −1               | 0         | 1                      | −1                      | −1                       | 1             | 0           | 0                    | −2    | Low      |
| Tulaipanji   | 0            | −1                  | 1                | 0         | 0                      | −1                      | 0                        | −1            | −1          | −1                   | −2    | Low      |
| Crosses                                      | Plant height | Main panicle length | Exsertion | Leaf area | Total effective tillers | Spikelet number/panicle | Filled grains per panicle | Fertility (%) | Test weight | Seed yield per plant |
|---------------------------------------------|--------------|---------------------|-----------|-----------|--------------------------|-------------------------|----------------------------|---------------|-------------|----------------------|
| Baskota × Pusa Basmati-1                   | 168.25       | 6.02                | 29.44     | −1.54     | 6.83                     | −1.81                   | 33.75                      | 15.30         | 3.71        | 282.75               |
| Baskota × BM-24                            | 171.50       | 24.7***             | 30.00     | 1.10      | 12.13                    | 4.91**                  | 30.58                      | 12.25         | −0.188      | 328.00               |
| Baskota × Govindobhog                      | 137.90       | −13.98**            | 30.54     | 1.35      | 5.04                     | −1.36                   | 38.82                      | −9.002        | 8.65        | 161.25               |
| Baskota × Dehradun Pahari                  | 148.75       | 3.53                | 28.38     | −0.439    | 9.13                     | 1.54                    | 44.59                      | 146.00***     | 7.00        | 231.75               |
| Baskota × Gopalbhog                       | 166.50       | 15.33***            | 29.38     | 0.745     | 9.10                     | 3.14                    | 30.84                      | −4.47         | 10.54        | 208.79               |
| Baskota × TulaiPanji                      | 169.19       | 19.7***             | 28.50     | −0.130    | 4.38                     | −4.51**                 | 38.17                      | 5.03          | 12.13        | 270.25               |
| Pusa Basmati-1 × BM-24                    | 149.59       | −12.21***           | 32.34     | 1.89***   | 5.86                     | −2.85                   | 48.82                      | 141.16**      | 12.84        | 299.92               |
| Pusa Basmati-1 × Govindobhog              | 164.38       | −2.54               | 32.55     | 1.82***   | 7.75                     | −0.147                  | 56.09                      | 12.80***      | 12.25        | −0.509               |
| Pusa Basmati-1 × Dehradun Pahari           | 166.50       | 6.24                | 29.50     | −0.857    | 10.33                    | 1.24                   | 32.18                      | −2.27         | 17.00        | 196.00               |
| Pusa Basmati-1 × Gopalbhog                | 184.50       | 18.3***             | 30.75     | 0.577     | 14.50                    | 7.05***                 | 39.10                      | −0.678        | 19.50        | 278.50               |
| Pusa Basmati-1 × TulaiPanji                | 147.25       | −17.28***           | 23.50     | −4.67***  | 4.50                     | −5.88***                | 41.63                      | 4.02          | 13.50        | 294.50               |
| BM-24 × Govindobhog                        | 155.75       | 4.3                 | 25.75     | −2.89***  | 12.00                    | 5.53*                   | 27.75                      | −13.19***     | 5.00         | 184.00               |
| BM-24 × Dehradun Pahari                    | 132.50       | −12.29**            | 30.25     | 1.98**    | 8.25                     | 0.598                   | 20.48                      | −5.64         | 24.50        | 10.52***            |
| BM-24 × Gopalbhog                          | 132.75       | −17.98***           | 32.00     | 3.91***   | 7.00                     | 0.974                   | 23.93                      | −7.51*        | 28.50        | 116.99***            |
| BM-24 × TulaiPanji                         | 156.40       | 7.34                | 29.30     | 1.21      | 9.86                     | 0.903                   | 37.58                      | 8.32*         | 11.80        | −2.65               |
| Govindobhog × Dehradun Pahari              | 162.44       | 12.53**             | 27.73     | −0.831    | 5.62                     | −1.23                   | 41.44                      | 6.7*          | 13.13        | 231.21***            |
| Govindobhog × Gopalbhog                    | 176.25       | 20.4***             | 28.25     | −0.126    | 1.25                     | −3.97                   | 36.63                      | 16.00         | 17.00        | 160.50               |
| Govindobhog × Tulai Panji                  | 123.10       | −31.08***           | 31.55     | 3.17***   | 9.26                     | 1.11                    | 29.67                      | −8.23**       | 12.40        | 135.23               |
| Dehradun Pahari × Gopalbhog                | 160.70       | 11.51***            | 24.90     | −3.10***  | 2.69                     | −3.71*                  | 29.80                      | −1.44         | 12.70        | −2.10               |
| Dehradun Pahari × Tulai Panji              | 162.10       | 14.58***            | 25.23     | −2.77***  | 16.32                    | 6.99***                 | 21.54                      | −7.53*        | 9.00         | −3.45               |
| Gopalbhog × Tulai Panji                    | 154.60       | 1.13                | 27.35     | −0.469    | 4.15                     | −3.55*                  | 45.12                      | 10.73*        | 10.00        | −5.28               |

*,** ***Significant at p = 0.05, 0.01, and 0.001, respectively.
significantly midparent heterosis, while six crosses including Pusa Basmati-1 × BM-24 (55.64%) presented positive. Heterosis for grain yield is the product of the interaction of simultaneous increase in the expression of heterosis of its components which was suggested by Grafius [38]. In this experiment, five hybrids showing extremely noteworthy heterosis over midparent explained cumulative heterosis for principal yield attributes like days to flowering, panicle number plant-1, panicle length, secondary branches panicle-1, and spikelet number plant-1.

3.5. Heterosis and Combining Ability Effects. Heterosis over midparent and SCA effects of crosses (Table 8) revealed that the majority of crosses showed significant heterosis over midparent, as well as positive and significant SCA effects in the desired direction, indicating the predominance of nonadditive gene action for the expression of observed average heterosis. Table 8 shows the heterosis over mid- and better-parent for ten quantitative characters in the F1 generation. A grouping of the parents was tendered as high GCA (significant GCA effect in the desired direction) and low GCA parents (nonsignificant and significant GCA effects in undesirable order). As per the above suggested grouping (Table 9), F1 hybrids show useful significant midparent heterosis as per the GCA effects of the parents associated in the three distinct groups. Peng and Virmani [39], Casco et al. [40], and Anusha et al. [41] reported no relation to forecast that parents with high positive GCA effects would always merge to give rise to hybrids with high positive SCA effects. The current results are in corroboration to that of Mallikarjuna et al. [26], wherein they argued that superior SCA effects were produced by crosses involving all kinds of combinations, viz., High × High, High × Low, Low × High, and Low × Low general combiners. There were maximum numbers of hybrids with significant heterosis-associated Low × Low GCA parents (59.68%) followed by High × Low GCA parents (37.09%) and High × High GCA parents (3.23%). The crosses show significant specific combining ability (SCA) effect which committed high performance [27, 42]. The crosses which involved the parents with Low × Low GCA effects and the superior performance were because of nonadditive (dominance and epistasis) genetic effects [43]. The high yield potential of crosses possessing high SCA with High × Low combining parents is assigned to interaction between positive alleles from good combiners and negative alleles from poor combiners.

### Table 7: Some of the best F1 hybrids in terms of high SCA effect and per se performance for different quantitative characters.

| Character                | Hybrids                          | SCA effect | Better parent heterosis | Per se performance |
|--------------------------|----------------------------------|------------|-------------------------|-------------------|
| Plant height             | Govindobhog × Tulaipanji         | –31.08***  | –20.38**                | 123.10            |
|                          | BM-24 × Dehradun Pahari          | –12.29**   | 5.83                    | 132.50            |
|                          | BM-24 × Gopalbhog                | –17.98***  | 1.49                    | 132.75            |
|                          | Baskota × Govindobhog            | –13.98***  | 15.37*                  | 137.90            |
| Main panicle length      | BM-24 × Gopalbhog                | 3.91***     | 18.30**                 | 32.00             |
| Exsertion length         | Baskota × BM-24                  | 4.91**      | 95.88*                  | 12.13             |
|                          | BM-24 × Govindobhog              | 5.53**      | 110.90**                | 12.00             |
| Leaf area                | Baskota × Dehradun Pahari        | 14.60***    | 55.50**                 | 44.59             |
|                          | Pusa Basmati-1 × BM-24           | 14.16***    | 55.64**                 | 48.82             |
|                          | Pusa Basmati-1 × Govindobhog     | 12.80***    | 21.26*                  | 56.09             |
|                          | BM-24 × Tulaipanji               | 8.32*       | 34.02*                  | 37.58             |
| Total effective tillers  | BM-24 × Dehradun Pahari          | 10.52***    | 108.51**                | 24.50             |
|                          | BM-24 × Gopalbhog                | 11.69***    | 99.30*                  | 28.50             |
| Spikelet number/panicle  | BM-24 × Tulaipanji               | 58.94***    | 71.28**                 | 328.00            |
|                          | Baskota × BM-24                  | 57.24***    | 50.70**                 | 270.25            |
|                          | Pusa Basmati-1 × BM-24           | 75.44***    | 14.33*                  | 340.50            |
|                          | BM-24 × Dehradun pahari          | 103.94***   | 78.07*                  | 341.00            |
|                          | BM-24 × Tulaipanji               | 171.36***   | 119.11**                | 419.60            |
| Filled grain/panicle     | BM-24 × Dehradun pahari          | 37.50**     | 48.63**                 | 163.25            |
|                          | Baskota × Tulaipanji             | 44.18***    | 82.89**                 | 200.88            |
|                          | BM-24 × Tulaipanji               | 139.11***   | 159.69**                | 295.40            |
|                          | Dehradun Pahari × Tulaipanji     | 34.96**     | 71.80**                 | 171.00            |
|                          | Dehradun Pahari × Tulaipanji     | 5.85*       | 8.09*                   | 83.75             |
| Test weight              | Baskota × Pusa Basmati-1         | 0.895**     | 12.01**                 | 6.30              |
|                          | Pusa Basmati-1 × BM-24           | 0.774**     | 29.07**                 | 5.15              |
| Seed yield/plant         | BM-24 × Dehradun pahari          | 25.43***    | 138.41**                | 47.46             |
|                          | Baskota × Tulaipanji             | 15.79*      | 74.66                   | 38.80             |

* , ** , ***Significant at p = 0.05, 0.01, and 0.001, respectively.
Table 8: Heterosis over mid- and better-parent for ten quantitative characters in the F1 generation.

| Crosses                  | Plant height (bp) | Main panicle length (bp) | Exsertion length (bp) | Leaf area (mp) | Total effective tillers | Spikelet number per panicle (mp) | Filled grains per Panicle (mp) | Fertility (%) | Test weight (mp) | Seed yield per Plant (mp) |
|--------------------------|-------------------|--------------------------|-----------------------|----------------|------------------------|---------------------------------|-------------------------------|---------------|-------------------|--------------------------|
| Baskota × Pusa Basmati-1 | 13.10**            | 40.77**                  | 12.13**               | 12.11**        | 0.14                   | 8.05                            | 19.2**                         | 8.31           | 5.06**            | 27.97**                  |
| Baskota × BM-24          | 27.56**            | 43.48**                  | 11.84**               | 3.81           | 187.32**               | 95.88**                         | 7.84                          | 11.57          | 1.07**            | 15.28**                  |
| Baskota × Gristmillbogg  | -1.95              | 15.37**                  | 7.92**                | 5.66           | -15.15**               | -18.58                          | 3.64                          | -16.08         | -28.17**          | -37.66**                 |
| Baskota × Dehradun Pahari| 21.57**            | 24.45**                  | -5.57**               | 9.05**         | 58.83**                | 47.42                           | 70.27**                       | -5.21          | 25.17**           | -31.44**                 |
| Baskota × Gopalbogg      | 33.03**            | 39.30**                  | 5.00                  | 1.64           | 65.68                  | 47.01                           | -10.12                        | 18.94          | 21.37**           | 34.38**                  |
| Baskota × Tulapanji      | 23.44**            | 41.55**                  | -2.65                 | -3.68          | -54.64**               | -66.60**                        | 39.49                         | 33.10**         | -13.73            | -32.26**                 |
| Pusa Basmati-1 × BM-24   | -8.62              | 0.14                     | 10.23**               | -4.67          | -13.60**               | -48.35**                        | 64.35                         | 55.64**         | 12.84**           | 22.58**                  |
| Pusa Basmati-1 × Govindobbg | -3.24            | 1.62                     | 5.66                  | -4.04          | -8.96                  | -36.63                          | 43.52                         | 21.26**         | -1.51             | -11.71**                 |
| Pusa Basmati-1 × Dehradun Pahari | 9.83**        | 32.99**                  | -9.40**               | -13.03**       | 24.14                  | -8.89                           | 16.88                         | 2.60            | 74.36**           | -30.19**                 |
| Pusa Basmati-1 × Gopalbogg | 19.49**        | 41.06**                  | 0.87                  | -9.35**        | 79.73**                | 27.92                           | 9.64                          | -2.14          | 54.15**           | 36.36**                  |
| Pusa Basmati-1 × Tulapanji | -11.46**      | -4.75                    | -19.77**              | -24.82**       | -63.17**               | -65.65**                        | 45.01                         | 32.71**         | -6.57             | -24.52**                 |
| BM-24 × Govindobbg      | 0.12              | 4.27                     | -1.79                 | -7.06          | 202.27**               | 110.90                          | -41.45**                      | -32.97**        | -60.98**          | -63.96**                 |
| BM-24 × Dehradun Pahari  | -3.49              | 5.83                     | 8.13**                | -3.04          | 118.54**               | 55.56                           | -20.85                        | 26.98**         | 148.91**          | 108.51**                |
| BM-24 × Gopalbogg       | -5.24              | 1.49                     | 23.55**               | 18.30**        | 98.58                  | 45.83                           | -29.62                        | -40.11**        | 118.81**          | 99.30**                  |
| BM-24 × Tulapanji       | 2.90              | 4.70                     | 7.72**                | -1.18          | 28.47                  | 24.73                           | 38.97                         | 34.02**         | -20.40            | -34.08**                 |
| Govindobbg × Dehradun Pahari | 13.22**      | 29.74**                  | -5.82                 | -11.22**       | 2.18                   | 1.72                            | 18.48                         | 10.40          | 17.32**           | -21.38**                 |
| Govindobbg × Gopalbogg   | 20.49**            | 34.75**                  | 3.22                  | 2.02           | -76.17                 | -28.03                          | -15.01                        | -20.80**        | 13.58             | -21.35**                 |
| Govindobbg × Tulapanji   | -22.17**           | -20.38**                 | 10.95**               | 6.41           | -1.44                  | -29.31                          | -17.92                        | -35.85**        | -21.95            | -30.73**                 |
| Dehradun Pahari × Gopalbogg | 25.55**       | 28.35**                  | -14.51**              | -20.19**       | -46.73                 | -49.25                          | -6.38                         | -25.42**        | 11.40             | -11.19**                 |
| Dehradun Pahari × Tulapanji | 15.87**      | 29.47**                  | 17.07**               | 19.13**        | 77.39**                | 25.48                           | 36.74                         | 13.00          | 31.82             | 42.92**                  |
| Gopalbogg × Tulapanji    | 8.34**             | 18.20**                  | -3.53                 | -7.37          | -56.33**               | -68.32**                        | 36.74                         | 12.94          | -37.89            | -44.13**                 |
| Range                    |                   |                          |                      |                |                       |                                 |                               |                |                   |                          |
| Minimum                  | -22.17             | -20.38                   | -19.77**             | -24.82**       | -76.17                 | -68.32                          | -41.45                        | -52.97**        | -60.98            | -63.96**                 |
| Maximum                  | 3.03               | 43.48                    | 23.55                 | 19.13          | 202.27                 | 110.90                          | 70.27                         | 55.64          | 141.98            | 108.51**                |
| Average heterosis        | 8.49               | 19.64                    | 2.09                  | -3.59          | 27.96                  | -1.12                           | 13.35                         | 1.24            | 14.46             | 37.24**                  |
| No. of crosses with positive heterosis | 14 (12)  | 19 (13)                  | 12 (8)                | 7 (2)          | 11 (5)                 | 8 (2)                           | 14 (7)                        | 11 (6)         | 14 (9)            | 12 (8)                   |
| No. of crosses with negative heterosis | 7 (3)       | 2 (1)                    | 9 (4)                 | 14 (8)         | 10 (3)                 | 13 (4)                          | 7 (2)                         | 10 (5)         | 10 (1)            | 12 (2)                   |

* *, ** Significant at p = 0.05, 0.01, and 0.001, respectively. Figures in parenthesis indicate significant values.
combiners (High \times High GCA) would involve interaction between positive \times positive alleles and can be settled in the succeeding generations due to additive type gene actions which are fixable in nature. Hence, superior segregants could be confined from Pusa Basmati-1 \times BM-24 if no repulsion phase linkage is involved and anticipated to throw some useful transgressive segregants in the breeding programme through pedigree method of selection. The result indicated that parental diversity in terms of GCA effect performed an important role for the expression of observed heterosis.

### Table 9: Frequency of crosses as per GCA effect of parents for economic characters.

| Characters                  | Number of significant heterotic (mp) hybrids | GCA effects of the parents involved |
|-----------------------------|---------------------------------------------|-----------------------------------|
|                             | High \times High | High \times Low | Low \times Low | Total |
| Plant height                | 0              | 2              | 1              | 3     |
| Main panicle length         | 0              | 1              | 7              | 8     |
| Exsertion length            | 0              | 2              | 3              | 5     |
| Leaf area                   | 1              | 2              | 4              | 7     |
| Total effective tillers     | 0              | 2              | 2              | 4     |
| Spikelet number/panicle     | 1              | 7              | 6              | 14    |
| Filled grain/panicle        | 0              | 1              | 8              | 9     |
| Fertility (%)               | 0              | 1              | 1              | 2     |
| Test weight                 | 0              | 4              | 3              | 7     |
| Seed yield/plant            | 0              | 1              | 2              | 3     |
| Total                       | 2              | 23             | 37             | 62    |
| Percentage                  | 3.23           | 37.09          | 59.68          | 100   |

**Figure 2: Performance verification using ANN.**

3.6. Validation of Results Using ANN. Both internal and external parameters should be considered. It is not intended to run a variety of algorithms on the available data to determine which one outperforms the others. Although this would be advantageous, and the researchers may consider it in the future, the authors of this work wish to focus on how machine learning techniques, specifically ANN, can be used more successfully in construction management. As a result, this study discusses the problem in broad strokes. In this case, the qualities proposed must first be justified. The ANN
Figure 3: Fit curve with ANN.
model is then presented. In the third step, the features of the accessible database are examined. Finally, the findings are scrutinized and compared to the previous research. ANN is used as a sophisticated tool for verifying and validating the experimental results. As for the input plant height, panicle length and other parameters are used in Tables 2–4. The initial test was carried out with 10 neuron in the hidden layer with 75% used for training, 15% used for validation, and 15% used for testing. Figure 2 shows the performance indices with the input parameters. The best performance is at epoch 6 with value 0.769. Similarly, the fit cure is shown in Figure 3. All have an accuracy of 99%. And, finally, Figure 4 shows the error histogram.

From Table 10, it is clear that the best hidden layer neuron number is 30.

### Table 10: Effect of hidden layer neuron of validation.

| No. of hidden layer neurons | Accuracy obtained (%) |
|-----------------------------|-----------------------|
| 10                          | 94                    |
| 20                          | 96                    |
| 30                          | 97                    |
| 40                          | 97                    |
| 50                          | 97                    |

### 4. Conclusion

In terms of per se performance, heterosis, and SCA effects for seed yield per plant and other important yield attributes, the crosses BM-24 Dehradun Pahari, Baskota × Tulaipanji, and Pusa Basmati-1 × Tulaipanji are of interest because all of these hybrids had high per se performance and positive heterosis for grain yield. The possibility of obtaining high yielding lines from this cross combination after fixation of additive genetic variance components in advance segregating generation cannot be ruled out. BM-24 and Pusa Basmati-1 used in the present investigation provided ample scope for utilization in the hybridization programme to recombine unique characters such as short stature, high tillering capacity with pleasant aroma, and slender grain size. Some selected F1 possessed high grain yield with semi-dwarf to medium stature, high tillering behavior, resistance to lodging, and pleasant aroma. However, the better performance of the selection may be due to the presence of heterosis and these selections need further evaluation in segregating generations and elaborate screening and extensive testing. An artificial neural network model of verification and validation yield from transplanting field parameters was designed and trained using experimental data to address the need for a simple and quick validation tool. The constructed ANN model, which has six inputs, two outputs, and ten hidden layers, was proven to be quite capable of learning the relationship.

### Data Availability

The data used in this study are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that there are no conflicts of interest.

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