GENETIC DIVERSITY ASSESSMENT OF SELECTED RICE (*ORYZA SATIVA* L.) GENOTYPES USING MORPHOLOGICAL TRAITS IN PAKISTAN

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(Received 17th Dec 2024; accepted 18th Mar 2025)

Abstract. Pakistan has occupied a prominent place among the world's high-quality rice producing and exporting countries. To improve the quality and value of exported rice, it is necessary to identify various genotypes of crop species when releasing new crop varieties, registering newly developed genotypes, characterizing various genotypes of wild relatives, and determining the purity of the cultivars. This study aimed to investigate the diversity between 74 genotypes from the indica, japonica, and aromatic (basmati) rice varieties from different regions in Pakistan based on morphological traits. Genetic diversity was determined using morphological characteristics. A significant degree of variability was observed across commercial and primitive genotypes, for several evaluated morphological features. The extent of variation was different among morphological traits. The maximum plant height (154 cm) was observed for Basmati-217 and panicle length (35.6 cm) were observed for PK386. The highest numbers of primary branches per panicle were observed in PAU-201 (15.2) and number of tillers per plant was noted in Nipponbare (34.6). Basmati-Pak showed highest paddy grain length (10.8 mm) and grain weight per plant (63 g) was noted in DR83. Days to heading, days to maturity, plant height, and grain yield per plant showed the most variation. Relatively, low level of variability was observed for flag leaf width, primary branches per panicle and grain

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

traits including grain length, width, and weight. Grain characteristics, days to heading, maturity and other functionally associated morphological parameters showed a highly significant level of correlation (+/-**) with each other. With very few exceptions, all local, exotic, and primitive cultivars were phenotypically categorized into two major groups (1 and 2). These groups were further subdivided into two subgroups A/B and C/D, which corresponded to the types of indica rice grown in Pakistan: aromatic (basmati) and non-aromatic (non-basmati). The cultivars' clustering revealed no pattern of correlation between the morphological traits and the cultivars' place of origin. Cultivar groupings were linked to the kind of indica rice grown in different parts of Pakistan and their morphological resemblances.
Keywords: *cluster analysis, food production, multivariate analysis, phenotypic diversity, principal component analysis, quantitative traits, rice varieties*

Introduction

Rice (*Oryza sativa* L.) is one of the major staple foods consumed by 70% of the world's population (Mohidem et al., 2022). Rice is high in nutrients, providing 20% of the world's nutritional protein and 27% of its dietary calories (Huang et al., 2020). Out of the one hundred countries that cultivate rice, nine of the top producers are in Asia, with China being the largest producer (Bashir et al., 2007). China, Indonesia, India, Vietnam, Thailand, Bangladesh, Myanmar, Philippines, Pakistan, Korea, and Japan produce the majority of the world's rice. Asian farmers produce 87% of the world's rice. It is thought that rice domestication began in a wide geographic area that included southern China, eastern India, and Indochina approximately 9000 years ago (Khush, 1997).

Oryza sativa is the scientific name for rice, and there are two cultivated and twenty-two wild species in the genus (Tiwari et al., 2020). *Oryza sativa* and *Oryza glaberrima* are the two cultivated species. While *Oryza glaberrima* has only been grown in West Africa for the last ~3500 years, *Oryza sativa* is grown all over the world (IRRI, 2001). *Oryza sativa* comprises two primary subspecies: the short-grained japonica and the long-grained indica (Singh et al., 2023).

The rice production of Pakistan was 9.32 million metric tons in 2021/2022. Pakistan ranked ninth among the leading rice-producing countries globally adding 0.6% to GDP and 3.0% in value added to the agriculture sector (Govt. of Pakistan, 2022). Since 1970, Pakistan has gained recognition as a significant supplier of rice, particularly Basmati rice. Pakistan Basmati rice is a special type of rice with long or extra-long grains which has a specific aroma after cooking (Akhter and Haider, 2020). As rice cultivars adapted to a wide range of climatic circumstances, thousands of rice varieties with a variety of physical, biochemical, and aesthetic qualities were produced.

In the loss of global biodiversity, the green revolution and the introduction of high-yielding semi-dwarf varieties, numerous rice varieties have been lost in Pakistan. Hence, in addition to conserving the land race genotypes, it is also important to study the gene pool of aromatic rice for breeding purposes (Sandhu et al., 2021). Several improved rice genotypes have been produced by rice research organizations for cultivation in diverse geographic regions of Pakistan that have narrow genetic bases due to greater homozygosity (Sandhu et al., 2021).

Rice germplasm contains a large reservoir of beneficial genes that investigators can harness for rice development programs. Rice germplasm comprises genetic heterogeneity permitting for a wide range of crop improvements. Genetic variability is the foundation for any effective breeding program. Therefore, measuring the level of genetic variation within germplasm is a significant concern of plant breeders. The prudent use of genetic resources requires knowledge of the genetic diversity both within

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

and between closely related crop varieties. It helps with germplasm monitoring and can be used to forecast possible genetic gains (Mandel et al., 2011). Breeders are interested in identifying variations in agronomic characteristics in breeding programs, whereas taxonomists are more focused on classifying various taxonomic groups (Jasim et al., 2018).

The molecular mechanisms underlying the important agronomic traits have advanced significantly over the past 20 years. Flowering and grain filling periods are key features that use sunshine, moisture and warmth to produce a high crop yield. Plant height, the number of tillers, and panicle architecture are other agronomic characteristics that influence crop yield. The growth of the tiller determines the number of panicles, which directly affects crop yield. The basis for lodging tolerance and the importance of cereal plant fiber as animal feed is tiller quality (Wang and Li, 2019). The majority of rice’s agronomic properties are controlled by several genes, exhibiting complex and numerical inheritance. Morphological variation of quantitative traits is the basis for genetic diversity in conventional plant breeding that is simple and economical to study.

Heterosis in crop plants must be utilized due to rapid human population growth and diminishing resources. The study of genetic diversity plays a crucial role in selecting diverse parents for rice, a crop that is mainly self-pollinated, in order to achieve maximum heterosis and transgressive segregants in the succeeding generations. Through the use of various multivariate statistical analysis, genotype diversity is understood. Principal Component Analysis simplifies the selection process by reducing the total number of variables to a small number of critical factors that account for the majority of the variation (Sheela et al., 2020; Devasena et al., 2023).

To demonstrate that a genotype is unique among all major species, a variety of morphological and physiological characteristics are available (Moukoumbi et al., 2011). The characterization and assessment of the genetic diversity of rice cultivars are essential for varietal improvement. In order to ensure global acceptance and economic stability, breeding programs should give greater weight to the quality attributes of rice grains, such as size, shape, chalkiness, translucency, color, milling quality, and eating and cooking quality.

After wheat, rice is a common staple meal in Pakistan. The primary goals of many rice research initiatives in Pakistan are yield enhancement and the creation of disease and insect resistance. Efforts have been made in the country to develop rice varieties with better grain quality at national level (Khanh et al., 2021). There are various characters directly or indirectly affect the grain quality. The quality of the rice grain changes when any of the characters are changed or combined. Commonly, milled whole rice is eaten as food. Both hulled and un-hulled rice grains contain considerable diversity in form and size. This could be due to a wide variety of agro-climatic conditions and increased selection for a wide range of rice grain uses (Nasir et al., 2020). Increased yields and smoother production in the face of disease outbreaks and changing environmental conditions depend on genetic variety (Debnath et al., 2023; Gonçalves et al., 2024).

Productivity has been successfully increased by utilizing rice’s genetic diversity. While other significant agro-morphological qualities have been overlooked, the majority of efforts aimed at increasing rice productivity have mostly concentrated on yield factors (Ahmad et al., 2022). In addition to preserving the current genotypes, it is crucial to investigate the gene-pool features to capture such significant agro-

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morphological properties. Hence, it is vital to discover the genetic diversity and the interactions among cultivars. Although morphological examination is a first step in estimating cultivar variability and relationships, other approaches are also often used (Smith et al., 1991; Zahid et al., 2022). The data will provide insights on the importance of these diverse genotypes in the breeding of rice and present prospects for creating high-yielding rice varieties to satisfy the constantly rising demand worldwide. This study aimed to investigate the diversity between the 74 genotypes from the indica, japonica, and aromatic (basmati) rice varieties from different regions in Pakistan based on morphological traits.

Materials and methods

Experimental site

The present study was conducted during the natural season at Experimental Rice Field, Plant Genetic Resource Program (PGRP), Bio-Resource Conservation Institute (BCI), National Agricultural Research Centre (NARC) Islamabad.

Plant material

Plant material used in this study was obtained from the Plant Genetic Resource Program (PGRP), Bio-Resource Conservation Institute (BCI) and National Agricultural Research Centre (NARC) Islamabad. A total of 74 different genotypes belonging to aromatic (basmati), non-aromatic (non-basmati) indica types and japonica types from different origins were used. Experimental material comprised of 33 local rice genotypes and 41 improved genotypes from different exotic origins including three check genotypes as control lines, i.e. IR6, JP5 and Super basmati (*Table 1*).

Experimental setup

Rice seeds were sown in pots (20 cm × 30 cm) to produce nursery seedlings during their natural growing season. Clay-loam soil with slightly alkaline pH were used to fill the pots. The pots were monitored frequently and watered as per requirements. After 30 days, the seedlings were transplanted to the field. The field layout was designed using a randomized complete block design with three replicates. Each genotype was planted in a three-row plot of 4 m length. Row to row (between genotypes) and plant to plant (within genotypes) distance was kept as 45 cm and 15 cm, respectively. Each experimental unit consisted of at least 25 plants, while ten randomly selected plants were used for data recording. Tractor drawn implements were used to prepare the paddy field by plowing five times with leveling and planking. Water was added into the field until it was 5–7 cm deep. After that, the rice nursery was transplanted, and the water level remained constant until the grain filling stages. The application rate of the nitrogen, phosphorus, and potassium (NPK) fertilizer was 80:60:40 kg ha^{-1} in the form of urea, di-ammonium phosphate and potassium sulfate, respectively. Three separate doses of nitrogen were applied at the basal, tillering, and panicle initiation stages, while the potassium and phosphorus were applied as a single basal dose at the time of transplanting. For each genotype, all agronomic, pest and disease control practices were rigorously maintained to ensure non-limiting growth conditions. All selected rice genotypes were maintained in the field until the harvesting stage.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

Table 1. *List of rice varieties and their country of origin*

Serial No.	Variety name	Country of origin	Serial No.	Variety name	Country of origin
1	Basmati-370	Pakistan	38	TN1	Taiwan
2	Sathra	Pakistan	39	Basmati-370a	India
3	Mahlar-346	Pakistan	40	Dehradun-Basmati1	Nepal
4	Palman-Sufaid	Pakistan	41	Dehradun-Basmati2	India
5	Basmati-C622	Pakistan	42	Basmati-217	India
6	Basmati-Pak	Pakistan	43	Punjab-Basmati	India
7	Basmati-198	Pakistan	44	Pusa-Basmati	India
8	PK177	Pakistan	45	Ranbir-Basmati	India
9	KS282	Pakistan	46	PK386	Pakistan
10	Basmati-2000	Pakistan	47	Pusa-1121	India
11	KSK133	Pakistan	48	PAU-201	India
12	Shaheen-Basmati	Pakistan	49	Mutant-370	India
13	Kashmir-Basmati	Pakistan	50	Mushkan-Rice	India
14	Pakhal	Pakistan	51	Purple-Marker	Unknown
15	Jajai-77	Pakistan	52	Basmati-370b	Unknown
16	Kangni-27	Pakistan	53	Dehraduni	Unknown
17	KangnixTorh	Pakistan	54	Dehradune	Unknown
18	Sugdasi-Sadagulab	Pakistan	55	Dehradun-Basmati3	Unknown
19	Sonehri-Sugdasi	Pakistan	56	Early-Basmati	Unknown
20	Sugdasi-Ratria	Pakistan	57	Karnal-Basmati	Unknown
21	Dokri-Basmati	Pakistan	58	Type-3	Unknown
22	Kharai-Ganja	Pakistan	59	ARC10025	Unknown
23	IR6	Pakistan	60	Lashmi-Digha	Unknown
24	DR82	Pakistan	61	Bhaturi	Unknown
25	DR83	Pakistan	62	Pank-Iraj	Unknown
26	Lateefy	Pakistan	63	Aus-133	Unknown
27	IR9	Pakistan	64	Aus-176	Unknown
28	DR92	Pakistan	65	Aus-190	Unknown
29	Kanwal-95	Pakistan	66	Aus-346	Unknown
30	Shakar	Pakistan	67	Korchampuri	Unknown
31	Shua-92	Pakistan	68	Naroi	Unknown
32	Khushboo-95	Pakistan	69	Saita	Unknown
33	Shadab	Pakistan	70	Balla-Bokri	Unknown
34	IR36	IRRI Philippines	71	Baturi	Unknown
35	Nipponbare	Japan	72	IR6	Check
36	Azucena	Philippines	73	JP5	Check
37	Kasalath	India	74	Super-Basmati	Check

Data collection

All selected rice genotypes were screened using nine qualitative and 13 quantitative morphological traits. Traits selection and measurement techniques were based on International Rice Research Institute (IRRI) Standard Evaluation System of Rice/Rice Descriptors by IBPGR- IRRI Advisory Committee (IRRI, 1980). Ten plants were

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

picked randomly. Certain characteristics (seed coat color, grain length and grain width) were measured in the field during the harvesting stage, and other characteristics were noted after harvest.

Qualitative traits

Qualitative attributes comprise nine distinct characters. These included leaf shape (LS), which might be upright, semi-erect, or droopy; flag leaf angle (FLA), which is the angle of attachment between the flag leaf blade and the main panicle axis erect, intermediate, horizontal, and falling; The width of a leaf is known as its leaf appearance (LA), and it can be thin (≤1.2 cm), intermediate (1.2 to 1.6 cm), or broad (≥1.6 cm); panicle type (PT), which is characterized as compact, intermediate, and open and can be either free or closed to one another; The degree to which the panicle is exerted above the flag leaf sheath at maturity is known as panicle exertion (PEx); it is observed as enclosed, partly exerted, just exerted, moderately well exerted, and well exerted; awning (An) is a small structure that resembles hair that is present at the tip of the rice spikelet at maturity and is recorded as awned, awnletted, and awnless; Seed coat color (SCC) can be observed as white, light brown, speckled brown, brown, red, variable purple, purple, reddish brown, and blackish brown. Awn color (AnC) can be observed as awnless, white, straw, gold, brown, light green, red, purple, and black at the maturity stage. Lodging incidence (Lg) can be observed as heavy, slight, and absent.

Quantitative traits

The quantitative characters were measured, *viz*. total tillers per plant (TTP^{-1}), plant height (PH), flag leaf length (FLL), flag leaf width (FLW), No. of primary branches/panicle (PBP^{-1}), panicle length (PL), days to heading (DH), days to maturity (DM), paddy grain length (PGL), grain length/breadth ratio (GLBR), paddy grain breadth (PGB), 100-seed weight (100-SW) and grain yield/plant (GYP^{-1}).

Data analysis

The data collected on 13 quantitative traits were analyzed using Minitab statistical package. The package was used to calculate mean, standard error, standard deviation, and coefficient of variation (CV). Relative means of each trait were calculated using Tukey’s test at a 0.05% level of significance. NTSYS-pc version 2.21 (Applied Biostatistics Inc., USA) was used to construct an unweighted pair group method with arithmetic averages (UPGMA) dendrogram to show the distance-based relationship using Euclidean distance among the rice genotypes based on the morphological traits. Statistical software “Statistica 7.0” was used for the correlation of quantitative traits. Using genotype mean values, simple correlation coefficients between all pairs of quantitative traits were computed in accordance with Steel and Torrie (1980). Principal component analysis and cluster analysis, two complementing numerical taxonomic approaches, were used to examine morphological features.

Prior to performing the cluster analysis and PCA, the means of each characteristic were standardized using Z-scores in order to prevent scaling differences. Euclidean distance coefficient estimates were calculated for every pair of genotypes. Following Sneath and Sokal (1973) methodology, the generated matrices of Euclidean dissimilarity coefficient were used to evaluate the genetic links between rice genotypes using a cluster analysis by complete linkage manner, i.e. NTSYS-pc, version 2.1

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

(Applied Biostatics Inc., USA). To determine the percentage contribution of each trait to the total genetic variation, Principal Components Analysis (PCA) was performed using the same data matrices. To identify the graphical display of the genetic diversity pattern among the rice genotypes, scatter plots of the first three PCs were created using Statista (version 7.0).

Results

Variation of the qualitative traits

Based on flag leaf angle, rice genotypes were separated into four major categories (FLA). 56 erect, 17 intermediate, and 1 horizontal type leaf angle were found among the 74 genotypes. No genotype exhibits a leaf angle that descends (*Table A1*). The prominent leaf shapes were erect types in 44 genotypes and semi-erect types in 27 genotypes, while droopy leaves were in only 3 genotypes (*Table A1*). Leaf appearance was identified as narrow in 27 genotypes, as intermediate in 40 and as broad leaves in 7 genotypes (*Table A1*). Majority of the genotypes showed intermediate panicle type (43), while 27 showed open and four genotypes with compact panicle type (*Table A1*).

Within this investigation, 21 genotypes' panicles were enclosed; 8 were partially exerted, 28 were merely exerted, and 7 were moderately well exerted (*Table A1*). 43 genotypes were awnless, 26 were awnletted, and 5 were awned based on awning (*Table A2*). Forty-three genotypes were awnless, thirteen were white, eight were straw, six were gold, and four were brown in hue (*Table A2*).

Lodging incidence at the maturity stage was observed as heavy lodging in 12 genotypes, slight lodging in 34 genotypes while 28 genotypes resistant to lodging (*Table A2*). Seed coat color varied among genotypes with four white, 47 light brown, 6 speckled brown, 10 brown, 3 red and 4 blackish brown color (*Table A2*).

Variation of quantitative traits

The performance and yield of rice genotypes may be seen and measured using quantitative attributes, which makes them extremely important. Basic statistics for various quantitative traits are presented in *Table 4* for different genotypes of rice. A considerable level of polymorphism was observed among various cultivars for most of the quantitative traits measured. Numerous agronomically significant parameters, such as days to heading and maturity, plant height, productive tillers plant^{-1}, flag leaf length, and grain yield plant^{-1}, varied across genotypes. A low level of variation was observed among the different genotypes of rice for leaf width, primary branches/panicle and grain traits including grain length, width and weight.

The number of days until heading or flowering is thought to be crucial for the ripening of crop plants. The days to heading ranged from 42 to 83 days, with Super-basmati recording the highest value of 83 days and Mahlar-346 recording the lowest value of 42 days. According to (*Tables 2* and *4*) the variance was 77.8, the standard deviation was 8.8, the coefficient of variation (CV) was 14.4%, and the mean value was 61.2 days.

Days to maturity (DM) ranged from 70 to 134, with Kangni × Torh showing the lowest value at 70 days and Super-basmati showing the highest value at 134 days. There were 95 days in the mean, 14.6 days in the standard deviation, 15.4% in the coefficient of variance, and 214.5 days in variance (*Tables 2* and *4*). The range of flag leaf length

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

(FLL), which was expressed in centimeters, was 21.4 to 52 cm. With a mean value of 34.2 cm, standard deviation of 7.2, coefficient of variation of 21%, and variance of 51.5, the lowest value of 21.4 cm was found in Palman-sufaid and the largest value of 52 cm in Baturi (*Tables 2* and *4*).

The flag leaf width (FLW) varied from 4 to 19 centimeters. With a mean value of 9.7 cm, standard deviation of 2.5, coefficient of variation of 26%, and variance of 6.3, the lowest value of 4.5 cm was recorded in Palman-sufaid and the highest value of 19 cm was recorded in ARC10025 (*Tables 2* and *4*). Majority of primitive cultivars and old landraces displayed narrow leaves with less than 10 mm (1 cm) width, whereas a number of the genotypes showed comparatively wider leaves showing > 10 mm (1 cm) leaf width. Overall, narrow leaf width was recorded in most of the genotypes under the Islamabad environmental conditions.

Table 2. *Quantitative traits showing days to heading, days to maturity, flag leaf length, flag leaf width, plant height, tillers per plant of 74 rice genotypes*

Serial No.	Genotypes	Days to heading	Days to maturity	Flag leaf length (cm)	Flag leaf width (mm)	Plant height (cm)	Tillers per plant
1	Basmati-370	67	109	24.8	7.3	137	15.0
2	Sathra	53	109	24.4	8.4	117	17.6
3	Mahlar-346	42	108	41.0	8.7	122	12.0
4	Palman-Sufaid	59	108	21.4	4.5	126	14.0
5	Basmati-C622	56	105	26.2	7.5	117	9.8
6	Basmati-Pak	80	105	38.0	8.8	115	19.0
7	Basmati-198	66	105	25.8	6.7	114	9.4
8	PK177	66	109	23.6	8.7	67	10.2
9	KS282	56	107	25.4	9.0	77	20.4
10	Basmati-2000	81	106	24.2	9.1	98	13.0
11	KSK133	57	109	31.4	8.8	92	13.4
12	Shaheen-Basmati	66	109	28.4	9.2	123	14.0
13	Kashmir-Basmati	60	77	27.0	8.0	117	8.8
14	Pakhal	66	74	33.8	9.2	127	15.2
15	Jajai-77	60	78	29.8	9.1	135	18.0
16	Kangni-27	56	78	33.4	9.6	115	15.0
17	KangnixTorh	57	70	31.8	10.0	143	12.0
18	Sugdasi-Sadagulab	57	108	22.2	7.0	117	14.4
19	Sonehri-Sugdasi	60	111	32.2	9.1	112	21.4
20	Sugdasi-Ratria	44	76	33.2	9.0	110	13.8
21	Dokri-Basmati	57	105	30.6	9.2	113	15.4
22	Kharai-Ganja	57	107	28.8	9.3	99	13.4
23	IR6	60	105	31.4	9.4	105	22.0
24	DR82	58	107	37.2	9.4	100	23.4
25	DR83	61	83	27.6	6.6	105	20.0
26	Lateefy	61	97	30.0	9.4	126	14.4
27	IR9	70	104	30.2	7.4	103	15.2
28	DR92	64	79	28.2	10.0	115	15.2
29	Kanwal-95	60	106	42.0	12.0	107	14.8
30	Shakar	65	106	34.2	9.0	109	20.6
31	Shua-92	68	105	41.4	7.4	115	10.6
32	Khushboo-95	61	105	41.6	7.1	144	21.2
33	Shadab	68	105	27.8	7.4	105	12.2
34	IR36	57	97	37.4	10.0	80	19.8
35	Nipponbare	63	97	41.8	9.4	100	34.6
36	Azucena	72	83	38.4	10.0	146	10.2

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 23(3):5253-5281.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

37	Kasalath	51	78	40.2	10.2	140	19.0
38	TN1	61	97	34.6	9.9	120	17.8
39	Basmati-370	66	109	31.2	10.8	138	14.4
40	Dehradun-Basmati1	66	97	34.4	11.6	110	20.4
41	Dehradun-Basmati2	63	97	48.4	13.0	119	18.8
42	Basmati-217	75	104	45.8	10.6	154	24.6
43	Punjab-Basmati	80	105	42.2	11.0	104	16.0
44	Pusa-Basmati	66	105	33.4	7.6	107	15.8
45	Ranbir-Basmati	55	84	30.4	8.4	105	15.0
46	PK386	67	105	38.2	11.0	117	12.4
47	Pusa-1121	59	107	30.0	10.0	117	18.8
48	PAU-201	66	105	35.0	13.2	93	11.0
49	Mutant-370	69	109	38.8	11.0	112	20.6
50	Mushkan-Rice	54	84	39.6	11.0	137	17.0
51	Purple-Marker	66	109	34.4	14.0	100	10.2
52	Basmati-370b	73	109	45.4	10.2	138	19.0
53	Dehraduni	59	97	47.6	8.2	110	13.0
54	Dehradune	51	84	34.2	14.4	114	8.2
55	Dehradun-Basmati3	63	104	48.2	17.0	116	10.6
56	Early-Basmati	47	84	30.8	10.0	118	13.0
57	Karnal-Basmati	80	110	35.8	9.0	119	20.4
58	Type-3	45	104	36.0	8.6	142	15.4
59	ARC10025	48	76	33.0	19.0	118	12.8
60	Lashmi-Digha	66	77	29.0	7.0	142	19.4
61	Bhaturi	44	77	27.0	7.0	113	15.8
62	Pank-Iraj	51	74	32.8	11.0	108	11.8
63	Aus-133	66	80	35.0	12.6	126	11.6
64	Aus-176	60	77	35.4	12.6	130	13.0
65	Aus-190	60	77	39.6	10.2	117	13.0
66	Aus-346	54	76	46.6	17.6	132	9.6
67	Korchampuri	53	73	26.4	9.4	116	10.8
68	Naroi	55	73	34.2	10.8	98	9.4
69	Saita	51	78	26.4	8.0	103	12.6
70	Balla-Bokri	60	71	32.0	9.0	100	12.4
71	Baturi	53	73	52.0	9.8	100	19.2
72	IR6	71	98	44.4	5.0	105.9	17.0
73	JP5	59	80	49.5	9.7	111	11.2
74	Super-Basmati	83	134	25.1	6.6	104	19.8
Mean		61.2	95.0	34.2	9.7	115.1	15.4
Minimum		42	70	21.4	4.5	67.0	8.2
Maximum		83	134	52.0	19.0	154.2	34.6
Standard deviation		8.8	14.6	7.2	2.5	16.2	4.5
Coefficient of variance (%)		14.4	15.4	21.0	26.0	14.1	29.4
Variance		77.8	214.5	51.5	6.3	262.9	20.5

Plant height of rice genotypes varied from 67 to 154.2 cm. Total tillers per plant were also measured which ranged from 8.2 to 34.6. (*Table 2*). The minimum panicle length was measured 15.2 cm in Kanwal-95 and the maximum panicle length was measured 35.6 in PK386 as shown in *Table 3*. The total number of primary branches per panicle extended from 7.6 to 15.2 (*Table 3* and *4*).

Grain yield per plant ranged from 9.4 to 63 g. With a mean of 35.2 g, standard deviation of 11.3 g, coefficient of variation of 32.2%, and variance of 128.4 g, the

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

smallest grain yield value of 9.4 g was recorded in Naroi and the greatest grain yield value of 63 g in DR83 (*Table 3*).

Table 3. *Quantitative traits showing panicle length, spikelet per panicle, paddy grain length, paddy grain breadth, grain length/breadth ratio, 100-seed weight and grain yield per plant of 74 rice genotypes*

Serial No.	Genotype	Panicle length (cm)	Primary Branches per panicle	Paddy grain length (mm)	Paddy grain breadth (mm)	Grain length/grain breadth ratio	100 seed weight (gm)	Grain yield per plant (gm)
1	Basmati370	31.4	13.4	8.9	1.8	5.1	2.0	44.0
2	Sathra	26.0	13.8	9.3	2.3	4.0	2.1	36.0
3	Mahlar-346	29.0	12.0	8.6	2.1	4.1	2.0	30.0
4	Palman-Sufaid	28.0	11.4	8.7	2.2	3.9	2.2	33.0
5	Basmati-C622	26.4	11.6	8.5	2.2	3.9	1.9	51.0
6	Basmati-Pak	29.2	11.4	10.8	2.2	5.0	2.4	38.0
7	Basmati-198	23.0	10.8	9.5	2.0	4.8	1.9	23.0
8	PK177	24.6	10.0	8.8	2.8	3.1	2.9	37.0
9	KS282	27.4	8.2	9.7	2.3	4.3	2.6	42.0
10	Basmati-2000	15.8	8.2	10.0	2.1	4.7	2.2	24.4
11	KSK133	24.6	10.2	10.5	2.4	4.4	2.9	46.0
12	Shaheen-Basmati	28.6	12.6	9.9	2.3	4.4	2.4	28.0
13	Kashmir-Basmati	26.6	8.8	9.1	1.8	5.1	2.1	34.0
14	Pakhal	24.2	11.6	8.9	2.4	3.8	2.6	35.0
15	Jajai-77	32.0	12.2	9.5	2.4	4.0	2.5	22.0
16	Kangni-27	31.2	11.6	8.5	2.0	4.3	2.2	50.0
17	KangnixTorh	28.8	12.0	8.9	2.5	3.6	2.3	17.0
18	Sugdasi-Sadagulab	26.0	11.0	9.5	2.2	4.3	2.6	53.4
19	Sonehri-Sugdasi	22.4	13.4	10.3	2.2	4.7	2.4	36.0
20	Sugdasi-Ratria	23.0	9.8	9.7	2.2	4.4	2.4	48.0
21	Dokri-Basmati	28.0	11.4	8.3	2.0	4.1	2.2	30.0
22	Kharai-Ganja	22.2	11.2	9.5	2.5	3.8	2.6	46.0
23	IR6	22.6	11.0	10.2	2.3	4.4	2.5	54.0
24	DR82	22.4	10.0	8.5	1.9	4.5	2.0	47.0
25	DR83	22.4	10.0	9.7	2.4	4.0	2.2	63.0
26	Lateefy	24.2	11.4	9.7	2.0	4.8	2.0	38.0
27	IR9	21.4	10.2	10.3	2.2	4.7	2.4	32.0
28	DR92	23.4	9.8	9.1	1.9	4.7	2.3	44.0
29	Kanwal-95	15.2	9.2	9.5	2.0	4.7	2.3	59.0
30	Shakar	30.4	10.4	9.5	2.1	4.5	2.4	49.0
31	Shua-92	26.0	11.4	10.3	2.4	4.4	2.4	46.0
32	Khushboo-95	32.4	10.4	9.2	2.2	4.1	2.3	40.8
33	Shadab	31.4	11.6	10.3	2.2	4.7	2.3	43.0
34	IR36	22.0	11.6	9.1	2.3	4.0	2.2	36.0
35	Nipponbare	25.4	9.8	8.5	2.2	3.8	2.1	19.0
36	Azucena	30.4	11.8	10.6	2.8	3.9	3.1	29.0
37	Kasalath	29.4	11.8	7.4	2.3	3.2	1.8	39.0
38	TN1	24.4	15.0	7.2	3.0	2.4	2.2	39.0
39	Basmati-370	17.6	12.2	9.6	2.2	4.4	2.1	40.0
40	Dehradun-Basmati1	31.2	14.2	8.6	2.0	4.3	1.6	34.0
41	Dehradun-Basmati2	25.8	11.4	9.4	1.9	5.0	1.9	61.6
42	Basmati-217	29.2	11.2	8.7	1.9	4.6	1.9	41.0
43	Punjab-Basmati	25.6	11.4	9.5	1.9	5.0	1.9	50.0
44	Pusa-Basmati	34.4	15.0	10.4	2.0	5.2	2.2	29.0
45	Ranbir-Basmati	24.4	11.2	10.0	1.9	5.4	2.0	29.0
46	PK386	35.6	11.2	9.7	1.9	5.2	2.1	36.0

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

47	Pusa-1121	25.4	13.2	10.6	2.0	5.2	2.4	36.4
48	PAU-201	24.6	15.2	8.5	2.5	3.5	2.5	36.0
49	Mutant-370	26.4	10.4	10.4	2.0	5.2	2.3	29.0
50	Mushkan-Rice	25.0	10.0	9.3	2.4	3.9	2.5	39.2
51	Purple-Marker	22.6	11.8	8.7	2.7	3.3	2.6	29.0
52	Basmati-370b	34.2	13.2	9.5	2.2	4.4	2.1	25.0
53	Dehraduni	30.6	13.0	9.7	2.3	4.2	2.4	42.0
54	Dehradune	22.6	11.6	7.0	2.8	2.8	2.3	38.0
55	Dehradun-Basmati3	18.6	12.6	9.8	2.5	3.9	2.0	29.0
56	Early-Basmati	29.4	7.6	9.5	2.0	4.9	2.1	23.2
57	Karnal-Basmati	21.2	10.0	10.1	1.9	5.4	2.3	28.0
58	Type-3	23.2	11.4	8.9	2.2	4.1	1.9	36.0
59	ARC10025	25.4	12.6	7.0	3.0	2.4	1.8	43.0
60	Lashmi-Digha	23.8	8.6	7.9	2.8	2.8	2.6	22.0
61	Bhaturi	31.4	11.8	8.0	2.9	2.8	2.4	12.0
62	Pank-Iraj	23.8	9.8	7.4	2.9	2.6	2.2	19.0
63	Aus-133	24.2	8.6	7.2	3.0	2.4	2.2	23.0
64	Aus-176	26.0	12.4	7.3	2.9	2.5	2.3	22.0
65	Aus-190	27.4	9.8	8.6	2.8	3.0	2.3	21.0
66	Aus-346	24.2	9.4	9.4	2.8	3.4	2.9	23.0
67	Korchampuri	30.6	11.6	7.5	3.1	2.4	2.6	25.0
68	Naroi	22.0	8.4	7.8	3.0	2.6	2.8	9.4
69	Saita	16.6	8.2	7.8	2.8	2.7	2.6	18.0
70	Balla-Bokri	20.8	12.0	7.8	2.8	2.8	2.5	29.0
71	Baturi	23.6	8.0	7.9	2.7	2.9	2.4	27.0
72	IR6	24.6	11.4	9.4	3.7	2.5	2.6	42.2
73	JP5	27.1	12.2	7.3	3.3	2.2	2.8	33.0
74	Super-Basmati	24.5	9.4	10.3	1.9	5.5	2.1	40.0
Mean		25.7	11.1	9.1	2.4	4.0	2.3	35.2
Minimum		15.2	7.6	7.0	1.8	2.2	1.6	9.4
Maximum		35.6	15.2	10.8	3.7	5.5	3.1	63.0
Standard deviation		4.2	1.7	1.0	0.4	0.9	0.3	11.3
Coefficient of variance (%)		16.5	15.1	11.0	17.3	22.5	12.4	32.2
Variance		17.9	2.8	1.0	0.2	0.8	0.1	128.4

Millimeters were used to measure the paddy grain length (PGL), which varied from 7 to 10.8 mm. Paddy grain length values ranged from 7 mm in Dehradune to 10.8 mm in Basmati-Pak, with the lowest value recorded in that region. With a standard deviation of 1.0, a variance of 1.0, a coefficient of variation of 11.0%, and a mean value of 9.1 mm (*Table 3*). The width of the paddy grain was measured in millimeters and ranged from 1.8 to 3.7 mm. Basmati-370 and Kashmir-basmati recorded a minimum paddy grain breadth value of 1.8 mm, while IR6 recorded a maximum paddy grain breadth value of 3.7 mm (*Table 3*).

The ratio of grain length to breadth varied between 2.2 and 5.5 mm. JP5 had the lowest grain length/breadth ratio of 2.2 mm, while Super-basmati had the highest value of 5.5 mm. The mean was 4.0 mm, the standard deviation was 0.9, the coefficient of variation was 22.5%, and the variance was 0.8 (*Table 3*).

The weight of one hundred seeds varied between 1.6 and 3.1 grams. Dehradun-basmati recorded the lowest 100-seed weight of 1.6 g, while Azucena recorded the highest 100-seed weight of 3.1 g. In the genotypes, the mean 100-seed weight was recorded as 2.3 g with the standard deviation of 0.3, coefficient of variance of 12.4% and variance of 0.1 (*Table 3*).

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

Table 4. *Descriptive statistics showing level of diversity of various traits among 74 rice genotypes*

Trait	Mean	Minimum	Maximum	SD	CV (%)	Variance
Days to heading (DH)	61.2	42	83	8.8	14.4	77.8
Days to maturity (DM)	95.0	70	134	14.6	15.4	214.5
Flag leaf length (FLL)	34.2	21.4	52.0	7.2	21.0	51.5
Flag leaf width (FLW)	9.7	4.5	19.0	2.5	26.0	6.3
Plant height (PH)	115.1	67.0	154.2	16.2	14.1	262.9
Tillers/plant (T/P)	15.4	8.2	34.6	4.5	29.4	20.5
Panicle length (PL)	25.7	15.2	35.6	4.2	16.5	17.9
Primary branches/panicle (PB/P)	11.1	7.6	15.2	1.7	15.1	2.8
Paddy grain length (PGL)	9.1	7.0	10.8	1.0	11.0	1.0
Paddy grain breadth (PGB)	2.4	1.8	3.7	0.4	17.3	0.2
Grain length/breadth (GL/B)	4.0	2.2	5.5	0.9	22.5	0.8
Hundred grain weight (HGW)	2.3	1.6	3.1	0.3	12.4	0.1
Grain yield/plant (GY/P)	35.2	9.4	63.0	11.3	32.2	128.4

Descriptive statistics

The quantitative features showed a wide range of variations, as indicated by the descriptive statistics of the recorded data. When productive genotypes were being identified, all the qualities had important genetic status and contributed, either directly or indirectly, to the yield. *Table 4* provides the fundamental statistical information (mean, minimum, maximum, standard deviation, coefficient of variation and variance) for each quantitative character recorded for each genotype.

Maximum variability was seen in days to heading and maturity, flag leaf length, plant height and grain yield per plant. The variances for the cited traits were 77.8, 214.5, 51.5, 262.9 and 128.4, respectively. Relatively low level of polymorphism was recorded for leaf width, tillers plant^{-1}, primary branches panicle^{-1}, and grain length, breadth, length/breadth ratio and grain weight. The variances for these traits were 6.3, 20.5, 17.9, 2.8, 1.0, 0.2, 0.8 and 0.1, respectively.

Correlation analysis

The agro morphological correlation analysis revealed a noteworthy degree of linkage between significant and functionally linked features (*Table 5*). Correlation analysis was performed on thirteen quantitative traits. A total of 78 correlation pairings were noted. Out of the 78 pairings, 41 had a positive correlation whereas 34 displayed a negative correlation. Plant height and days to heading, panicle length and days to heading, and panicle length and days to maturity were the only three combinations that were determined to be uncorrelated (*Table 5*).

The paddy grain length and the grain length/breadth ratio had the strongest positive connection, measuring 0.80. Grain length/breadth ratio and spikelets per panicle and paddy grain length and spikelets per panicle had the lowest positive association values, both at 0.01. Grain length/breadth ratio and paddy grain breadth showed the strongest negative association value (-0.92). Similarly, the lowest negative correlation value of -0.01 was observed between 100-grain weight and days to heading (*Table 5*).

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

Table 5. *Correlation of the quantitative morphological traits of the rice cultivars*

Trait	DH	DM	FLL	FLW	PH	TP^{-1}	PL	PBP^{-1}	PGL	PGB	GL/B	HGW	GYP^{-1}
Days to heading (DH)	1.0												
Days to maturity (DM)	0.47**	1.0											
Flag leaf length (FLL)	0.06 ns	-0.11 ns	1.0										
Flag leaf width (FLW)	-0.13 ns	-0.23 ns	0.41**	1.0									
Plant height (PH)	0.00 ns	-0.19 ns	0.19 ns	0.06 ns	1.0								
Tiller per plant (TP^{-1})	0.21 ns	0.27*	0.18 ns	-0.20 ns	0.02 ns	1.0							
Panicle length (PL)	0.00 ns	0.00 ns	0.08 ns	-0.18 ns	0.32**	0.09 ns	1.0						
Primary branches per panicle (PBP^{-1})	0.05 ns	0.23	0.06 ns	0.10 ns	0.19 ns	-0.02 ns	0.36**	1.0					
Paddy grain length (PGL)	0.44**	0.56**	-0.06 ns	-0.27*	-0.08 ns	0.17 ns	0.05 ns	0.01 ns	1.0				
Paddy grain breadth (PGB)	-0.24*	-0.49**	0.15 ns	0.18 ns	-0.08 ns	-0.31**	-0.15 ns	-0.02 ns	-0.54**	1.0			
Grain length/breadth (GL/B)	0.40**	0.59**	-0.12 ns	-0.25*	0.02 ns	0.28*	0.13 ns	0.01 ns	0.80**	-0.92**	1.0		
Hundred grain weight (HGW)	-0.01 ns	-0.20 ns	-0.04 ns	-0.07 ns	-0.23 ns	-0.25*	-0.11 ns	-0.20 ns	0.09 ns	0.54**	-0.35**	1.00	
Grain yield per plant (GYP^{-1})	0.09 ns	0.37**	0.03 ns	-0.08 ns	-0.12 ns	0.18 ns	-0.06 ns	0.12 ns	0.29*	-0.35**	0.37**	-0.16 ns	1.0

*Significant at 0.05 level of probability
**Highly significant at 0.01 level of probability, NS = non-significant

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Cluster analysis

The link between the genotypes of rice was represented by matrices with Euclidean dissimilarity coefficients. The genotypes 15232 and 15014 showed the greatest Euclidean genetic distance of 17.8, suggesting that they are highly varied. The genotype 15329 and 15232 showed the second highest distance, 17.7. With a genetic distance of only 2.7, genotypes 24670 and 24669 were the most comparable (*Table A3*).

Euclidean distance was calculated based on morphological traits for all rice genotypes (*Table 2* and 3). Different pairs of genotypes showed different Euclidean distances. Given that these genotypes were classified into several clusters (*Table A3*), which indicate the largest diversity, the genotypes Pank-Iraj and Karnal-Basmati and Pank-Iraj and Super-Basmati had the greatest distance (11.1). Similarly, the lowest distance of 2.4 was recorded among Pusa-1121 and Sonehri-Sugdasi (*Table A3*).

Based on the morphological traits all the rice genotypes selected from different origins were clustered into two main groups each further sub-divided into sub-clusters as cluster A/B and C/D at the similarity level of closer to 11.1. Euclidean distance (*Fig. 1*). Cluster A is comprised of 25 rice genotypes and it is again sub divided into two sub-groups at the similarity level of around 9.14. Cluster B is comprised of 39 rice genotypes. Cluster C included only 2 rice genotypes, whereas Cluster D contained 8 rice genotypes.

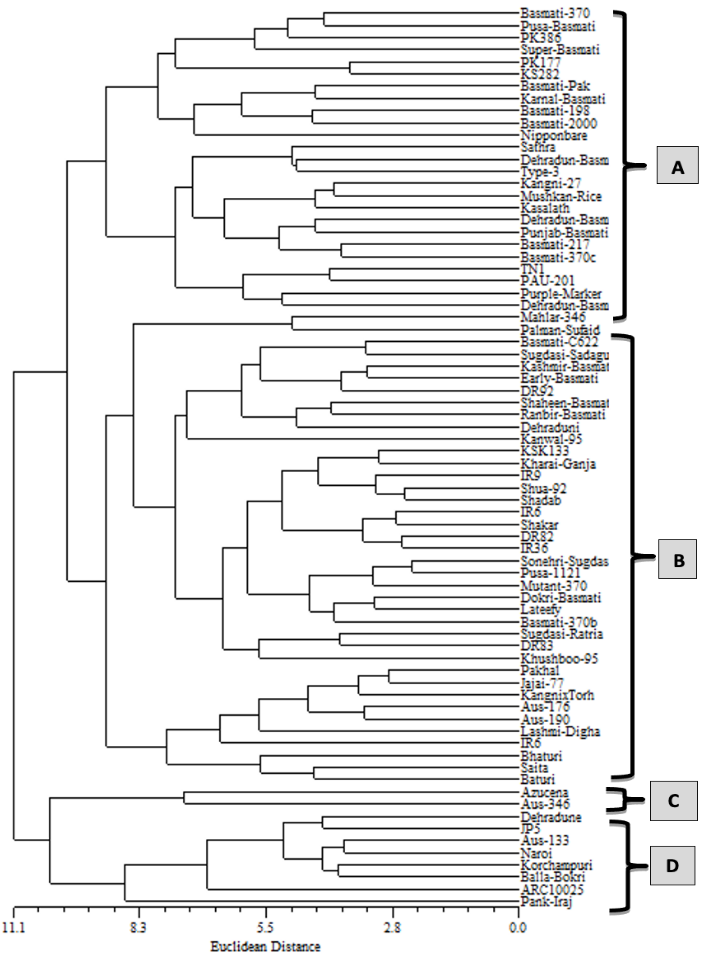

Figure 1. *Dendrogram made from 13 quantitative traits revealing the morphological similarities of 74 rice genotypes (enlisted in Table 1) and showing Euclidean distance among each other*

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

Principal component analysis (PCA)

The data exhibited some similarities as well as variations. Seventy-six percent of the variation was explained by five components. Principal Component-1 (PC-1) consisted of 5 negative and 8 positive qualities, making up 29.32% of the total (*Table 6*). PC-2 has 6 positive and 7 negative features, with a percentage of 14.26% (*Table 6*). PC-3 has a 10.42% trait count, consisting of 5 positive and 8 negative characteristics (*Table 6*). PC-4 had 4 positive and 9 negative qualities, making it 9.32% (*Table 6*). PC-5 had five favorable and eight unfavorable features, or 8.30% (*Table 6*). *Table 6* as well as *Figures 2a, b* and *3a, b* displayed the entire study.

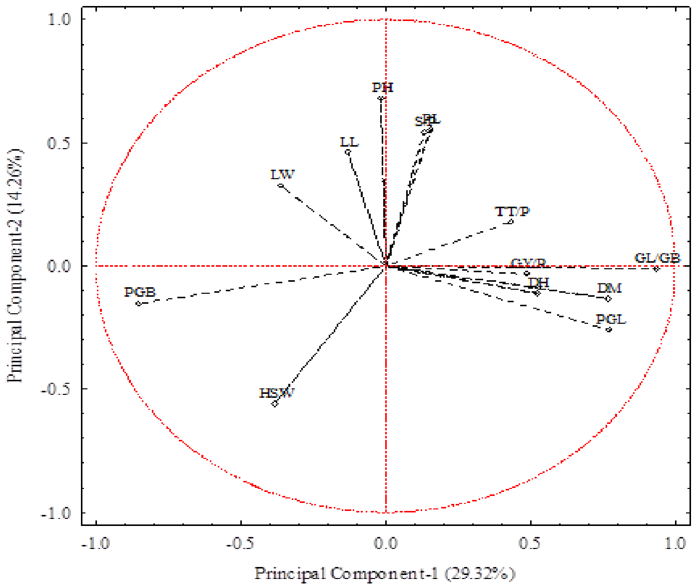

***Figure 2a.** Scattered diagram showing the correlation trend of 13 quantitative traits of (as shown in Table 4) 74 rice genotypes*

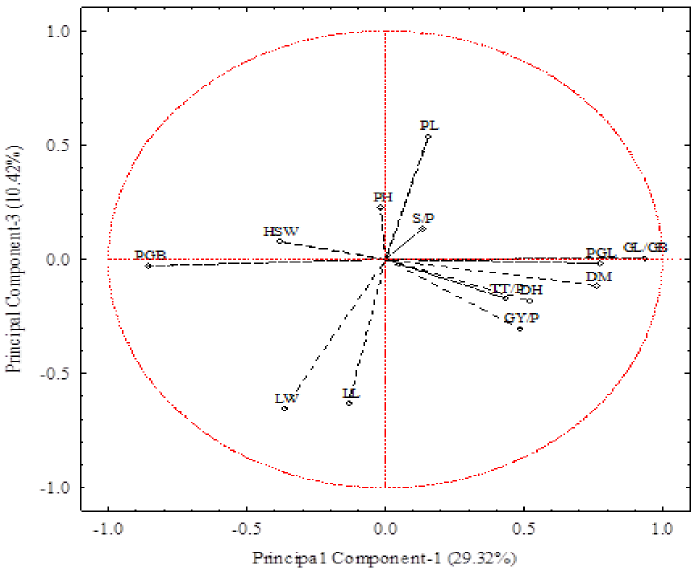

***Figure 2b.** Scattered diagram displaying the trend of relationship for 13 quantitative traits of the 74 rice genotypes as shown in Table 1*

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

Table 6. *Principal component analysis of rice population based on morphological data*

	PC1	PC2	PC3	PC4	PC5
Eigen value	3.81	1.85	1.36	1.21	1.08
Cumulative eigen value	3.81	5.66	7.02	8.23	9.31
Percent of variance	29.32	14.26	10.42	9.32	8.30
Cumulative variance	29.32	43.57	54.00	63.32	71.61
Trait of interest	**Eigenvectors**				
Days to heading (DH)	0.521	-0.110	-0.180	-0.521	-0.180
Days to maturity (DM)	0.765	-0.134	-0.118	-0.177	0.264
Flag leaf length (FLL)	-0.130	0.462	-0.630	-0.323	-0.270
Flag leaf width (FLW)	-0.362	0.328	-0.652	0.017	0.205
Plant height (PH)	-0.016	0.682	0.226	-0.070	-0.275
Tillers per plant (TP^{-1})	0.431	0.178	-0.171	0.068	-0.483
Panicle length (PL)	0.154	0.557	0.539	-0.303	-0.039
Primary branches panicle (PBP^{-1})	0.130	0.542	0.133	-0.344	0.626
Paddy grain length (PGL)	0.772	-0.260	-0.015	-0.312	-0.055
Paddy grain breadth (PGB)	-0.854	-0.151	-0.028	-0.350	0.053
Grain length/breadth (GL/B)	0.933	-0.010	0.008	0.092	-0.066
Hundred grain weight (HGW)	-0.384	-0.558	0.079	-0.582	-0.062
Grain yield per plant (GYP^{-1})	0.487	-0.033	-0.301	0.133	0.380

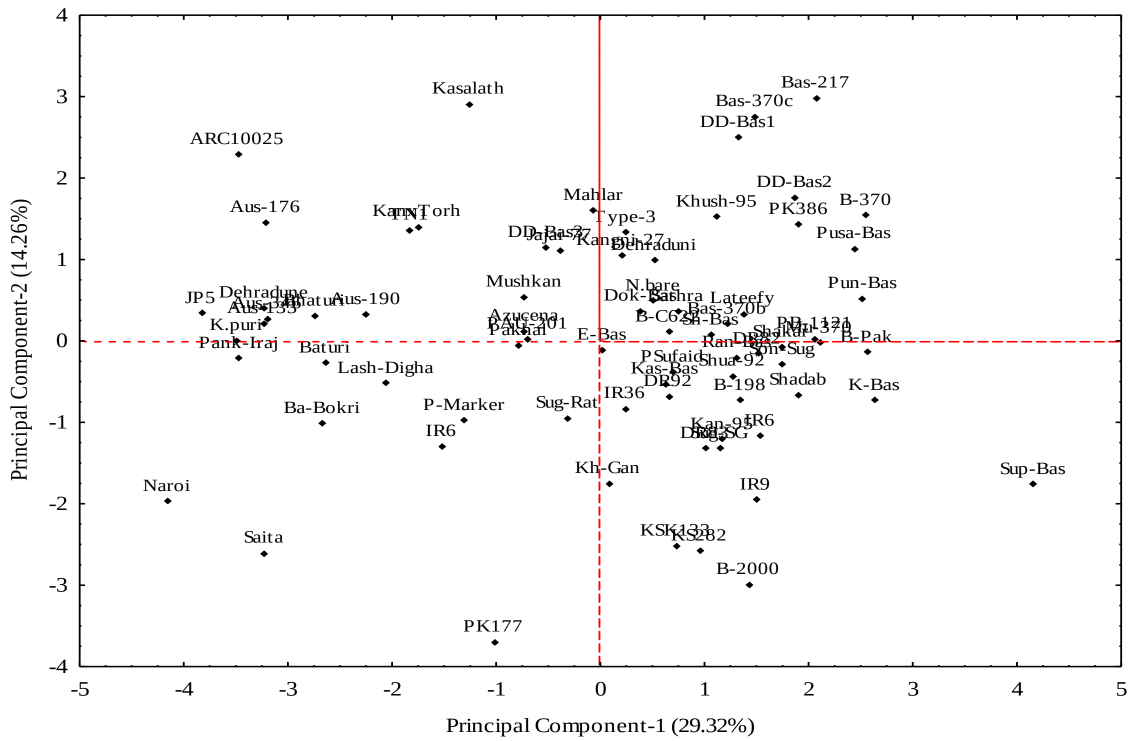

Figure 3a. *Scattered diagram showing the correlation pattern among the 74 rice genotypes as shown in Table 1*

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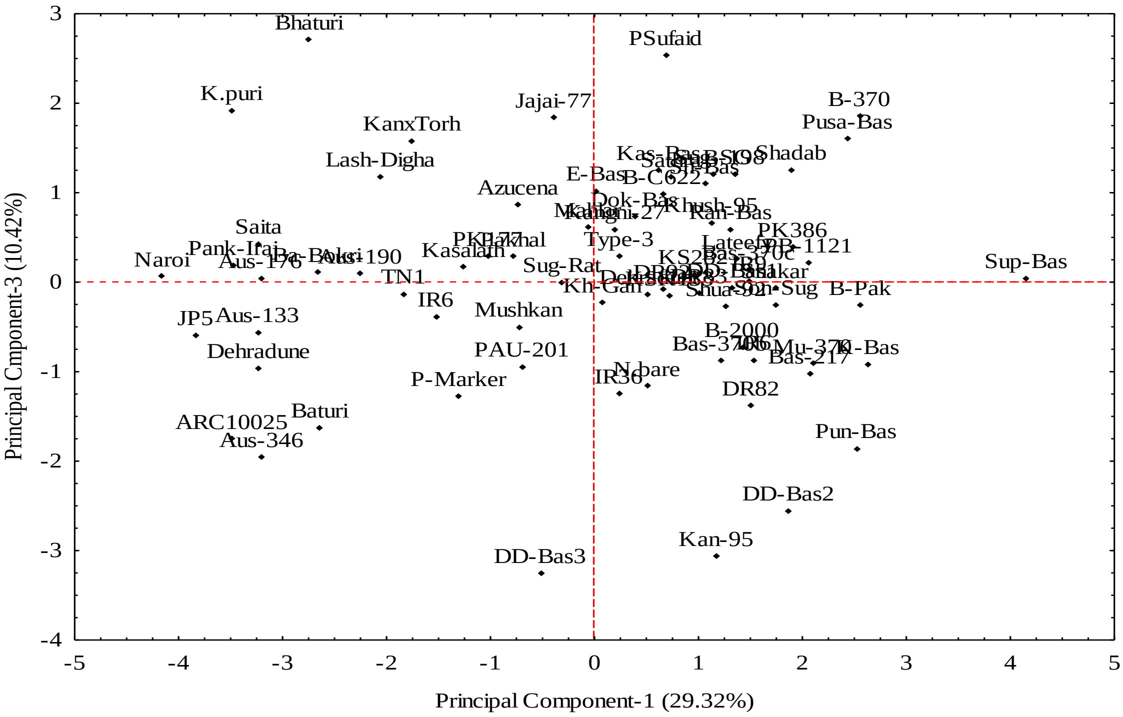

Figure 3b. *Dispersed diagram shows the correlation pattern among the 74 rice genotypes as shown in Table 1*

Discussion

Among rice exporting countries, Pakistan is one of the few countries that export high quality rice all over the world. Although rice is grown in a range of climatic conditions, little is known about Pakistan's genetic diversity in relation to the world's rice germplasm (Shahzadi et al., 2018). A wide range of genetic tolerance against biotic and abiotic challenges depends on having a diverse range of genetic variation in the genome. The primary source of genetic variation that breeders may use in the future to improve crops through hybridization or breeding programs is germplasm. The germplasm is the primary source for crop breeding efforts aimed at improving and developing any variety since it contains conserved traits that are necessary for high crop yield production, tolerance to environmental stressors, and improved crop quality. The evaluation of germplasm collections is crucial for tracking and assessing the diversity and key genes among crops (Zulfiqar et al., 2022). Germplasm are essential for both securing our food supply and creating new varieties. The new cultivars are more nutritious and feature unique genetic characteristics that protect them from most diseases and insects. Landraces, traditional varieties, breeding lines, and elite genotypes are all examples of rice germplasm. Approximately 4,500,000 plant accessions have been gathered globally, with approximately 400,000 accessions recorded for rice, in particular (Fao, 1998; Gaballah et al., 2022). However, pests and diseases can harm crops. Therefore, new methods of husbandry, improved genotype adaptation, and the use of diverse biotechnological approaches for disease resistance are required (Sarif et al., 2020). To resolve these issues, the current research was aimed at studying the genetic diversity of 74 genotypes.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

In the present study, the qualitative and quantitate agro-phenotypic characteristics have high phenotypic variation including plant height, number of tillers per plant, main panicle length, primary branches per panicle, paddy grain length, grain yield per plant, days to maturity and 100 grain weight. The most important agronomic trait to attain better rice production is grain yield in both favorable and adverse conditions (Gaballah et al., 2022). Similar findings with highly significant variance in all 14 rice germplasm attributes were shown in a prior study (Karimah et al., 2021; Gaballah et al., 2022).

When showing intricate relationships across populations with different origins in a more basic way, cluster analysis is very helpful (Ezugwu et al., 2022). Additionally, it works well for identifying genotypes with beneficial features that belong to various clusters and utilizing them for hybridization (Soe et al., 2019; Nihad et al., 2021). Based on morphological features, the 74 genotypes from seven different nations in the study were grouped into four primary clusters with a similarity coefficient of 0.11. This indicates that the genotypes differ genetically. The genetic difference that was seen between the genotypes revealed that morphological characteristics could provide insight into the rice genotypes. Efisue et al. (2014) also reported that morphological characteristics can distinguish different rice genotypes.

Various quantitative features were analyzed in morphological analysis. The genotypes were divided into four groups, A, B, C, and D, based on these characteristics. Cluster C had the fewest genotypes (2), while cluster B had the most genotypes (39) of any cluster. Cluster A consisted of 25 genotypes. In a few instances, Genetic samples taken from the same genotyping region were found in both the same cluster and different clusters, indicating that there was no parallelism in morphology, grain quality, or geographic location, according to the distribution pattern into distinct clusters in this study.

This shows that, despite the fact that geographic diversity and genetic diversity are typically linked, divergence can also result from processes other than physical separation, such as selection, genetic drift, and ongoing genetic material interchange between nations. Considering this, choosing parents should be based more on genetic variety than location. Given that the genotypes were divided into several clusters, the greatest distance was measured between Pank-Iraj and Karnal-Basmati and between Pank-Iraj and Super-Basmati. It signifies that these have the maximum diversity. Due to their membership in the same cluster, Pusa-1121 and Sonehri-Sugdasi have the lowest Euclidean distances. Oladosu et al. (2014) also proposed that genotype differences in a population might be classified and distinguished using genetic divergence analysis among rice genotypes based on quantitative features. This outcome is consistent with research conducted by Mazid et al. (2013) on 41 rice genotypes that were categorized into six groups according to 13 morphological and yield characteristics. The efficacy of morphological or quantitative features in classifying rice genotypes was demonstrated by this study. This genetic divergence analysis is helpful in the selection of genotypes for future improvement of rice genotypes.

There was also a correlation between quantitative traits. The paddy grain length and the grain length/breadth ratio showed the most positive association. The ratio of grain length to breadth and the number of days before maturity showed yet another strong positive association. Grain length to breadth ratio and paddy grain breadth showed the most negative association. Both paddy grain length and paddy grain width showed a strong negative connection. Plant height, days to heading, panicle length and days to maturity are the characteristics that did not show any correlation. These data were also supported by Nihad et al. (2021).

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Many researchers have conducted principal component analysis for diversity studies in rice to identify and rank the most critical characteristics that account for a substantial portion of the variability across the genotypes under study (Solis et al., 2015). Furthermore, the genetic diversity of the genotypes of rice under study was explained by the PCA results. While each coefficient of proper vectors represents the degree of contribution of each original variable with each principal component related, it quantifies the significance and contribution of each component to the total variance (Greenacre et al., 2022). Regardless of the positive or negative sign, the higher the coefficients, the more successful they will be in differentiating between genotypes (Nachimuthu et al., 2014). PCA in the current analysis showed each character’s overall contribution to the variation. Of the overall variation, the five components accounted for 71.61%. Characters with high variability are predicted to offer large levels of gene transfer during breeding programs, according to both Aliyu et al. (2000) and Barman et al. (2020). The first principal component showed a correlation with the factor scores of Days to heading, Days to maturity, Paddy grain length, and Grain length/breadth ratio. Soe et al. (2019) also had a similar finding. It is clear from the study that the aforementioned features mostly contributed to the genetic diversity of the genotypes of rice that were examined. A high level of variability existing within the genotypes and traits will make room for further improvement of the cultivars in breeding programs. Fazal et al. (2023) carried out similar research on 191 rice genotypes and found that panicle length, leaf length and seedling height greatly influenced the plant height and when these traits were improved plant height was improved and resulted a higher grain yield.

Conclusions

Investigating genetic variation is crucial for improving rice varieties, which contribute to global food security. This is due to the fact that genetic variations allow for recombinants, which are crucial for the development of new varieties. The present work has identified the divergence among Pakistani rice germplasm by genotypic and phenotypic analysis. The current study detected highly significant differences for the agro-morphological traits including plant height, number of tillers per plant, main panicle length, primary branches per panicle, paddy grain length, grain yield per plant, days to maturity and 100 grain weight. The greatest distance was measured between Pank-Iraj and Karnal-Basmati and between Pank-Iraj and Super-Basmati. Based on the current study, genetic diversity exists among local rice and exotic genotypes which are recommended to be included in the rice breeding program. This genetic variability information will be helpful for breeding programs like marker-assisted selection (MAS) in rice improvement, as well as for selection, classification, conservation, and identification of the parental source.

Acknowledgments. The authors extend their appreciation to the Researchers Supporting Project number (RSP2025R349) King Saud University, Riyadh, Saudi Arabia. The authors are grateful to Plant Genetic Resource Program (PGRP), Bio-Resource Conservation Institute (BCI), and National Agricultural Research Centre (NARC) Islamabad for providing the research facilities.

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APPENDIX

Table A1. *Different qualitative characters of various rice genotypes*

S.No	Genotype	Flag leaf angle	Leaf shape	Leaf appearance	Panicle type	Panicle exertion
1	Basmati-370	Erect	Semi-erect	Narrow	Open	Just exerted
2	Sathra	Erect	Semi-erect	Intermediate	Intermediate	Moderately exerted
3	Mahlar-346	Intermediate	Semi-erect	Intermediate	Open	Partly exerted
4	Palman-Sufaid	Erect	Erect	Narrow	Open	Partly exerted
5	Basmati-C622	Erect	Erect	Narrow	Intermediate	Just exerted
6	Basmati-Pak	Intermediate	Semi-erect	Intermediate	Intermediate	Just exerted
7	Basmati-198	Erect	Erect	Narrow	Intermediate	Just exerted
8	PK177	Erect	Erect	Intermediate	Intermediate	Enclosed
9	KS282	Erect	Erect	Intermediate	Intermediate	Enclosed
10	Basmati-2000	Erect	Erect	Intermediate	Intermediate	Enclosed
11	KSK133	Intermediate	Semi-erect	Intermediate	Intermediate	Enclosed
12	Shaheen-Basmati	Intermediate	Semi-erect	Intermediate	Open	Partly exerted
13	Kashmir-Basmati	Erect	Erect	Narrow	Open	Just exerted
14	Pakhal	Erect	Erect	Intermediate	Open	Just exerted
15	Jajai-77	Erect	Erect	Intermediate	Open	Just exerted
16	Kangni-27	Erect	Erect	Intermediate	Intermediate	Partly exerted
17	KangnixTorh	Erect	Erect	Intermediate	Intermediate	Moderately exerted
18	Sugdasi-Sadagulab	Erect	Erect	Narrow	Open	Partly exerted
19	Sonehri-Sugdasi	Erect	Erect	Intermediate	Intermediate	Enclosed
20	Sugdasi-Ratria	Intermediate	Semi-erect	Intermediate	Open	Moderately exerted
21	Dokri-Basmati	Erect	Semi-erect	Intermediate	Intermediate	Just exerted
22	Kharai-Ganja	Erect	Erect	Intermediate	Intermediate	Enclosed
23	IR6	Erect	Erect	Intermediate	Intermediate	Enclosed
24	DR82	Erect	Erect	Intermediate	Intermediate	Enclosed
25	DR83	Intermediate	Semi-erect	Narrow	Open	Just exerted
26	Lateefy	Erect	Semi-erect	Intermediate	Intermediate	Just exerted
27	IR9	Erect	Erect	Narrow	Intermediate	Enclosed
28	DR92	Erect	Erect	Narrow	Intermediate	Just exerted
29	Kanwal-95	Erect	Droopy	Intermediate	Intermediate	Moderately exerted
30	Shakar	Erect	Erect	Intermediate	Intermediate	Enclosed
31	Shua-92	Erect	Erect	Narrow	Intermediate	Enclosed

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

32	Khushboo-95	Intermediate	Erect	Narrow	Intermediate	Just exerted
33	Shadab	Erect	Erect	Narrow	Intermediate	Enclosed
34	IR36	Erect	Erect	Intermediate	Intermediate	Enclosed
35	Nipponbare	Erect	Erect	Intermediate	Intermediate	Enclosed
36	Azucena	Horizontal	Semi-erect	Intermediate	Compact	Just exerted
37	Kasalath	Erect	Erect	Intermediate	Open	Moderately exerted
38	TN1	Erect	Erect	Intermediate	Compact	Enclosed
39	Basmati-370	Erect	Semi-erect	Intermediate	Open	Just exerted
40	Dehradun-Basmati1	Intermediate	Semi-erect	Broad	Open	Just exerted
41	Dehradun-Basmati2	Erect	Erect	Intermediate	Open	Moderately exerted
42	Basmati-217	Erect	Semi-erect	Broad	Open	Just exerted
43	Punjab-Basmati	Erect	Erect	Intermediate	Open	Enclosed
44	Pusa-Basmati	Erect	Erect	Narrow	Intermediate	Enclosed
45	Ranbir-Basmati	Intermediate	Semi-erect	Narrow	Open	Just exerted
46	PK386	Erect	Semi-erect	Intermediate	Intermediate	Enclosed
47	Pusa-1121	Erect	Erect	Intermediate	Intermediate	Partly exerted
48	PAU-201	Erect	Erect	Intermediate	Intermediate	Enclosed
49	Mutant-370	Erect	Erect	Intermediate	Intermediate	Enclosed
50	Mushkan-Rice	Erect	Semi-erect	Intermediate	Open	Just exerted
51	Purple-Marker	Erect	Erect	Broad	Intermediate	Enclosed
52	Basmati-370b	Erect	Erect	Intermediate	Open	Just exerted
53	Dehraduni	Intermediate	Erect	Narrow	Open	Moderately exerted
54	Dehradune	Erect	Erect	Intermediate	Compact	Moderately exerted
55	Dehradun-Basmati3	Erect	Erect	Broad	Compact	Just exerted
56	Early-Basmati	Erect	Erect	Intermediate	Intermediate	Just exerted
57	Karnal-Basmati	Erect	Erect	Intermediate	Intermediate	Partly exerted
58	Type-3	Intermediate	Droopy	Broad	Open	Moderately exerted
59	ARC10025	Intermediate	Semi-erect	Broad	Intermediate	Moderately exerted
60	Lashmi-Digha	Intermediate	Semi-erect	Narrow	Open	Moderately exerted
61	Bhaturi	Erect	Semi-erect	Narrow	Intermediate	Just exerted
62	Pank-Iraj	Erect	Droopy	Narrow	Open	Moderately exerted
63	Aus-133	Intermediate	Semi-erect	Narrow	Intermediate	Moderately exerted
64	Aus-176	Erect	Erect	Intermediate	Open	Moderately exerted
65	Aus-190	Erect	Semi-erect	Intermediate	Open	Just exerted
66	Aus-346	Intermediate	Semi-erect	Broad	Intermediate	Just exerted
67	Korchampuri	Intermediate	Semi-erect	Narrow	Intermediate	Just exerted
68	Naroi	Intermediate	Semi-erect	Intermediate	Intermediate	Moderately exerted
69	Saita	Erect	Erect	Narrow	Open	Just exerted
70	Balla-Bokri	Erect	Semi-erect	Narrow	Intermediate	Just exerted
71	Baturi	Erect	Erect	Narrow	Open	Moderately exerted
72	IR6	Erect	Semi-erect	Narrow	Intermediate	Moderately exerted
73	JP5	Erect	Erect	Intermediate	Intermediate	Just exerted
74	Super-Basmati	Erect	Erect	Narrow	Intermediate	Partly exerted

Table A2. *Qualitative characters showing awning, awn color, lodging and seed coat color*

S.No	Genotype	Awning	Awn color	Lodging	Seed coat color
1	Basmati-370	Awn-letted	White	Absent	Light brown
2	Sathra	Awn-less	Awn-less	Heavy Lodging	Red
3	Mahlar-346	Awn-letted	Straw	Heavy Lodging	Light brown
4	Palman-Sufaid	Awn-letted	Straw	Heavy Lodging	Brown
5	Basmati-C622	Awned	Gold	Heavy Lodging	Light brown
6	Basmati-Pak	Awned	Gold	Heavy Lodging	Light brown
7	Basmati-198	Awn-letted	Gold	Heavy Lodging	Light brown
8	PK177	Awn-letted	White	Absent	Light brown

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

9	KS282	Awn-letted	White	Absent	Light brown
10	Basmati-2000	Awn-letted	White	Heavy Lodging	Light brown
11	KSK133	Awn-less	Awn-less	Absent	Light brown
12	Shaheen-Basmati	Awn-letted	Straw	Absent	Light brown
13	Kashmir-Basmati	Awn-letted	Straw	Absent	Light brown
14	Pakhal	Awn-less	Awn-less	Slight Lodging	Brown
15	Jajai-77	Awn-less	Awn-less	Slight Lodging	Light brown
16	Kangni-27	Awn-letted	Brown	Slight Lodging	Brown
17	KangnixTorh	Awn-less	Awn-less	Absent	Brown
18	Sugdasi-Sadagulab	Awned	Gold	Heavy Lodging	Light brown
19	Sonehri-Sugdasi	Awn-letted	White	Absent	Speckled brown
20	Sugdasi-Ratria	Awn-less	Awn-less	Slight Lodging	Light brown
21	Dokri-Basmati	Awn-letted	White	Absent	Brown
22	Kharai-Ganja	Awn-less	Awn-less	Absent	Light brown
23	IR6	Awn-less	Awn-less	Slight Lodging	Light brown
24	DR82	Awn-less	Awn-less	Absent	Light brown
25	DR83	Awn-less	Awn-less	Absent	Light brown
26	Lateefy	Awn-less	Awn-less	Absent	Light brown
27	IR9	Awn-less	Awn-less	Slight Lodging	Light brown
28	DR92	Awn-less	Awn-less	Slight Lodging	Light brown
29	Kanwal-95	Awn-less	Awn-less	Heavy Lodging	Light brown
30	Shakar	Awn-less	Awn-less	Absent	Light brown
31	Shua-92	Awn-less	Awn-less	Absent	Light brown
32	Khushboo-95	Awn-less	Awn-less	Absent	Brown
33	Shadab	Awn-less	Awn-less	Absent	Light brown
34	IR36	Awn-less	Awn-less	Absent	Light brown
35	Nipponbare	Awn-letted	Brown	Slight Lodging	Light brown
36	Azucena	Awn-less	Awn-less	Heavy Lodging	White
37	Kasalath	Awn-letted	Straw	Slight Lodging	Brown
38	TN1	Awn-less	Awn-less	Slight Lodging	Light brown
39	Basmati-370	Awn-letted	White	Absent	Light brown
40	Dehradun-Basmati1	Awn-less	Awn-less	Slight Lodging	Brown
41	Dehradun-Basmati2	Awn-less	Awn-less	Slight Lodging	Light brown
42	Basmati-217	Awn-letted	White	Slight Lodging	Light brown
43	Punjab-Basmati	Awn-letted	White	Absent	Light brown
44	Pusa-Basmati	Awn-letted	Straw	Absent	Light brown
45	Ranbir-Basmati	Awn-letted	Straw	Slight Lodging	Light brown
46	PK386	Awn-less	Awn-less	Slight Lodging	Brown
47	Pusa-1121	Awned	White	Absent	Light brown
48	PAU-201	Awn-less	Awn-less	Absent	Light brown
49	Mutant-370	Awn-letted	White	Absent	White
50	Mushkan-Rice	Awn-letted	Brown	Absent	Red
51	Purple-Marker	Awn-letted	Gold	Slight Lodging	Speckled brown
52	Basmati-370b	Awn-letted	White	Absent	Light brown
53	Dehraduni	Awn-letted	Gold	Slight Lodging	Red
54	Dehradune	Awn-less	Awn-less	Slight Lodging	Light brown
55	Dehradun-Basmati3	Awn-less	Awn-less	Slight Lodging	Speckled brown
56	Early-Basmati	Awn-letted	White	Slight Lodging	Light brown
57	Karnal-Basmati	Awned	Brown	Slight Lodging	Brown
58	Type-3	Awn-less	Awn-less	Slight Lodging	Light brown
59	ARC10025	Awn-less	Awn-less	Slight Lodging	Light brown
60	Lashmi-Digha	Awn-less	Awn-less	Slight Lodging	White
61	Bhaturi	Awn-less	Awn-less	Heavy Lodging	Blackish Brown
62	Pank-Iraj	Awn-less	Awn-less	Slight Lodging	Speckled brown
63	Aus-133	Awn-less	Awn-less	Slight Lodging	Light brown

64	Aus-176	Awn-letted	Straw	Slight Lodging	Light brown
65	Aus-190	Awn-less	Awn-less	Slight Lodging	White
66	Aus-346	Awn-less	Awn-less	Slight Lodging	Blackish brown
67	Korchampuri	Awn-less	Awn-less	Heavy Lodging	Speckled brown
68	Naroi	Awn-less	Awn-less	Slight Lodging	Speckled brown
69	Saita	Awn-less	Awn-less	Slight Lodging	Blackish Brown
70	Balla-Bokri	Awn-less	Awn-less	Slight Lodging	Light brown
71	Baturi	Awn-less	Awn-less	Slight Lodging	Blackish Brown
72	IR6	Awn-less	Awn-less	Absent	Light brown
73	JP5	Awn-less	Awn-less	Slight Lodging	Light brown
74	Super-Basmati	Awn-less	Awn-less	Absent	Light brown

Table A3. *Euclidean distances among pairs of genotypes*

No.	Cultivars	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Basmati-370	0.0															
2	Sathra	5.4	0.0														
3	Mahlar-346	6.6	6.7	0.0													
4	Palman-Sufaid	5.4	6.1	5.0	0.0												
5	Basmati-C622	5.2	5.6	6.5	5.5	0.0											
6	Basmati-Pak	6.3	6.7	7.2	7.3	5.9	0.0										
7	Basmati-198	5.3	5.4	6.7	5.4	3.6	5.5	0.0									
8	PK177	7.5	7.2	8.6	7.7	6.9	7.5	6.9	0.0								
9	KS282	6.6	6.6	8.0	7.3	6.6	6.7	6.5	3.7	0.0							
10	Basmati-2000	7.4	6.8	8.4	7.1	6.4	6.1	4.5	5.9	5.7	0.0						
11	KSK133	6.8	6.4	7.6	7.9	7.5	6.7	7.2	4.6	4.1	6.5	0.0					
12	Shaheen-Basmati	4.2	5.7	5.5	5.8	5.9	4.7	5.4	5.8	5.5	6.3	4.7	0.0				
13	Kashmir-Basmati	4.6	6.6	6.7	5.7	5.1	6.8	4.4	6.5	5.6	6.1	6.5	5.1	0.0			
14	Pakhal	5.6	4.7	6.6	5.8	6.4	6.6	5.9	6.2	6.0	6.2	5.6	5.0	5.0	0.0		
15	Jajai-77	5.2	4.7	6.3	5.8	6.7	6.6	6.1	6.9	6.2	7.0	6.1	4.7	5.3	2.9	0.0	
16	Kangni-27	5.4	5.7	6.5	6.3	4.4	5.8	5.3	6.6	5.6	7.0	6.6	5.3	4.7	5.1	5.4	0.0
17	KangnixTorh	6.0	5.3	7.6	7.4	7.1	7.8	6.5	7.3	7.2	7.8	6.9	5.6	5.4	3.5	3.2	5.8
18	Sugdasi-Sadagulab	5.4	6.1	6.4	4.5	3.4	5.4	4.7	6.2	5.6	6.1	6.6	5.4	5.3	6.1	6.3	4.9
19	Sonehri-Sugdasi	5.1	5.2	7.2	6.8	6.2	5.8	5.8	5.6	4.3	5.8	4.7	4.1	5.9	5.0	5.2	5.3
20	Sugdasi-Ratria	6.5	5.4	5.9	7.0	6.6	7.0	6.6	7.1	6.1	7.3	4.9	5.5	5.3	4.4	5.1	5.9
21	Dokri-Basmati	4.1	4.2	6.3	6.1	5.1	6.0	5.0	5.5	4.7	6.2	5.4	3.9	4.4	4.4	4.5	4.2
22	Kharai-Ganja	6.0	5.4	7.5	7.0	6.4	7.2	6.2	3.7	3.6	5.7	3.1	4.9	5.7	4.4	5.2	5.7
23	IR6	6.1	5.0	7.5	7.0	6.4	6.3	6.3	5.4	3.9	5.4	3.9	5.4	6.3	4.6	5.2	5.5
24	DR82	5.9	5.9	7.5	7.5	6.8	7.3	6.6	6.2	4.2	6.1	5.2	5.9	5.9	5.4	6.0	5.6
25	DR83	5.7	6.2	7.4	6.9	6.8	7.1	7.0	6.7	5.6	7.3	4.9	5.6	5.5	5.2	6.0	6.4
26	Lateefy	4.0	4.3	6.9	6.8	5.9	6.4	5.1	6.5	5.4	5.9	5.0	4.3	4.4	4.1	4.3	5.2
27	IR9	5.7	5.5	7.6	6.3	6.2	6.2	4.6	5.2	4.5	3.9	4.4	5.1	5.1	4.6	5.2	6.1
28	DR92	5.1	5.0	7.4	6.5	5.5	6.5	4.8	6.2	5.2	5.3	5.4	5.6	3.8	3.6	4.4	5.0
29	Kanwal-95	7.5	5.8	7.8	8.5	7.0	7.0	6.7	7.8	7.0	6.3	6.2	7.3	7.1	5.9	7.3	7.1
30	Shakar	5.1	5.6	7.5	7.1	6.7	6.3	6.5	5.4	3.6	6.2	4.1	4.8	5.6	4.7	4.7	5.1
31	Shua-92	5.3	6.2	7.6	7.0	6.4	6.6	5.8	5.5	5.3	6.1	4.3	5.0	5.3	4.8	5.4	5.9
32	Khushboo-95	5.2	5.9	7.2	7.2	7.1	6.6	6.9	7.9	6.5	8.1	5.9	5.1	6.1	5.2	5.0	6.0
33	Shadab	4.4	5.7	7.7	6.6	6.2	6.6	5.5	5.3	4.6	6.1	4.4	4.6	4.9	5.2	5.0	5.6
34	IR36	6.5	5.7	7.4	7.6	6.9	7.3	6.5	4.9	3.9	5.9	4.5	5.5	6.0	4.9	5.5	5.7
35	Nipponbare	7.9	7.6	8.1	8.1	7.6	6.6	7.1	7.8	6.0	7.1	8.0	6.9	7.6	7.1	7.0	6.0
36	Azucena	8.8	7.9	9.0	9.8	9.0	6.6	8.4	8.7	9.0	8.7	6.6	6.6	8.8	6.7	6.6	8.4
37	Kasalath	5.8	5.5	5.8	6.3	5.5	7.2	6.4	8.4	7.5	8.4	8.3	6.2	5.7	4.8	4.9	4.3
38	TN1	7.1	5.5	8.3	8.2	6.8	8.1	7.3	6.5	7.0	7.7	6.9	6.6	8.0	5.4	5.8	6.3
39	Basmati-370	4.3	5.3	6.5	6.3	5.7	6.1	5.4	6.7	6.2	5.8	6.0	4.1	5.0	4.6	5.4	5.9
40	Dehradun-Basmati1	5.9	5.0	6.2	7.4	7.5	6.7	7.2	8.4	7.5	7.9	7.2	5.3	7.3	5.7	5.5	6.2

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

41	Dehradun-Basmati2	5.9	5.9	6.9	7.7	6.8	6.8	7.0	8.4	7.0	7.6	6.9	6.5	6.3	5.2	5.9	5.8
42	Basmati-217	5.6	6.5	6.9	7.5	7.3	5.8	7.2	9.1	7.7	7.6	8.1	5.9	7.1	5.8	5.7	6.1
43	Punjab-Basmati	5.1	6.9	7.1	7.1	6.4	5.8	6.1	6.5	5.6	5.8	6.1	5.0	5.4	5.6	6.3	5.4
44	Pusa-Basmati	4.3	6.3	7.4	6.8	6.1	5.9	5.6	6.7	5.9	7.3	6.3	4.4	5.7	6.3	5.5	5.3
45	Ranbir-Basmati	4.9	5.6	5.2	5.7	5.2	5.2	4.3	7.2	6.0	6.1	5.8	4.1	3.8	5.4	5.4	5.1
46	PK386	5.1	5.3	6.8	7.1	6.7	6.1	6.0	7.0	5.9	6.6	5.6	5.0	5.8	5.2	4.9	5.2
47	Pusa-1121	4.6	5.8	7.2	7.0	5.6	5.2	5.6	6.1	4.7	6.1	5.5	4.0	5.4	5.6	5.4	5.2
48	PAU-201	6.4	6.0	7.8	8.0	7.2	7.7	7.0	4.9	5.9	6.9	5.2	5.3	6.9	5.1	5.7	6.2
49	Mutant-370	5.4	6.5	7.4	7.4	6.7	5.2	5.7	6.0	4.2	5.2	5.1	4.3	5.4	5.5	5.3	5.5
50	Mushkan-Rice	6.1	6.4	6.4	6.6	6.2	6.3	6.4	7.1	6.2	7.6	6.6	5.0	5.1	4.7	5.4	4.1
51	Purple-Marker	7.6	6.5	7.4	7.7	6.4	6.4	6.3	4.6	5.6	5.7	5.9	5.3	6.9	5.6	6.4	5.4
52	Basmati-370b	4.5	6.3	6.6	6.8	6.9	5.7	6.5	7.8	6.9	7.7	7.2	4.4	6.1	5.3	4.5	5.8
53	Dehraduni	5.8	6.1	5.6	6.3	5.6	5.2	5.9	7.5	7.1	8.1	6.5	4.9	5.8	5.5	5.9	4.8
54	Dehradune	7.8	5.9	8.4	8.9	6.7	8.7	7.1	6.7	7.3	7.8	7.1	7.3	7.0	5.3	6.1	6.3
55	Dehradun-Basmati3	8.4	6.4	8.6	9.9	8.1	7.8	7.4	7.9	7.9	7.0	7.2	7.1	8.1	6.1	6.9	7.3
56	Early-Basmati	5.8	6.0	6.6	6.5	5.2	6.7	4.5	6.9	5.3	6.2	6.4	5.7	3.3	5.4	4.9	5.0
57	Karnal-Basmati	6.2	7.3	8.2	7.0	5.8	4.5	4.7	7.4	6.3	5.1	7.5	5.7	5.8	6.7	7.3	5.8
58	Type-3	6.3	5.0	5.2	7.3	7.2	7.3	7.0	8.6	7.7	8.0	6.6	5.4	6.8	5.6	5.6	6.8
59	ARC10025	9.0	7.3	8.1	9.9	8.2	9.2	8.9	8.9	9.0	9.7	8.7	7.7	8.7	7.2	7.6	7.1
60	Lashmi-Digha	7.1	7.0	7.3	6.7	7.3	7.3	6.7	7.7	7.5	7.6	7.2	5.9	6.2	5.1	5.2	7.0
61	Bhaturi	8.3	5.4	8.2	7.2	7.9	9.2	7.6	8.2	8.2	9.0	8.4	7.9	7.9	6.0	6.0	7.2
62	Pank-Iraj	9.4	8.3	9.1	9.8	9.8	10.5	9.6	9.8	10.0	10.3	9.4	9.0	9.1	8.3	8.7	9.7
63	Aus-133	7.7	6.8	7.8	8.2	7.4	8.0	7.0	7.4	7.8	7.6	7.2	6.7	6.7	5.4	6.0	7.3
64	Aus-176	6.7	6.1	6.5	6.7	6.1	7.3	6.4	7.0	7.5	7.7	7.9	5.8	6.1	4.3	4.6	5.5
65	Aus-190	6.6	5.9	5.9	6.5	6.4	6.8	5.8	6.3	6.3	6.7	6.3	5.2	5.2	3.9	4.0	5.3
66	Aus-346	10.2	8.1	9.1	10.4	10.1	9.1	9.8	9.0	9.1	9.4	7.7	8.1	9.1	6.5	7.5	8.3
67	Korchampuri	7.7	5.9	7.3	7.3	7.0	8.1	7.1	7.0	7.7	8.3	6.9	6.6	7.2	5.3	5.3	6.8
68	Naroi	9.1	7.2	8.2	8.8	8.4	8.5	7.7	6.4	7.3	7.7	6.5	7.0	7.3	5.5	6.3	7.8
69	Saita	9.0	6.9	8.7	7.3	8.3	9.9	7.7	7.2	7.6	7.7	7.8	8.2	7.1	5.5	7.1	7.9
70	Balla-Bokri	6.9	5.4	7.7	7.2	6.5	7.8	6.1	5.6	6.4	6.7	6.1	6.3	5.9	3.9	5.0	6.2
71	Baturi	9.1	7.3	8.4	8.3	8.7	9.3	8.5	8.4	8.0	8.9	8.3	8.6	7.6	5.6	7.0	7.5
C1	IR6	7.6	7.0	9.0	8.3	7.7	7.7	7.7	6.4	7.1	8.3	6.5	6.8	7.6	5.8	6.5	7.6
C2	JP5	8.3	6.9	8.0	8.4	7.7	8.4	8.0	6.4	7.5	8.5	6.9	7.1	7.7	4.7	5.6	6.8
C3	Super-Basmati	5.5	6.8	9.2	7.5	7.4	6.8	6.0	6.8	5.5	5.4	6.0	6.0	6.3	6.8	7.0	7.6

Table A3. *Continuation*

No.	Cultivars	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
17	KangnixTorh	0.0															
18	Sugdasi-Sadagulab	7.7	0.0														
19	Sonehri-Sugdasi	6.0	5.5	0.0													
20	Sugdasi-Ratria	5.6	6.5	6.2	0.0												
21	Dokri-Basmati	4.4	5.6	3.9	5.3	0.0											
22	Kharai-Ganja	5.7	5.9	3.6	5.2	4.3	0.0										
23	IR6	6.5	5.6	3.3	5.2	5.0	2.8	0.0									
24	DR82	6.6	6.9	4.0	5.7	4.4	3.8	3.2	0.0								
25	DR83	6.7	6.4	5.8	3.9	5.7	5.0	4.7	5.1	0.0							
26	Lateefy	4.3	6.4	4.0	4.5	3.2	4.0	4.2	4.0	4.7	0.0						
27	IR9	6.2	5.6	4.0	5.8	5.0	3.5	3.3	4.3	5.2	4.1	0.0					
28	DR92	4.9	5.6	5.1	4.3	4.4	4.3	4.0	4.4	4.3	3.3	3.4	0.0				
29	Kanwal-95	7.7	7.1	6.6	5.0	6.2	5.9	5.1	5.7	6.1	5.2	5.8	5.0	0.0			
30	Shakar	5.9	6.2	3.6	5.7	4.1	3.2	2.7	2.9	5.0	3.7	3.8	4.1	6.3	0.0		
31	Shua-92	5.8	6.2	4.3	5.9	5.0	3.4	4.0	4.7	5.2	4.0	3.1	4.3	6.3	3.4	0.0	
32	Khushboo-95	5.3	7.1	5.6	5.7	4.9	5.9	5.5	5.4	5.2	4.8	5.6	5.2	7.4	4.4	4.8	0.0
33	Shadab	5.9	5.9	4.3	6.1	4.6	3.6	4.1	4.8	5.2	3.9	3.2	4.1	7.1	3.0	2.5	5.0

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

34	IR36	6.0	6.9	3.6	5.5	4.3	2.9	3.3	2.6	5.3	4.2	3.9	4.5	6.0	3.4	4.3	6.0
35	Nipponbare	8.1	7.4	5.7	8.2	6.2	7.3	6.3	5.5	7.9	7.2	6.8	7.1	8.4	6.2	7.7	7.2
36	Azucena	7.1	8.7	8.2	7.0	8.1	7.8	7.7	9.3	8.1	7.6	7.5	7.4	8.4	7.8	7.3	6.8
37	Kasalath	4.8	6.6	6.5	5.9	4.6	7.0	6.8	6.2	6.7	5.5	7.4	5.7	7.3	6.4	7.1	5.7
38	TN1	5.8	7.6	5.6	7.3	5.6	5.0	5.5	5.7	7.2	5.8	6.2	6.2	7.6	5.7	5.9	6.6
39	Basmati-370	5.5	5.8	4.0	5.5	4.1	4.8	5.0	5.1	5.5	3.2	5.0	4.8	5.4	5.2	5.0	6.0
40	Dehradun-Basmati1	6.2	8.2	6.1	6.1	5.1	6.8	6.3	5.8	6.6	5.1	7.0	6.4	7.3	5.8	7.1	6.1
41	Dehradun-Basmati2	6.6	7.2	5.9	5.3	5.6	6.1	5.1	4.8	5.8	4.6	6.2	4.7	4.7	5.0	5.6	5.7
42	Basmati-217	6.7	7.5	6.0	7.2	5.5	7.4	6.3	5.9	7.4	5.3	7.2	6.5	6.8	5.6	6.9	5.8
43	Punjab-Basmati	7.1	6.4	4.4	6.8	5.0	5.2	4.9	4.2	6.0	4.6	4.9	5.2	6.4	4.0	4.4	6.2
44	Pusa-Basmati	6.5	6.0	4.1	7.5	4.9	5.7	5.8	6.0	7.0	5.2	5.1	6.0	8.6	4.8	4.6	5.9
45	Ranbir-Basmati	6.2	5.3	5.3	4.3	4.7	6.0	5.8	5.9	4.9	4.5	5.0	4.5	6.4	5.9	5.8	5.8
46	PK386	5.7	6.9	5.2	6.3	4.3	5.3	5.1	5.1	6.8	4.1	4.9	5.0	6.6	3.8	4.4	5.2
47	Pusa-1121	6.2	5.1	2.4	6.4	4.0	4.8	4.6	5.2	6.4	4.4	5.0	5.3	7.0	4.5	5.1	6.1
48	PAU-201	5.9	7.3	4.6	6.8	5.0	3.6	5.0	5.3	6.9	5.1	5.2	5.6	7.1	4.8	4.6	6.9
49	Mutant-370	6.3	6.2	3.0	6.5	4.4	4.5	4.0	3.9	6.3	4.1	3.9	4.9	6.5	3.2	4.2	5.5
50	Mushkan-Rice	5.3	5.9	5.4	5.6	4.4	6.0	6.1	6.3	6.3	5.3	6.6	5.8	6.8	5.9	6.2	5.8
51	Purple-Marker	6.6	6.4	5.1	7.2	5.1	4.8	5.7	6.3	8.0	6.2	6.0	6.5	7.0	5.9	6.2	7.9
52	Basmati-370b	5.3	7.0	5.0	7.2	4.6	6.4	6.3	6.0	7.2	4.9	6.2	6.2	7.9	4.9	5.3	4.8
53	Dehraduni	6.3	5.7	6.0	5.6	5.3	6.6	6.6	7.0	6.2	6.2	6.5	6.1	7.3	6.3	5.7	5.1
54	Dehradune	4.9	7.9	7.1	6.0	5.5	5.5	6.6	6.6	7.3	5.7	6.9	5.4	6.4	6.8	6.7	7.3
55	Dehradun-Basmati3	6.2	9.0	6.2	7.1	6.2	6.0	6.3	6.4	8.4	5.5	6.7	6.5	5.9	6.7	6.5	7.7
56	Early-Basmati	5.1	5.7	5.9	5.1	4.4	5.8	5.9	5.7	6.3	4.6	5.1	3.9	6.7	5.5	5.7	5.7
57	Karnal-Basmati	7.9	5.4	5.1	8.1	5.7	7.0	6.4	6.6	7.6	6.4	5.4	6.1	7.5	6.4	6.3	7.0
58	Type-3	5.8	7.7	6.5	4.2	5.2	6.4	6.4	6.2	6.0	4.5	7.1	6.3	5.8	6.5	7.0	5.9
59	ARC10025	6.8	9.4	8.6	6.9	7.1	7.8	8.3	8.1	8.3	7.3	9.4	7.8	7.9	8.4	9.1	8.6
60	Lashmi-Digha	5.7	7.1	7.5	5.7	6.3	7.0	7.2	7.5	5.8	6.4	6.6	5.7	7.7	7.1	7.1	5.8
61	Bhaturi	5.7	8.2	8.0	7.3	6.3	7.6	8.0	8.4	8.2	7.5	7.6	7.1	9.1	8.0	8.1	7.2
62	Pank-Iraj	8.4	10.3	10.2	7.9	8.0	9.3	9.9	9.8	8.7	8.3	9.5	8.7	8.3	9.9	9.7	9.8
63	Aus-133	5.2	8.2	8.0	5.9	6.1	6.7	7.4	7.3	6.5	6.2	6.8	5.6	7.1	7.2	6.9	6.2
64	Aus-176	4.3	6.8	6.7	6.3	5.1	6.4	7.1	7.2	7.4	6.0	7.1	6.0	7.6	7.0	7.0	6.9
65	Aus-190	4.3	6.7	6.3	5.1	4.8	5.4	6.0	6.1	6.2	5.0	5.7	5.1	6.5	5.7	5.7	6.2
66	Aus-346	6.5	10.1	8.6	7.2	7.6	7.9	8.4	9.0	9.2	8.0	8.8	8.2	8.1	8.5	8.6	8.1
67	Korchampuri	5.4	7.3	7.9	5.8	6.2	6.6	7.3	8.0	6.8	6.9	6.9	6.1	8.1	7.3	7.1	6.6
68	Naroi	5.6	8.6	8.1	5.6	6.4	6.5	7.6	7.9	7.3	7.0	7.0	6.5	7.5	7.8	7.6	7.6
69	Saita	6.4	8.2	8.0	6.9	6.7	6.8	7.7	7.8	7.5	7.5	6.9	6.5	8.2	8.1	7.8	7.9
70	Balla-Bokri	4.8	6.9	6.2	5.3	5.1	4.8	5.7	6.1	5.6	5.2	5.1	4.4	6.3	6.1	5.5	6.7
71	Baturi	6.5	8.9	8.2	6.8	6.8	7.6	7.7	7.4	7.5	7.7	7.6	6.8	7.7	7.7	7.6	6.8
C1	IR6	6.6	7.8	6.8	7.0	6.5	5.9	6.4	7.2	6.0	6.5	6.2	6.7	7.5	6.4	5.4	6.3
C2	JP5	5.3	8.1	7.2	6.5	6.2	5.7	6.7	7.1	7.5	6.8	6.9	6.5	7.5	6.6	6.1	6.8
C3	Super-Basmati	7.9	7.0	5.2	7.7	5.9	5.5	5.0	5.0	6.0	5.0	3.8	5.3	7.1	4.5	4.8	6.1

***Table A3.** Continuation*

No.	Cultivars	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
33	Shadab	0.0															
34	IR36	4.5	0.0														
35	Nipponbare	7.7	5.7	0.0													
36	Azucena	7.7	8.7	10.1	0.0												
37	Kasalath	7.3	6.5	6.5	9.0	0.0											
38	TN1	6.2	5.0	7.2	8.0	6.1	0.0										
39	Basmati-370	5.5	5.3	7.3	8.3	5.6	6.4	0.0									
40	Dehradun-Basmati1	6.6	5.8	7.4	8.3	5.5	6.5	6.0	0.0								
41	Dehradun-Basmati2	6.2	5.5	7.6	8.7	5.3	7.1	5.1	5.3	0.0							
42	Basmati-217	7.2	6.9	6.4	8.7	5.1	7.3	5.1	5.1	4.7	0.0						

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

43	Punjab-Basmati	4.7	4.6	6.6	9.1	6.5	6.9	4.5	5.7	4.5	5.0	0.0					
44	Pusa-Basmati	3.7	5.6	6.9	8.5	7.1	6.8	6.0	6.6	6.9	7.0	5.0	0.0				
45	Ranbir-Basmati	5.5	5.6	6.9	7.7	5.9	7.8	5.0	5.8	6.0	6.8	5.7	5.3	0.0			
46	PK386	3.9	5.3	7.4	7.5	6.4	6.5	5.9	5.1	5.3	5.6	4.6	4.7	5.8	0.0		
47	Pusa-1121	4.8	5.0	6.5	8.3	6.5	6.8	4.1	6.5	6.1	6.0	4.7	4.0	5.0	5.5	0.0	
48	PAU-201	4.8	3.8	7.8	8.0	7.1	4.1	5.5	6.1	6.4	7.5	5.3	5.5	6.9	5.4	5.5	0.0
49	Mutant-370	4.3	4.0	5.3	8.0	6.8	6.7	4.6	6.3	5.5	5.2	3.5	4.3	5.3	4.4	3.2	5.3
50	Mushkan-Rice	6.7	6.3	6.3	8.3	4.5	7.3	4.8	7.0	6.1	5.8	6.1	6.7	5.5	6.3	5.5	6.9
51	Purple-Marker	6.5	5.3	6.7	8.0	6.8	5.6	5.6	7.0	7.3	7.2	5.8	6.7	7.0	6.2	5.7	4.4
52	Basmati-370b	5.5	6.1	6.6	8.0	5.2	6.7	4.9	5.2	5.3	3.9	4.5	4.5	6.1	4.7	4.8	5.9
53	Dehraduni	6.1	6.6	7.5	7.3	5.4	7.5	6.2	6.3	5.9	6.9	6.1	5.5	4.7	6.1	6.0	6.7
54	Dehradune	7.1	5.9	8.7	7.9	5.8	4.7	6.4	7.2	6.6	8.1	7.7	8.3	7.4	7.0	7.5	5.2
55	Dehradun-Basmati3	7.4	5.7	8.3	8.0	7.1	6.1	5.8	6.5	5.8	7.0	6.5	7.9	7.7	6.2	6.7	5.2
56	Early-Basmati	5.3	5.8	6.9	8.2	5.5	7.6	5.9	7.2	6.3	7.1	6.5	6.0	4.2	5.3	5.4	7.2
57	Karnal-Basmati	6.5	6.9	5.7	9.2	7.3	8.4	5.6	8.1	7.3	6.5	5.3	5.7	5.6	6.7	4.9	7.8
58	Type-3	7.3	6.5	8.3	7.6	5.5	7.0	5.0	4.9	5.7	5.6	7.2	8.0	5.6	6.4	6.8	7.3
59	ARC10025	9.3	7.6	9.1	8.8	6.0	6.5	7.5	6.5	7.4	8.2	8.7	9.7	8.1	8.3	8.9	7.1
60	Lashmi-Digha	7.4	7.4	7.4	6.8	6.2	7.2	6.5	7.8	7.9	7.4	8.2	8.3	6.1	8.0	8.0	8.0
61	Bhaturi	7.8	7.6	8.8	8.9	6.6	7.0	8.6	7.9	9.2	9.4	9.7	8.3	7.6	7.4	8.6	8.0
62	Pank-Iraj	9.9	9.2	10.6	10.3	8.8	9.3	8.7	9.2	9.9	10.0	10.5	10.7	8.5	9.3	10.5	9.5
63	Aus-133	7.4	6.8	8.4	6.8	6.1	6.2	6.7	7.2	7.4	7.8	7.9	8.7	6.7	7.3	8.3	6.9
64	Aus-176	7.4	6.5	7.2	7.9	3.8	5.4	5.6	6.5	6.7	6.5	7.1	7.4	6.4	7.1	6.7	5.9
65	Aus-190	6.1	5.4	6.5	7.2	4.8	5.9	5.5	6.3	6.1	6.2	6.4	6.8	5.5	5.8	6.7	5.8
66	Aus-346	9.3	8.3	10.0	7.3	8.0	8.6	8.3	8.2	8.4	8.9	9.3	10.2	8.8	7.7	9.0	8.0
67	Korchampuri	7.0	7.1	8.9	6.1	6.5	5.7	7.8	7.3	8.4	8.9	8.9	8.1	6.7	7.2	8.3	6.7
68	Naroi	8.0	6.7	8.7	6.8	7.4	7.1	7.6	8.1	8.6	9.2	9.0	9.3	7.1	8.0	8.5	7.0
69	Saita	8.1	7.1	9.0	9.9	7.4	7.9	7.8	9.0	9.0	9.9	9.2	9.6	7.6	8.6	8.8	8.0
70	Balla-Bokri	5.9	4.9	7.7	7.4	6.1	4.7	5.9	7.1	7.0	8.1	7.1	7.1	5.9	6.8	6.9	5.0
71	Baturi	8.4	6.9	8.0	9.8	6.2	8.0	8.2	8.2	7.3	8.6	8.4	9.3	7.8	7.9	8.9	8.2
C1	IR6	6.4	6.3	8.1	7.8	7.4	6.1	6.8	8.4	7.5	8.2	7.5	7.5	7.7	7.8	7.6	6.6
C2	JP5	7.1	6.0	8.2	7.1	6.1	4.6	7.3	7.7	7.2	7.9	7.7	8.0	8.0	7.2	7.9	5.3
C3	Super-Basmati	4.1	5.7	7.6	9.4	8.7	8.0	5.8	7.5	6.8	7.2	5.1	5.8	6.5	5.8	5.8	6.9

Table A3. *Continuation*

No.	Cultivars	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
49	Mutant-370	0.0															
50	Mushkan-Rice	5.7	0.0														
51	Purple-Marker	5.4	5.6	0.0													
52	Basmati-370b	4.2	5.6	6.5	0.0												
53	Dehraduni	6.4	5.0	6.7	5.3	0.0											
54	Dehradune	7.5	6.8	5.7	7.6	7.4	0.0										
55	Dehradun-Basmati3	6.1	7.1	5.2	6.7	7.6	5.0	0.0									
56	Early-Basmati	5.1	5.5	6.9	6.2	6.1	6.3	7.3	0.0								
57	Karnal-Basmati	4.6	5.8	6.4	6.1	6.2	9.0	8.0	6.2	0.0							
58	Type-3	6.9	6.1	7.4	6.4	6.7	6.6	6.7	6.5	8.6	0.0						
59	ARC10025	8.9	7.2	6.7	8.4	8.1	4.7	6.3	8.2	10.3	6.5	0.0					
60	Lashmi-Digha	7.5	5.9	7.7	7.2	6.7	6.9	8.9	6.3	7.6	6.4	7.9	0.0				
61	Bhaturi	9.0	7.4	8.2	8.5	7.3	7.0	9.0	6.8	9.3	7.9	8.7	7.1	0.0			
62	Pank-Iraj	10.3	8.5	9.7	10.1	9.7	8.3	10.0	8.8	11.1	7.8	8.6	7.7	7.9	0.0		
63	Aus-133	7.6	6.8	7.0	7.4	7.0	4.6	6.9	6.1	8.5	6.5	5.9	4.2	6.8	6.9	0.0	
64	Aus-176	6.9	5.0	5.2	5.7	6.0	4.5	6.5	6.0	7.6	6.4	5.3	5.2	6.6	8.0	4.7	0.0
65	Aus-190	5.9	4.6	5.2	5.5	5.8	5.1	6.3	5.0	7.3	5.6	6.2	4.4	6.5	6.9	4.3	3.4
66	Aus-346	8.7	6.8	7.0	8.7	7.9	6.9	6.4	8.3	9.8	7.7	7.3	8.4	7.6	9.4	6.9	7.3
67	Korchampuri	8.3	7.3	7.1	8.0	6.7	5.2	8.2	6.4	9.2	6.9	6.6	5.0	4.7	7.2	4.1	5.1

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_52535281

68	Naroi	8.1	7.0	6.5	8.5	7.5	5.1	7.3	6.5	9.2	6.9	6.9	5.2	6.4	7.1	3.8	5.5
69	Saita	8.8	7.0	7.7	9.3	7.9	6.9	8.7	7.0	8.7	8.3	9.1	6.7	5.0	8.4	6.3	6.8
70	Balla-Bokri	6.8	6.3	6.0	7.2	6.6	4.1	6.7	5.9	7.9	6.7	6.8	5.1	5.7	6.6	4.2	4.5
71	Baturi	8.3	6.4	8.2	8.1	6.6	7.0	8.1	6.9	8.6	8.1	8.7	7.1	5.7	8.6	6.4	6.7
C1	IR6	7.2	6.7	7.3	6.9	6.4	6.8	7.9	7.8	8.1	7.8	8.8	6.0	7.7	8.5	6.2	6.4
C2	JP5	7.5	6.6	5.9	6.9	6.6	4.3	6.5	7.3	9.1	7.3	6.8	6.3	6.7	8.5	5.2	4.4
C3	Super-Basmati	4.6	8.0	7.9	6.5	7.8	8.9	8.3	6.8	5.8	8.2	10.9	8.1	9.7	11.1	8.5	9.0

Table A3. *Continuation*

No.	Cultivars	65	66	67	68	69	70	71	C1	C2	C3
65	Aus-190	0.0									
66	Aus-346	7.0	0.0								
67	Korchampuri	5.0	7.3	0.0							
68	Naroi	4.6	6.0	4.3	0.0						
69	Saita	6.5	7.2	6.2	5.4	0.0					
70	Balla-Bokri	4.0	7.7	4.0	4.3	5.3	0.0				
71	Baturi	6.1	6.6	7.0	6.2	4.5	6.1	0.0			
C1	IR6	5.4	9.0	6.6	6.7	7.6	5.0	7.0	0.0		
C2	JP5	4.3	7.0	4.9	5.0	7.0	4.1	6.1	4.9	0.0	
C3	Super-Basmati	7.9	10.9	9.3	9.4	9.1	7.8	9.4	7.6	9.3	0.0

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DOI: http://dx.doi.org/10.15666/aeer/2303_52535281