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The Public Sector's Role Towards Sustainable Agricultural Economy and Rural Development: Techno-economic Feasibility Analysis of Hybrid Paddy Production

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ABSTRACT
Rice is the major food crop and a significant source of foreign exchange of Pakistan. In order to meet food demands, high quality varieties of rice, including early and late maturing varieties, as well as hybrid and conventional rice varieties must be developed with the adoptability and suitability of different hybrid rice varieties in local soil. The hybrid varieties revealed supremacy regarding the growth characters over the inbred rice. The study results pretended that the highest plant height was recorded in hybrid variety ennpova-55 (106.5 cm) while inbred IRRI-9 produced the shortest height (65.5 cm) at reproduction stage. Whereas highest number of tillers was observed in Winner-55, Tahafuz-121, and Ashoka (24 m^{-2}) and have highest seedling number and lowest number of tillers were recorded in Komal 21 m^{-2}. Highest plant dry matter per hill was found in Ennova-55 (95.9/cm and lowest observed in IRRI-9 (69.8 cm) as compared to all other rice verities studied in this study. In chlorophyll studies, highest chlorophyll parameter was observed in Ennova-08 and Pukhraj and lowest was observed only in inbred varieties. Shoot and root length showed significant variation among the different rice varieties. The tallest shoot was found in Ennova-55 (82.3 cm) which was statistically identical with Thafuz-121 (78.1 cm), while shortest was found in IRRI-9 (54.1 cm) at harvest. However, the maximum Leaf area index was recorded from Komal (4.50) at the heading stage followed by Ennova-55 (4.20), but significantly lower in Shakar (2.70). Compared with inbred, hybrid rice produced a higher yield with BCR of 12.03. However, further research studies are obligatory to perform for adoptability of hybrid rice locally for sustainable rice production.

Keywords: Hybrid paddy rice, Physiological characteristics, Grain, Biological yield, Economic analysis

1. Introduction

Agriculture is the primary driver for global sustainability and socioeconomic improvement (Aslam et al. 2020) which aim to guarantee food security and economic diversification; therefore, appropriate attention must be taken to ensure the use of optimal crop production technologies. In 2018, agriculture contributed to 24% of Pakistan's GDP, playing a significant role in the country's economy. It is recorded that more than 40% of Pakistan's total land area is under cultivation over the last sixty years of cultivation (FAO 2017).

The most significant cereal crop in the world is rice (*Oryza sativa L.*), which is the main source of nutrition for about half of the world's population, especially in Asia, where around 90% of the world's rice is grown and consumed (Noora et al. 2020). For 2.7 billion people, rice provides 50–60% of their daily caloric intake (Metwally et al. 2010; Chukwu et al. 2019). In terms of acreage cultivated, rice is the second-largest crop in the world, accounting for around 11% of all agricultural land (Amanullah 2016). It is the most significant grain crop in the world and an annual semi-aquatic plant. According to estimates, in order to feed the anticipated increase in global population, farmers must produce 60% (Fageria 2010) and 21% (Uzzaman et al. 2015) more rice than they do now. High-yielding types are being developed more frequently recently for uses other than human consumption, like rice flour and animal feed (Yoshinaga et al. 2018). Breeders' top priorities now include developing and implementing rice cultivars with increased grain zinc content and high production potential.

Within a population, variability refers to the differences in individual genotypes (and corresponding traits) as well as the speed at which a particular genotype might vary in response to environmental or genetic variables (Zhang et al. 2011). The requirement for increasing the number of micronutrients in rice grains is influenced by both their inherent genetic diversity and cultural traditions. Therefore, to achieve the objectives of creating high yielding rice varieties as well as better grain micronutrients, a breeding program's performance will depend on the genetic diversity of a crop (Swamy et al. 2016). China has a significant role in the production and consumption of rice, but would struggle to increase the land area already used for rice cultivation considering recent economic growth and urbanization, in part due to the lack of agricultural water (Cui et al. 2014).

In general, hybrids are more robust and bigger than the parent stock. Young seedlings develop long roots and large leaves that allow them to absorb more nutrients and therefore produce more grains. According to Bhuiyan et al. (2014) hybrid rice has a high tiller capacity. In the early and middle growth stages of vegetative growth, hybrid rice collects more dry matter, leading to more spikelet per panicle. They have panicles that are larger and more spikelet per panicle. These elements lead to better yields, typically 15% or more, than regular rice, commonly known as inbred rice (Chakrabarti et al. 2010; Bhuiyan et al. 2014). Pakistan produces 6.95 million tons of rice annually on an area of 2.96 million hectares: with an average yield of 2.35 t ha^{-1}. In order to produce hybrid rice, two different types of seeds must be planted and cultivated side by side. Pollination can be done both naturally and artificially. The average rice production in Pakistan has increased by more than 2% annually as a result of numerous research initiatives. Despite this, it is still a lot less than the leading nations for rice production (Amanullah 2016; Amanullah & Inamullah 2016). Low temperatures with late sowing impact seed germination, which delays tillering, leaving less time for plants to grow properly (Noor et al. 2019.)

In Pakistan, unbalanced nutrient application is one of the main causes of low paddy output (Amanullah 2016). Thus, various characteristics such as the quantity of tillers per plant, panicle size, panicle count, number of fertile grains per panicle, number of spikelet per panicle, grain weight per 1000 grains, plant height, etc. combine to produce the yield. The genes and QTLs that influence the traits that contribute to yield have been found. The qTSN4 shown to be rice QTL increases the total number of spikelet produced per panicle and the area of the flag leaf, but depending on the environment, it may also decrease the number of panicles (Adriani et al. 2016). The Gn1 gene similarly regulates plant height and the quantity of grains per panicle. For the quality of the rice population and grain yield, tillering is a crucial agronomic feature (Wang et al. 2017a). This is because insufficient tiller production leads to insufficient panicles, while excessive tiller production creates a dense canopy that creates a damp microenvironment that is favorable for diseases and pests (Noor et al. 2020b). Since nitrogen (N) fertilizer raises the cytokinin content in tiller nodes and further promotes the germination of the tiller primordium, it is the most popular and efficient strategy to expand the tiller population under field settings (Liu et al. 2014). Unlike the lateral branching of dicotyledonous plants, gramineous plants contain a specific kind of side shoot known as a tiller. The sprouting of new tillers from the main stem occurs continuously, and these produce their own roots to grow independently, ensuring the survival of plants in a variety of environments (Wang et al. 2017b). Additionally, it has been noted that the quantity of tillers is positively correlated with plant biomass and rice yields (Xing et al. 2017). The most crucial traits to consider while selecting for improved yield in rice segregating generations are the number of panicles per plant and the quantity of grains per panicle. At the genotypic level, grain number per plant displayed a positive correlation with fertility percentage but a negative correlation with grain length, grain L/B ratio, and 1000 grain weight (Senapati & Semenov 2020)

A well-known measure of plant growth is the leaf area index LAI was first described by Zhao et al. (2012) and is the ratio of leaf area to a specified unit of land area. Spectral reflectance and the ratio are functionally connected (Yang et al. 2009). Modelling canopy interception, ET, and net photosynthesis depend on LAI, a significant structural element of vegetation canopies. Most land surface models also use LAI as a crucial biophysical parameter to control how energy, carbon, and water fluxes are distributed between the soil and canopy components of the land surface system (Zhao et al. 2012). Indicators of crop development dynamics, such as LAI or the amount of leaf area per unit ground area), can be used to assess the condition of paddy rice during the growing season (Wang et al. 2017a).

Studies on rice grains have shown that the grain's morphological characteristics vary greatly depending on where it is grown (Soe et al. 2019). Different rice hybrids' yields and yield components were also assessed by Ashraf & Akram (2009). Few hybrids have greater grain quality compared to checks, which is one of the most significant characteristics of hybrids, thus there is a need to work to increase quality traits (Riaz et al. 2017). The primary goal of the breeding program to create new rice varieties is to increase rice grain production. A complicated trait with numerous genes under control and a strong environmental influence is grain yield. Moreover, additional characteristics including the type of plant, the length of the development cycle, and the components of the yield also influence grain production (Uzzaman et al. 2015). Most of them are resistant to pests, illnesses, and extreme climatic conditions, and many have therapeutic benefits in addition to having great nutritional value. As natural resources are depleted, genetic material preservation has become more significant (Ranawake et al. 2013).

The main objective of study was to evaluate the adoptability and suitability of different hybrid rice varieties and inbred rice in local growing conditions. This study was performed to investigate the agronomic traits and yield variation among the afore mentioned hybrid and inbred paddy varieties, and to recognize the higher yield contributing characters for hybrid rice varieties compared with inbred rice varieties. The rice varieties have not always been higher in yields due to vigour as well as physiological characters and environmental conditions. For this reason, our study mainly focused on the agronomical perspective in the environmental condition of Larkana Sindh, so that these verities must be used in further research studies and to provide a good knowledge for the adoptability of these hybrid paddy. Finally, the economic analysis was carried out to test the feasibility of hybrid rice adoptability in the domestic growing environment producing higher yield and better source of revenue for farmers.

2. Material and Methods

The field tests for rice production were carried out across two cropping seasons in 2020-21 at the experimental field on the Dokri. 27.565° N Latitude and 68.771° E Longitude are the site's coordinates. The experimental area is level and has a drainage and irrigation system that is readily available. Table 1 provides an overview of the topsoil characteristics (0-15 cm) of the experimental plot. Extremely hot summers and mild winters characterized the climate over the whole crop period.

The highest temperature of study site was recorded as 50-53 °C and the lowest recorded temperature was below 20 °C. The annual rainfall was also recorded as 109-127.4 mm, higher in the monsoon season (July) while 41 mm rainfall was recorded in the crop period. At a weather station near to the experimental location, the average temperature, precipitation, and sunlight hours throughout the rice growing seasons of 2020-21 were measured. At the middle and late stages of growth, 2020 had higher temperatures, more sunlight hours, and less precipitation than 2021. The objective of this study is to evaluate the adoptability and suitability of different hybrid rice varieties in local conditions. However, the performance of hybrid rice varieties was evaluated with crop vegetative growth, yield, and their yield characteristics (Noor et al. 2020a). Prior to the commencement of field trails, the soil characteristics recorded were presented in Table 1.

Table 1- Physical and chemical properties of the initial soil of the experimental plots

Characteristics	***Value***
Textural class (% sand, silt, clay)	Silty clay loam (15.5, 36.3, 42)
Ph	7.6-8.3
% OM (organic matter)	<0.86)
Total N%	0.07
P (µ g/g soil)	3.67
S (µ g/g soil)	5.89
B (µ g/g soil)	0.10
CU (µ g/g soil)	0.11
Fe (µ g/g soil)	2.4
Mn (µ g/g soil)	0.57
Zn (µ g/g soil)	0.40
Available K (meq/100g)	0.09
Ca (meq/100g)	1.10
Mg (meq/100g)	0.025

2.1. Plant materials

There were twenty (20) hybrid and four inbred rice varieties were selected for the experimental study. The experiment was conducted in a rice-wheat cropping zone by applying traditional field preparation conditions. The hybrid varieties were selected based on market demand. The hybrid rice seed was purchased from different companies like as Guard seed company, AG pharma, Kanzo seeds, Greenlet group, Suncrop group, Chodri khair din group, Tara group, Afroz crop science, Comega group, Rachnna group, Soni dharti and Tahfuz, Haji sons' group, Sayban group corporations, while Inbred (local rice) seed was collected from Abdul Sattar Sons, Larkana, Sindh. In this experiment, the hybrid rice varieties were given different codes for the better understanding i.e. V1 (Ennova 08), V2 (Komal), V3 (Guard 53), V4 (Winner 40), V5 (Ennova 55), V6 (Winner 05), V7 (winner 55), V8 (Bakhtwar 121), V9 (Bakhtawar 275), V10 (Dimond121), V11 (Tara 786), V12 (Thafuz 121), V13 (Red star), V14 (Comrage), V15 (Karshma), V16 (Ashoka), V17 (Shakar), V18 (Anmol), V19 (Royal), V20 (Pukhraj) and Inbred (local rice) variety was V21 (Shua92), V22 (Shandar), V23 (sharshar), and V24 (Irri-9).

2.2. Nursery preparation

The nursery was prepared using the wet bed technique. Under the irrigated method of rice growing, saturated nurseries were preferred. The soil was prepared using local ploughings (2-4 pass). The nursery area was divided into small plots of 30 sq. meters. This makes it easier to perform irrigation, weeding, chemical spraying, and planting tasks. The drainage ditches (30 cm) were built between the seed beds and provided 500g of single super phosphate, 500 g of ammonium sulphate, or 225 g of urea evenly over 10 square meters. Rice seeds were evenly dispersed throughout following manure application and puddling. For the first five days, the sowing plots were kept completely submerged in water; as the seedlings grew, the water level was gradually raised to a height of five centimeters. During instances of heavy rain during the first week of sowing, excess water was drained out. The appropriate disease and pest management methods were employed. In the event of symptoms of nitrogen deficiency, a top-dressing application of 50 g of urea per square meter was made. Additionally, two applications of zinc sulphate (5 kg zinc sulphate + 2.5 kg calcium hydroxide mixed in 1000 litters of water for one hectare) were made on soils that were lacking in zinc.

2.3. Field experiment layout

Three replications of each variety were used in the complete randomized design (CRD) studies. The field experiments were conducted at or around the beginning of August. The experimental field's total area was 9 hectares (2.25 acres), which was divided into 24 sub-fields (27×150 feet) for treatments. Each sub-field was further divided into three replication plots (27× 50 feet). The traditional method was used to prepare the experimental field area, and each subplot had a 500 m^2 (25 m×20 m) space.

2.4. Soil preparation for field experiments

After harvesting the wheat crop, the sufficiently dried soil was cultivated to aerate the soil, lessen weeds and other pests, and mix organic elements into the soil. A four-wheel tractor mounted with a rotary or multiple discs plow was used for soil cultivation. The field soil was irrigated and puddled until saturation to soften and to spill rice seeds to germinate. Puddling of soil involves churning of soil in rice fields while it's flooded with water. This practice converts the soil into a semi-liquid state, resulting in puddled soil. This technique is particularly essential for lowland rice cultivation, where fields are flooded to create a waterlogged environment. The seedling/nursery was transplanted in the main field after 25 days.

2.5. Fertigation

The soil was in the best physical condition for crop growth before the rice was planted, and the soil surface was level. The land was prepped for rice farming, and chemical fertilizers such as urea, tri-superphosphate, muriate of potash, gypsum, and zinc sulphate were applied at rates of 270, 130, 120, 70, and 10 kg ha^{-1}, respectively. Equal amounts of fertilizer were administered to each crop. At the middle and late stages of growth, the temperature was recorded higher, less precipitation, and more sunny hours. However, throughout the field trial, adequate weed and pest management techniques were also used to maintain the crop.

2.6. Nursery transplantation

The prepared nursery was transplantations manually into the rice field July 25^{th} and July 5^{th} in 2018 and 2019 cropping seasons, respectively. The approximate plant to plant distance was measured as 15×15 cm.

3. Studied Characters

3.1. Morphological growth

The data were collected on the following characters of the crops i.e. Plant height (cm) (PH), no of tillers, shoot and root length, LAI and Chlorophyll. From the first flowering day until the harvest the plant's height was measured. From the level of the ground surface to the top of the plant, the height was measured and then averaged. From the first flowering to the harvest, the number of tillers was counted and then averaged on a per-hill basis. The leaf area index of rice plant was determined at the days from flowering to harvesting stage. The data recorded were then computed by multiplying with a factor (0.75) as discussed by Mariana & Hamdani (2016). The chlorophyll content was measured using a chlorophyll meter (SPAD-502, Minolta Camera Co. Ltd, Osaka) (SPAD value). The mean of five readings per plant was recorded, and a fully grown leaf from the top of the plant was chosen for recording the SPAD values. For the measurement of SPAD value, five plants were chosen randomly from each plot. Additionally, Duncan's multiple range tests was used to determine for the analysis of recorded data of various study parameters (Duncan 1955).

3.2. Yield characteristics

The parameters, days to harvesting, number of panicles (Per plant and meter square), panicle length, number of filled and empty grains per panicle, grain length (mm), 1000 grain weight (g), number of panicles (t/ha), straw yield (t/ha), biological yield (t/ha), and harvest index are some of the different yield characteristics (%).

The number of days required to harvest each plot was computed to determine the days to harvesting. Every plot's number of panicles per plant, panicle length, and grain length were noted from the start of blooming until harvest (Noor et al. 2020c). Additionally, the average value was determined for each plant. From randomly selected plot plants, the total number of filled and empty grains was counted according to the presence of grain in spikelet and the absence of grain in spikelet. The average number of filled and empty grains in each panicle was then determined. Each plot's 1000 grains from seed were counted and weighed using any digital balance. Weighing and complete sun drying were done on the grains from each plot. The dried weight of the grains was considered for the plot in order to calculate the total grain yield per plot, which was then converted into tons/hectare. Each plot's straw was weighed and carefully dried in the sun. The dried weight of the straw was considered while calculating the plot's final straw output before being converted to tons per hectare. Biological yield was defined as both grain yield and straw yield combined. The formula below was used to compute the biology. The biological yield of rice production is equal to the grain yield obtained plus straw collected from the rice field. It stands for the ratio of economic yield (grain yield) to biological yield. The rice crop's grain and straw yield was also used to generate the harvesting index, which was displayed as a percentage. The following formula was used to calculate it (Mariana & Hamdani 2016):

$$Harvest\ Index\ (\%) = \frac{grain\ yield}{biological\ yield} \times 100 \quad (1)$$

3.3. Statistical analysis

The data of all parameters were statistically analyzed using the analysis of variance (ANOVA) and the significance of means among the treatments were compared using LSD (least significant difference) test at probability < 0.05.

3.4. Economic analysis

The production of hybrid and inbred rice was examined economically. The costs of chemicals, fuel, labor, seeds, fertilizers, and irrigation were among the variable costs. The gross, absolute, and relative profit metrics were calculated using the following formulas. In the conducted research, economic calculations were made according to the equations given below (Semerci 2020, 2021).

Straw Income (PKR ha^{-1}) = Straw Yield (kg ha^{-1}) × Straw Sales Price (PKR kg^{-1})

Product Revenue (PKR ha^{-1}) = Product Yield (kg ha^{-1}) × Product Sales Price (PKR kg^{-1})

Total Revenue (PKR ha^{-1}) = Product Revenue (PKR ha^{-1}) - Straw Income (PKR ha^{-1})

Production Cost (PKR ha^{-1}) = Variable Costs (PKR ha^{-1}) + Fixed Costs (PKR ha^{-1})

Gross Profit (PKR ha^{-1}) = Total Revenue (PKR ha^{-1}) - Variable Costs (PKR ha^{-1})

Net Profit (PKR ha^{-1}) = Total Revenue (PKR ha^{-1}) - [Variable Costs (PKR ha^{-1}) + Fixed Costs (PKR ha^{-1})

Benefit / Cost Ratio = Total Revenue (PKR ha^{-1}) / Production Cost (PKR ha^{-1})

4. Results and Discussion

4.1. Crop growth and development characteristics

Table 1 contains data on growth characteristics. The parameters under consideration were significantly influenced by both the hybrid and conventional varieties.

4.2. Tillers

The effective tillers/hill produced by the V_5 and V_{22} were both high (16.0, 14) and statistically comparable. V20 showed little variation, whilst V24 had the lowest number (Table 2). Regarding non-effective rice tillers, inbred rice demonstrated the lowest number per hill (2), while the value (4) was higher for the hybrid V1. An essential element of rice productivity is productive tillers in the transplanted rice culture, the variety or hybrid with a low tillering capacity is not desired. According to the statistics on mean values for productive tillers/hills, all hybrids generated the same number of productive tillers/hills, with the exception of V19; hybrid V19 generated substantially more tillers per hill (16). These findings are confirmed by Uzzaman et al. (2015), who claim that hybrid rice has a high tillering capacity. Together with V24, which is second in producing the least number of productive tillers, V12 generated the least productive tillers (13). Due to their great tillering capacity, high yielding varieties (HYVs) may be to blame for the noticeable variances (Uphoff 2006).

Table 2- Crop growth and development characteristics

Rice variety	*Seedling transplanted (No.) m^{-2}*	*Tillers mortality (No.) at 15-DAT*	*Tillers (No.) effective*	*Tillers (No.) un-effective*	*Plant DM (g)*
Hybrid rice					
Ennova 08 (V1)	22	2	13	2	84.6
Komal (V2)	21	3	15	2	92.1
Guard 53 (V3)	23	2	13	3	84.6
Winner 40 (V4)	22	1	14	2	92.1
Ennova 55 (V5)	23	2	16	3	95.9
Winner 05 (V6)	22	3	14	4	80.6
winner 55 (V7)	24	2	13	2	95
Bakhtwar 121 (V8)	22	0	13	3	91.6
Bakhtawar 275 (V9)	23	1	14	3	79.3
Dimond121 (V10)	22	3	14	3	92.1
Tara 786 (V11)	22	4	15	2	79.3
Thafuz 121 (V12)	24	1	13	2	80.6
Red star (V13)	23	2	14	3	87.6
Comrage (V14)	23	2	13	3	89.4
Karshma (V15)	22	1	15	1	90.3
Ashoka (V16)	24	3	14	1	93.1
Shakar (V17)	22	3	15	2	90.8
Anmol (V18)	23	4	15	3	78.3
Royal (V19)	22	2	12	1	78
Pukhraj (V20)	22	2	13	4	90.5
Mean	22.55	2.15	13.9	2.45	87.29
Inbred rice					
Shua 92 (V21)	22	2	12	3	72.3
Shandar (V22)	23	1	14	2	70.4
sharshar (V23)	23	2	14	2	72.7
Irri-9 (V24)	22	3	12	4	69.8
Mean	22.5	2	13	2.75	71.3

DM: dry matter, DAT: days after transplanting.

In this investigation, the vegetative phase of rice production took far longer. The tested hybrid varieties accumulated noticeably more dry matter at heading than the inbred due to robust vegetative growth at the intermediate growth stage. At the grain filling stage, a large amount of dry matter accumulated and remobilization of seed was activated. In terms of assimilate remobilization from shoot reserve in early planting, both the hybrids V5 and V16 significantly outperformed the elite inbred V24 (Table 1). Several other studies have reported a similar outcome (Wang et al. 2008; Ranawake & Amarasinghe 2014). Due to the prolonged vegetative lifetime caused by low temperature and the efficient source activity, dry matter accumulation was more in V5 at early planting. This indicates that the examined hybrid rice dry matter accumulation before heading was particularly thermo-sensitive. According to our study results, hybrids produce greater yields than modern inbred due to the accumulation of more dry matter before heading and its higher translocation into the growing grain during the filling stage. This outcome was comparable to that of (Ranawake et al. 2013).

4.3. Plant height

In terms of plant height, the examined cultivars varied statistically from one another. The inbred variety V22 generated plants that were statistically taller (96.4 cm) than all other treatment produced plants. However, as shown in figure 2, the hybrid V5 had a noticeable height (106.5 cm), which was far greater than V15 (81.2 cm), V13 (75.5 cm), and V20 (69.8 cm).

4.4. Root and shoot length

Significant differences in shoot and root length were observed among the production of inbred and hybrid rice. At harvest (Figure 2), the smallest shoot was identified in V24 (54.1 cm), whereas the tallest shoot was identified in V5 (82.3 cm), which was statistically identical with V12 (78.1cm). The longest root was identified in V12 (21.3), which was statistically similar to V5 (19.6 cm), whereas the shortest root was identified in V24 (13.3 cm) as given in Figure 2. This might be because the cultivars reached their full maturity at harvest, and as a result, the roots stopped growing and began to deteriorate, resulting in shorter roots. In conventional rice, the plant root growth noticeably increased (Uzzaman et al. 2015); additionally, SRI had deeper roots than SMP. The simplest technique to increase a crop's rooting depth and root distribution is to lengthen the vegetative stage (Qados 2011). This can be accomplished by either delaying flowering or seeding early.

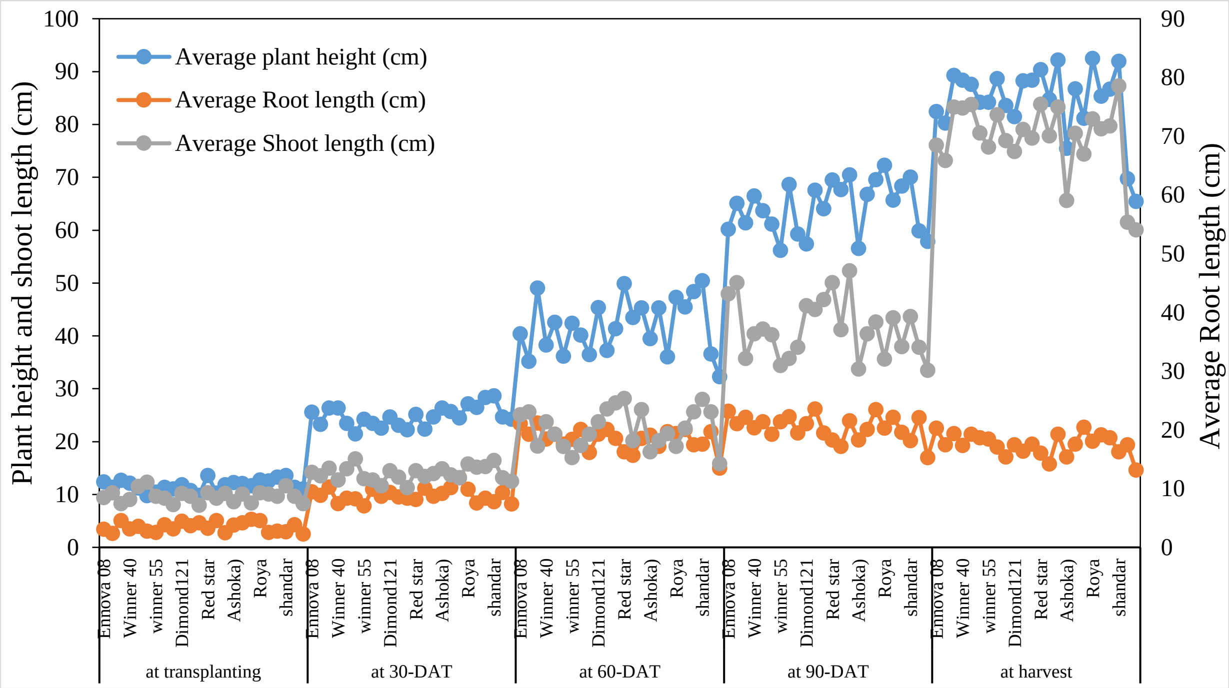

Figure 1- Plant Height, Root and shoot length of rice crop

4.5. Leaf area index

In comparison to inbred rice, hybrid rice has a much longer leaf area duration (LAD) and a quickly increasing LAI during vegetative growth. In all the examined rice seeds and planting dates up to heading, the LAI steadily rose, and for the most part, the differences are not statistically significant. However, at the heading stage, the highest LAI was obtained from V2 (4.50), followed by V5 (4.20), and was substantially reduced in V17 (2.70). The inbred rice varieties V22 and V23 had the highest LAI (3.40), while V24 had the lowest LAI (3.10). This outcome shows similar results to that of Qados (2011) and Howlader et al. (2017) (Figure 3).

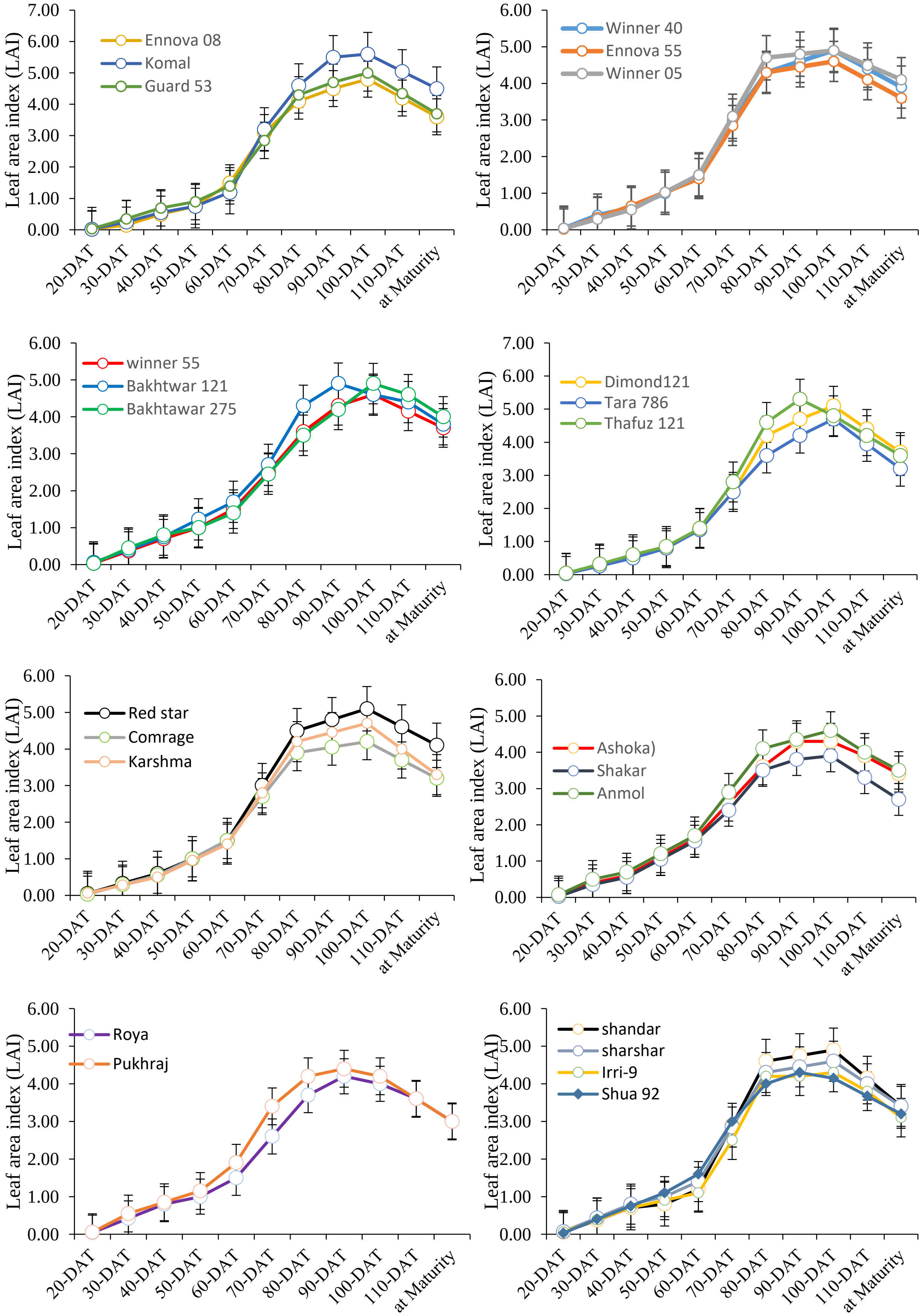

Figure 2- LAI of hybrid and inbred rice varieties at different DAT

4.6. Chlorophyll content

Rice grain output is primarily and actively photosynthesized by flag leaves (Uzzaman et al. 2015). Chlorophyll content reveals the leaves' capacity for photosynthetic activity (Swamy et al. 2016; Jagadish 2007). Hybrid rice, according to Chakrabarti et al. 2010), has more chlorophyll in its leaves. No distinction in leaf chlorophyll concentration was reported between hybrid and contemporary inbred types Haque et al. (2015). The amount of chlorophyll in flag leaves varied little between planting dates. It demonstrated that the hybrids under study possessed a higher flag leaf chlorophyll content as their distinctive traits. Flag leaf in hybrid rice has a better capacity for photosynthetic activity, according to Charkrabarti et al. (2010). In contrast to the inbred, the hybrid showed a decreased single-leaf photosynthetic rate at the grain filling phase, according to Cui et al. (2014).

The Flag leaf chlorophyll characters were studied based on twenty-four hybrid and conventional rice varieties in the naturally environmental system of Sindh province; however, significant results were identified in flag leaf chlorophyll. The hybrid and conventional rice varieties synthesized a higher amount of chlorophyll at 7, 15, 21 and 30th different DAT. The results obtained from both inbred and hybrid rice production were compared on 7th and 30th DAT. In hybrid rice, V19 at the 7th DAT showed least levels of chlorophyll (1.67 mg/g), whereas V1 showed higher levels of chlorophyll (2.87 mg g−1). Whereas conventional rice Varieties at the 7th DAT showed the least level of chlorophyll in V24 (1.11mg/g), V22 showed higher chlorophyll levels (1.46 mg/g). However, at the 30th DAT, the V7 showed minimum levels of chlorophyll (0.70 mg/g) and V20 showed the maximum levels of chlorophyll (0.98 mg/g). Overall, V20 had high leaf chlorophyll as when compared to the other experimental treatments. While the conventional rice varieties (V21, V22) showed similar trends in Chlorophyll (0.72mg/g) at 30th DAT 7th DAT, which is less then hybrid Varieties. While V24 showed least significant results of leaf chlorophyll as compared to other conventional varieties. The total amount of chlorophyll in a flag leaf was largely unaffected by the environment. Additionally, there were variations between observations. According to some theories, the amount of chlorophyll in leaf tissues may vary depending on a plant's age, species, and growth season (Ramesh et al. 2002).

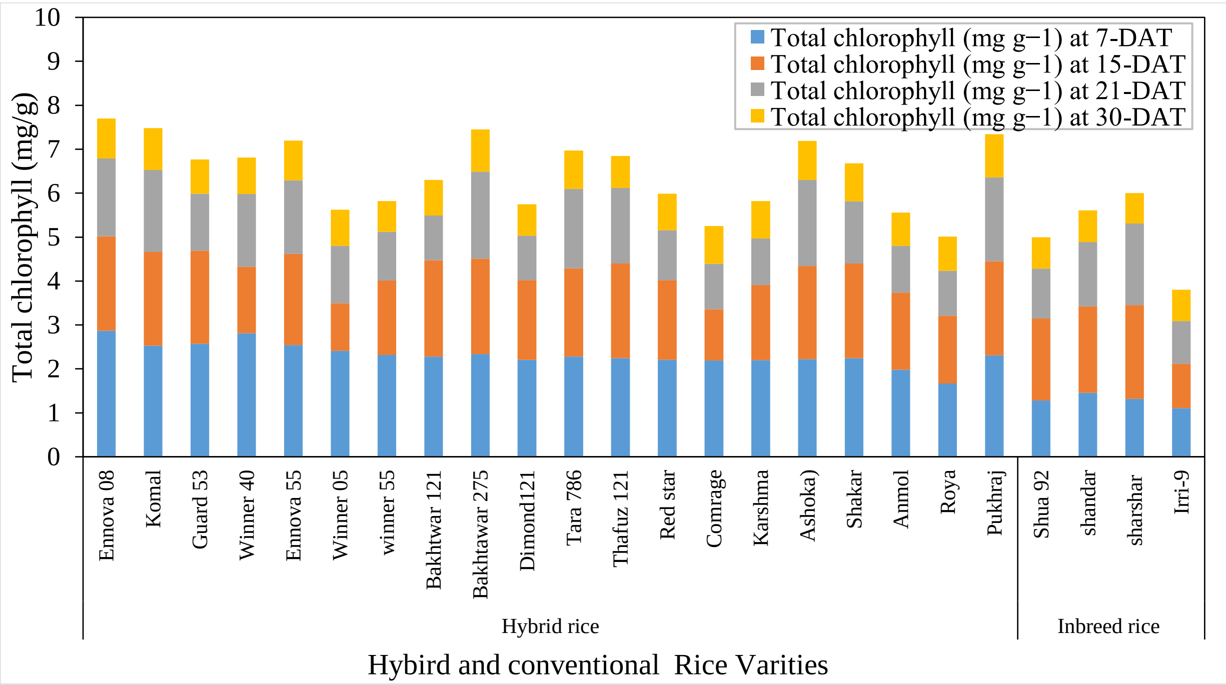

Figure 3- Comparison of total leaf chlorophyll (mg/g) among hybrid and inbred rice varieties

4.7. Yield attributing characters

Table 3 displayed the grain yield characteristics of the experimental cultivars at various planting dates. The number of days of rice flowers differs significantly. Hybrid varieties V10 and V18 showed early flowering (55 and 64 days, respectively), and V5 showed late flowering (60 and 65 days, respectively) (Table 3), while the inbred types of rice V21 (55 days and 60 days respectively). Regardless of the distance between transplants, the rice plant reached 50% flowering as the age of the transplanted seedling gradually decreased (Ram et al. 2014). The 8 days seedling transplantation showed early flowering (5-8 days) before 25-day old seedling transplanting. This might be the result of older seedlings taking longer than younger seedlings to initiate panicles due to slower growth in the main field (Uzzaman et al. 2015). This outcome is comparable to the research being discussed in this experiment.

In comparison to the predicted 105-day harvest period, the hybrid rice variety V4 matured and was ready for harvest at 90 days. Similar to V2, V3, V1, V5, V6, V7, V8, V9, V10, V11, V12, V13, V14, V15, V16, V17, V18, V19, and V20, which had a difference in maturity days of 11, 14, 13, 13, 8, 9, 6, 10, 8, 9, 8, 10, 11, 9, 8, and 7, while conventional rice varieties V21, V22, V23, and V24 had minimum days to maturity of 8, 8, 8, and 15, respectively. Under best management practices, traditional rice is harvested and ripe before the maturity period advised by the relevant released organization. Regarding paddy production, panicle length is also a crucial characteristic. In terms of panicle length, V4 and V10 had the longest panicles, measuring 27.2 cm, while V5 had the shortest panicles, measuring 26.5 cm. V24 and V20 were found to have the lowest value for panicle length among inbred and hybrid plants at 23.2 cm; V16 had the longest panicle length at 29 cm. The research study Idikut et al., (2009) identified various factors affecting the growth and the length of panicles under various crop production circumstances (Kim et al., 2012).

The highest number of filled grains per panicle (379) was identified in V5, while for the inbred the highest number of grains per panicle (285) was identified in V21, and the lowest number (190/panicle) was identified in V24 (Table 2). This outcome is consistent with that of Dutta et al. (1998), who found that the amount of grain per panicle affected yield. Maximum was discovered in V22 (33/panicle), which was statistically identical with V7 (26/panicle), while the minimum number of unfilled grains per panicle (12) was found in V14, which was statistically identical with V15 (15/panicle) and V16 (14/panicle) (Table 3). Similar findings were made by Dutta et al. (1998), who also noticed a wide range of changeability in the number of empty grains per panicle. The rice variety V14 had the longest seeds, measuring 9.2mm, while V24 had the shortest, measuring 6.21mm.

Table 3- Determination of yield characteristics of hybrid and inbred paddy varieties

Rice variety	*Avg. Days to flowering*	*Average DAT to harvest*	*No. of panicle*		*Panicle length (cm)*		*Grains per panicle*	
			Per plant	*Per m²*	*Filled grains*	*Unfilled grains*		
	Hybrid rice							
Ennova 08	63	92	13	286	24.2	267	25	
Komal	64	94	15	315	25.3	269	20	
Guard 53	64	91	13	289	24.1	272	23	
Winner 40	62	90	14	308	27.2	268	25	
Ennova 55	65	92	12	276	26.5	379	24	
Winner 05	61	97	14	310	25.5	274	22	
Winner 55	59	96	13	312	24.3	312	26	
Bakhtwar 121	63	99	13	290	25.2	305	24	
Bakhtawar 275	62	95	14	310	25.3	260	17	
Dimond121	64	96	14	318	27.2	270	19	
Tara 786	57	97	16	319	24.5	265	18	
Thafuz 121	60	96	13	312	25.3	270	20	
Red star	57	97	14	320	24.2	281	18	
Comrage	61	95	13	305	25.5	285	12	
Karshma	58	95	17	320	26.3	280	15	
Ashoka)	62	94	14	315	24.3	268	14	
Shakar	63	96	15	317	24.3	272	25	
Anmol	64	97	15	322	23.5	268	17	
Roya	59	96	16	321	23.7	285	17	
Pukhraj	60	98	13	286	23.2	285	20	
Mean	61.4	95.15	14.05	307	24.98	281.75	20.05	
	Inbred rice							
Shua 92	60	97	12	264	27.1		285	20
Shandar	58	97	14	322	24.1		280	33
Sharshar	61	97	14	322	26.4		275	15
Irri-9	55	90	12	260	23.2		190	18
Mean	58.5	95.25	13	292	25.2		257.5	21.5

Among the traditional rice varieties, V22 produces maximum 1000-grain weight (20.6 g), which gave lower crop yield; the maximum 1000-grain weight (35.2 g) was observed in hybrid V5 (Table 4). The lowest amounts (12.7g) and (6.2g) were identified in V8 (hybrid) and V24 (inbred), respectively, which were statistically like V10's (16.4g) as given in Table 3. The thickness and length of rice were found to favorably correlate with the weight of 1000 grains (Coronel et al. 1984). The variance in the weight of 1000 grains may be caused by the genic basis of rice strength. Table 3 showed that the V5 had the highest grain yield (4.51 t/ha), whereas V10 and V12 had the lowest (2.42 t/ha), while conventional rice yields the most grain (2.95 t/h). Compared with V22, the hybrid rice produced more grain yield per hectare than the conventional rice, as evidenced by the lowest (2.52t/h) grain yield also achieved from V24 (Howlader 2017). The rice variety V5 had the highest straw yield (7.1 t/ha), while the conventional rice variety V24 showed the lowest (5.2 t/ha). This outcome is consistent with that of Ndour et al. (2016), who found that plant height could influence straw yield. Maximum biological yield was discovered in V5 (11.61 t/ha), and minimum biological yield in V24 (7.92 t/ha). Compared to all conventional rice varieties, the biological yield of the V5 hybrid rice variety was 21.81% higher. The rice's grain yield and biological yield were favorably connected. Hybrid variety V15 had the highest harvest index (39.3%), while V24 had the lowest (35.5%). In comparison to V8, V9, and V24, hybrid rice variety V18 showed a higher harvest index. Amanullah and Inamullah, (2016) also noted that hybrid cultivars had greater harvest indices than inbred varieties.

Table 4- Performance of hybrid and inbred paddy varieties along with different parameters

Rice variety	*Grain length (mm)*	*1000 grain weight (g)*	*Grain yield (t ha^{-1})*	*Straw yield (t ha^{-1})*	*Biological yield (t ha^{-1})*	*Harvest index (%)*
Hybrid rice						
Ennova 08	7.3	30.5	3.54	6.2	9.74	35.1
Komal	6.8	23.3	2.62	5.4	8.02	36.3
Guard 53	8.1	20.5	2.52	6.2	8.72	35.5
Winner 40	7.4	25.4	2.98	5.4	8.38	37.3
Ennova 55	8.3	35.2	4.51	7.1	11.61	36.8
Winner 05	7.76	25.4	3.15	6.2	9.35	37.2
Winner 55	8.24	22.8	2.57	5.4	7.97	35.6
Bakhtwar 121	8.97	25.8	3.05	5.4	8.45	38.3
Bakhtawar 275	6.9	12.7	2.48	6.5	8.98	36.5
Dimond121	8.5	16.4	2.42	6.2	8.62	36.8
Tara 786	8.11	19.5	2.52	5.4	7.92	38.6
Thafuz 121	7.76	18.3	2.42	6.3	8.72	35.5
Red star	7.87	23.5	2.73	6.2	8.93	37.8
Comrage	9.21	28.6	3.32	5.4	8.72	39.1
Karshma	7.89	29.3	3.45	6.3	9.75	39.3
Ashoka	8.32	13.7	2.62	6.5	9.12	38.3
Shakar	8.21	25.4	3.13	5.3	8.43	36.9
Anmol	9.15	25.1	2.98	6.5	9.48	38.6
Royal	7.91	25.5	2.88	5.3	8.18	38.5
Pukhraj	8.32	25.8	3.31	6.2	9.51	37.8
Mean	8.051	23.635	2.96	5.97	8.93	37.29
Inbred rice						
Shua 92	8.85	19.2	2.49	6.3	8.79	38.5
Shandar	9	20.6	2.95	6.2	9.15	38.6
Sharshar	9.2	19.3	2.84	6.3	9.14	37.4
Irri-9	6.21	12.7	2.52	5.4	7.92	35.5
Mean	8.315	17.95	2.7	6.05	8.75	37.5

4.8. Economic analysis

The economic analysis of production of hybrid and inbred paddy cultivars was carried out (Table 5). The overall fixed and variable costs served as the foundation for the economic inputs of different paddy cultivars. However, the costs of chemicals, gasoline, labor, fertilizer, seed, irrigation water, repair, energy, maintenance, and revolving interest are included in the variable costs. This does not include the fixed costs, which include general administrative costs, land value interest, irrigation machine and tool interest, depreciation value, facility cost amortization, and facility capital interest (Aslam et al., 2020).

Table 5- Economic analysis of hybrid and inbred rice varieties

Cost indicators	*PKR/quantity (inbred/hybrid)*	*Quantity*	*Inbred paddy (PKR)*	*Hybrid paddy (PKR)*
Nursery preparation				
Land ploughing (ha^{-1})	8000	4	32 000	32 000
Seed (Kg)	3000/4500	40	120 000	180 000
Fertilizers-organic (trolley)	2500	5	12 500	12 500
Irrigation (h^{-1})	1150	22	25 300	25 300
Fertilizers (Bags)	3000	1.5	4 500	4 500
Labor hours	300	42	12 600	12 600
Total			206 900	266 900
Field paddy transplantation				
Land ploughing (ha^{-1})	8000	5	40 000	40 000
Fertilizers (Bags)	18000	2.5	45 000	45 000
Irrigation	1150	16	18 400	18 400
Transplanted charges (h^{-1})	1800	7	12 600	12 600
Skilled labor hours	500	7	3 500	3500
Total			119 500	119 500
Spraying and chemicals application				
Sprays (liquid)	7500	4	30 000	30 000
Chemical (Powder/granular)	1500	3	4 500	4 500
Labor hours	500	60	30 000	30 000
Total			64 500	64 500
Irrigation and fertigation				
Irrigation charges	1150	85	97 750	97 750
Fertilizers (Bags)	18000	6	108 000	108 000
Labor hours	300	90	27 000	27 000
Total			232 750	232 750
Harvesting				
Combine harvester (h^{-1})	5500	3	16 500	16 500
Skilled labor hours	500	8	4 000	4000
Total			20 500	20 500
Total Variable Cost			694 150	754 150
Fixed Cost (land rent)			50 000	50 000
Total cost (ha^{-1})	744 150	804 150		
Crop yield				
Grain yield (kg h^{-1})			3 096	3 780
Grain Revenue			6 037 200	9 639 000
Straw yield (kg ha^{-1})			5 200	6 200
Straw revenue (PKR ha^{-1})			31 200	37 200
Total revenue			6 068 400	9 676 200
Total production cost (PKR ha^{-1})			744 150	804 150
Gross Profit			5 374 250	8 922 050
Net Profit			5 324 250	8 872 050
Benefit cost ratio (BCR)			8.15	12.03

The manual labor was engaged for planting, plant care, harvesting, and clean-up, while the tractor power or electric power was used to run agricultural machines for the manufacturing of rice. According to Noor et al. (2020e), the economic inputs to produce hybrid rice and inbred rice are largely based on total fixed and variable costs. The fixed costs included general administrative costs, interest on land value, interest on irrigation machine tool depreciation value, amortization of facility costs, and facility capital interest.

The variable costs included the costs of chemicals, fuel, human labor, seed, fertilizers, irrigation water, and electricity. For the purpose of calculating gross, absolute, and relative profit indicators, the following formulas were utilized (Noor et al. 2020f; Zhanbota et al. 2021). Hybrid rice production had a maximum BCR of 12.03 compared to inbred rice production's (8.15), which demonstrated that hybrid rice was more profitable to sow because it produced a higher yield, as well as other economic advantages. The highest total production costs were measured in inbred rice production at 744 150 PKR per hectare, while the hybrid rice production at 804 150 PKR per hectare (Zhanbota et al. 2022).

5. Conclusions

The development of high-quality varieties of rice, including early and late maturing varieties, hybrid and conventional rice varieties are needed to sustain global agricultural production. For this reason, the present study evaluated the different agronomical traits under the natural opening field at Larkana Sindh Pakistan. The tested hybrid and inbred rice varieties showed different responses toward adoptability, morphological growth, and yield characteristics. Broad variations have been found in these agronomic characters. Hybrid rice development has higher crop yield as compared to inbred varieties.

To meet the feeding requirement of the glowing global population there is need to produce new hybrids. From this study's results, it can be concluded that the Ennova-55, Winner-05 and Ennova-08 are at ensuring productive yields than inbred varieties. The results of our study indicate that the hybrid rice varieties can be adopted in Pakistan for sowing and increasing the productivity due to higher production. These hybrids rice varieties can be developed and further utilized in breeding programs. Further research work should be carried out to validate the results and adoptability of hybrid rice production. The economic analysis shows that hybrid rice production had a maximum BCR of 12.03 when compared with inbred rice production (8.15), which demonstrated that hybrid rice production is more profitable because it produces a higher yield and further economic advantages for rice growers.

Abbreviations

The abbreviations used in this study are listed below.

IRRI	International Rice Research Institute
BCR	Benefit Cost Ratio
FAO	Food and Agriculture Organization
QTL	Quantitative trait locus
LAI	Leaf area index
ET	Evapotranspiration
CRD	complete randomized design
LSD	Least significant difference
HYVs	High yielding varieties
DAT	Days after transplanting
LAD	Leaf area duration

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