Research Article

Evaluation of Fine Basmati Rice Varieties for Morphology, Yield and Economic Benefits in Gujranwala Cropping Zone

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Abstract | Determination of crop maturation duration, yield and economic benefits of different Basmati rice varieties is imperative for enhancing the output of rice-wheat cropping system. Hence, two-year study was accomplished to find out the differences in growth, crop maturation duration, yield and economic benefits of Basmati rice varieties (Super Basmati, PK-1121 aromatic, Chenab Basmati, Kissan Basmati, Punjab Basmati, Noor Basmati and NIAB Basmati 2016) in Gujranwala rice-wheat cropping zone. Among all varieties, NIAB Basmati 2016 produced the greatest plant height. However, Kissan Basmati and NIAB Basmati 2016 matured earlier while Super Basmati matured at last. The highest productive tillers and grains number per panicle were produced by Super Basmati and Chenab Basmati, respectively; however, maximum 1000-grain weight was produced by Noor Basmati and PK-1121 Aromatic. Among all varieties, the Chenab Basmati was highest yielder while NIAB Basmati 2016 produced the lowest yield. However, Super Basmati gave highest net returns and benefit cost ratio (BCR) due to its high paddy market price, and it was followed by Chenab Basmati. In conclusion, Super Basmati and Chenab Basmati could be adopted in Gujranwala rice-wheat cropping zone to achieve better yield and economic benefits; while Kissan Basmati could be adopted for increasing the cropping intensity and productivity of cropping zone due its earlier maturity and better yield.

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Introduction

Rice (*Oryza sativa* L.) is utilized as an important staple food crop in more than half world and also it is consumed after wheat in Pakistan. Its productivity is affected by various factors including crop management and socio-economic ones. Likewise, selection of a suitable variety in a cropping zone is of major concern to improve production and economic benefits (Alam *et al*., 2008). There exists a great variation in different varieties pertaining to morpho-physiological attributes which greatly add towards yield formation and choice of variety to be sown in a cropping zone (Yang and Hwa, 2008; Hussain *et al*., 2014). Moreover, breeding and hybridization techniques are being utilized for developing new rice varieties having resistance to diseases, insets and environmental effectors (Khush, 2005). Hence, introduction and selection of such varieties in a cropping zone is required to improve the productivity of rice. However, there are various factors that determine the suitability and adaptability of a variety in the cropping zone, among which the important are phenology and crop growth duration, grain yield, produce quality and consumer preference, and economic benefits.

Phenology of rice crop refers to the occurrence of successive growth stages and crop maturation period (Moldenhauer and Slaton, 2001; Zheng *et al*., 2016). Hence, it is important that the occurrence and duration of different growth stages of a variety must match the climatic conditions for optimum growth and yield. The crop growth duration of a variety or crop determine its suitability in a cropping system (Waha *et al*., 2020). For instance, short duration varieties provide a chance to increase the cropping intensity by providing more time for sowing operations leading to double and/or triple cropping (Khush *et al*., 2001; Chen *et al*., 2020). In contrast, long duration varieties are usually high yielding and have better grain quality but the sowing of succeeding crops is delayed due to their late maturity thereby affecting the productivity of cropping system (BalajiNaik *et al*., 2016). The long duration or late maturing varieties require more inputs and/or could have more chances to be prone to adverse climatic conditions especially when sown late (Cheng *et al*., 2013; Chen *et al*., 2020). Furthermore, varieties differ in their resistance to insect and disease attack which is also an important factor in adopting a variety in a cropping zone (Hong-Xing *et al*., 2017).

Different rice varieties differ in the yield potential and yield formation i.e. tillering behavior, grains/panicle and grain size (weight) (Ghoneim *et al*., 2018). Adequate tillering and canopy closure are necessary for weed suppression through shading effect and acquiring optimum yield of rice (Anwar *et al*., 2010; Cheng *et al*., 2013; Mahajan *et al*., 2014). Similarly, optimum grain density is required to produce optimum grain size and yield as trade off relationship exists between different yield components (Ghoneim *et al*., 2018). Likewise, rice varieties could be sown on the basis of produce quality and consumers' preference (Cuevas *et al*., 2016). For example, some consumers use steamed rice (saila rice) while others use non-steamed polished rice of fine Basmati varieties. Hence, produce quality and consumer demand determine the market price and in turn economic benefit which is the most imperative factor in deciding the varietal selection for rice (Hussain *et al*., 2008). Moreover, different varieties differ in input and management requirements which determine the cost of production and ultimately benefit cost ratio (Dash *et al*. 1995; Hussain *et al*., 2008).

Grain yield and economic benefits of rice are determined by different factors. Selection of appropriate variety of rice is imperative for optimum crop growth duration, grain yield and economic benefits of rice-wheat cropping system in a cropping zone. However, information is lacking pertaining to growth and development, yield formation and economic benefits of different rice varieties in rice-wheat cropping system of Gujranwala. Therefore, this two years study was performed with objectives to find out the differences in morphology, crop growth duration, yield and economic benefits of different varieties of rice in the rice-wheat cropping system of Gujranwala.

Materials and Methods

Experimental site and design

The study was accomplished during 2019 and 2020 at Adaptive Research Farm, Gujranwala, Pakistan (32°12′15′N 74°13′48′E, 227 m above sea level). Prior to sowing, soil was analyzed for physico-chemical properties by collecting samples (depth 0-30 cm) and submitting in Soil and Water Testing Laboratory, Gujranwala. Soil texture was found heavy loam with 0.91% organic matter, 7.6 pH, 1.3 mS/cm electrical conductivity (EC), 0.05% total N, 10.5 mg/kg available P and 142 mg/kg available K. The laying out of experiment was performed by using the randomized complete block design (RCBD) and replicating thrice. The area of net plot was maintained at 7.5 m × 10 m. The treatments included different Basmati rice varieties viz. Super Basmati, PK-1121 Aromatic, Chenab Basmati, Kissan Basmati, Punjab Basmati, Noor Basmati and NIAB Basmati 2016. The meteorological data prevailing during the growing season is presented in Table 1.

Crop husbandry

Nursery of all varieties was sown on June, 14 and 15 during 2019 and 2020, respectively using fungicide (Thiophenate Methyl @ 2 g/kg seed) treated 12.5

kg seed for nursery required for on hectare. Nursery transplantation was carried out manually in puddled soil having water standing (depth 5 cm) on July, 12 and 14, during 2019 and 2020, respectively. The spacing between plants as well as rows was sustained at 22.5 cm. The fertilizers NPK were applied @ 120-88-62 kg/ha. All PK and one-third N fertilizer was used as basal dose. Left over N was applied 30 and 45 days after transplanting (DAT) in equal splits. Zinc sulfate (33%) was applied 10 DAT @ 15 kg ha^{-1}. Irrigations were applied to keep standing water in field up to a depth of 5 cm for 25 days and afterwards the soil was kept just moist. The last irrigation was applied 15 days prior to harvesting. Plant protection was ensured by following local recommendations. Harvesting and threshing of the crop was carried out manually on November, 4 and October, 27 during 2019 and 2020, respectively.

Measurements

Measurement of plant height was performed at maturity using meter rod from soil level to the tip of randomly selected five plants and averaged. Days to maturity were determined by recording the calendar time (days) from transplanting to 100% maturity from randomly selected area in each replication. Productive tillers were counted from selected one m^2 area. Number of grains/ panicle was found out by counting and averaging the grains from four randomly selected plants. Counting and weighing of 1000-grains was performed from each replication to ascertain 1000-grain weight. Paddy yield was recorded by manually threshing and weighing paddy using an electric weight balance from selected area and expressed as t/ha.

Economic analyses

Procedures of CIMMYT (1988) were used to calculate the total cost, net returns and BCR. Prices of all used inputs were summed to calculate the fixed cost. Variable cost was comprised of the harvesting charges which were calculated on yield basis (charges per kg). Total cost was determined as sum of the variable and fixed cost. Net returns were calculated as follows; Net returns = (gross income - total cost). Benefit cost ratio was determined as follows; BCR = (Gross income/total cost).

Statistical analyses

Scatter plot technique was used for determining the normality of data. Afterwards, upon confirmation of data normality, Fisher's analysis of variance (ANOVA) was employed for analyses of data on different observations (Steel *et al*., 1997). Treatments' means were compared by employing least significant difference (LSD) as post-hoc test at 5% probability.

Results and Discussion

The results of this study revealed that different Basmati rice varieties significantly differed in morphological traits, crop growth duration, paddy yield and related traits, and economic benefits.

Plant height and crop growth duration

The different Basmati rice varieties differed significantly in plant height and days to maturity during both years. It was observed that NIAB Basmati 2016 was the tallest among all varieties during both years and it was followed by PK-1121 Aromatic and Super Basmati during 2019 and 2020, respectively. On the other hand, Noor Basmati produced least plant height among all varieties during both years. The earliest maturity was commenced by Kissan Basmati among all varieties and exhibited minimum days to maturity during both years. However, NIAB Basmati 2016 was statistically similar with Kissan Basmati regarding days to maturity during both years. Conversely, the maximum days to maturity were taken by Super Basmati during years (Table 2).

In present study, the plant height of different Basmati rice varieties differed (Table 2) which is attributed to genetic variation among different varieties (Mohammad *et al*., 2002). It has been observed that the varieties which produce longer internodes have higher plant height as compared to those which produce shorter internodes and this phenomenon is controlled by genetic and environmental factors (Mohammad *et al*., 2002; Hussain *et al*., 2014). In current study, variation existed in different varieties pertaining to crop maturity. It was observed that Kissan Basmati matured earlier while Super Basmati matured later than other varieties indicating them the early and late maturing varieties (Table 2) and this variation was associated with their genetic makeup. Similarly, Ashrafuzzaman *et al*. (2009) reported that different varieties of rice took different days to maturity some being early and others being late maturing varieties.

Table 1: *Meteorological conditions during rice growing seasons.*

Month	Total rainfall (mm)		Relative humidity (%)		Temperature (°C)					
					Monthly maximum		Monthly minimum		Daily mean	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
June	96.5	97.6	74.3	75.1	37.5	37.5	25.3	23.9	31.4	30.7
July	240.0	79.6	82.4	80.3	39.3	35.9	25.5	26.5	32.4	31.2
August	138.3	333.3	85.7	89.5	36.1	34.3	27.2	26.5	31.7	30.4
September	52.9	49.2	84.1	85.4	34.9	36.1	24.7	25.0	29.8	30.6
October	28.9	0.0	83.4	82.2	31.5	33.6	17.9	17.7	24.7	25.6
November	17.3	15.5	85.2	84.3	24.6	24.8	13.3	10.8	19.0	17.8

Source: *Meteorological Department, Punjab.*

Table 2: *Growth, days to maturity and yield related attributes of different Basmati rice varieties.*

Varieties	Plant height (cm)		Days to maturity		No. of productive tillers m^{-2}		No. of grains per panicle		1000-grain weight (g)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Super Basmati	118.3 bc	118.7 b	118.3 a	115.3 a	321 a	337 a	109.3 f	106.0 d	21.67 c	22.17 d
PK-1121 Aromatic	120.7 ab	117.0 b	112.7 b	111.3 b	287 b	303 b	132.3 d	123.7 c	24.67 ab	26.67 a
Chenab Basmati	113.0 de	111.7 c	111.0 b	110.0 b	226 d	257 d	177.0 a	181.3 a	23.67 b	24.50 c
Kisan Basmati	110.7 ef	112.7 c	104.0 d	100.3 d	226 d	239 e	152.7 c	158.0 b	25.33 a	25.17 bc
Punjab Basmati	116.0 cd	117.3 b	108.0 c	104.0 c	247 c	259 d	160.0 b	163.7 b	24.00 b	24.33 c
Noor Basmati	108.3 f	109.7 c	105.7 cd	102.7 c	228 d	231 e	158.0 bc	162.3 b	25.33 a	25.83 ab
NIAB Basmati 2016	124.7 a	123.3 a	105.0 d	100.7 d	281 b	277 c	121.3 e	124.3 c	20.67 c	20.50 e
LSD	4.1480	3.0154	2.3720	1.9668	18.078	11.024	5.7121	7.0646	1.1207	1.1511

Means in a column sharing different letters are significantly different at $P < 0.05$

Yield and related attributes

The different Basmati rice varieties significantly differed in different yield related attributes i.e. number of the productive tillers, grains/panicle as well as 1000-grain weight, during both years. Highest number of productive tillers was produced by Super Basmati and it was followed by PK-1121 Aromatic during both years. Maximum grains per panicle were produced by Chenab Basmati and it was followed by Punjab Basmati during both years. The greatest 1000-grain weight was achieved by Kissan and Noor Basmati during 2019 and PK-1121 Aromatic during 2020; however, PK-1121 aromatic and Noor Basmati produced statistically similar 1000-grain weight during 2019 and 2020, respectively (Table 2).

In present study, number of productive tillers, grains/panicle and 1000-grain weight of all Basmati rice varieties differed (Table 2) which might be attributed to their differential genetic behavior (Yang *et al*., 2007; Yang and Hwa, 2008). It was observed that Super Basmati produced higher productive tillers but had smaller sink size as indicated by fewer grains/panicle and lower 1000-grain weight showing trade-off relationship among yield forming traits (Table 2; Wang *et al*., 2014). The smaller sink size of Super Basmati also indicates that there could be greater inter-tiller competition due to ripening of greater number of tillers (Duy *et al*., 2004; Badshah *et al*., 2014). This phenomenon was confirmed by other varieties including Chenab Basmati, Punjab Basmati, Kissan Basmati, Noor Basmati and PK-1121 Aromatic which had less productive tillers but higher grains per panicle and/or 1000-grain weight (Table 2). Previous studies have confirmed that similar genetic variations exit among different varieties of rice pertaining to yield related attributes (Mondal *et al*., 2005; Ashrafuzzaman *et al*., 2009).

The paddy yield of Basmati rice varieties was differed significantly during both years. The highest paddy yield was recorded by Chenab Basmati during both years, and it was followed by PK-1121 Aromatic during 2019 and Punjab Basmati during 2020, respectively (Figure 1). The high yield of Chenab Basmati was associated mainly with higher grains/panicle (Table 2). However, higher yield of PK-1121 Aromatic was due to high number of tillers and 1000-grain weight; whereas, Punjab Basmati exhibited high yield due to greater number of grains/panicle (Table 2). The

Table 3: *Economic efficiency of different rice Basmati varieties.*

Varieties	Average Adjusted paddy yield (t ha^{-1})	Gross income (Rs/ha)	Variable cost (Rs/ha)	Total Cost (Rs/ha)	Net returns (Rs/ha)	Benefit cost ratio
Super Basmati	3.77	240100	26408	132059	108042	1.82
PK-1121 Aromatic	4.61	212664	32288	137939	74726	1.54
Chenab Basmati	5.36	233155	37517	143168	89987	1.63
Kisan Basmati	4.49	207230	31406	137057	70174	1.51
Punjab Basmati	4.87	214473	34062	139713	74760	1.54
Noor Basmati	4.69	204119	32802	138453	65666	1.47
NIAB Basmati 2016	3.61	157990	25242	130893	27097	1.21

Average adjusted paddy yield = 10% less than actual paddy yield averaged over two years (2019 and 2020); Cost and income was estimated by using the prevailing market prices for inputs and paddy, respectively, in Pakistan and averaged over two years (2019 and 2020).

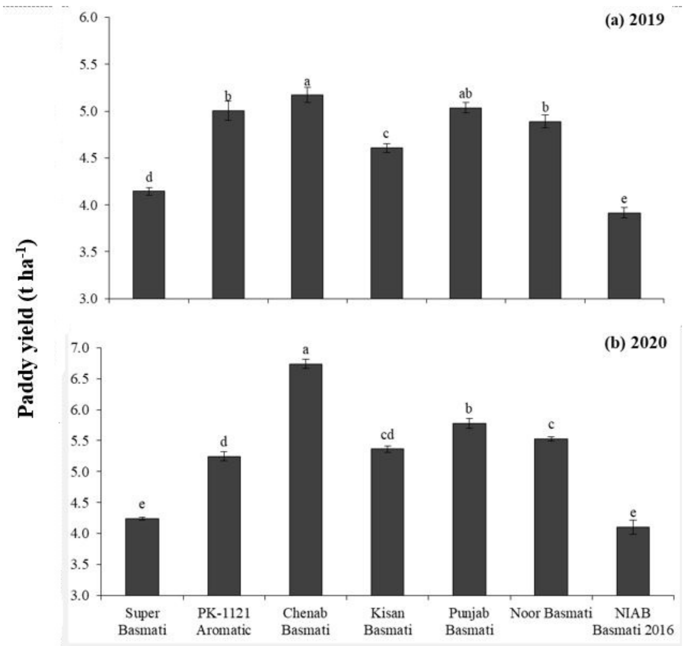

Figure 1: *Paddy yield of different Basmati rice varieties during (a) 2019 and (b) 2020; The bars are means ± S.E (n = 3). The bars sharing different letters are significantly different at P < 0.05.*

variation in paddy yield of Basmati rice varieties due to different yield traits might be attributed to their differential genetic behavior Ashrafuzzaman et al. (2009). Similarly, Hussain et al. (2014) and Uzzaman et al. (2015) stated that various tested rice varieties exhibited differences in yield attributes which was translated in to differential paddy yield of each variety.

Economic benefits

The economic analysis exhibited that maximum gross income, net returns and BCR was attained by Super Basmati followed by Chenab Basmati. However, minimum gross income, net returns and BCR was recorded by NIAB Basmati-2016 (Table 3). The highest net returns and BCR of Super Basmati were associated with high gross income which was in turn due to high paddy market price than the other varieties (Table 3). In contrast, Chenab Basmati had low paddy price which resulted in lower gross income, net returns and BCR as well than Super Basmati (Table 3) in spite of its high paddy yield (Figure 1). However, NIAB Basmati 2016 had low paddy yield as well as price which resulted in lowest gross income, net returns and BCR (Table 3). Likewise, Hussain *et al*. (2008) and Chandra *et al*. (2019) described that different rice varieties had different paddy yield and market price in studied cropping zone which resulted in differential net returns and BCR.

Conclusions and Recommendations

Different rice Basmati varieties significantly differed in growth, crop growth duration, paddy yield and related traits, and economic benefits. In conclusion, Super Basmati and Chenab Basmati could be adopted in Gujranwala rice-wheat cropping zone to achieve better yield and economic benefits; while Kissan Basmati could be adopted for increasing the cropping intensity and productivity of cropping zone due to its earlier maturity and better yield.

Novelty Statement

Determining the crop maturation duration, yield and economic benefits of different Basmati rice varieties could improve output and economic benefits of rice-wheat cropping system. This study was performed to determine the most suitable fine rice Basmati variety with short growing season, better yield and economic benefits to enhance the cropping intensity and productivity of Gujranwala cropping zone.

Author's Contribution

Ali Zohaib: Planned the study, carried out experiment, statistical data analysis and write-up, and did overall

management of article.
Muzzammil Hussain: Provided technical guidance during study.
Iftikhar Ahmad: Supervised study and reviewed the paper.
Mushtaq Ali: Supervised the study.
Tahira Tabassum: Helped in literature review.
Adnan Bashir: Managed crop in the field.

Conflict of interest

The authors have declared no conflict of interest.

References

Alam, M.M., M. Hasanuzzaman and K. Nahar. 2008. Growth pattern of three high yielding rice varieties under different phosphorus levels. Adv. Biol. Res., 3(3-4): 110-116.

Anwar, M.P., A.S. Juraimi, A. Man, A. Puteh, A. Selamat and M. Begum. 2010. Weed suppressive ability of rice (*Oryza sativa* L.) germplasm under aerobic soil conditions. Aust. J. Crop Sci., 4(9): 706-717.

Ashrafuzzaman, M., M.R. Islam, M.R. Ismail, S.M. Shahidullah and M.M. Hanafi. 2009. Evaluation of six aromatic rice varieties for yield and yield contributing characters. Int. J. Agric. Biol., 11(5): 616-620.

Badshah, M.A., T. Naimei, Y. Zou, M. Ibrahim and K. Wang. 2014. Yield and tillering response of super hybrid rice Liangyoupeijiu to tillage and establishment methods. Crop J., 2(1): 79-86. https://doi.org/10.1016/j.cj.2013.11.004

BalajiNaik, B., G. Sreenivas, D.R. Reddy and P.L. Rani. 2016. Tillering Behaviour and yield of different duration rice varieties under different dates of sowing under aerobic culture. Int. J. Curr. Res., 8(5): 30143-30146.

Chandra, S.C., M.A. Ali, M.E. Haque, M.R. Abdullah and A.G. Sarwar. 2019. Cost of production and cost benefit analysis of different rice in Sirajganj district. Asian J. Crop Soil Sci. Plant Nutr., 1(1): 7-14. https://doi.org/10.18801/ajcsp.010119.02

Chen, J., R. Zhang, F. Cao, X. Yin, Y. Zou, M. Huang and F.F. Abou-Elwafa. 2020. Evaluation of late-season short-and long-duration rice cultivars for potential yield under mechanical transplanting conditions. Agronomy, 10(9): 1307. https://doi.org/10.3390/agronomy10091307

Cheng, Y., J. Huang, Z. Han, J. Guo, Y. Zhao, X. Wang, R. Guo. 2013. Cold damage risk assessment of double cropping rice in Hunan, China. J. Integr. Agric., 12(2): 352-363. https://doi.org/10.1016/S2095-3119(13)60235-X

CIMMYT. 1988. From agronomic data to farmers recommendations: An economics training manual. Completely revised edition. Mexico DF.

Cuevas, R.P., V.O. Pede, J. McKinley, O. Velarde and M. Demont. 2016. Rice grain quality and consumer preferences: a case study of two rural towns in the Philippines. PLoS One, 11(3): e0150345. https://doi.org/10.1371/journal.pone.0150345

Dash, J.K., R.P. Singh and R.K. Pandey. 1995. Economic analysis of summer rice production in Baharagora block of Singhbhum district, Bihar. A case study. J. Res. Birsa Agric. Univ., 7(2): 131-135.

Duy, P.Q., M. Hirano, S. Sagawa and E. Kuroda. 2004. Varietal differences in tillering and yield responses of rice plants to nitrogen-free basal dressing accompanied with sparse planting density in the Tohoku region of Japan. Plant Prod. Sci., 7(1): 3-10. https://doi.org/10.1626/pps.7.3

Ghoneim, A.M., E.E. Gewaily and M.M.A. Osman. 2018. Effects of nitrogen levels on growth, yield and nitrogen use efficiency of some newly released Egyptian rice genotypes. Open Agric., 3(1): 310-318. https://doi.org/10.1515/opag-2018-0034

Hong-Xing, X.U., Y. Ya-jun, L.U. Yan-Hui, Z. Xu-song, T. Jun-ce, L. Feng-xiang, F.U. Qiang and L.U. Zhong-xian. 2017. Sustainable management of rice insect pests by non-chemical-insecticide technologies in China. Rice Sci., 24(2): 61-72. https://doi.org/10.1016/j.rsci.2017.01.001

Hussain, A., N.R. Khattak and A.Q. Khan. 2008. Cost benefit analysis of different rice varieties in District Swat. Sarhad J. Agric., 24(4): 745-748.

Hussain, S., T. Fujii, S. McGoey, M. Yamada, M. Ramzan and M. Akmal. 2014. Evaluation of different rice varieties for growth and yield characteristics. J. Anim. Plant Sci., 24(5): 1504-1510.

Khush, G.S., 2001. Green revolution: The way forward. Nat. Rev. Genet., 2(10): 815-822. https://doi.org/10.1038/35093585

Khush, G.S., 2005. What it will take to feed 5.0 billion rice consumers in 2030. Plant Mol. Biol., 59(1): 1-6. https://doi.org/10.1007/s11103-005-2159-5

Mahajan, G., M.S. Ramesha and B.S. Chauhan. 2014. Response of rice genotypes to weed competition in dry direct-seeded rice in India. Sci. World J., 2014: 41589. https://doi.org/10.1155/2014/641589

Mohammad, T., W. Deva and Z. Ahmad. 2002. Genetic variability of different plant and yield characters in rice. Sarhad J. Agric., 18(2): 207-210.

Moldenhauer, K. and N. Slaton. 2001. Rice growth and development. Rice Production Handbook. pp. 7-14.

Mondal, M.M.A., A.F.M. Islam and M.A. Siddique. 2005. Performance of 17 modern transplant Aman cultivar in the northern region of Bangladesh. Bangladesh J. Crop Sci., 16: 23-29.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw Hill Book Co. Inc. New York. pp. 400-428.

Uzzaman, T., R.K. Sikder, M.I. Asif, H. Mehraj and A.J. Uddin. 2015. Growth and yield trial of sixteen rice varieties under system of rice intensification. Sci. Agric., 11(2): 81-89.

Waha, K., J.P. Dietrich, F.T. Portmann, S. Siebert, P.K. Thornton, A. Bondeau and M. Herrero. 2020. Multiple cropping systems of the world and the potential for increasing cropping intensity. Glob. Environ. Change, 64: 102131. https://doi.org/10.1016/j.gloenvcha.2020.102131

Wang, D., S. Chen, Z. Wang, C. Ji, C. Xu, X. Zhang and B.S. Chauhan. 2014. Optimizing hill seeding density for high-yielding hybrid rice in a single rice cropping system in south China. PLoS One, 9(10): e109417. https://doi.org/10.1371/journal.pone.0109417

Yang, W., S. Peng, R.C. Laza, R.M. Visperas and M.L.D. Sese. 2007. Grain yield and yield attributes of new plant type and hybrid rice. Crop Sci., 47(4): 1393-1400. https://doi.org/10.2135/cropsci2006.07.0457

Yang, X.C. and C.M. Hwa. 2008. Genetic modification of plant architecture and variety improvement in rice. Heredity, 101(5): 396-404. https://doi.org/10.1038/hdy.2008.90

Zheng, H., T. Cheng, X. Yao, X. Deng, Y. Tian, W. Cao and Y. Zhu. 2016. Detection of rice phenology through time series analysis of ground-based spectral index data. Field Crops Res., 198: 131-139. https://doi.org/10.1016/j.fcr.2016.08.027