REVIEW OF LITERATURE
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All the relevant literature on the subject have been reviewed and presented under the following subheads:-

2.1 Basmati Improvement Work
2.2 Effect of environmental factors on yield and its components
2.3 Effect of environmental factors on grain quality and related characters
2.4 Genetic diversity for grain yield and related traits in germplasm
2.5 Correlation and path coefficient analysis

2.1. Basmati Improvement Work

Varietal improvement of basmati rice was initiated in 1920 at Kala Shah Kaku in erstwhile Punjab (now in Pakistan). Early efforts were directed towards developing varieties through pure line selection from available land races/cultivars. Basmati 370 was selected and released by late Sardar Mohammad Khan at Kala Shah Kaku in 1933 (Ahuja et al. 1995). Since then Basmati 370 has turned out to be the most valuable traditional quality rice for export and led to export boom in Pakistan and India (Mann, 1987).

Organized research attempts have also been made since 1921 at Nagina, Uttar Pradesh. Subsequently, rice samples collected were evaluated at Kanpur by the Economic Botanist. Since 1932, research work at Nagina focussed on development of better quality high yielding rice varieties. Several improved strains of varying maturity groups were isolated including fine grain aromatic rice varieties such as N
105 (Sel. Hansraj - Pilibhit), N12 (Sel. Safeda - Punjab), T3 (Sel. Basmati - Dehradun), T9 (Sel. Duniapet - Basti), T1 (Sel. Ramjiwain - Saharanpur) and T23 (Sel. Kalasukhdas - Banda). Varieties T3, N105 and T9 are still grown in Uttar Pradesh.

Despite having excellent quality, none of these varieties could replace Basmati 370. After 1966, dwarf high yielding rice varieties for various ecosystems and maturity groups were developed and released yet the traditional tall, low yielding, pest/disease susceptible variety, Basmati 370 stood up as a hallmark for basmati quality and remained popular with the farming community and traders till eighties (Shobha Rani et al., 2006).

Within India, success in developing a dwarf high yielding prototype of basmati by the breeders through pureline selection, use of mutagenesis and hybridization was limited due to environmental factors, (DRR, 1994, DRR, 1995, Normita et al. 1989), inter group sterility barriers (Glazmann, 1985), complicated polygenic mode of inheritance and complex breeding behaviour of quality parameters (Chang and Somrith, 1979; IARI, 1980). Even the understanding of basmati traits was a limitation. Khush and Juliano (1991) identified multiplicity of breeding objectives, lack of infrastructure for grain quality evaluation and lack of well-defined selection criteria as main hurdles for grain quality and aroma improvement programmes.

Since most of the traditional basmati varieties were poor combiners, breeding-selection methodologies especially convergent and backcross strategies were adopted to break the undesirable genetic blocks and increase the frequency of favourable recombinants. As a result several aromatic varieties with medium to long
slender grains were released in India in the late eighties, but none could replace traditional Basmati 370, as the basic understanding of what combination of traits make basmati was inadequate. In the next phase, considerable stress was laid on linear elongation on cooking with least breadth wise swelling resulting in high volume expansion, flaky texture of cooked rice without sacrificing the previous gains such as dwarf plant stature, long slender grains and aroma (IARI, 1980). Following stepwise convergent mode of character improvement and selection procedure, IARI scientists identified Pusa 615, a derivative of Pusa 150/Karnal local. In 1989, a sister selection of Pusa 615 was released as Pusa Basmati 1, the first semi-dwarf high yielding basmati variety with superfine grain, pleasant aroma, soft texture and higher linear elongation on cooking, which is at par with traditional basmati varieties in quality. Pusa Basmati 1 has 1.0 to 1.5 t ha⁻¹ yield advantage over them (Siddiq, 1990). By adopting similar convergent breeding technique at DRR, Hyderabad, Kasturi, a semi dwarf basmati variety with high yield potential possessing several quality features of traditional basmati varieties, commendable milling quality and resistance to blast and tolerance to stem borer was developed and released for commercial cultivation (Shobha Rani, 1992).

In 1990, the Indian Council of Agricultural Research (ICAR) initiated basmati research network entitled “Improvement of basmati rices for increased productivity and export purposes” that has helped in the adoption and spread of the above mentioned two dwarf aromatic varieties of proven merit, which was a significant milestone in the basmati improvement programme in recent years. Emphasizing the need to pursue systematic efforts in developing dwarf basmati rices, work was started at seven centers (Kaul, Kapurthala, Ludhiana, IARI,
Kotnagar, CRRI and DRR). The major objective was to stabilize the yields of basmati varieties through incorporation of genes for resistance to pest/diseases and development of production and post harvest packages.

In this programme, 69 cultures were evaluated under multi location testing and five more cultures possessing better yield and quality were identified for on farm trials (DRR, 1994). These include IET 10367, IET 10650, IET 11348, IET 11341 and IET 12019. Among these, IET 10367 (HKR228) was released as Haryana Basmati 1. In addition to higher yield potential in dwarf basmati background, it possesses resistance to blast and WBPH (Panwar et al., 1991). IET 11348 (selection of Basmati) which matures 30-35 days earlier to Basmati 370 with comparable yield and quality was released as Ranbir Basmati in Jammu and Kashmir, to fit into the prevailing cropping pattern of the region (Bijral et al., 1989). Purified HBC 19 (Kamal Local), which has high demand as traditional export quality rice was released in 1992 as Taroari Basmati in Haryana.

Attempts were made to develop dwarf resistant varieties using induced mutation and selections. However, none of the mutant selections in advanced stages of testing could make as varieties acceptable to farmers. Shobha Rani (1992) reported a high yielding mutant of Pusa Basmati 1, namely, line No. CR 839. This is the first report in basmati rice of a high yielding line with significantly higher yield over Pusa Basmati 1 developed through induced mutation.

Improvement of Basmati rice to develop non-lodging, high yielding, long-grain rices from three elite basmati cultivars, i.e., Basmati 370, Pusa Basmati 1 and Pakistan Basmati, employing mutation approach was done. The mutants were isolated from gamma ray treated populations and the homozygous mutants were
evaluated in the multi location trials. A mutant derived from Basmati 370, CR 2007-1 (IET 17276) was found to be highly promising in the basmati growing areas of Haryana and Punjab in multi location trials. This promising mutant consistently showed significant yield superiority over Pusa Basmati 1 (5.36 per cent) and Taroari Basmati (64.04 per cent) and had all the desirable basmati grain quality traits that are closer to Taroari Basmati (Rao et al. 2006).

Another research network under AP cess fund with clearly defined objectives relating to development of basmati and non basmati rices was organized by the ICAR during 1994 to 1999 entitled “Genetic Enhancement of Quality Rices for Higher Productivity and Export”. It involved 11 research centers (Kapurthala, Kaul, Ludhiana, Pantnagar, R S Pura and IARI in traditional basmati growing areas; Aduthurai, Nellore, Raipur and Faizabad in the non basmati areas) and three testing centers (Banswara, Varanasi and Siruguppa) with the Directorate of Rice Research (DRR), Hyderabad as the coordinating center. Testing breeding materials developed through convergent breeding methodology using diverse gene sources to transfer the array of quality parameters into semi dwarf plant stature, has resulted in the identification of 11 elite cultures for on farm testing (DRR 2000, Shobha Rani and Singh 2003). Among this elite collection, IET 14707 (CSR 30) was released as Yamini, the first basmati variety suitable for sodic soils; IET 15391 as Vasumati, a semi dwarf basmati variety with higher yield than Pusa Basmati 1 for traditional basmati growing areas; Pusa Sugandh 2 and Pusa Sugandh 3, semi dwarf high yielding basmati varieties earlier in maturity to Pusa Basmati 1; Pusa RH 10, the first fine-grained aromatic hybrid of the country coming from the hybrid breeding programme and IET 13549 released as Mugad Sugandha in Karnataka state and also
In Maharashtra suitable for parboiling (sela basmati). In 2002, another variety Pant Sugandh Dhan 15 was released in Uttarakhand. In 2004, Sugandhamati (IET 16775) from the DRR and Pusa Sugandh 5 from IARI, were approved for release for traditional basmati growing areas of north-western India by the Central Sub Committee. With significant yield superiority of 24% over Pusa Basmati 1 and comparable quality, Sugandhamati possesses leaf blast and brown spot resistance. It has long slender aromatic grains with good quality features of basmati rice. Pusa Sugandh 5 is medium duration variety with extra long slender aromatic grains having high yield advantage over Pusa Basmati 1. Pusa Sugandh 4 (IET 18004) is unique in having aromatic extra long slender grains and very high elongation on cooking. Other aromatic and super fine rices released from different states include Rajendra Sweta (IET 18052), a medium duration variety from Bihar and Pant Sugandh Dhan 17 (IET 17263), a medium maturing variety from Uttarakhand and Geetanjali from CRRI in Orissa. Thus the research efforts made in the last two decades has been instrumental in the identification and release of several traditional as well as dwarf high-yielding basmati types combining the typical basmati quality features (Shobha Rani et al. 2006).

Most of the quality traits either show maternal or polygenic nature of inheritance and hence breeder has to face unreliable phenotyping of the segregating material. Here is the need of molecular markers for precision breeding for getting desired quality traits. Many quality traits have been mapped and genes/QTLs have been reported for amylose content on chromosome 6, aroma on chromosome 8, kernel length after cooking (KLAC) on chromosome 8 (Biswa et al. 2004; Jain et al. 2004), gel consistency (GC) on chromosome 6. Along with these, many QTLs
have been reported for head rice recovery (HRR), protein content, grain length and grain length/breadth ratio. Hence, to exploit these genes/QTLs with tightly linked markers, validation for each one is needed in alternate populations before going for molecular assisted breeding.

2.2. Effect of environmental factors

2.2.1 Yield and its components:

Choi et al. (1984) evaluated stability for grain yield of rice breeding lines and identified the environmental status of some rice breeding sites. Twenty one breeding lines (13 of japonica type and 8 of indica type) and four check cultivars were grown at seven locations and the data for grain yield and other agronomic characters was analyzed by the method of stability analysis and principal component analysis.

Acharya and Sharma (1985b) evaluated 20 genotypes of rice (Oryza sativa L.) at five locations and in six environments created by varying nitrogen (N) levels and sowing dates at one location during wet seasons of 1978 and 1979. Data were recorded on days to maturity, plant height and 1000-grain weight. The rank correlations of stability parameters for the locations vs created environments showed high repeatability of mean values.

Kasno and Mattjik (1986) tested 12 rice varieties in randomized block design with four replications at 25 locations in wet season. Data on grain yield were analyzed with Eberhart and Russell model to evaluate yield and varietal stability. The rice line 743 was the top yielder (45% higher than the lowest line 557). The mean yield among 10 lines did not differ significantly, but were higher than the mean over all the varieties. Yield stability analysis indicated that line 030 had a
regression coefficient $> 1$, and line 661 had a regression significantly $< 1$. The other lines had a regression coefficient which did not differ significantly than 1. However, all the lines had highly significant variances due to deviation from the regression, indicating that none of the varieties studied could be identified as a stable variety.

Ganesh and Soundrapandian (1988) evaluated 10 short duration rice cultivars under three environments and studied genotype-environment interaction for days to 50% flowering, plant height, number of ear-bearing tillers, panicle length, number of filled grains/ear, spikelet fertility, harvest index and plot yield. Although both the linear and non-linear components of genotype-environment interaction contributed to the total genotype environment interaction, the linear component predominated. IR 50 was the genotype adapted to a wide range of environments while Co 41 performed well in a low yield environment and ADT 36 and ACM 2 performed well in a high yield environment.

Sumantri et al. (1991) conducted field experiment at Bogor Research Institute for Food Crops (BORIF) in different locations during wet season. The data were divided into two groups of C.V., one group with C.V. of $< 10$ per cent (6 locations) and the other group with C.V. lying between 10 and 20 per cent (7 locations). The result showed that C.V. affected not only the yield stability estimates but also the deviation from regression and rank of the tested varieties. Experiments conducted under good management (C.V. of $< 10$ per cent) has a slightly more homogeneous regression coefficients ($B_i$), more significant deviation from regression and smaller changes in the ranking order. They can explain more about the relationship between mean yield of each variety and the environmental index. The experiments also have
more power to reject varieties that can be considered unstable ones. The ratio of rejection between the two groups was 5:3.

El (1993) carried out field experiments on 25 rice cultivars sown on three different dates each year. Giza 181 and Ewan 4 were the most widely adapted and stable cultivars while Jai Hu 4, Sheng Feng 1, GZ 1108 and IR 36 were unstable. It was concluded that selection indices should be constructed using the mean grain yield and 1 or 2 of the stability performances for selection of high-yielding stable cultivars.

Geetha et al. (1994) carried out pooled analysis of variance and showed significant differences among genotypes and N treatments for all characters. Genotype × N interaction was also significant for all characters except 100-grain weight. ADT38 and CO45 were adaptive and stable across all N levels for single plant yield. Mean single plant yield was low for ADT38 and average for CO45. The stable yield was due to stable grains/panicle and harvest index for ADT38 and panicles/plant and 100-grain weight for CO45. Although the mean of AD 40 was high, its yield was unstable across the N levels. The correlation analysis among stability parameters revealed that genotypes with a high mean for single plant yield are responsive to high N. There was no significant association between the stability parameters of regression coefficient b sub i and duration from regression coefficient S raise to the negative 2 power d sub i. It can be inferred that these two characters are not linked and are inherited separately.

Perez et al. (1996) studied the effect of quantity and timing of nitrogen application at LARI (late nitrogen application at flowering) on rough rice yield and some grain quality characteristics of a hybrid and two inbred lines. The hybrid IR
64616 H not only yielded significantly higher but also had significantly higher head rice yield, protein content and grain translucence than inbred lines, IR 72 and IR 58109-113-3-3-2 during the dry season.

Reddy and Kumar (1996) evaluated 12 rice genotypes and observed significant GxE interactions for nine quantitative characters at two locations. Number of productive tillers/hill showed significant positive correlation and had significant effect on grain yield.

Chikkalingaiah et al. (1997) carried out an investigation to identify stable scented rice genotypes for varied agro climatic zones of Karnataka. The experiment was conducted in three diverse zones during kharif 1993. The study revealed the presence of substantial interaction of the genotypes with environments. The 24 genotypes tested differed significantly in their responses to varying environments in plant height, grain yield/hill and grain yield/ha. The variation in the performance of the genotypes was predictable for grain yield/hill and grain yield/ha. Ambrose was stable for earliness while MLF-5 was suitable for favourable environments for grain yield/ha. MLF-18 was regarded as highly stable for grain yield/ha. In general, no single genotype was stable for all the characters.

Shanta Kumar et al. (1997) studied 34 genotypes of rice for phenotypic stability during the dry, wet and winter seasons. The results indicated the presence of genotype × environment interactions for all five yield related characters studied. None of the genotypes was stable for all characters. Jaya, HP10 and IR54R were most suitable for dry and wet environments, while KBCP1 was the most suited genotype to all the environments.
Katyal et al. (1998) conducted an experiment on integrated nutrient supply in a rice-wheat cropping sequence at five sites in India and showed that 50% recommended NPK + 50% through crop residue in rice followed by 100% NPK in wheat could stabilize yields of rice and wheat at Kanpur, whereas 50% N need of rice can be substituted by FYM, followed by 100% NPK in wheat at Ludhiana. At Jabalpur, the 50% recommended NPK + 50% through green manuring could stabilize yields of both the crops, whereas at Faizabad, yields of rice and wheat were stabilized when 50% recommended NPK was used in conjunction with 50% recommended crop residues. At Kalyani, 75% recommended NPK + 25% by green-manuring in the rainy season followed by 75% recommended NPK in the winter season could stabilize yields of rice and wheat and save 25% of N fertilizer in the winter season. Continuous rice-wheat cropping increased the organic carbon status at Masodha and Kanpur whereas it remained same at Jabalpur. It also increased available P and K at Masodha and Kanpur. However, at Jabalpur a decrease in available P and increase in K was observed. Integrated nutrient supply had favourable effect on organic carbon status and available P and K at all the centers except P at Jabalpur.

Mahal et al. (1999) studied the influence of planting date and irrigation management on Basmati 385 and Basmati 370 and observed that planting in the second fortnight of July gave higher yield.

Muhammad et al. (1999) evaluated six basmati genotypes for yield across five locations and observed highly significant genotype X location interaction. Stability analysis showed that two of the genotypes, Super Basmati 4048 and Basmati 385 were stable for paddy yield.
Reddy et al. (1999) conducted a long-term experiment in an Udic Ustochrepts soil with a rice cropping system at Hyderabad to evaluate the effect of continuous cropping and fertilizer application on yield and soil fertility. The highest fertilizer rate of 120 kg nitrogen (N) and 80 kg phosphorus (P)/ha increased grain yield by about 0.6-0.7 t/ha compared to 40 kg N or no P. There was little response to 40 kg potash (K)/ha. Net returns for the cropping system were maximum (Rs.13180/ha) with 120 kg N + 80 kg P + 40 kg K/ha. Stability analysis of grain yield indicated that consistent productivity is possible with 80 kg N + 40 kg P + 40 kg K/ha in both rainy and winter seasons. After 10 consecutive years of cropping, available soil P and K were depleted compared to their initial status. Available iron, zinc, pore space, water holding capacity and volume expansion increased over the experimental period.

Prakash et al. (2002) carried out field experiments to evaluate relative efficacy of organic manures in combination with chemical fertilizers (CF) to assess the usefulness of such treatments against application of only CF. Organic manures were applied at 50 per cent recommended N on equivalent basis and balanced with chemical fertilizers to attain the recommended N, P and K levels. Results of the experiment indicate that organic manure treatment on balancing with chemical fertilizers to the recommended dosage of N, P and K favored higher dry matter production and grain yield as compared to application of only CF. The extent of increases in yield (average of two years) with treatments PCW (Processed City Waste) + CF, VC (Vermi Compost) + CF, OCP (Oil Cake Pellets) + CF, FYM (Farm Yard Manure) + MC + CF and FYM + CF were 20, 16, 4, 26 and 23% respectively, over CF. Among the different manures tested, FYM + MC + CF proved best while
OCP + CF has been least effective. A higher total uptake of N, P and K by rice was recorded in treatments with organic manures in combination with CF.

Sarkar et al. (2003) carried out stability analysis on fertility restoration, yield and other attributes. It was revealed that fertility restoration in hybrids from different CMS lines was highly sensitive to the changes in the environment with gradual delay of sowing dates. Estimates of stability parameters showed that the hybrids were unstable over the environments for both fertility restorations and grain yield, with the exception of PRH 3. A linear (predictable) response was shown by nearly all hybrids for all characters, as revealed by a significant genotype × environment interaction (linear) variance, though part of variation was unpredictable in nature as shown by significant pooled deviation values. Hybrids PRH 21, PRH 16 and PRH 12 showed capability to sustain higher grain production (b>1, high S²d values) in highly favourable environments whereas, for spikelet fertility, hybrids PRH 22, PRH 21, PRH 16 and PRH 6 along with the controls IR 64, Pusa 44 and Jaya fell under the same checks (b→1, high S²d values). These results indicate the specificity of the hybrids to various environmental conditions.

Bose et al. (2004) evaluated 21 lowland rice genotypes for their stability parameters in terms of grain yield in a multi-location trial at five different sites of eastern India. Pooled analysis of variance reflects the existence of genotype × environment interactions and contribution of both linear and non-linear components to genotype × environment interactions. Through stability parameter analysis (Eberhart and Russell, 1966), it was found that Rayda B3, CR 778-95 and CR 661-236 were suitable for all environments whereas Sabita, OR 1334-16 and OR 1358-RGA-4 were suitable for rich environments. PSR 1209-2-3-2, CR 780-1937,
Ambika, OR 877-51-4-2 and CR 662-2211 were identified as suitable genotypes for poor environments.

Shanmuganathan and Ibrahim (2004) studied the stability for per day productivity of grain in 11 different ruling rice hybrids under three different environments in Tamil Nadu, during kharif and rabi seasons. The environmental index indicated that Kollukalam favored the fullest expression of this trait. Pooled analysis of variance showed significant differences among genotypes, environments and genotype × environment interaction. A significant pooled deviation indicated that genotypes differed considerably with respect to their stability for per day productivity of grain. After considering all the three stability parameters, ADTRH 1 and KRH 1 were identified as stable hybrids for per day productivity of grain.

Shanmuganathan and Ibrahim (2005) evaluated 11 rice hybrids in six different environments for their stability. The data were analyzed using Eberhart and Russell (1966) approach for yield and its contributing characters. Significant mean sum of square due to genotypes, environments and G × E interaction was observed. Both linear and non-linear components of G × E interaction were important for the expression of most of the traits. However, linear component was larger in magnitude than the non-linear component. The hybrid CORH 2 was found to be stable for maximum of five characters. Among the six environments, Agriculture College and Research Institute, Madurai was the most suitable environment for the expression of most of the characters.

Devi et al. (2006) evaluated 10 promising genotypes for stability parameters with respect to grain yield and its components in four environments, i.e. E1 (1 May sowing, 20×10cm spacing), E2 (1 May sowing, 20×20cm spacing), E3 (1 June
sowing, 20×10cm sowing), and E4 (1 June sowing, 20×20cm sowing) in Manipur, India. The linear components of genotypes × environment interaction were significant only for three characters, viz., plant height at maturity, days to 50% flowering and grain yield/plot, whereas the non-linear component was significant for all the characters. Among the genotypes, CAUR-2 and KD-2-7-6-2 produced better grain yield. However, on the basis of estimated parameters of stability, the genotypes RCM-9 and KD-2-7-6 could be considered better for grain yield for general cultivation in Manipur valley.

Kumar and Shadakshari (2006) conducted study to assess 18 elite rice genotypes in lowlands for their yield stability at three different locations during the kharif season. The mean sum of squares due to genotype (G) and environment (E) differences tested against the G×E interaction were significant for all the traits studied. Both linear and non-linear components were significant for days to 50% flowering, plant height and panicle number. The deviation from regression for grain yield were significant in genotypes Intan, IET 14080, Sharavathi, IET 10472, IET 14320 and KHR-22, IET 16695. KHR-21 and KHR-28 and showed unit regression and non-significant deviation from regression. The deviation from regression for days to 50% flowering was significant for genotypes Intan, IET 15656, IET 14080, Sharavathi, IET 13736 and IET 9926. However, Hemavathi and IET 16695 showed unit regression and less deviation from regression. For panicle number, all the genotypes showed non-significant regression. However, a unit regression was observed for genotypes Padma and IET 14320. Based on individual stability parameters, genotypes KHR-21, KHR-22 and KHR-28 exhibited higher grain yield over the population mean, with regression coefficient near unity and
negligible deviation from regression, indicating their average stability. Genotypes KHRS-21, KHRS-22 and KHRS-28 were ideally adaptable and stable. They could be recommended for cultivation in the hill zone of Karnataka.

2.2.2. Grain quality and related characters

Batcher et al. (1957) evaluated the cooking qualities of milled white rice of 26 varieties for physical and chemical characteristics and palatability tests. Variety and environment as well as grain type influenced cooking qualities. Long grained varieties of rice tend to absorb more water than the other grain types, although there were exceptions. Variations in starch and total solids in the residual cooking liquids were apparently due to varietal factors.

Halick and Kelly (1959) measured water uptake number of 17 varieties at three temperature levels (72, 77, and 82°C). The water uptake number changed from 52-249 at 72°C to 88-432 at 77°C and 177-502 at 82°C temperature.

Juliano et al. (1964) and Heu and Park (1976) reported that the relative proportion of amyllose content and amyllopectin in the endosperm is influenced by environment. Amylose content, a linear fraction of starch is the main determinant of cooking quality.

Latchumanan et al. (1979) reported increase in grain protein content on application of nitrogen along with mixed culture of Azotobacter and blue green algae. Eating and cooking quality of rice produced organically, are better than those produced by using chemical fertilizers and/or pesticides.

Acharya and Sharma et al. (1985a) evaluated 20 indica and japonica genotypes grown at five localities (9 macro-environments) and the results were compared with those obtained from the same genotypes grown in six micro
environments produced by combining three sowing dates with two doses of nitrogen fertilizer application. Rank correlation coefficients based on mean performance for three characters studied showed that both sets of environments produced similar results, but different results were obtained in an analysis of the non linear component of the genotype × environment interaction, which was not correlated between sets of environments for any of the three characters. For the linear component of the interaction, the results across sets of environments were correlated for percentage amylose content and gelatinization temperature, but not for percentage crude protein content.

Maskina et al. (1985) found that the application of 120 kg N/ha proved significantly superior to 60 kg N/ha in terms of dry matter, plant height and seedling quality. Addition of green manure, poultry manure, Azolla and FYM improved the quality of rice seedlings in order of 76, 54, 21 and 10% respectively, over inorganic fertilizer treatment. Content of N and Zn decreased with age of seedling and increased with application of organic materials.

Cruz et al. (1989) studied the effect of temperature during grain development on amylose content, gelatinization temperature and gel consistency. Thirty one varieties representing five amylose categories were grown under four controlled temperature regimes in the IRRI phytotron. Stability analysis revealed predominance of the linear component of variety-temperature interaction for all three components. In general, amylose content decreased with increasing temperature. All varieties in the waxy group and the majority of those in the high amylose group showed no genotype × temperature interactions for amylose content. Varieties in the very low, low and intermediate categories were either responsive or unstable. Similarly, for
gelatinization temperature and gel consistency, a number of varieties showed no genotype \times temperature interactions, some were responsive and others unstable. The waxy varieties IR 29 and Malagkit Sungsong and the high amylose variety IR 42 were stable for all the three quality components.

\textit{Li et al.} (1989) reported that environmental factors like temperature, photoperiod and relative humidity had little effect on the length (L), breadth (B), L/B ratio of grains compared with that on chalkiness, GT, AC and GC. Grain elongation is influenced by environmental factors such as temperature at the time of ripening (Dela Cruz, 1991).

Late planting coinciding with the flowering and maturity in cooler days has also been reported to enhance the grain quality, but reduce grain yield of all aromatic rice varieties tested by Singh \textit{et al.} (1995), Rao \textit{et al.} (1996), Thakur \textit{et al.} (1996) and Chandra \textit{et al.} (1997).

Mishra and Agrawal (1992) evaluated 12 early, dwarf and high-yielding rice cultivars at four locations. Analysis of variance was carried out and stability parameters calculated for each cultivar. The most stable cultivars had a high mean performance and regression co-efficient (b) with variance due to deviation from regression (S^2d) approaching zero. The most stable cultivars were RWR 19-86-212 (b, 0.914, S^2d, -0.289) and RP 1669 (b, 1.309, S^2d, 0.2985). The negative b of cv. JT 80-8 (-0.172) indicated good response under poor conditions.

Gupta (1995) reported significant effect of nitrogen levels on both yield and elongation ratio. Chander and Pandey (1996) observed that neither the herbicides nor nitrogen caused noticeable change in grain quality traits like hulling, milling, head rice recovery and grain length (L), breadth (B) and L/B ratio.
Suwanarit et al. (1996) reported that the aroma, softness, whiteness, stickiness and glossiness of cooked milled rice of Khao Dak Mali 105 were inversely related to applied dosages of nitrogen. Split nitrogen applications are recommended for obtaining high grain quality (Hou, 1988; Perez et al. 1996).

Canellas et al. (1997) found cultivation practices like land preparation method, cultivation type, time of transplanting and harvesting have great influence on quality and productivity of aromatic rices. Basmati rice requires a relatively cooler temperature (25°C/21°C- day/night temperature during crop maturity) for better retention of aroma (Juliano, 1972; Mann, 1987). Meng and Zhou (1997) observed that a mean daily temperature of 18°C produced best quality rice.

Khan et al. (2003) conducted a field experiment to evaluate the comparative effect of Zn levels applied by different methods, i.e., nursery root dipping in 1.0% ZnSO₄, 0.20% ZnSO₄ solution spray after transplanting and 10 kg Zn ha⁻¹ by field broadcast method. A significant increase in Zn content of rice leaf before and after flowering and a significant decrease in P content of straw and paddy and starch content of paddy were recorded for all the methods. N, K and Zn of paddy and straw and Zn contents of roots increased significantly over control with the application of zinc irrespective of the methods. Soil application of Zn was rated superior because it gave significantly higher content of N in rice paddy.

Priyadarsini and Prasad (2003) carried out an experiment involving application of various nitrogen sources using different rice varieties. Grain quality characteristics like, head rice recovery, grain length and breadth and protein content and amylose content were the highest with the variety BPT 5204 and the integrated use of 50% nitrogen through inorganic source (urea) and organic sources (FYM +
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Priyadarshini and Prasad (2003) carried out an experiment involving application of various nitrogen sources using different rice varieties. Grain quality characteristics like, head rice recovery, grain length and breadth and protein content and amylose content were the highest with the variety BPT 5204 and the integrated use of 50% nitrogen through inorganic source (urea) and organic sources (FYM +
chalkiness were higher relative humidity, lower mean daily air temperatures and minimum air temperature in the period of 0-20 days after full heading.

Ghosh et al. (2004) studied the effect of two planting dates and four fertilizer levels on different aromatic rice cultivars during the dry season while nine cultivars were evaluated during the wet season. Thermal and photoperiodic conditions significantly influenced the vegetative (leaf area index and light extinction coefficient) and reproductive (filled spikelets/panicle) growth of the crop. Delayed planting reduced the grain yield by 0.88 ton/ha, amyllose content by 0.5% and duration by 10 days; but increased the summed heliothermal units (17806 v. 18505). Thus, the cultivars became less efficient (27%) in heat use with delay in planting. Relative availability of NH$_4^+$-N from urea and Azolla influenced the crop growth (leaf area index [LAI], tiller production and leaf chlorophyll content) and nutrient uptake. Supply of inorganic N alone or in conjunction with Azolla, significantly increased grain yield (18-41%) and protein content (0.1-0.7%) over 15 ton/ha of Azolla alone. However, combined application of Azolla and urea lowered the amyllose content below that achieved by application of either substance alone. Correlation studies among quality attributes indicated that long-grained varieties have lower head rice recovery ($r = -0.69$) due to more breakage during milling and greater test weight ($r = 0.93$).

Zhang et al. (2004) evaluated 18 rice cultivars for grain length, grain breadth, grain length/breadth ratio, grain: chalkiness ratio (CR), size of chalkiness/grain (SC) and degree of chalkiness. Analysis was performed using additive main effects and a multiplicative interaction model. Genotype-environment interaction was significant at 1% level and the performance for the parameters varied among the cultivars. The
stability of the cultivars in terms of rice appearance decreased with the increase in the corresponding traits. The indica hybrid Shanyou 63 was the most stable cultivar for all parameters. Conventional cultivars 93272, Nanjing 16, W002 and Suxiangjing showed low RC and SC, and higher stability for these traits.

2.3. Genetic diversity in germplasm

The degree of genetic divergence, which literally means how two or more populations are different from each other, when several characters are taken into account, was first quantified by Mahalanobis (1936). The idea of generalized distance ($D^2$), when the effect of the environment has the same $D^2$ value between any pair of populations amounts to a measure of genetic divergence (Rao, 1952).

Multivariate analysis (utilizing Mahalanobis’ $D^2$ statistic and canonical variate analysis of Rao, 1952) has been found to be potent biometrical tool in quantifying the degree of divergence in the germplasm collections of various crop plants. This method permits one to classify and group a number of lines into various genetically diverse groups or clusters. The parental lines belonging to different and distantly located clusters have higher probabilities of giving heterotic hybrids than those parental lines belonging to the same cluster or group. The results of the earlier studies on genetic divergence in rice are presented here in briefly.

Ram and Panwar (1970) estimated inter-specific divergence in rice using $D^2$ statistic. They reported that characters like plant height, number of panicles/plant, panicle length, yield and fitness were potent enough to distinctly discriminate indica and japonica rices.
Sjam *et al.* (1971) studied 31 rice varieties for their yield potential by $D^2$ method. They suggested that the parents should be chosen for hybridization from diverse groups to provide variability in yield components.

Maurya and Singh (1977) selected 43 varieties having different plant types and recorded data on 12 characters. Nature and magnitude of genetic divergence was assessed in 43 varieties of rice using $D^2$ statistic. The population was grouped into sixteen clusters. The $D^2$ statistic was found useful as conventional, morphological and physiological groups like tall, dwarf, early, medium and late etc., were discriminated further into clusters. Maturity time, plant height and tillers contributed most to divergence.

Singh *et al.* (1979) studied 35 spontaneous and induced dwarfs of rice for genetic divergence by $D^2$ analysis for 12 characters related to yield and fitness. The study showed the dwarfs fall into 10 different clusters irrespective of their allelic relationships and geographical area of collection. Plant height followed by area of the second leaf, length of the first internode and test grain weight appeared to contribute maximum to genetic divergence. Genetic drift and selection in different environments seemed to cause greater diversity.

Mahajan *et al.* (1981) studied the relationship between pedigree data and genetic diversity in rice. The observations suggested that most of the cultivars in the same cluster came from the same cross.

Rao *et al.* (1981) studied the genetic divergence for grain yield and its components in 120 brown plant hopper (BPH) resistant rice varieties using Mahalanobis' $D^2$ statistic. The 120 varieties were grouped into 32 clusters. The clustering pattern generally followed the geographical distribution of the varieties.
Kanwal et al. (1983) studied 100 rice strains which included 74 indigenous collections (having about 10 dwarfs and semi dwarfs), improved plant types from the IRRI, CRRI and AICRIP and commercially grown cultivars endemic to the area. Observations were recorded on 12 characters viz., days to panicle emergence, and days to maturity, effective tillers/plant, plant height, panicle length, panicle weight, number of grains/panicle, length of grain, breadth of grain, L/B ratio, test weight and seed yield/plant. Mahalanobis’ $D^2$ statistic was used for assessing genetic divergence between the populations. Simple criterion suggested by Tocher (Rao, 1952) for determining the group constellations was also used. All the varieties were grouped into nine clusters.

Singh (1983) used $D^2$ statistic to evaluate 59 rice varieties from high and low yielding environments. They found that this method was able to group most of the high-yielding dwarf varieties into one cluster.

Ratho (1984) studied 39 rice varieties from India and four from Afghanistan and reported low genetic divergence. The five clusters and clustering pattern were not related to geographical distribution.

Juffiquar et al. (1985) carried out study on 100 elite lines, 67 of which were restorers and 33 maintainers, from 63 crosses made at IRRI and 18 improved varieties from five countries using Mahalanobis’ $D^2$ statistic and canonical analysis to understand the nature and magnitude of divergence and to assess the importance of a set of quantitative characters related to yield in genetic differentiation. All the genotypes were grouped into 13 clusters. Results showed that the yield, number of tillers/plant, days to maturity and 1000 grain weight contributed largely to the divergence. There was no indication of a relationship between geographical diversity
and genetic diversity in the study. Disposition of IRRI developed maintainers and restorers into various clusters indicated the presence of large amounts of diversity within the IRRI elite lines, which suggested that these materials could be used in crossing programme to produce heterotic F₁ hybrids. Crossing of maintainers and restorers among the highly diverse groups was suggested as it may produce F₁'s that will give higher magnitude of heterosis.

Singh et al. (1987) analyzed genetic divergence among lowland rice cultivars and observed that the genetic divergence among cultivars under study was not due to geographical diversity. Plant height, grain length and breadth, test weight, panicle length and spikelet number were mainly responsible for the divergence.

Anandkumar and Subramanian (1989) studied genetic divergence in upland rice using Mahalonobis’ D² analysis for plant height, productive tillers, boot leaf length and breadth and yield. They identified highly divergent genotypes which could be used in breeding programs to generate large degree of heterosis.

Buu and Tuan (1989) used Mohalanobis’ D² statistic for clustering of 32 rice varieties from different countries (21-IRRI; 3-India; 1-Srilanka, 6-Vietnam) based on plant height, days to 50% flowering, panicle length, number of grains/panicle, unfilled grain percentage, effective tillers/plant, grain weight and grain yield. Five clusters were formed with cluster I having maximum number of varieties. The maximum divergence was shown between clusters IV (IR68) and V (Basmati 370). Plant height and days to 50% flowering contributed the most to genetic divergence.

Biswa and Sasmal (1990) analyzed genetic divergence in seven rice varieties and their 21 F₁ hybrids by using Mahalanobis’ D² statistic. The grouping of
genotypes did not follow a geographic pattern. The shoot fresh weight was main
factor contributing to genetic divergence.

Sinha et al. (1991) used Mahalanobis $D^2$ statistic to study ten growth and
yield related traits in rice. Thirty traditional varieties were assigned to one of the six
clusters. Cluster I included 66.6% of genotypes, while IV, V and VI were
monogenotypic. Varieties from north-eastern region showed the greatest diversity,
being represented in all the clusters, except cluster VI.

Reddy and Mahana (1992) published the information on cluster means and
intra- and inter-cluster distance using $D^2$ statistic, from the data on seven yield
related characters in 25 diverse genotypes of short duration (70-110 days) rice. The
genotypes were distributed among either cluster, differentiated mainly by days to
50% flowering. Maximum inter-cluster distance was shown between cluster I
(CR66658 and CR 54416) and cluster III (Narendra 2 and Narendra 1).

Roy and Panwar (1993) studied 99 genotypes of rice for genetic divergence
using $D^2$ analysis for a set of characters related to bacterial blight severity, yield and
its contributing characters. The genotypes were grouped into 16 clusters. The genetic
diversity was not related to geographic diversity. Yield/plant, panicles/plant,
spikelets/panicle, grains/panicle and bacterial blight severity were mainly
responsible for genetic divergence. M. Sungsong, BKN 6819-33-3-2-1-3 (of cluster
X), DV 85, BJ1 (of cluster VI), PR 103, IR 50 (of cluster VIII) and HKR 119 (of
cluster X) were found most promising material on the basis of their statistical
distance and cluster mean values. The use of these genotypes was suggested in
hybridization program to evolve desirable segregants.
Vivekanandam and Subramanian (1993) evaluated 28 genotypes of rainfed rice using $D^2$ statistic. The populations were grouped into five clusters. The geographical distribution was not related to genetic diversity.

Kaw (1995) studies genetic divergence of rice genotypes and their 74 hybrids over three cold stress environments using $D^2$ statistic and canonical analysis. The genotypes were grouped into 18 clusters and the clustering pattern suggested that the genetic and geographical diversities were not necessarily related. Plant height, days to flowering, fertile spikelets/panicle and percent fertility of panicles emerged as important contributors to the genetic divergence for cold tolerance in rice.

Mahapatra et al. (1995) studied 40 genotypes of rice with the objectives of grouping the entries into different clusters following various methods of analysis, such as $D^2$ statistic, canonical analysis, metroglyph analysis and numerical classification analysis (UPGMA). They found that UPGMA method was more potent to distinctly discriminate mutant lines as well as the standard varieties. This method was more potent for analysis of biological populations compared to other methods.


Caldo et al. (1996) analyzed morpho-agronomic traits of 81 ancestral lines of Philippines modern rice varieties using multivariate statistical analysis. They observed that diversity existed in the parental lines. However, most varieties shared common ancestors resulting into narrow genetic base in modern varieties.
Singh et al. (1996) studied genetic divergence among 40 genotypes of scented and fine rice using Mahalanobis' $D^2$ statistic for 10 characters. The population was grouped into six clusters. Grain yield contributed 16.5% to the divergence. The genotypes belonging to clusters having greater distance were recommended for inclusion in the hybridization programme as they were expected to produce good segregants.

Kumari and Rangaswami (1987) studied genetic divergence using Mahalanobis' $D^2$ statistic in 62 early rice genotypes obtained from 16 countries and from CIAT, IITA and IRRI. Based on eight important yield contributing characters, these genotypes were grouped into six clusters. There was no relationship between geographical distribution and genetic diversity. Characters like grain yield/plant, panicle exertion and plant height made the largest contribution to the total divergence. It was suggested that these characters could be the basis for selection of parents from distantly placed clusters for obtaining highly heterotic combinations.

Rao and Gomathinayagam (1997) reported genetic divergence in 40 drought tolerant rice genotypes for eight yield components using Mahalanobis' $D^2$ analysis. Genetic divergence was not related to geographic diversity. Favourable environment yielded in lesser number of clusters by exploiting high genetic potential of different traits expressed by genotypes. Varieties with stable genotype × environment interaction in the expression of different traits tended to group together in one cluster. Such stable genotypes with high order of genetic divergence can provide best breeding material for the exploitation of heterosis and high degree of variability in segregating generations.
Mehtre et al. (1994) worked out the genetic diversity among 37 upland rice varieties using Mahalanobis’ $D^2$ statistic. Based on genetic distance, these varieties were grouped into seven different clusters. Cluster I, II and III included 10, 9 and 13 varieties, respectively, while clusters V, VI and VII were monogenotypic. There was no parallelism between genetic diversity and geographical diversity.

Ahmed and Borah (1999) studied genetic divergence for 13 agronomic characters in 85 indigenous glutinous rice varieties by using Mahalanobis’ $D^2$ statistic. The genotypes were grouped into 12 clusters. Number of panicles/plant, number of grains/panicle and grain yield accounted for the major portion of divergence.

Bansal et al. (1999) assessed genetic diversity in 34 rice stocks using Mahalanobis’ $D^2$ statistic. Thirty-four genotypes belonging to seven countries were divided into 15 clusters. The pattern of distribution of genotypes within various clusters was random and independent of geographical isolation. Based on the mean performance, genetic distance and clustering pattern, intercrossing of Bindli semi-dwarf mutant, ACC 747, Basmati 1, Begami, Karjat, Pediepet Bulan 2, Akhrisail, Major Djambon, IET 2686, Xiang geng deo, Hsiang Nhe, Dwarf hasmati and Dornshah was suggested for creating wider variability for early maturity, dwarf and high-yielding segregants.

Kandhala and Panwar (1999) studied genetic diversity among 52 indigenous and exotic rice genotypes using Mahalanobis’ $D^2$ statistic. On the basis of 16 agromorphological and quality traits, these genotypes were grouped into 11 clusters. Cluster I with 26 genotypes was the largest, while, cluster VII, VIII, IX, X and XI were monogenotypic. There was no association between genetic and geographic
diversity. The maximum inter-cluster distance was observed between clusters V and IX.

Soni et al. (1999) studied genetic divergence in 132 rice genotypes for 18 quality traits using Mahalanobis’ $D^2$ statistic. Genotypes were grouped into 10 clusters. High order of genetic divergence was recorded between cluster VI and VIII.

Hegde and Patil (2000) reported the genetic divergence in 40 genotypes of rainfed rice using Mahalanobis’ $D^2$ statistic. The cultivars fell into seven clusters. Cluster I, II, III and IV comprised 18, 14, 3 and 2 genotypes, respectively, while clusters V, VI and VII were solitary cluster. The average inter cluster $D^2$ value was highest between cluster V and VII. The highest contributing characters to $D^2$ values were number of spikelets/panicle, photosynthetic rate and 1000 grain weight.

Rather et al. (2001) applied $D^2$ statistic to study the divergence in 56 diverse rice cultivars and grouped them into eight clusters. Geographical origin was not found to be a good parameter to genetic divergence.

Sarawagi and Rastogi (2001) studied the genetic diversity among 300 traditional Basmati rice accessions using non-hierarchical Euclidean cluster analysis. These accessions were grouped into 16 clusters, of which the largest cluster had 61 genotypes. The maximum intra-cluster distance was observed in cluster XII followed by cluster XI and cluster XV. Cluster XII and XIII were identified as genetically most divergent. The average genetic distance for all possible pairs of combinations ranged from 1.165 (II, VI) to 6.475 (XI-XIII). They concluded that accessions viz. H 411, S 715, D 1017 and T 150 of cluster XII and A 36711, W 48, B 801 and A 283 of cluster XIII may be utilized as donors in rice breeding programme for developing
semi-dwarf, high-yielding and early maturing aromatic rice varieties with good grain quality.

Pradhan (2003) estimated the genetic divergence among 38 improved *basmati* genotypes on the basis of 12 quantitative characters using Mahalanobis’ $D^2$ statistic as suggested by Rao (1952). Based on this analysis, all the genotypes were grouped into 10 different clusters. Twenty-one genotypes fell into cluster I, which was the biggest cluster and accommodated the maximum number of genotypes. It was followed by cluster V that accommodated four genotypes. Cluster VI to X consisted of only one genotype each. Cluster II and IV contained three each, while cluster III contained only two genotypes. High cluster means were recorded for spikelets fertility (89.67%), number of panicles/plant (16.33) and plant height (153.67 cm) in cluster VIII. Cluster VII contained only one genotype and gave highest mean for harvest index (48.47%), panicle length (30.70 cm) and 1000 grain weight (29.43 g), while low seed weight (21.06 g) and short stature (102.33 cm) was observed in cluster II. High cluster means for grain yield/plant (30.33 g), grain length (9.8 mm), total dry matter/plant (36.67 g) and earliness (80 days) was estimated in cluster VI. Cluster III with two genotypes possessed high mean number of spikelets/panicle (221) followed by cluster VI (214.7). It was observed that days to 50% flowering alone contributed more than 69% to genetic divergence among the genotypes studied. It was followed by grain length (9.96%) and grain yield/plant (9.82%).

Shiv Datt and Mani (2003) grouped 61 elite *basmati* genotypes into four clusters by Jocker’s method using Mahalanobis’ $D^2$ statistic. Maximum numbers of genotypes (43) were included in cluster I. This was followed by cluster II (13) and cluster III (4). Only one genotype appeared in cluster IV. Cluster IV (Basmati Aman)
had high mean values for days to 50% flowering (131.33 days), plant height (144.33 cm), number of panicles/plant (14.67) and number of spikelets/panicle (171.0). Cluster II had high mean values for panicle length (28.33 cm), length of flag leaf (52.09 cm), 1000 grain weight (22.50 g), length of brown rice (7.50 mm) and width of brown rice (1.85 mm). Cluster III had high value for grain yield/plant (18.0 g). The observations revealed that the plant height contributed maximum towards genetic divergence (52.24%). It was followed by days to 50% flowering (22.56%) and grain yield/plant (8.63%).

Chand et al. (2005) studied 19 genotypes of Aman rice for their genetic divergence using Mahalanobis’ $D^2$ statistic for 12 characters. Based on D$^2$ values, the genotypes were grouped into six clusters. Cluster I was the largest with eight genotypes followed by cluster II with four genotypes. Intra-cluster distance was the highest in cluster VI and lowest in cluster IV. The maximum inter-cluster distance was found between clusters IV and VI suggesting wide diversity between these groups. The major part of total divergence was imparted by single trait, i.e., 1000 grain weight. Panicle length, grain length and plant height were also very important in this regard.

2.4. Correlation and path coefficient analysis

Chauhan and Landon (1984) studied 30 hill rice varieties for the extent of genetic variability and character association under two cultural environments: rainfed upland direct seeded and irrigated transplanted. Plant height, number of grains/panicle and 100 grain weight were positively and significantly correlated with grain yield under upland environment while the number of ear bearing tillers showed
positive and significant association under irrigated environment. The path analysis supported the results obtained from correlation studies.

Madaan et al. (1984) reported that cooking quality was positively and significantly correlated with amylose content. Kongserre and Juliano (1972) reported that kernel elongation has significant positive correlation with amylose content but not with gelatinization temperature.

Kim (1987) carried out correlation and path-coefficient analysis on the culm length and length of five upper internodes by using five parental varieties and their 10 F1’s. Culm length was correlated positively with internode length regardless of positions. The closer the internode position, the higher was the positive correlation between internode length and culm length. The fourth internode length was the most effective factor in determining culm length, whereas the second internode length was the least.

Saha et al. (1989) evaluated 11 high-yielding and four local boro rice varieties for several yield contributing characters to find out the associations and direct and indirect effects on yield. The correlation and path coefficient analysis revealed that shorter seedling and plant height along with heavy grains have appreciable contribution to yield. Other yield contributing characters like panicle number/plant and spikelet number/panicle are contributing to yield indirectly. Seedling height, plant height, and 1000 grain weight along with panicle number/plant and spikelet number/panicle should be taken into consideration for further improvement of rice for Boro season of Bangladesh.

Sutaryo and Suprihatno (1990) studied the relationship among grain characters such as grain yield, seed set, panicle exertion, tiller number/hill and plant
height in hybrid rice seed production. Path coefficient analysis was made for the five characters. Yield was positively associated with plant height, seed set and panicle exsertion but negatively associated with tiller number/hill. The correlation coefficient (r = 0.93) and path coefficient (P = 0.828) indicated that the true relationship between plant height and panicle exsertion are the most yield influencing factors to which attention should be given in hybrid rice seed production using V20A and probably other male sterile cultivars originated from China such as gen 97A and V41A.

Haque et al. (1991) studied phenotypic and genotypic correlations and path coefficients in seven characters including yield/plant for two indica and one japonica rice groups. In most of the cases, genotypic associations were higher than the phenotypic associations. Yield/plant was found highly and positively associated with plant height, growth duration and fertile grains/panicle. Modern varieties/lines had negative association between yield and panicle/plant. The traditional group showed no association except yield and 1000 grain weight showed negative relation. In path coefficient analysis, direct effects on yield were high for plant height, growth duration and number of fertile grains/panicle. The direct effects as well as correlation coefficients between 1000 grain weight and yield were negative for traditional varieties. Improvement of yield could be effective by direct selection for plant height, growth duration and number of fertile grains/panicle for modern and japonica groups and decreasing 1000 grain weight for traditional varieties. Direct effects did not always fit with the association because of the influence of indirect causal factors like number of panicles/plant.
Das et al. (1992) evaluated 30 rice genotypes for variability and genetic association. The highest GCV was found in grain yield/plant followed by number of fertile spikelets/panicle, total number of spikelets/panicle and number of fertile tillers/plant. High heritability was observed for all the characters except total number of spikelets/panicle. High H(b) with high GAPM was found in plant height, number of fertile tillers/plant, number of fertile spikelets/panicle, 1000 grain weight, days to 50% flowering, days to maturity and grain yield/plant. In most of the cases, genotypic correlations were higher than the phenotypic correlations. Number of fertile spikelets/panicle, 1000 grain weight, days to 50% flowering and days to maturity showed highly significant positive correlation with grain yield/plant both at genotypic and phenotypic levels. Path coefficient analysis revealed that number of fertile spikelets/panicle, heavy grains, number of fertile tillers/plant and days to maturity had higher direct effects on yield/plant.

Dhaliwal and Sharma (1992) evaluated 78 diverse rice genotypes to estimate genetic variation and heritability for grain and agronomic characters. Path analysis was used to partition the genetic correlations between characters into direct and indirect effects. Number of grains/panicle, number of panicles/plant and 100 grain weight showed high genotypic and phenotypic coefficient of variation. Good amount of genetic variability also existed for grain yield, plant height and panicle length. Number of grains/panicle, number of panicles/plant, panicle length and 100 grain weight showed positive and significant correlation with grain yield and also had high direct positive effect. Indirect effect of panicle length via number of grains/panicle was also high. It suggested that grain yield could be improved by selecting for
number of grains/panicle, number of panicles/plant, panicle length and 100 grain
weight.

Jufiqual and Topora (1992) evaluated 100 elite lines of maintainers and
restorers of “WA” cytostereility systems of rice and studied the correlation and path
coefficients. Grain yield showed positive correlation with plant height, days to
maturity, number of spikelets/panicle, number of fertile spikelets/panicle and 1000
grain weight. Path analysis indicated that the number of panicles/plant had the
highest positive direct effect on yield followed by number of fertile spikelets/panicle
and 1000 grain weight. Direct effect of plant height and days to maturity were
positive but low. One thousand grain weight had positive correlation coefficient with
grain yield which was almost equal in magnitude with its positive direct effect on
this trait. It was revealed from the contribution of individual characters to the
variance of yield that the contribution of the characters to the determination of yield
was the largest for 1000 grain weight followed by number of fertile spikelets/panicle
and plant height. The study indicated that selection for higher yield among the
maintainers and restorers may be based on 1000 grain weight, number of fertile
spikelets/panicle and plant height.

Mirza et al. (1992a) studied two cultivars and 13 promising strains of basmati
rice to find out all possible relationships between plant height and its components.
Plant height showed a positive correlation with all internodes. The path coefficient
analysis showed that peduncle length and second and third internode had positive
direct effect on plant height while first and fifth internode had negative direct effect.

Mirza et al. (1992b) evaluated six crosses and their parents to study
interrelationships and path analysis between plant height, yield and yield
components. Plant height showed positive correlation with number of panicles/plant, panicle length, number of grains/panicle, 1000 grain weight and grain yield/plant. Number of panicles/plant was positively correlated with panicle length, 1000 grain weight and grain yield/plant while it was negatively correlated with number of grains/panicle. Panicle length was positively correlated with number of grains/panicle, 1000 grain weight and grain yield/plant, whereas number of grains/panicle also showed positive correlation with 1000 grain weight and grain yield/plant. A positive correlation was observed between 1000 grain weight and grain yield/plant.

Pantone et al. (1992) employed path analysis to evaluate the competitive interaction between weedy rice (red rice) and cultivated rice (Mars). The path analysis quantified direct effects of red rice and Mars rice densities on the yield components (grain weight, percent filled florets, number of florets/panicle, and panicles/plant) of red rice and Mars rice. The model illustrated the direct and indirect effects of the yield components on fecundity and grain yield/plant. The direct effects of Mars and red rice densities on number of panicles/plant and number of florets/panicle were always negative. In contrast, the effects of density on percent filled florets and grain weight varied from positive to negative and were relatively small, implying that they were determined primarily by density-independent factors. Path analysis indicated that the number of panicles/plant and florets/panicle were the most important yield components determining the responses of fecundity and grain yield to competition.

Gravois and McNew (1993) estimated and used genetic correlations in developing selection methodologies in rice breeding programs. Additive genetic
components. Plant height showed positive correlation with number of panicles/plant, panicle length, number of grains/panicle, 1000 grain weight and grain yield/plant. Number of panicles/plant was positively correlated with panicle length, 1000 grain weight and grain yield/plant while it was negatively correlated with number of grains/panicle. Panicle length was positively correlated with number of grains/panicle, 1000 grain weight and grain yield/plant, whereas number of grains/panicle also showed positive correlation with 1000 grain weight and grain yield/plant. A positive correlation was observed between 1000 grain weight and grain yield/plant.

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Gravois and McNew (1993) estimated and used genetic correlations in developing selection methodologies in rice breeding programs. Additive genetic
weight and panicle length. Path analysis, on the other hand, revealed that number of productive tillers, followed by panicle length, and 1000 grain weight had higher direct effects on grain yield/ plant.

Mebet et al. (1994) carried out analysis of variance showing significant differences among genotypes for all characters. Considerable range of variation was expressed for plant height, panicles/m², straw yield/ m², grain yield/ m², and filled grains/panicle indicating better scope for genetic improvement in these characters. Grain yield/ m² had maximum genotypic coefficient of variation. Grain yield/ m² was positively and significantly correlated with straw yield/ m² (r = 0.604) and filled grains/panicle (r = 0.434), while it was negatively and significantly correlated with days to 50% flowering (-0.495) and maturity (r = -0.405).

Rim and Li (1999) studied the selective norm on 20 characters by the coefficient of correlation in order of the relative importance by the path analysis. The caliper gradation of the yield per stool and the relative importance of every character was number of grains/ear > number of ears/stool > length/width of grain > culm length > prolificacy > number of earing days > bearing leaf area > resistance of the neck blast > leaf drop resistance > resistance of the check die back > panicle length > grain terminal color > cold resistance > angle standard bearing leaf > resistance of leaf blast, and so on. Four independent principle components out of 20 were extracted by the major component analysis and the path figure was charted respectively to each one.

Ashura (1998) evaluated 36 rice lines/cultivars for yield and other components at two sites within the University farm of Sokoine University of Agriculture, Tanzania. Data generated were used to provide information on relative
direct and indirect contribution of various biological components towards yield. Correlation coefficient analysis revealed grain yield/plant positively correlated with all the characters except per cent unfilled grains and days to 50% flowering. Results from path analysis identified number of filled grains/panicle, number of panicles/plant and 1000 grain weight to be important characters to influence grain yield. However, the number of filled grains/panicle had a significant negative indirect effect through number of panicles/plant and 1000 grain weight. Heritability estimates revealed plant height, number of filled grains/panicle and 1000 grain weight to be highly heritable characters. The study suggested that number of filled grains/panicle and grain weight to be used as selection criteria when selecting for increased yield in rice.

Ehati et al. (1998) carried out correlation and path coefficient analysis of yield and yield components in 20 diverse genotypes of coarse quality rice which revealed strong positive association of grain yield/plant with plant height, panicle length and 1000 grain weight. A very high heritability was estimated for the number of spikelets/panicle, 1000 grain weight and number of productive tillers/plant and number of spikelets/panicle and 1000 grain weight had marked direct effects on grain yield.

Samante et al. (1998) performed path analysis of 15 rice genotypes and observed that panicle weight, number of filled grains/panicle, panicle density, maximum tiller density, number of spikelets/panicle and 100 grain weight had positive effects on grain yield while panicle node number had a negative effect.

Suhartini et al. (1999) studied path coefficient and correlation analyses in 48 rice lines. Correlation analysis showed that significant positive correlation with yield
were found for number of filled grains per panicle, total number of grain/panicle and 1000 grain weight, and negative correlation for iron toxicity score. Path coefficient analysis revealed that iron toxicity score, filled grains/panicle and 1000 grain weight had high direct effect on yield which suggests that these traits may be effective for selection criteria. Other characters suitable for selection criteria were high to medium plant type, less tillering and long panicle. Iron toxicity score could be used as the main criteria for selecting high-yielding lines, as it showed the highest path and correlation coefficients with grain yield.

Christopher et al. (2000) studied superior cross combinations of crosses involving IR50 with Pusa Basmati and Kasturi. F₂ and F₃ generations were studied. Grain yield showed no correlation with most of the quality characters. Kernel length had a significant positive correlation with kernel L/B ratio in both the crosses and generations. Linear elongation ratio (LER) and breadth wise expansion ratio (BER) had relationship with elongation index in positive and negative direction, respectively. Path analysis also indicated that LER and BER are prime grain quality characters for improvement of genotypes.

Fathi et al. (2000) conducted path analysis of characters affecting grain yield of two rice cultivars with nitrogen splitting in a field experiment in Iran. The main plots consisted of split rates of N applied at four growth stages. Statistical analysis indicated that there was a significant difference between various split rates of N for grain yield and yield components. The maximum yield was obtained for Amo13 compared with Anboori. However, Anboori had the highest biological yield, desirable tillering and the greatest plant height. The highest yield was obtained with split rate of N applied at P3 and P4 stages (3.4 and 3.1 tonnes/ha, respectively).
Number of spikes and 1000-grain weight had positive correlation with grain yield. Among yield components, the number of spikes showed positive direct (0.319) and indirect (0.072) effects on grain yield. Path analysis indicated that spike number and grain number/spike had the greatest direct effect on grain yield, and these characters can be used in the selection of high-yielding rice cultivars in response to N fertilizer.

Nayak et al. (2001) studied genotypic and phenotypic correlations and path analysis using 10 quantitative traits of 200 scented rice genotypes, including 1 non-scented rice control, Ratna. Grain yield/plant showed positive correlation with plant height, panicle number/plant, panicle length, total number of spikelets/panicle and total number of grains/panicle at both genotypic and phenotypic levels. Path coefficient analysis revealed that panicle number/plant, total number of grains/panicle and 1000 grain weight contributed to the grain yield of the plant.

Babu et al. (2002) studied association and path coefficient analysis for eight quantitative characters in 33 genotypes. Plant height and number of productive tillers/plant were the principal characters responsible for single plant yield. Plant height recorded the highest positive direct effect on single plant yield via positive indirect effect of panicle length, number of grains/panicle and spikelet fertility. Selection based on these characters would be efficient.

Chen et al. (2002) conducted experiment on variety, Liangyoupeii grown in China, and treated with 7, 9, 11, 13 and 15kgN/667 m². N fertilizer was applied as base fertilizer (60%), at tillering (20%), during heading (10%), and grain filling (10%) stages. The correlation analysis between yield components and yield, and the path analysis of yield components to yield were conducted. Total grain number/ear was the most important trait affecting the yield. An extremely significant difference
in yield was recorded among different N treatments. The highest yield (580.8kg/667 m²) was obtained with 13kg N/667 m².

Guo et al. (2002) investigated the genetic relationships between rice yield and its components using correlation and path analysis involving a set of 241 recombinant inbred line (RIL) population of Shanyou 63, in China. Data were recorded on grain weight/plant (GWP), number of filled grains/panicle (FGP), number of panicles/plant (PN) and 1000 grain weight (TGW). The results showed tremendous transgressive variation in all the traits examined.

Hu et al. (2002) conducted an experiment to study the relationship between yield and yield components of different rice populations. A decrease in rice density also decreased the number of panicles, number of grains/panicle, and 1000 grain weight. Path coefficient analysis showed the number of grains/panicle as the highest yield determinant, followed by the number of panicles, 1000 grain weight, and blighted grain.

Mishra and Verma (2002) did correlation and path coefficient analysis for 20 yield and quality characters in rice. Grain yield/plant was significantly and positively correlated with number of ear-bearing tillers/plant, biological yield and harvest index at genotypic and phenotypic levels. Head rice recovery and biological yield were the major factors contributing to grain yield/plant and harvest index.

Singh et al. (2002) carried out correlation analysis during the kharif season of 2000 and revealed that rice seed yield was positively and significantly correlated with number of tillers/plant, length of panicle, days to maturity, test weight and number of grains/panicle. The experiment was conducted on 28 genetically diverse rice genotypes. Number of tillers/plant had maximum positive direct effect on seed
yield and positive indirect effect via length of panicle, days to maturity and number of grains/panicle. The present study revealed the importance of tillers/plant, length of panicle, 1000 grain weight and number of grains/panicle for yield improvement in paddy.

Zhou et al. (2002) analyzed the correlation between eating quality and cooking apparent or milling quality of indica rice and showed a significant negative correlation between eating quality and amylose content, chalkiness and chalky grain percentage. A significant positive correlation was observed between eating quality and gel consistency or grain shape. Principal component analysis revealed that the principal components were chalky grain percentage, brown rice recovery and GC.

Chaudhary and Motiramani (2003) evaluated 54 traditional aromatic rice accessions for 19 descriptors to obtain information on genetic variability and character association of grain quality and yield attributes. A wide range of variation was recorded for most of the characters. Grain yield/plant showed significant positive correlation with effective tillers/plant, spikelet density and biological yield/plant. Path analysis indicated a greater contribution of effective tillers/plant, spikelet density and biological yield/plant towards grain yield.

Mahto et al. (2003) evaluated 26 early maturing upland rice genotypes, for genetic variation, character association and path analysis based on days to 50% flowering, plant height, number of panicles/plant, panicle length, number of branches/panicle, number of filled grains/panicle, 1000-seed weight and grain yield/plant. The genotypic variance ranged from 5.36 for panicle length to 24.83 for grain yield. The difference between phenotypic and genotypic coefficient of variation was minimum for 1000 grain weight (0.12) and days to 50% flowering.
High values of heritability were observed for 1000 grain weight (98.30%) and days to 50% flowering (97.33%). The number of grains/panicle and panicle length showed significant difference between phenotypic and genotypic coefficient of variation. The association of high heritability with high genetic advance was observed for 1000 grain weight, days to 50% flowering, grain yield, number of branches/panicle and plant height. Grain yield was positively and significantly correlated with days to 50% flowering, number of panicles/plant, number of branches/panicle and number of filled grains/panicle. The characters which showed a significant positive correlation with grain yield were also positively and significantly interrelated with each other. However, plant height showed a negative association with grain yield. Path coefficient analysis showed that the number of branches/panicle (0.424) had the highest positive direct effect on grain yield followed by number of filled grains/panicle (0.411), number of panicles/plant (0.159) and days to 50% flowering (0.07). The same characters showed positive and highly significant correlation with grain yield. Thousand grain weight and plant height had a negative correlation with grain yield but had a positive direct effect on grain yield.

Nayak et al. (2003) evaluated 29 scented rice genotypes including one non-scented check Ratna to know the inter-relationship among different quality characters with amylose content. The amylose content had significant positive correlation with elongation ratio and volume expansion, whereas significant negative association with alkali spreading value and water uptake. The alkali-spreading value showed significant positive correlation with water uptake number and kernel elongation ratio. The volume expansion had significant positive correlation with
water uptake, but significant negative correlation with cooked kernel length and elongation ratio. Path analysis also showed the importance of elongation ratio and cooked kernel length in the improvement of amylose content.

Surek and Beser (2003) investigated the association among yield components and their direct and indirect influence on the grain yield of rice. For this purpose, 80 breeding lines derived from 11 different cross populations in the F<sub>6</sub> generation and their 10 parents were tested in a randomized complete block design with two replications at the Thrace Agricultural Research Institute, Turkey. According to the results from the first year, 49 breeding lines were selected. These lines and their 10 parents were tested in a randomized complete block experiment design with three replications in the same institute. The phenotypic correlations among the traits and their path coefficient were estimated for both years. Grain yield was significantly correlated with its component characters like the number of productive tillers/m² (r = 0.241** and r = 0.274**), biological yield (r = 0.803** and r = 0.312), harvest index (r = 0.250** and r = 0.677**), and the number of filled grains/panicle (r = 0.495** and r = 0.633**) in both years. Path coefficient analysis revealed that biological yield (0.748 and 0.481) and harvest index (0.413 and 0.704) had the highest positive direct effects on grain yield in both years. In addition, the yield components had positive direct effects on grain yield. According to the magnitude of the direct effects on grain yield, the order of yield components was the number of filled grains/panicle (0.297 and 0.285 > the number of productive tillers/m² (0.233 and 0.197) > 1000 grain weight (0.165 and 0.136). The improvement in grain yield will be efficient, if the selection is based on biological yield, harvest index, number of productive tillers/m² and the number of filled grains/panicle under temperate conditions. These traits
revealed that panicle weight had the highest positive direct effect followed by panicle length and secondary branches/panicle. Hence, selection on the basis of higher panicle weight and higher number of secondary branches/panicle could be effective for yield improvement in scented rice.

Naik et al. (2005) conducted study on 50 selected traditional rice accessions along with improved aromatic varieties as checks viz. Pusa Basmati-1, Taraori Basmati, Indira-9, Dubraj and Madhuri-11. Data recorded on quality and yield components were subjected to correlation coefficient analysis and path analysis. It revealed that selection criteria based on number of effective tillers/plant, grain yield/plant and biological yield/plant can provide better result for improvement of yield. The study of path analysis indicated that the direct selection of biological yield/plant and effective tillers/plant would be used as selection criteria for improvement.

Patil and Sarawgi (2005) conducted genetic variation and correlation analysis for seven traits on 128 aromatic rice accessions. The genotypic and phenotypic coefficients of variation were high for number of unfilled grains/panicle, unfilled grain percentage, grain yield/plant, 1000 grain weight, number of ear-bearing tillers/plant, and number of filled grains/panicle. High heritability estimates coupled with high genetic gain were recorded for grain yield/plant, number of ear-bearing tillers/plant, number of filled grains/panicle, and unfilled grain percentage. The grain yield showed a positive and significant correlation with number of days to 50% flowering, plant height, number of ear-bearing tillers/plant and number of filled grains/panicle at the genotypic and phenotypic levels. Path analysis revealed that 1000 grain weight had the maximum positive direct effect on grain yield, followed
number of ear-bearing tillers/plant, number of filled grains/panicle and number of days to 50% flowering. However, 1000 grain weight had no significant correlation with grain yield/plant due to its negative indirect effect on grain yield/plant through number of filled grains/panicle and plant height. Thus, direct selection for number of ear-bearing tillers/plant, number of filled grains/panicle and number of days to 50% flowering may be effective in increasing grain yield/plant.

Sabori et al. (2005) conducted an experiment to investigate the relationship among various characters of rice in two planting patterns (15 × 15 and 30 × 30 cm²) and the direct or indirect effects of these traits on yield. Significant differences were observed between cultivars, planting patterns and their interaction effects. The direct effect of number of panicles/m² on yield was positive and significant under both planting patterns. Heading date showed a positive and direct effect on the number of panicles/m² under both planting patterns. A positive correlation was observed between biomass at heading date and number of panicles/m² only under the 30 × 30 cm² planting pattern. Grain filling rate and effective grain filling period increased in 30 × 30 cm² planting patterns and showed positive direct effects on yield under both planting patterns. Native cultivars showed longer latent period. Results indicated that the traits that would enhance grain yield include number of panicles/m², grain filling rate and effective grain filling period.

Gazafrodi et al. (2006) evaluated 49 Iranian and foreign rice cultivars to investigate the correlation among 16 agronomic traits. Analysis of variance showed a significant variation among cultivars for all the traits studied. Phenotypic and genotypic correlation analysis showed positive and significant correlations between grain yield and number of productive tillers and total tillers and number of
grains/panicle. Based on the path analysis of the traits, the number of productive tillers had the highest direct effect on grain yield. The number of grains/panicle and 100 grain weight showed direct effects on yield.

Monalisa et al. (2006) estimated genetic variability, correlation and path coefficient from 20 lowland rice cultivars grown in West Bengal, India. The highest GCV was recorded for flag leaf length, high density grains/panicle and panicle weight. High heritability (broad sense) accompanied by high genetic advance was observed in flag leaf length, number of spikelets, filled grains and high density grains/panicle. Grain yield/plant was positively and significantly associated with number of effective tillers/plant, panicle weight, number of spikelets and high density grains/panicle. High positive direct effects were recorded coupled with significantly positive associations of effective tillers/plant and high density grains/panicle with grain yield/plant.

Muthuswamy and Kumar (2006) collected some 22 drought-resistant rice cultivars and studied them for estimating genotypic and phenotypic correlation coefficients and path effects of various yield contributing characters. Days to flowering, plant height, boot leaf length, panicle length, 100 grain weight and dry matter production showed positive significant correlation with yield/plant. The root traits viz., root length and root volume had positive and significant correlation with days to flowering, plant height, panicle length and dry matter production. Panicle length, root volume and plant height had highly positive direct effect on yield. Under such circumstances, simultaneous selection based on plant height and panicle length will improve the yield in drought-resistant cultivars.
Tayeng and Singh (2006) carried out study on correlation and path analysis for early rice genotypes in a field experiment in Uttar Pradesh. A significant positive correlation of grain yield with all the characters studied at both the genotypic and phenotypic levels was recorded. Panicle length, followed by number of spikelets/panicle showed the highest positive correlation with yield. The number of days to 50% flowering had high positive correlation with the number of spikelets/panicle, panicle length and 1000 seed weight. Direct effects of the number of grains/panicle, harvest index and panicle length on grain yield were recorded. Panicle weight, number of spikelets/panicle and number of effective tillers had negative direct effect.

Zaheer et al. (2006) conducted experiment to study the phenotypic and genotypic coefficient of variance, genetic advance, heritability, correlation coefficient and path analysis for yield, yield components and grain quality characteristics in 14 basmati rice genotypes. Plant height had a negative correlation with yield. Grains/panicle had positive and significant genotypic and phenotypic correlation with yield. Hence, the number of tillers/plant, grains/panicle and 1000 grain weight contributed maximum direct effects on yield indicating that these traits should be given emphasis while selecting high-yielding basmati rice cultivars for Kallar Tract. Plant height and 1000 grain weight had positive correlations with grain quality characteristics, i.e. grain length and cooked grain length, while number of tillers/plant had negative correlation with these quality traits. Grain length had positive and significant correlation with cooked grain length indicating that basmati cultivars elongate lengthwise, which is the typical basmati character.