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Impact of Hybrid Varieties on the Productivity of Rice Cultivation: The Case of Sindh, Pakistan

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ABSTRACT

Agriculture is a very important sector and crucial for poverty reduction and employment generation. The use of hybrid seeds leading to increased yield of crops and farmers' income has been widely discussed in the literature. Through this study, an effort has been made to identify factors that impact obtaining high crop yield of rice by using the hybrid varieties. This study focuses on the use of hybrid varieties in the rice crop and presents a comparison in yield with the traditional open-pollinated varieties. The plot level information collected from eight major rice-producing districts of Sindh province of Pakistan was used to conduct this study and a propensity score matching technique was used to estimate the results of the study by using plot level variation between hybrid varieties and open-pollinated varieties. The results of the study showed significant improvement in rice yield with the adoption of hybrid rice varieties in the study area. This study highlights that the farmers have achieved a higher average yield of rice by using hybrid seeds as compared to open-pollinated varieties. Besides the crop yield, the overall income and profit of farmers have also increased by using hybrid seeds in the Sindh province. The study illustrates different interesting patterns relating to different characteristics of the household cultivating rice crops, different plot-level characteristics, and their comparison with hybrid and traditional varieties.

Keywords: hybrid seeds, open-pollinated

INTRODUCTION

A large number of crops are cultivated and harvested around the world, rice crop accounts for 8 percent of world crop production, making it 3rd largest crop grown on the planet after sugarcane and Maize. The world produced 0.8 million tons of rice in 2019 with 90 percent production in Asia (FAO 2021). There are over 144 million farms that cultivate rice across an area of about 167 million hectares (ha) in more than 100 countries (FAOSTAT 2019). Rice-based farming systems have also been the main source of income for a large proportion of rural farmers located in several developing countries (Fan et al. 2005). Rice feeds more than half of the world's population (Maclean, 2002) whereas only China and India consume more than 50% of total world rice production. Rice is the third most nutrient-rich crop, providing 20% of the world's calorie intake including carbohydrates, minerals, and vitamins, (Fresco, 2005) and 80% of the total calorie intake in countries like China, India, Vietnam, Cambodia, Philippine and Bangladesh.

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Cropland area per capita decreased in all regions between 2000 and 2019 as the population increased faster than cropland the increase in agricultural production over the same period indicates higher efficiency in feeding the population with limited land resources (FAO 2021). It is therefore important to increase the crop yield with the increasing population of the world which is estimated to be 9 billion by the year 2050 (UN, 2008). Since rice is a major food crop therefore the demand for high-yielding rice varieties will be high. The consumption of rice crops by 2030 is predicted to be 40 percent higher than the present rice demand (Khush 2005).

Over the years, enormous research goals were achieved by improving several quantitative and qualitative characteristics of rice. Between 1950 and 1960, a breakthrough in the rice green revolution resulted in the breeding of a semi-dwarf variety by the International Rice Research Institute (IRRI) (Chandler, 1992), which resulted in the development of époque-making variety, IR8, and succeeding varieties. The variety IR8 contained several favorable traits that contributed to high rice grain yield. Also, several elite rice cultivars such as IR36 and IR64 were released by the IRRI. This Modern variety (MVs) of rice has "semi-dwarf" characteristics, with short and stout stems for sustaining heavier grain yields and pointed leaves for better reception of solar radiation. These characteristics make MVs fertilizer responsive and they can achieve high yields at high levels of fertilizer input (Hayami and Godo 2005). As a result of the addition of different traits and genes the yield of these MVs substantially increased (Davies, 2003). The MVs of rice have been widely diffused in Asian countries and this phenomenon is called Green Revolution. Technological and agronomic advances in the growing of rice and other crops dramatically increased crop yields across the globe (Llewellyn, 2018). Accordingly, the global production of cereals increased by 174% between 1950 and 1990 while the global population increased by 110% (Otero & Pechlaner, 2021). The increased production of cereals enabled the nations to feed their growing population (Davies, 2003). Modern rice varieties significantly contribute to improving farmers‟‟ well-being over traditional rice varieties (Hazell, 2010). There is a large economic literature that investigates the effects of modern rice technology adoption on poverty alleviation and improvement in farmers‟‟ welfare (Bellon et al. 2006; Evenson and Gollin, 2003; Just and Zilberman, 1988). There are several pathways through which modern technologies could potentially benefit poor farmers (Hazell and Haddad, 2001). Although the Green Revolution is truly époque-making and has contributed to the increase of productivity and total production of rice in the world (Evenson and Gollin 2003), it is also true that the yield potential of conventional breeding is largely achieved and new technological advancement is required for further yield improvement.

Hybrid vigor or heterosis is the superiority of the heterozygous genotype (F1) over the two homozygous parents (Shull, 1908). This phenomenon in cereal crops is occurring commonly, but its level of expression is highly variable. Heterosis research in crops has a long history of 100 years, which showed great practical applications in breeding field crops (Alam et al., 2004). Heterosis in rice was first reported by Jones in 1926. In his study, he observed that hybrid rice had more culms and higher grain yield than their homozygous parents (Jones, 1926). Soon after the discovery of heterosis in rice, breeders from many rice-producing countries such as Japan, China, the United States, India, the former Soviet Union, and the Philippines studied and utilized heterosis breeding in rice (Capinpin and Punyasingh, 1938; Idsumi, 1936; Kadam et al., 1937). In 1964, in China, Yuan Long Ping (the father of hybrid rice) initiated research work on the utilization of heterosis in rice. He focused on the development of breeding methods for hybrid rice seed production i.e. three-line hybrid rice breeding method, two-line hybrid rice breeding method, and one-line (apomixes) (Cao and Zhan, 2014). Unlike conventionally bred rice varieties farmers can store and use their harvested grains as seeds in the following year, hybrid rice compels farmers to purchase new seeds in each season if they want to achieve higher yields continuously (Mottaleb et al. 2015). Hybrid rice is a modern rice variety that has a 20% yield performance advantage compared to inbred rice, high protection against insect pests, improved response to fertilizer use, and better adaptation to various rice environments (Tu et al. 2000; Janaiah and Xie 2010; Prakash et al. 2017). Hybrid rice was introduced as one of the options to address the need for increased rice production while using fewer resources (Khush 2005). Hybrid rice technology has the potential to improve the profitability of smallholder rice production systems. The development of hybrid seed and higher rice-yielding varieties is one of the most important recent innovations that are expected to increase paddy yields (Vijayaragavan, 2011) and also result in less land usage (Tunio et al., 2017).

With the advancement of technology and research, the use of hybrid varieties of seeds for different corps has shown a tremendous impact. The use of hybrid varieties of rice has shown significant growth. Takahashi et al. (2020) studied the technology adoption and its impact in developing countries and found that the adoption of improved seed varieties had a significant impact on farm output and farmer's income. However, he also argues that most of the farming community is not able to adopt these technologies due to many associated factors. Wang et al. (2020), studied the adoption of high-yielding varieties in Yunnan, China, and showed that by adopting new rice varieties the income from rice has increased and also positively contributed towards household income level. Another study conducted by Islam (2018), in Bangladesh, assessed the impact of the adoption and usage of the improved rice variety "wet (aman)" on farmer's income levels and showed that improved rice seeds had a significant positive impact on farmer's income with a higher benefit to small scale farmers.

Although high-yielding modern rice varieties (MVs) have been gradually disseminated over Sub-Saharan Africa, little is known about how the adoption of MVs influences agriculture productivity and household income. Several studies have been conducted at the national and International levels to see the effect and impact of using hybrid rice varieties on overall production, improved supply, change in farmer's income, and an overall increase in exports. For example, a study conducted by Wagan (2015), in Badin district collected primary data from 60 rice producers and compared conventional and hybrid rice production in Sindh and found a 14.14% increase in production of rice by using Hybrid seed. Chandio et al. (2019) examined the impact of agricultural credit and farm size on the technical efficiency of rice productivity and showed a positive relationship between rice productivity and factors such as seed variety, credit, farm size, fertilizer, labor, etc. A study conducted by Bashir et al. (2007), examined the various rice varieties in Pakistan and factors of decline in rice productivity found similar results. Wagan et al. (2016), also carried out a study on socio-economic factors and rice production cost by comparing hybrid and conventional rice growers in Sindh province showed an increase in productivity of 14% by using hybrid seeds as compared to conventional rice seed used in the study area. The study conducted by Khushik et al. (2011), revealed similar results for Sindh and Baluchistan provinces. The study also revealed that the higher cost of hybrids is limiting farmers from adopting new technology as they are short of cash at the time of sowing.

Table 1 shows the effect on yield and income of farmers by using different rice seeds. The studies compared traditional, modern, and hybrid rice varieties.

Table 1: Impact of Rice Varieties on Yield and Income

Reference	Country	Rice Variety Compared	Data & Methodology	Outcome		Results
				Yield	Income	
Wang et al 2020	China	Traditional Vs Modern	448 households Propensity Score Matching (PSM)	Yes	Yes	30% higher yield and 35% higher income, were received by farmers using hybrid rice varieties. The net return was also higher i.e 31% for farmers using hybrid rice varieties.

Islam 2018	Bangladesh	Traditional Vs Modern	Data set of 1435 observations was used and DID-PSM technique was adopted for analysis of results.	Yes	Yes	The per capita income was 25.4% - 29.6 % higher for farmers using improved rice varieties as compared to farmers using traditional varieties. The yield was recorded 24% to 55% higher for improved rice varieties.
Khushk et al 2011	Pakistan	Hybrid Vs Modern	Data from 100 rice growers was used. Farm cost analysis and Gross margin analysis was conducted.	Yes	No	29% higher yield was achieved by using hybrid rice varieties, however, market rate was Rs.8-PKR less as compared to Modern varieties due to bad grain quality.
Noorain 2015	Pakistan	Hybrid Vs Conventional (traditional and Modern)	Data set of 60 farmers was used Cobb Douglas Production Model	Yes	Yes	14% yield and 28% high income were received by farmers by using hybrid varieties.
Islam et al 2019	Bangladesh	Traditional Vs Modern	Panel data 587 households for two time periods by using the same households. Difference in Difference treatment effect approach	Yes	Yes	18% higher yield was achieved and farmers received 67% higher income.
Gollin et al 2021	Multiple countries	High Yielding varieties performance 1960-2000	Sample data set of 84 countries was used for 10 major crops from 1960-2000 to analyses the performance of high yielding varieties.		Yes	10-percentage point increase in high-yielding varieties. The adoption increased world GDP by 15 %.
Negi et al 2020	India	Hybrid Vs Modern Vs Traditional	Farm Household data of 30540 was used from IFPRI 2017-18 and for analysis 17836 observations were used Instrumental Variable	Yes		Hybrid varieties have not shown a significant increase as compared to modern varieties. Results showed a 5.6% higher yield of hybrid varieties as compared to Modern Varieties. Findings demonstrate that the relative yield advantage of hybrids over inbred modern varieties is not much, and therefore possibility is marginal cost of adopting hybrids may be higher than their marginal benefit.
Hassen et al 2017	Italy	Traditional vs Modern	Two fields divided into small plots of size 1.33m2 to evaluate a diversity panel of 284 varieties released from 1904 to 2012.	Yes		This study shows that moving from irrigated to alternately irrigated conditions increases the total production costs. Also, yield between the modern and traditional varietal groups did not differ significantly but the variation was higher within each group.

			Economic analysis of water on productivity was calculated.			It varied only between the water management methods with higher production for the irrigated conditions. However, a significant reduction of irrigation water was observed for the alternately irrigated condition, inducing higher water productivity.

Rice is an important food commodity as well as a cash crop in Pakistan. After wheat, rice is the second main staple food crop and the second major exportable after cotton. Pakistan ranked 10th among the rice-producing countries with annual production of 7.2 million tonnes adding 3.0 percent in value added to the agriculture sector and 0.6 percent to GDP (Economic Survey of Pakistan 2019/20). Pakistan shares more than 8% of the world's total rice trade dominating the Asian rice market after Thailand, Vietnam, and India. Sindh and Punjab are the largest (90 percent of the total rice) rice-producing provinces where millions of farmers rely on rice cultivation.

This study was an attempt to understand the varietal adoption trend in Sindh, Pakistan. The Rice Monitoring Survey was conducted in 2016, funded by the International Rice Research Institute (IRRI) to collect the data to explore the varietal adaptation by farmers in Sindh province of Pakistan. Using plot-level primary data, the main objective of the study is to analyze the effect of hybrid seed use on yield and income. At first, an attempt was made to understand the selection of the hybrids i.e. the key determinants for using hybrid rice varieties. Then to investigate the impact of hybrid rice varieties on yield, income, and profit. To account for the endogenous selection of the adoption of hybrid seeds by the households, we use Oster's (2019) OLS methods. As a robustness check, we also estimate the average treatment effect on treated (ATT) by using propensity score matching methods. We conduct sensitivity tests proposed by Rosenbaum (2002) to examine the robustness of the PSM estimates to unobservable characteristics. The findings of the study showed that improved rice technology had a robust and positive effect on the average yield of rice crops, which increased by around 1.4 tons per hectare as compared to OPV's. The increase in yield enhanced farmers' income and profit, which will ultimately increase household income and consumption expenditure and ultimately result in a reduction of poverty in the area.

The remainder of the paper is organized as follows: In Section 2, we discuss data and the study site. The methodology is explained in section 3 followed by results and discussion in section 4 and last we discussed the conclusion in section 5.

Data and Study Sites

Pakistan has an agro-based economy and the majority of the population depends upon agriculture for employment (Begum & Yasmeen, 2011; GoP, 2016). Especially, rice is an important export crop for Pakistan that contributes to feeding a large portion of its population and contributes in countries exports (Jafar *et al.*, 2015). Pakistan also had to put more effort into its research and development department for introducing high-yielding rice varieties (Jafar *et al.*, 2015). In Pakistan, the province of Sindh is the major rice producer after Punjab. Rice in Sindh is cultivated in an area of around 800,000 hectares with an average yield of around 1.8 – 2.0 tons per acre (1 acre = 0.40 ha), employing almost 50 percent of the rural labor force (Chandio *et al.*, 2019). Data was collected through a survey funded by the International Rice Research Institute (IRRI) in 2016 from eight major rice-producing districts in Sindh including Shikarpur, Larkana, Qambar Shahdadkot, Badin, Thatta, Kashmore, Jacobabad, and Dadu. A total of 42 villages and 420 households, namely ten households per village, were randomly selected for this survey. The information collected in the interview included the demographic characteristics of the households, rice production practices, other income sources, and the assets in the household. After cleaning the data, 670 out of 720 plots of 419 households were left for analysis.

Methodology

Our analyses start with a probit model for the selection of hybrids to understand the important factors that play a role in the adoption of the hybrids. The main variable dependent variable is the dummy variable i.e. usage of hybrid rice seed which is equal to 1 if the household is using hybrid rice seed and is 0 otherwise. The independent variables are the explanatory variables that are expected to determine the decision of the farmers to choose hybrid varieties. These independent variables include economic factors such as plot size, taking dry seed at home, ownership of land, source of irrigation, availability of electricity, access to mobile and distance to market, the institutional factors such as extension services in the area. Further, we included household characteristics like size of household, age, education, gender, and marital status.

The size of the plot (hectare) is an important characteristic as it will influence the farmer's decision to use hybrid varieties, it is because larger plot size will give the farmer an added advantage to use hybrid varieties to fetch higher crop yield and to invest in purchase of hybrid seed at higher cost instead of using lower yielding varieties. Taking dry seed at home is also important, as having a seed at home will reduce the chances of farmers going for hybrid varieties because seed has to be purchased every year for using hybrid varieties. Land ownership (hectare) is a continuous variable, which is expected to have a positive effect on farmer's decision to use hybrid. It is also an important variable because many farmers in the study area are living as tenants and seed is provided by the landlord. Therefore, the decision of the farmer in the case of the tenant is not given any weightage. The source of irrigation is an important factor and it plays an important role in deciding the quality of seed input. Canal irrigation is a major source of irrigation for rice farmers in the study area. It is important to see if the decision of farmers to use hybrid varieties is influenced by the source of irrigation he is using. We, therefore, estimated the probability of a farmer's decision to use hybrids if he has canal irrigation, tube well irrigation, or has no source of irrigation and depends only on rainfall. Since canal and tube well irrigation requires pumping water to the field, we included the availability of electricity in the area as an independent variable to see its influence on the decision of farmers to use hybrid varieties. Distance to the market from farmers is also important because if the market is near to the farmer it may influence positively for getting the hybrid seed and selling the crop. Our hypothesis for this study is that this variable is negatively related to the adoption of hybrid variety (Idrisa *et al* 2012). To understand the benefits of hybrid varieties, extension services are helpful in the decision-making of farmers to choose the best seed for their crop. In the study, if the farmer is getting extension service, we coded it as 1 and 0 otherwise (Akudugu *et al* 2012). Mobile access will help farmers to get the latest information about new technologies and seeds available in the market. We assume that accessibility to a mobile phone will have a positive relation with using hybrid seed. We coded access to the mobile as 1 and 0 otherwise in our dataset. The size of a household is a continuous variable that shows the total number of people living in a household. It is expected that large family size will have a negative effect in opting for hybrid seed because hybrid varieties are expensive and it will be difficult for larger households to have enough resources to buy new seed each year. We also included the age of the household, his education, and marital status to see how they influenced the decision to choose hybrid varieties. The cultural factors also influence the decision-making process, since in the study area decisions are mostly made by male members of the household and therefore it is expected that gender affects the adoption decision of hybrid rice variety. The code for males is 1 while 0 for females for this study.

After the probit model estimation, we estimated the association between using hybrid rice varieties and our outcome variables like yield, income, and profit. With the condition of a random selection of hybrid, impact through OLS regression can be identified. The farmers in the study area had a choice to use hybrid rice seed and Open Pollinated Varieties (OPV). It can be shown in equation form as under:

$$\mathbf{Y_{ij} = \beta_0 + X_i \beta_1 + U_{ij}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

In the above equation, Y_i is the outcome variable in plot j of the households i. Xij is the main variable of interest which is equal to 1 if the farmer is using hybrid seed in plot j β is the coefficient and Uij is the error term. The main explanatory variable in the study is rice yield or output and the main dependent variable in this study is in binary form. The income from rice cultivation here is defined as gross output value minus paid-out cost. The paid-out cost includes the cost of seeds, fertilizer, pesticides, herbicides, and other purchased inputs. Paid-out cost also includes the cost of hired labor, contractual labor (including the cost of rental machinery), and the cost of irrigation. The profit is calculated by subtracting the cost of imputed family labor from the income. The imputed cost of family labor is calculated by taking the average median wage rate at the village level. The wages for men and women were different in each village and hence they are calculated separately before merging as imputed family labor cost.

There would be a possibility of Uij to be correlated with β_1 and other unobservable characteristics, as the condition of random allocation of hybrid is not likely to hold which may cause bias in OLS estimates of β_1. To address this issue, Oster estimates were used. The methodology was developed by Oster (2019). This test allows to have the information only if the selection of observables is informative about the selection of the unobservable. The Oster estimates have considered firstly the coefficient movement and secondly the movements of the value of R-squared, which allow us to identify the omitted variable bias. The test can be conducted by using two methods, by calculating the value of δ. The appropriate cutoff point of δ is 1 and it can be written in mathematical form as

$$\delta = \frac{(\tilde{\beta} - \beta^*)\,(\tilde{R} - R^o)}{(\beta^o - \tilde{\beta})\,(R_{max} - \tilde{R})}$$

Where δ = degree of section of unobservable to the observables that are required to derive the estimated coefficient to zero

$\tilde{\beta}$ and $\tilde{R}$ = values that included observable controls

R^o = value of R^2 in simple regression

β^o = coefficient of treatment dummy

β^* = value of coefficient

R_{max} = value of R^2 which is $1.3\tilde{R}$ for R_{max}

Estimating coefficient bounds is the second approach to conduct other estimates. In this case, one bound is $\tilde{\beta}$. It is the value of β when δ = 0. The second bound is β* which is the value of β when δ = 1 and $R^2 = R_{max}$ as defined earlier. The estimate assumes that the estimated coefficient bounds interval does not have zero value. If that is the case, we can say with confidence that estimates are robust to unobservables. To verify and correlate our results, we used both methods to carry out our results.

Further robustness checks of our estimates, we used the Average Treatment Effect on Treated (ATT) of adopting hybrid varieties by using the propensity score matching (PSM) technique by Rosenbaum & Rubin (1983). Estimating ATT by matching has become a popular method Becker & Caliendo (2007). The propensity score provides a way to infer causality in conditions were randomized controlled trials are not possible (Beal & Kupzyk, 2014). The PSM technique estimates the propensity of farmers to use hyrid variety and is estimated by using the probit regression as a function of observable characteristics. Further, it matches the farmer with similar propensities and produces a variable that is called propensity score, which in our case is the probability that the farmer would use hybrid rice varieties based on the farmer's observable characteristics as discussed earlier. PSM technique, therefore, balances the distribution of covariates among the users of hybrid (adopters) and OPVs (non-adopters) based on predicted probabilities for using hybrid rice varieties. The propensity score matching technique by calculating ATT is consistent with Mendola (2007) where the results have shown the positive effect of technology adoption on farm household wellbeing.The propensity score (P(x)) can be written as:

$P(x) = Pr(T = 1| X = x)$ ………………………..

In the estimation of the PSM technique, two matching algorithms i.e. kernel-based matching (KBM) and nearest neighbor matching (NNM), which are widely used in the literature, were used. KBM measures the treatment effect by subtracting from each observed outcome in the treatment group and the weighted average of outcomes in the comparison group, whereas, NNM pairs the non-users and users having similar propensities. The average treatment effect on treated (ATT) is then estimated by the average of differences within the match of outcome variables among the non-users and users of hybrid varieties. Mathematically it can be written as:

$$\boldsymbol{ATT^{PSM}} = \boldsymbol{E}\left[Y_{ij} | X_{ij} = 1, p(Z_{ij})\right] - \boldsymbol{E}\left[Y_{ij} | X_{ij} = 0, p(Z_{ij})\right] \ldots\ldots \text{(ii)}$$

Where p(Zij) represents propensity score for adopting hybrid varieties and E (·) represents the expectation operator. Propensity scores were obtained through the estimation of the probit model for selection into hybrids as discussed above. This technique of using PSM has enabled us to control for the bias due to observable characteristics. However, the major limitation of PSM is that it cannot yield unbiased estimates if there are certain unobservable characteristics, which affect both the adoption of hybrids and outcome variables. To check the robustness of the PSM estimates to the unobserved heterogeneity, we carried out a sensitivity test proposed by Rosenbaum (2002). Individuals with the same observed covariates may have different probabilities of being exposed if they have different unobserved covariates. A sensitivity parameter is used to quantify the difference in the odds of exposure for two individuals with the same observed covariates (or the same propensity score) but diverging on unobserved covariates. The goal is to determine the smallest value of this parameter that will change the p-value of the "true" outcome-exposure association to a non-significant level.

Results and Discussion

Table 2. shows the results of t-tests of the mean difference between hybrid and OPV varieties. We also conducted a basic descriptive analysis of household and farm characteristics (Appendix Table A). The results of t-tests are significant for hybrid rice varieties in terms of yield, revenue, income, and profit. The yield has increased by 1.53 tons per hectare by using hybrid rice varieties in comparison with OPV varieties. This shows that the usage of hybrid rice varieties in the area had significantly increased the crop production per hectare. Similarly, the results of the t-test are also significant for the income and profit of farmers. The farmers are earning a higher income of 315.29 USD/ha more by using hybrid rice varieties in the study area. Input costs for using fertilizers, pesticides, labor, and machinery are non-significant but remain on the lower side for hybrid varieties showing that germination and growth of hybrid varieties do not require more intake of inputs in comparison with OPV's or taking into account the fact that hybrid varieties require more inputs i.e irrigation and fertilizer.

Table 3 shows probit model estimates for the participation of farmers in selecting hybrid seeds. It was an important check since the hybrid seed is not randomly assigned. There is a likelihood that farmers in the study area have different traits as compared to farmers who are not using hybrid seed or OPV. Therefore, these characteristics were estimated by running a probit model. For the estimation of the probit model, different household characteristics and plot level characteristics were used. Table 3 shows the results of estimates that show that plot size has a significant impact on farmer's decision to choose hybrid rice varieties for cultivation. More the plot or farm area means more likelihood of getting higher yield by changing the quality of seed. There is also a likelihood that farmers with larger plot sizes have better resources, they can easily afford the cost of hybrid seed, and that is why there is a positive association between selection into hybrid and plot size. We also see a negative relation between farmers who hold the dry seed for cultivation in the next year. That is because hybrid varieties have to be changed every year and there is a negative effect on selection into hybrid seed where farmers are saving the seed. The results showed a positive association for the selection of hybrid rice varieties for the households that own agricultural land in the area. Since, the tenant farming system is also a source of agriculture cultivation in the study area and tenants get the seed provided by the landowner or they can only cultivate what is allowed by the landowners, the household that owns agriculture land has the freedom of choice to select the rice variety. It should also be noted that owning land makes a farmer better off in terms of financial position as compared to the farmers who have rented the agricultural land or are tenants. We also checked the link for the source of irrigation on the farmer's selection into a hybrid.

The probit results showed tube well irrigation having a positive connection with farmers' choice for selection into hybrids. While canal irrigation and no source of irrigation (dependence on rainfall) have no impact on the choice of farmer for hybrid seed preference. This shows that well-being of farmers to have an addition source of irrigation has a link with selection into a hybrid. Since tube-well installation needs high cost and running the tube-well in the area is mostly carried out through diesel generators because of electricity shortage in the area, the cost of the generator is also high and therefore, only financially well-off farmers can have an additional source of irrigation and that is the reason it is positively related to farmers choice for selection into a hybrid. In addition, the availability of electricity is negatively linked because people in the area are using generators to meet the energy requirements. Distance to the market is also negative which means that the greater the distance of farmers from the market there is less likelihood that they will go for hybrid seed. Furthermore, agriculture extension services in the study area also have a positive association with farmers' decision to select hybrid rice varieties and results are highly significant at a 1% level of significance. Access to mobile phones is also positive and this confirms that communication through an extension service or mobile phone increases the chances of a farmer's selection into a hybrid. The size of households is negatively related because large families have more consumption expenditure and less savings and therefore there are fewer chances to buy expensive seeds that also have to be changed every year. There is no association between age, education, and marital status of household on selection. The possible explanation of this could be the fact that farming is the main source of household income and is traditionally in the family system and therefore age, education level of marriage status do not affect the household's decision in selecting hybrid seed. Male household is significantly linked with choice for selection, which is an obvious fact, as males are major decision-makers in the study area.

Table 2. Yield and costs of inputs across traditional and hybrid rice varieties (plot level data)

Variable	**OPV Variety**	**Hybrid Variety**	**t-test**
	(a)	**(b)**	**(a) - (b)**
Use of chemical fertilizer (kg/ha)	229	232	-3.06
Use of insecticide and herbicide (kg/ha)	0.020	0.1280	-0.11
Yield (t/ha)	4.666	6.195	-1.53***
Revenue (USD/ha)	897.3	1191.3	-294.08***
Total input costs (USD/ha)	259.8	238.6	21.22

Paid-out cost of labor use (USD/ha)	29.7	19.8	9.97
Imputed costs of family labor (USD/ha)	160.9	139.5	21.39
Paid-out cost of machinery and animal use (USD/ha)	99.0	91.2	7.80
Imputed cost of machinery and animal use for (USD/ha)	2.6	2.4	0.20
Income (USD/ha)	637.5	952.8	-315.29***
Profit (USD/ha)	476.6	813.3	-336.68***
Observations	316	354	

*** p<0.01, ** p<0.05, * p<0.1

Table 3: Probit model estimates for the selection of hybrid

VARIABLES	Dummy hybrid (1=yes)
Size of Plot	0.0144*
	(0.00756)
Dry seed at home	-0.876***
	(0.132)
Land ownership of household	0.254*
	(0.130)
Canal irrigation	0.550
	(0.542)
Tube-well irrigation	0.416*
	(0.245)
No Irrigation source	0.311
	(0.199)
Availability of electricity	-0.309*
	(0.178)
Distance to market	-0.0178*
	(0.00932)
Extension Services	0.567***
	(0.164)
Access to mobile	0.271*
	(0.163)
Household size	-0.0308**
	(0.0133)
Household Age	0.00294
	(0.00499)
Household education	-0.0498
	(0.134)
Male households	0.0767**
	(0.0390)
Married	-0.306
	(0.200)
Disrict fixed effect	Yes
Constant	-1.806***
	(0.669)
Observations	670

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

After the probit model, we analyzed the association between our dependent variable i.e. hybrid variety and outcome variables. In the third column of Table 4. The farmers using hybrid rice varieties receive a significantly higher yield of 1.2 tons per hectare. The revenue, income, and profit are also significantly higher for the hybrid rice growers. We did not see any significant difference in the use of fertilizer and pesticides. In addition, there is also no significant difference in machinery and labor costs for hybrid users. Table 4 also shows the Oster estimates that were carried out to check the robustness of OLS estimates. The results of Oster's (2019) estimates further ensure that the coefficients are robust to unobservable as both the value of δ and coefficient bounds point to the robustness of our analysis. Our alpha value is greater than 1 for the use of fertilizer, pesticides, yield, revenue, input cost, paid-out cost of machinery, income, and profit, while it is negative for the paid-out cost of labor and imputed cost of machinery. The negative value implies that this test is not appropriate to test for unobservables in the case of these variables. The identified set on the other hand also shows that the results are robust to the unobservables. Hence, we can justify our OLS estimates with confidence that unobservables are not creating any biasedness in our estimates. This implies that the value of δ as well as coefficient bounds showed robustness in our estimates. However, the value is greater than 1, therefore estimates are robust to the unobserved heterogeneity problem. In addition, the identified set or coefficient bounds interval does not contain zero, which also shows that the estimates are robust to the unobserved heterogeneity. For example, the value of δ = 1.99 in row three column four for the effect of hybrid seed on yield of rice crop shows that the unobservable has to be 1.99 times as important as the control variables to drive this treatment effect to be zero. As the value is greater than 1, the effect can be considered robust to the observed heterogeneity problem. Similarly, if we see the coefficient bounds interval in the case of yield [1.529, 1.20], which does not contain zero, therefore we can imply that the estimates are robust.

Prosperity score matching (PSM) was used to estimate the input of hybrid rice variation on our outcome variable. The Prosperity score is a predicated probability of use, estimated from probit regression of hybrid rice varieties on prediction. To test the quality of the match, we draw a common support graph as shown in Appendix 3. The test shows the visual presentation of an overlapping proposition between treatments and controls. The good match of treatment and the control cases is a result of larger overlapping. The graphs show a considerable overlap of propensity scores among treatments and controls, which shows a balanced and good match. The results of balancing tests are shown in Annexure 2. The empirical results of the hybrid rice varieties' impact on crop yield, input costs, income, and profit are shown in Table 5. The result showed that the use of hybrid rice varieties had a significant and positive effect on rice yield, income, and profits in the study area. Our estimates showed that ATT hybrid rice varieties on crop yield for the user were 0.94/ha for KBM and 1.01 t/ha for NNM, which shows that the casual effect of using hybrid rice varieties on crop yield is between 0.94 t/ha to 1.01 t/ha. Similarly, the income and profit of farmers using hybrid rice varieties are also significant which shows that farmers using hybrid varieties received an increased profit of 309.02 USD/ha and 316.71 ISD/ha for KBM and NNM matching respectively as compared to the farmer using OPV’s in the study area. Table 5 also shows the value of the odds ratio, carried out by using the Rosenbaum bounds test for sensitivity analysis. The value of the odds ratio of hybrid variety use can alter the results and values of the estimates. The odds ratio to alter the result ranged from 4.25 (KBM) to 4.5 (NNM) for crop yield implying that unobservable characteristics have to increase the odd ratio of hybrid varieties use by 425% to 450% before it can alter the result.

Table 4. Estimation results of Oster's OLS

Outcome variables	**Coefficient**	**S.E**	**δ for β = 0**	**Coefficient bounds**	**N**
Use of chemical fertilizer (kg/ha)	9.264	29.65	-6.74	[3.058, 9.264]	670
Use of insectcide and herbicide (kg/ha)	0.079	0.069	2.42	[0.108, 0.079]	670
Yield (t/ha)	1.200***	0.213	1.99	[1.529, 1.200]	670
Revenue (USD/ha)	230.849***	41.067	1.99	[294.076, 230.849]	670
Total input costs (USD/ha)	-36.054	55.37	8.84	[-21.215, -36.054]	670
Paid-out cost of labor use (USD/ha)	-22.821	14.159	-4.88	[-9.97232 , -22.821]	670

Imputed costs of family labor (USD/ha)	-5.228	23.906	0.59	[-21.39121, -5.228]	670
Paid-out cost of machinery and animal use (USD/ha)	-9.426	22.694	9.12	[-7.80305, -9.426]	670
Imputed cost of machinery and animal use for (USD/ha)	0.702	2.165	-2.43	[-0.199, 0.702]	670
Income (USD/ha)	266.903***	55.693	2.12	[315.291, 266.903]	670
Profit (USD/ha)	272.132***	66.723	2.05	[336.282, 272.132]	670

Note: The identified set is bounded below by βˇand above by β^∗ calculated based on R_max and δˇ = 1 ∏ = 1.3
Beta calculate treatment effect, Delta calculate relative degree of selection
*** p<0.01, ** p<0.05, * p<0.1

Table 5. ATT Estimation Results

Treatment : **Control :**										
			Kernel Matching			**NN Matching**				
	Treatment	**Control**	**ATT**	**S.E.**	**Rosenbaum bounds critical level of odds ratio**	**ATT**	**S.E.**	**Rosenbaum bounds critical level of odds ratio**	**N**	**Off support in PSM**
Use of chemical fertilizer (kg/ha)	232.44	229.38	-5.69	46.66	1.5	13.11	38.98	1.75	670	11
Use of insectcide and herbicide (kg/ha)	0.30	0.03	0.22	0.16	1.00	0.25*	0.15	8	670	11
Yield (t/ha)	6.19	4.67	0.94***	0.37	4.25	1.01***	0.41	4.5	670	11
Revenue (USD/ha)	1191.34	897.26	181.44***	70.59	4.25	194.38***	79.22	4.5	670	11
Total input costs (USD/ha)	238.56	259.77	-100.32	91.28	n.a	-110.07	104.85	n.a	670	11
Paid-out cost of labor use (USD/ha)	19.76	29.73	-47.11	36.42	n.a	-57.29	44.44	n.a	670	11
Imputed costs of family labor (USD/ha)	139.50	160.89	-27.26	34.78	n.a	-12.26	34.34	n.a	670	11
Paid-out cost of machinery and animal use (USD/ha)	91.17	98.97	-45.22	47.43	n.a	-55.67	55.32	n.a	670	11
Imputed cost of machinery and animal use for (USD/ha)	5.28	6.07	3.82	2.65	1	5.03**	2.56	n.a	670	11
Income (USD/ha)	952.78	637.49	281.76**	122.77	8.25	304.45**	139.29	5.75	670	11
Profit (USD/ha)	813.28	476.60	309.02**	140.48	7.75	316.71**	156.30	5.25	670	11

Standard errors are obtained by bootstrapping with 100 replications.
*** p<0.01, ** p<0.05, * p<0.1

Conclusion

This study mainly focused on providing an answer to the concern of how much impact on rice crop yield is achieved by using hybrid rice varieties and what is its contribution to farmer's income and profit. We found that plot size, ownership of land, source of irrigation, access to mobile distance to market, and extension services are among the main drivers of using hybrid rice varieties. This study showed that the usage of hybrid seeds had significantly increased the average yield of rice, which has benefited the farmers in the area. The findings of the study showed that improved rice technology had a robust and positive effect on the average yield of rice crops, which increased by around 1.2 tons per hectare in Sindh Province, Pakistan. The increase in yield enhanced farmer's income and profit, which increased household income. We also found that the hybrid rice varieties used in the study area have no significantly higher cost as compared to open-pollinated varieties grown in the area. This is an important finding of the study because hybrid varieties are mostly associated with higher input costs to generate higher yields, however, in our case, we found that input cost is almost the same between hybrid varieties and OPVs. We suggest to governments, policymakers, and other funding agencies with similar interests to exploit and disseminate the use of certified hybrid rice varieties to create further awareness to achieve higher rice crop yield and farmers' livelihood.

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Appendices

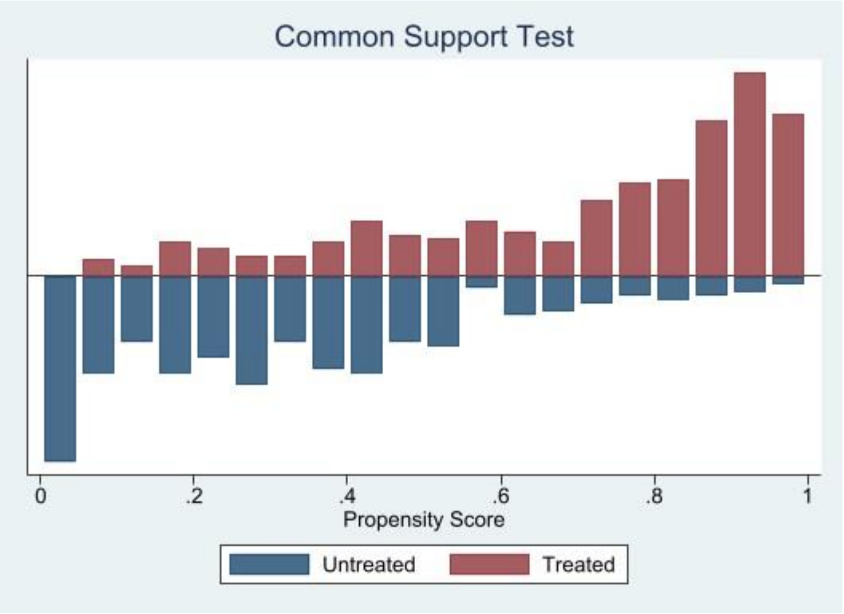
Appendix 1. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Household Size	670	13.44	7.29	1	40
School Education (1=any level of schooling)	670	0.61	0.49	0	1
Age of Member (Number of years)	670	40.40	13.45	16	80
Children below 5 years (Numbers)	670	2.58	2.28	0	12
Children over 4 and below 15 years (Numbers)	670	3.71	3.82	0	40
Male Member of Household (Numbers)	670	3.83	2.48	1	20
Female Member of Household (Numbers)	670	3.52	2.23	0	20
Married (1=yes)	670	0.88	0.33	0	1
Distance from Nearest Market (Kilometer)	670	7.09	5.77	0	50
Mobile (1=yes)	670	0.82	0.39	0	1
Electricity (1=yes)	670	0.81	0.39	0	1
Extension Services	670	0.83	0.37	0	1
Size of Plot	670	5.39	7.59	0.5	150
Dry seed at home	670	0.34	0.47	0	1
Land ownership of household	670	0.61	0.49	0	1
Canal irrigation	670	0.99	0.11	0	1
Tube-well irrigation	670	0.22	0.42	0	1
No Irrigation source	670	0.70	0.46	0	1
Use of chemical fertilizer (kg/ha)	670	230.99	276.03	0	2965.26
Use of insectcide and herbicide (kg/ha)	670	0.08	1.00	0	22.24
Yield (t/ha)	670	5.47	2.52	0.10	17.91
Revenue (USD/ha)	670	1052.64	484.91	19.01	3444.32
Total input costs (USD/ha)	670	248.56	323.85	0	4272.07
Paid-out cost of labor use (USD/ha)	670	24.46	85.78	0	1915.07
Imputed costs of family labor (USD/ha)	670	149.58	240.96	0	1760.75
Paid-out cost of machinery and animal use (USD/ha)	670	94.85	161.63	0	2357.00
Imputed cost of machinery and animal use for (USD/ha)	670	2.54	20.73	0	298.99
Income (USD/ha)	670	804.07	559.68	-3511.74	3444.32
Profit (USD/ha)	670	654.49	652.81	-3706.96	3444.32

Appendix 2. Results of balancing tests

Variable		Mean		%reduct		t-test	
		Treatment	Control	%bias	bias	t-test	p>t
Size of Plot	Unmatched	5.3234	5.4565	-1.7		-0.23	0.821
	Matched	5.3234	3.8887	18.6	-978.5	2.8	0.005
Dry seed at home	Unmatched	0.16384	0.53165	-83.6		-10.89	0
	Matched	0.16384	0.19209	-6.4	92.3	-0.98	0.327
Land ownership of household	Unmatched	0.64124	0.56962	14.7		1.9	0.058
	Matched	0.64124	0.55838	17	-15.7	2.26	0.024
Canal irrigation	Unmatched	0.99153	0.98418	6.7		0.87	0.383
	Matched	0.99153	0.99906	-6.9	-2.5	-1.46	0.144
Tube-well irrigation	Unmatched	0.27401	0.16139	27.5		3.54	0
	Matched	0.27401	0.30132	-6.7	75.8	-0.8	0.423
No Irrigation source	Unmatched	0.68079	0.72785	-10.3		-1.33	0.184
	Matched	0.68079	0.6742	1.4	86	0.19	0.851
Availability of electricity	Unmatched	0.78531	0.83228	-11.9		-1.54	0.124
	Matched	0.78531	0.66855	29.7	-148.6	3.51	0
Distance to market	Unmatched	7.3927	6.75	11		1.44	0.151
	Matched	7.3927	6.4736	15.8	-43	2.81	0.005
Extension Services	Unmatched	0.88983	0.76899	32.5		4.23	0
	Matched	0.88983	0.84652	11.6	64.2	1.7	0.089
Access to mobile	Unmatched	0.82203	0.81329	2.3		0.29	0.77
	Matched	0.82203	0.84463	-5.8	-158.5	-0.81	0.421
Household size	Unmatched	13.22	13.693	-6.5		-0.84	0.403
	Matched	13.22	13.667	-6.1	5.6	-0.83	0.407
Household Age	Unmatched	40.466	40.316	1.1		0.14	0.886
	Matched	40.466	39.303	8.6	-677.1	1.22	0.223
Household education	Unmatched	0.63277	0.57911	11		1.42	0.156
	Matched	0.63277	0.62618	1.3	87.7	0.18	0.856
Male households	Unmatched	3.9774	3.6614	12.8		1.65	0.1
	Matched	3.9774	3.9793	-0.1	99.4	-0.01	0.993
Married	Unmatched	0.86158	0.89557	-10.4		-1.34	0.181
	Matched	0.86158	0.86158	-1.7	83.4	-0.22	0.827

Appendix 3.


Common Support Test
0
.2
.4
.6
.8
1
Propensity Score
Untreated
Treated

تأثير الأصناف الهجينة على إنتاجية زراعة الأرز: حالة السند، باكستان

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ملخص

تعتبر الزراعة قطاعا هاما للغاية وحاسما للحد من الفقر وتوليد فرص العمل. لقد تمت مناقشة استخدام البذور الهجينة التي تؤدي إلى زيادة إنتاجية المحاصيل ودخل المزارعين على نطاق واسع في الأدبيات. من خلال هذه الدراسة تم بذل جهد لتحديد العوامل التي تؤثر في الحصول على إنتاجية عالية من محصول الأرز باستخدام الأصناف الهجينة. تركز هذه الدراسة على استخدام الأصناف الهجينة في محصول الأرز وتقدم مقارنة في المحصول مع الأصناف التقليدية مفتوحة التلقيح. تم استخدام المعلومات على مستوى قطعة الأرض التي تم جمعها من ثماني مناطق رئيسية لإنتاج الأرز في مقاطعة السند في باكستان لإجراء هذه الدراسة، كما تم استخدام تقنية مطابقة درجة الميل لتقدير نتائج الدراسة باستخدام تباين مستوى قطعة الأرض بين الأصناف الهجينة وأصناف مفتوحة التلقيح. أظهرت نتائج الدراسة تحسناً ملحوظاً في محصول الأرز مع اعتماد أصناف الأرز الهجين في منطقة الدراسة. حيث اظهرت هذه الدراسة أن المزارعين قد حققوا متوسط إنتاجية أعلى من الأرز باستخدام البذور الهجينة مقارنة بالأصناف مفتوحة التلقيح. وإلى جانب إنتاج المحاصيل، زاد الدخل الإجمالي وأرباح المزارعين أيضًا باستخدام البذور الهجينة في مقاطعة السند. توضح الدراسة أنماطًا مختلفة مثيرة للاهتمام تتعلق بخصائص مختلفة للأسرة التي تزرع محاصيل الأرز، وخصائص مختلفة على مستوى قطعة الأرض، ومقارنتها بالأصناف الهجينة والتقليدية.

الكلمات الدالة: البذور الهجينة، مفتوحة التلقيح

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