

Field-Based Yield Gap Analysis of Basmati Rice: A Case Study of Two Districts in Central Punjab, Pakistan

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Understanding the yield gaps in rice-based farming systems is crucial for achieving food security. Pakistan is the 11th largest rice producer, and rice contributes 0.7 percent to the country's GDP. The country faces a yield gap across farms and rice-producing districts, with actual yields falling short of potential yields. This study assesses the productivity and yield differences in paddy rice farming in selected districts of Central Punjab. Two major rice-producing districts, Gujranwala and Sheikhupura, were randomly selected for analysis. This study finds significant yield gaps in rice production across the selected districts. On average, the combined yield gap is 31 percent, rising to 36 percent for Basmati rice. At the district level, Gujranwala records a total yield gap slightly lower than that of Sheikhupura. For Basmati rice, the gaps are even higher for both districts. These results highlight significant potential for productivity gains, underscoring the importance of reducing inefficiencies in rice farming systems. The exploitable yield gap was calculated by comparing the yield of the top 10 percent of farmers with the population average using the top-decile approach, also known as on-farm yield potential. The study identifies the importance of farm extension services in limiting the yield gap. Policymaking should focus on improving the relationship between farm extension agents and farmers and on ensuring the timely, affordable availability of necessary resources.

Keywords: Rice, Small-Scale Farmers, Yield Gap, Exports, Punjab, Pakistan.

1. INTRODUCTION

Rice is a major cereal in Pakistan, considerably contributing to export base and the domestic food security. Rice is one of the five major crops and the second most widely cultivated staple food in the country. Pakistan produces a surplus of rice and exports it to build foreign reserves. Rice is Pakistan's second-largest export commodity after cotton (Government of Pakistan, 2021).

There are two primary types of rice varieties cultivated in Pakistan: coarse and fine. Fine varieties, including Basmati rice, are preferred worldwide for their exceptional taste and aromatic qualities. Basmati rice attracts customers and commands a higher sales price than that of non-Basmati rice. Super Kernel, PK-386, Super Basmati, Kainat, and Basmati-515 are the most common fine varieties known for their aroma, texture, colour, and taste (Ejaz, et al. 2020).

Pakistani Basmati rice has been a popular choice among consumers, but its market share has been declining internationally over the years. Pakistan lost its share of Basmati

from 46 percent to 10 percent between 2006 and 2017 due to India capturing the global Basmati market with the introduction of the Pusa-1509 variety (Saeed, et al. 2020). Technological innovations, increased production efficiency, and effective marketing tactics have made India more competitive, while rice farmers in Pakistan face higher production costs and inefficiencies related to conventional methods (Abdullah, et al. 2013; Javed, et al. 2015; Rizwan, et al. 2020; Saeed, et al. 2020).

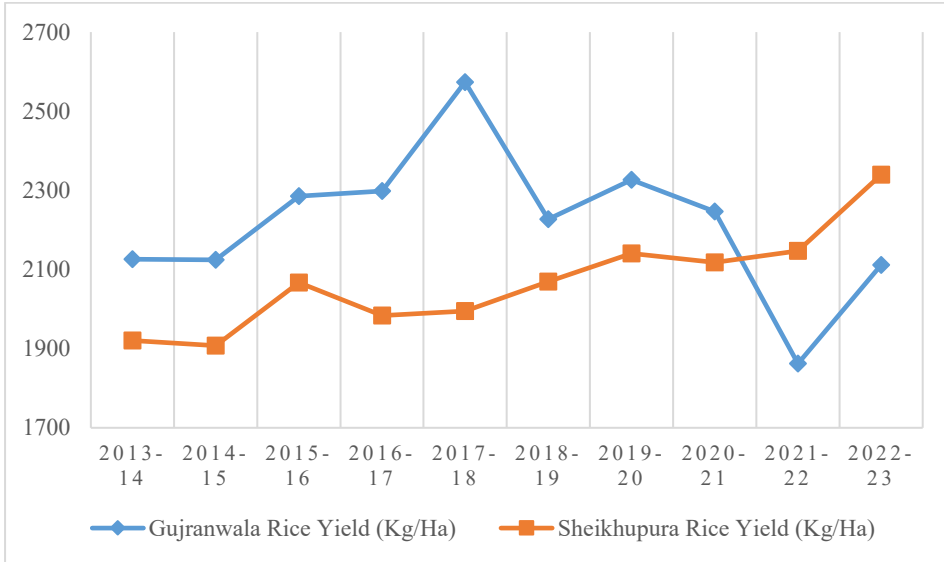
Pakistan is divided into four provinces: Punjab, Sindh, Khyber Pakhtunkhwa (KPK), and Balochistan. Punjab is the leading rice-producing province, contributing 5.779 million tonnes in 2021–22, followed by Sindh with 2.566 million tonnes (Table 1). A major policy concern is the minimum per-hectare yield of Punjab among all provinces despite its dominance in production and output share. Punjab is widely known for Basmati rice, considered unique worldwide and preferred for its aroma, whereas Sindh is renowned for coarse IRRI varieties (Taniguchi, 2018). Kainat PK-1121 and Super Basmati are two widely cultivated varieties in Punjab that account for 28.3 percent and 69.2 percent of the total Basmati area, respectively (Saeed, et al. 2020).

Punjab is known for Basmati production, accounting for over 3600 thousand tons. Punjab consistently produces an average of 54.5 percent of the country's rice, followed by Sindh at 36.2 percent, Balochistan at 7.2 percent, and KPK at 2.1 percent. Punjab's basmati yield followed an upward trend from 2011 to 2018 but showed variations afterward: a slight drop of 50 kg/ha in 2019, a rise of 193 kg/ha in 2020, and a decrease of 87 kg/ha in 2022. Despite the low and fluctuating yields, Punjab remains the leading region for Basmati rice production in Pakistan (API, 2020).

In recent years, rice yields observed in Pakistan have been low. Yield gaps are more noticeable in Punjab, which endures considerable variations in rice yields and still contributes over half of the domestic output. We sampled from Punjab's top rice-producing districts: Gujranwala and Sheikhupura. Historical data from the crop reporting survey (CRS) show that rice yields in Gujranwala fluctuate more than those in Sheikhupura (see Figure 1). Rice production is adversely affected by environmental factors, including erratic rainfall and temperature trends, as well as biotic and abiotic stresses, leading to sharp reductions in rice yields (Ahmed, et al. 2019; Rizwan, et al. 2020; Abbas & Mayo, 2021). Besides environmental challenges, agronomic factors such as suboptimal fertilizer uptake, which are essential for plant growth, also reduce rice output (Khaliq, et al. 2019). Combined stress from climate factors and inadequate nutrient delivery poses significant obstacles to achieving optimal yields in Pakistan's rice sector.

Rice farmers need to monitor these trends and adapt their farming practices accordingly to ensure stable and consistent yields in the future. Additionally, seeking guidance from agricultural experts (Ferroni & Zhou, 2012; Danso-Abbeam, et al. 2018) and adopting modern farming technologies can help ensure stable, consistent yields in the future (Barham, et al. 2018; Verma & Sinha, 2018).

Rice farmers are facing numerous problems due to rising input prices (Rizwan, et al. 2020) and the high cost and limited availability of fertilizers (Javed, et al. 2015), both of which pose a serious threat to their exports. There is a need to manage the export process for rice, as there is a greater scope to increase net exports of Super Basmati Rice in the international market. The Rice Exporters Association of Pakistan (REAP) encourages rice exporters to use their brand names and labels to secure higher prices and own their products (Javed, et al. 2015). Socioeconomic factors, such as limited information and low levels of education, exacerbate the situation for rice farmers in Punjab, Pakistan.

Fig. 1. Rice Yield Trends in Gujranwala and Sheikhupura Districts

Source: crop reporting survey, unit: kg/ha.

To overcome these challenges, farmers require training in every aspect of production, including land preparation, seed and seedling management, water and weed control, fertilization, disease and pest control, harvesting, and post-harvesting procedures, with particular emphasis on weed and water management training, which are the most important aspects for training rice growers (Riaz, et al. 2021). These issues have led to disparities in rice yields among farmers, as the national potential rice grain yield is 9,267 kg/ha, whereas actual yields average just 2,483 kg/ha, creating a yield gap of 6,784 kg/ha (ZTBL, 2020). The average yield gap for Basmati rice in Gujranwala is 33 percent. Khaliq et al. (2019) identify Nitrogen deficiency as a leading factor for yield gaps in this region.

In order to overcome the increasing challenges of rice growers, there is a need to shift from the conventional sowing method, which demands abundant labour, to direct seeding of rice (Ishfaq, et al. 2021) and invest in human capital to increase the technical and allocative efficiency of small-scale farmers (Mahmood, et al. 2022). Small-scale rice growers can increase their efficiency by incorporating advanced agricultural machinery and technologies into their cultivation methods (ADB, 2018).

Overall, the existing literature provides key understandings of rice yield fluctuations in Pakistan and comparable contexts. Although, it highlights environmental, economic, and institutional barriers, it often lacks a detailed, segmented analysis of heterogeneous productivity among farmers. In this regard, the present study applies the top decile approach in Gujranwala and Sheikhupura districts, in order to identify evidence-based strategies aligned with the context of smallholder rice systems in Pakistan.

The rest of the paper is as follows. Section 2 describes the policy significance of the yield gap, followed by the theoretical framework given in Section 3. The research methodology is delineated in Section 4. The results are discussed in Sections 5 and 6, while Section 7 concludes the study.

2. POLICY SIGNIFICANCE OF THE YIELD GAP

Basmati rice is a cash crop of Pakistan's agricultural economy and a leading pillar of food security and export earnings. While it is crucial, yield differentials are a major policy concern, as Punjab's basmati-producing regions consistently fall short of their potential. A significant body of research has examined rice yield optimization, focusing on agronomic practices (Riaz, et al. 2021; Arshad, et al. 2017), varietal performance (Zohaib, et al. 2022), and the impact of biotic and abiotic stresses (Rizwan, et al. 2020). Despite this, these studies do not provide a quantification of a sufficiently localized yield gap, restricting their scope for tailored strategies. Furthermore, although limited research has been conducted to explore yield-limiting factors, there is a lack of structured, empirical yield-gap analysis across various agro-climatic regions. These shortcomings obstruct the identification of primary regions where intervention could successfully produce optimal results by enhancing yield and export development, and underscore the demand for a more systematic, field-based yield-gap analysis in key basmati-producing districts of Punjab, Pakistan. It further identifies area-wise patterns of yield gaps and site-specific measures for optimizing resource allocation. These evidence-based findings would be critical for informing policies and guiding future research into the determinants of yield constraints.

This study examines the above analytical issues by applying a rigorous, data-driven approach through systematic field trials in Gujranwala and Sheikhupura districts. These districts were chosen because they are within the basmati-producing hub of Punjab and were among the 32 districts that sustain some of the highest financial and yield losses due to climate change. Such characteristics make these districts significant cases for quantifying basmati rice yield and climate-smart agricultural adaptations. Although identifying directly the underlying factors that drive yield gaps is not the aim of this study, yet this analysis lays the groundwork for subsequent investigations of determinants by linking on-ground surveys with primary data. This investigation underscores the role of the agricultural department in rationalizing resource allocation and infrastructure development to minimize yield gaps and adopt actionable strategies for export-driven agricultural growth. Furthermore, it implies that extension services must disseminate tailored solutions, such as precise agriculture tools and climate-resilient practices, to address key challenges facing rice cultivators.

3. THEORETICAL FRAMEWORK

The research framework of this study is based on Production Economics and Efficiency Theory, and the Diffusion of Innovations Theory (Rogers, 2003). Taken together, our frameworks elucidate both the structural and behavioral aspects of heterogeneous production among rice cultivators. The production efficiency theory provides an analytical foundation for assessing on-farm yield gaps, whereas the Diffusion theory offers a behavioral rationale for why such productivity variance persists within the rather similar agro-ecological environments.

3.1. Production Economics and Efficiency Theory

Production Economics and Efficiency Theory conceptualise productivity differences as variations in farmers' distance from the production frontier (Farrell, 1957; Kumbhakar & Lovell, 2000). The production frontier represents the maximum attainable output under existing technology, resource endowments, and agro-ecological conditions. Farmers operating below this frontier exhibit technical inefficiency, as measured by the yield gap.

Formally, let $\hat{y}_d^{90}$ denote the average yield of the top 10 percent of farms in district d and y_{id} , the observed yield of farm i . The yield gap for farm i is as below.

$$YieldGap_{id} = \hat{y}_d^{90} - y_{id} \quad (1)$$

The relative efficiency (or yield-gap ratio) can be expressed as follows.

$$TE_{id} = \frac{y_{id}}{\hat{y}_d^{90}} \quad (2)$$

The key objective of this study is to determine the yield gap as a percentage.

$$Yield\ Gap\ \% = \frac{Yield\ Gap}{Economic\ Yield} \times 100 \quad (3)$$

Equation (1) measures the absolute shortfall from the empirical frontier in kg/ha. Equation (2) measures the proportional efficiency of each farm relative to the top-performers benchmark, but this study will instead focus on Equation (3), which estimates the yield gap as a percentage, providing a more intuitive metric than Equation (2). Lobell et al. (2009) introduced the top-decile approach, which is an explicit and empirically supported estimation method. This approach evaluates each farmer's productivity relative to the mean output in a district.

This model highlights that productivity differentials are not limited to agro-ecological constraints, but suboptimal production techniques also contribute to yield disparity when implemented on rice growers in Punjab. The study investigates rice farmers in selected villages of Gujranwala and Sheikhpura districts. The study provides a district-specific analysis of the productivity gap by contextualizing it within efficiency theory and applying the top-decile approach. These estimates offer a benchmark for future research seeking to identify the drivers of performance bottlenecks and implement optimized solutions to reduce productivity gaps.

3.2. Diffusion of Innovations Theory

The determinants of yield gaps are theoretically aligned with diffusion of innovation theory (Rogers, 2003). This framework posits that behavioral tendencies, information availability, farmers' knowledge and technology adoption drive variation in technical efficiency. These factors determine the farm efficiency levels. Diffusion can be defined in four parts: (1) communication network (2) adoption period (3) Inherent innovation, and (4) Social framework within which diffusion takes place.

Rogers (2003) emphasized that adoption is a gradual process, influenced by individual perceptions and interactions within Peer-to-peer (P2P) networks. This framework explains how information dissemination and learning through community networks help in adoption of agricultural technology. Normally, Farmers do not adopt new practices based primarily on technical skills. Adoption often depends on components such as access to extension services, P2P influence, and expected risk.

Generally, innovations spread through extension systems, farmer networks, and local knowledge exchanges. As a result, differences in exposure and learning can explain variations in efficiency, even in similar agro-climatic conditions. Yield gaps are viewed in this study as arising from uneven diffusion of agronomic knowledge and management practices among rice farmers in Punjab. Hence, yield gaps are basically the result of inconsistent productivity trends, shaped by resource use and the diffusion of agronomic

knowledge. The framework offers a theoretical rationale for understanding these fluctuations without requiring the estimation of a causal model. It places yield gap measurements within the broader theoretical context that incorporates information diffusion and technical efficiency. The theoretical framework of the study incorporates behavioral diffusion of opinions and technical efficiency to provide an understanding of inconsistent productivity. Measurable parameters of yield gaps are explained by this Production Efficiency Theory. Diffusion of Innovation theory helps to interpret the informational and behavioral dimensions in these differences. Combining both theories provides a coherent basis for analyzing the variations in productivity without assuming a causal relationship between inputs and outcomes. The top-decile approach measures yield shortfalls relative to locally attainable yields and cannot estimate the causal effects of potential determinants such as input prices, extension exposure, or adoption. Any discussion of causal relation can be seen as descriptive and hypothesis-generating. The estimates from this research will serve as a baseline for future studies that might focus on pinpointing inefficiency sources and developing interventions to narrow yield gaps.

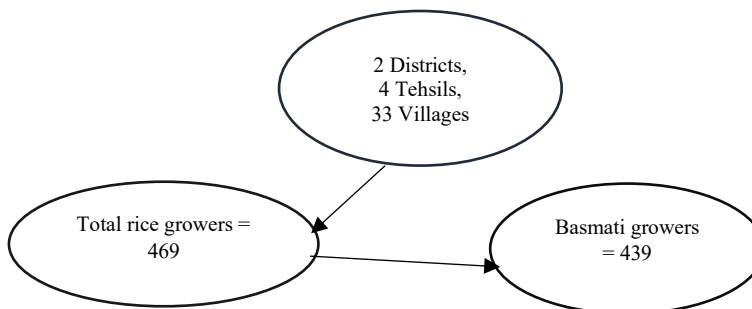
4. RESEARCH METHODOLOGY

4.1. Study Site and Sample Design

The study focuses on small- to medium-scale farmers with landholdings ranging from 5 to 30 acres.² Farmers in the selected districts with at least two years of rice farming experience were included. These inclusion criteria lead to findings that differ from official crop reporting statistics. We collected primary data from 469 farmers on total rice productivity and 439 on basmati production, across 33 villages in the two districts (for a summary, see Figure 2).

Our sampling design was as follows. A random sampling method was employed. Initially, five districts of the Basmati rice hub of Punjab were considered, including Sialkot, Nankana Sahib, Sheikhupura, Hafizabad, and Gujranwala. Table 2 presents the overall yield and basmati yield for these five districts. Among these, Gujranwala and Sheikhupura were selected for detailed analysis, as their yields fall in the mid-range rather than at the extremes, making them suitable for sampling. Within each selected district, two tehsils were chosen: Sheikhupura and Muridke from Sheikhupura, and Kamoke and Nowshera Virkan from Gujranwala. Rice cultivation in these regions normally begins in May every year and concludes in November, spanning approximately 120 days.

Fig. 2. Research Design–Sample Selection



² We used an Acre in our data collection because it is a commonly used unit of land measurement in Pakistan. 1 acre = 8 Kanals.

Table 2

<i>District-Wise Rice Yield</i>				
District	Rice Avg. Yield (Kg/ha)	Basmati Avg. Yield (Kg/ha)	Rice Avg. Yield (Kg/ha)	Basmati Avg. Yield (Kg/ha)
	(2023-24)		(2022-23)	
Shiekhupura	2084	2080	2282	2288
Nankana Sb	2257	2237	2474	2467
Hafizabad	2238	2238	2448	2430
Sialkot	1880	1847	2017	1912
Gujranwala	2177	1898	2269	1996

Source: CRS, 2023.

The research was carried out among small-scale rice cultivators in the selected villages of Gujranwala and Sheikhupura. The survey used a structured questionnaire to gain a deeper insight into the rice cultivation process. Our research involved collecting detailed information from farmers on their socioeconomic characteristics, crop yields, agricultural practices, overall cost of rice farming, and input use. This analysis covers all authorized rice varieties typically grown in the region, and specifically basmati varieties. The category of total rice varieties encompasses all types grown in the region, including both basmati and non-Basmati varieties. The analysis of basmati rice is conducted separately due to its particular significance. Data for this study were collected in collaboration with the agricultural extension department, leveraging farmers' familiarity with local extension agents to facilitate information sharing and to ensure that the treatment group received the information.

The total number of rice varieties included in this study was 7, comprising PK-386, Super 515, Kissan Basmati 1509, Super Basmati, PK-1121 Kainat, Chenab, and Super Fine. However, for the Basmati-specific analysis, Super Fine and PK-386 were excluded as they are non-basmati varieties. All varieties included in this analysis are government-approved. While a small number of farmers cultivate unapproved varieties, their proportion was negligible; therefore, these varieties are not considered in this survey. Deepening our understanding of yield gaps in rice farming involves comparing economic yields with actual yields. This approach offers valuable insights into exploitable yield gaps. Employing the same dataset enables an investigation of how various socio-economic, management, and environmental factors affect crop productivity. Examining yields would help to determine the limiting factors, including both physical impediments and social constraints.

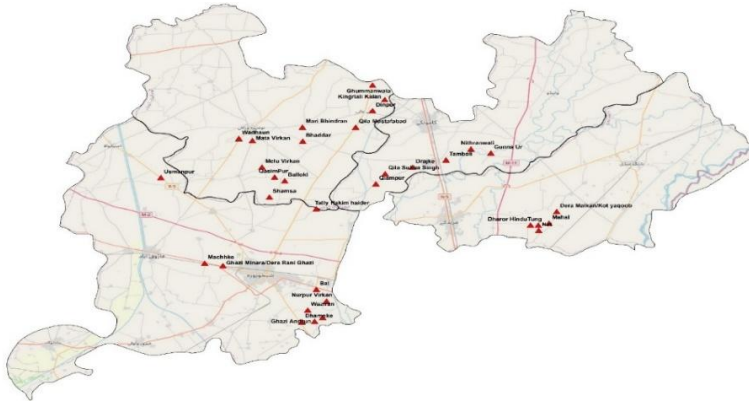
4.2. Empirical Strategy

This research adopted a mixed-method approach, combining diagnostic field measurements with statistical analysis to assess yield disparities among rice farmers. The primary analytical framework is based on the top-decile approach, accompanied by one-way ANOVA and independent-samples T-tests to assess the statistical significance of yield variation across the region.

The top-decile approach was applied to isolate the top 10 percent of high-performing farmers in the sample, based on yield. This method segregates the most productive segment to baseline realistic yield potential under current agro-ecological conditions, serving as a reference point for estimating yield gaps among the remaining 90 percent of farmers. This approach is particularly relevant for small- to medium-scale growers where productivity is widely disparate. The top-decile approach provides a

transparent benchmark for analyzing yield gaps, but it does not incorporate multivariate models to account for the multiple factors driving them. Consequently, the analysis was constrained in identifying the underlying determinants and interactions shaping rice productivity.

Fig. 3. Distribution of Clusters in the Selected Districts



To assess the statistical significance of yield differences between districts, a t-test was conducted. The independent variable was the district, with two levels (Gujranwala and Sheikhupura), and the dependent variable was measured rice yield (kg/acre). The t-test was chosen to compare group means while considering within-group variability. ANOVA is typically used to compare means when there are three or more groups. To compare rice yields between tehsils, ANOVA is used.

Furthermore, an independent-samples Bonferroni test was performed to confirm the observed differences in mean yield between the tehsils.

4.3. Yield Gap Analysis

The yield gap analysis helps identify key factors affecting yield and future yield trends across different regions. Yield gap is defined as the difference between potential yield (Y_p) or water-limited yield potential and farmers' actual yield (Lobell, et al. 2009; Fischer, 2015). Yield potential is the theoretical maximum amount of a crop grown in an idealised state where the crop's growth is not limited by biophysical factors but rather by factors that are beyond human control in rain-fed farming (Lobell, et al. 2009; Van Ittersum, et al. 2013; Fischer, 2015; Stuart, et al. 2016). As the definition shows, attaining yield potential under unrealistic conditions and moving from potential yield to economic yield can pave the way for yield gap analysis. Economic yield refers to the exploitable yield, which highlights the maximum output achieved by farmers adopting best agronomic practices and input strategies, despite variable weather conditions (Van Ittersum, et al. 2013; Fischer, 2015). In a typical scenario with world prices and reasonable transport costs, the economic yield is expected to fall 20-30 percent below its potential (Fischer, et al. 2012); however, it is usually considered to be 80 percent of the potential yield (Van Ittersum, et al. 2013). The factors contributing to the difference between the achievable (attainable) and potential yield involve three key factors: fertilisation strategies, fungal diseases (Montaner, et al. 1997), and water deficit (Calvino & Sadras, 2002).

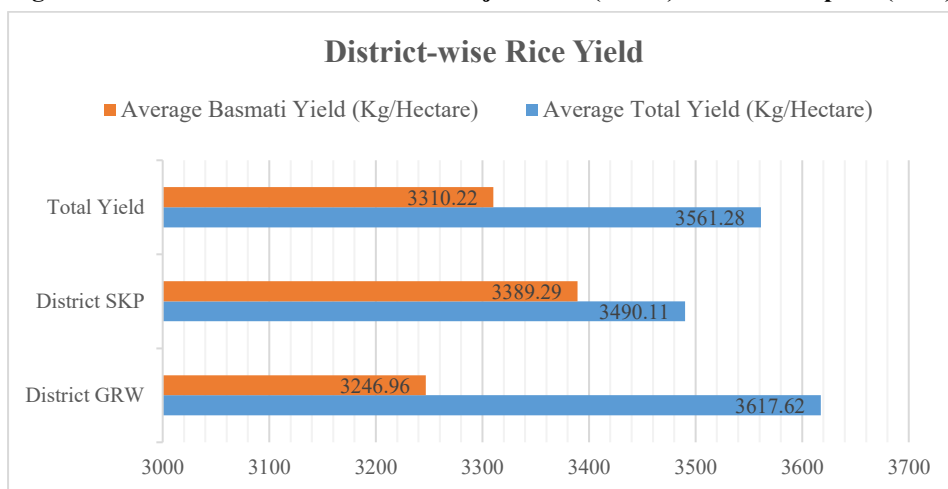
The economic yield gap defined as the difference between actual yield and economic yield was analyzed using the top-decile approach. Using this approach, we estimated the economic yield as the mean of the upper 10 percentiles; these farmers are considered progressive. Progressive farmers are defined as agents who update their information and farming practices, engage in self-initiated experimentation (Stephens, 1991). The top decile approach is widely used in yield gap analysis because it provides a concise way to identify areas for improvement. This approach provides a reliable method for determining yield gaps that is both methodologically sound and relevant. This technique substantiates that estimates are consistent and transparent across regions and agricultural commodities (Van Ittersum, 2013). It explores what can realistically be achieved given the relevant socioeconomic and ecological factors of a specific area (Stuart, et al. 2016).

The application of econometric techniques: top decile approach, ANOVA, and T-tests are technically integrated. Together, these approaches provide a detailed examination of yield variability. The top-decile approach underscores the potential for productivity gains across districts, while ANOVA and T-tests investigate whether yield patterns demonstrate structured heterogeneity within each district. This multidimensional empirical framework not only measures current yield volatility but also highlights spatial and management-based productivity dynamics. As a result, it establishes a robust empirical foundation for future studies to examine and identify the causal factors behind yield gaps. It suggests context-specific policy measures aiming to enhance smallholder performance.

5. RESULTS AND DISCUSSION

The results show significant spatial heterogeneity in rice yields across districts and tehsils, reflecting both yield response and explanatory determinants of productivity. Understanding these yield trends would pave the way for determining through which mechanism interventions could minimize yield gaps and improve farm revenue.

Fig. 4. Total Rice and Basmati Yield in Gujranwala (GRW) and Sheikhpura (SKP)



Our results indicate that the mean total yield is 3,561.28 kg/ha, compared with 3,310.22 kg/ha for basmati rice. The District Gujranwala has a higher average total yield per hectare (3617.62) than Sheikhpura (3490.11), while Sheikhpura has a higher average yield per

hectare for basmati rice (Figure 4). The P-value for total yield and basmati yield is 0.11, indicating that we cannot reject the null hypothesis, which posits that there is no difference in total yield and basmati yield between the two districts.

Among the four tehsils, Sheikhpura has the highest average total yield (4083.16 kg/ha) and basmati yield (3999.15 kg/ha). In contrast, Muridke has the lowest average total yield and basmati yield, at 2950 kg per hectare and 3435.75 kg per hectare, respectively (Table 3a). The dataset used in this study was collected initially under a quasi-experimental setup, in which Tehsil Muridke served as the control site with extension staff present. The relatively lower yields observed in Muridke may therefore reflect differences in extension exposure, rather than a tested causal effect within this analysis. Effective communication and collaboration between these groups are crucial for disseminating modern agricultural practices and technologies, which can significantly enhance crop productivity (Balasubramanian, et al. 2000).

The results below indicate a p-value of zero, suggesting a significant difference among one or more tehsils (Table 3a). To identify yield differences among tehsils, we applied the Bonferroni correction. The findings reveal that the total rice yield is not significantly different between Nowshehra Virkan and Kamoke, whereas all other pairs show significant differences in total yield. Similarly, there is no significant difference in basmati yield between Muridke and Kamoke tehsils; however, all other pairs of tehsils exhibit significant differences in basmati yields (Table 3b).

Table 3

Tehsil-wise Average Total Paddy Rice Yield and Basmati Rice Yield in 2023-24

(a) Tehsil	Average Total Yield (Kg/Hectare)		Average Basmati Yield (Kg/Hectare)	
KMK	3546.45 (7.25)		3036.43 (9.03)	
MDK	2950.43 (29.85)		2821.94 (9.26)	
NV	3681.86 (37.25)		3435.75 (8.25)	
SKP	4083.16 (41.31)		3999.15 (9.42)	
Total	3561.28 (8.81)		3310.22 (9.59)	
P-value	0.00		0.00	

(b) Tehsil-wise Analysis of Variance using Bonferroni							
	Total Rice Yield				Basmati Yield		
	KMK	MDK	NV		KMK	MDK	NV
MDK	-6.03 (0.00)			MDK	-2.17 (0.35)		
NV	1.37 (0.97)	7.39 (0.00)		NV	4.04 (0.00)	6.21 (0.00)	
SKP	5.44 (0.00)	11.46 (0.00)	4.06 (0.00)	SKP	9.74 (0.00)	11.91 (0.00)	5.70 (0.00)

Note: (a) One-way ANOVA is used. Within brackets are standard deviations. (b) Bonferroni correction is applied, and within brackets are p-values. MDK=Muridke, SKP=Sheikhpura, KMK=Kamoke, NV=Nowshehra Virkan.

Our focus now shifts to conducting a yield gap analysis, using the upper 10-percentile method. By taking the average yield of the upper 10-percentile as the economic yield, we found that the attainable yield gap for rice (Basmati and Non-Basmati) is

1523.16 kg/ha (30.88 percent), and for basmati rice, the yield gaps are larger at 1745.55 kg/ha (35.57 percent) in both districts (Table 4). The Gujranwala district has an economic yield of 4902.56 kg/ha, with a yield gap of 1413.44 kg/ha (28.83 percent), while the Sheikhupura district has an economic yield of 4960.88 kg/ha, with a yield gap of 1658.57 kg/ha (33.43 percent). Gujranwala and Sheikhupura rank among the leading districts in Punjab, out of 32 districts, that suffer the most significant financial and yield losses due to climate vulnerability (Janjua, et al. 2021). Our findings are consistent with those of Khan et al. (2021), who reported a significant rice yield gap of 7,476 kg/ha in the Punjab province. A recent study evaluating rice yield gaps in Punjab province found substantial yield disparities, particularly in the Gujranwala and Sheikhupura districts (Hussain, Akmal & Altaf, 2025).

The yield gaps for basmati rice are even higher, with the Gujranwala district having a yield gap of 1721.83 kg/ha (35.70 percent) relative to an economic yield of 4822.5 kg/ha, while the Sheikhupura district has a slightly higher yield gap of 1760.38 kg/ha (35.24 percent), with an economic yield of 4995.47 kg/ha (Table 4). Our results corroborate those of Khaliq (2019), who documented a 33 percent yield gap in basmati rice in the Gujranwala district. Farmers from the Sheikhupura district show higher yield gaps for both overall rice and basmati rice, indicating significant potential to increase rice productivity by addressing farmers' challenges and reducing these yield gaps. A T-test assessed the significance of differences between two districts. The results show that both districts exhibit significantly different actual total yields. At the same time, there is no significant difference between the actual yield of basmati rice. Additionally, while the economic yield of basmati rice varies between the two districts, their total yields are comparable.

Table 4

<i>Total Yield Gaps and Basmati Yield Gaps during 2023-24</i>				
	Total Yield Gap (Kg/Hectare)		Basmati Yield Gap (Kg/Hectare)	
Actual Yield	3409.06		Actual Yield	3161.96
Economic Yield	4932.22		Economic Yield	4907.51
Yield Gap	1523.16		Yield Gap	1745.55
	Total Yield Gap (Kg/Hectare)		Basmati Yield Gap (Kg/Hectare)	
	District GRW	District SKP	District GRW	District SKP
Actual Yield	3489.12 (0.44)	3302.31 (0.67)	3100.67 (0.50)	3235.10 (0.70)
p-value	0.01		0.11	
Economic Yield	4902.56 (0.53)	4960.88 (0.40)	4822.50 (0.39)	4995.47 (0.39)
p-value	0.40		0.00	
Yield gap	1413.44	1658.57	1721.83	1760.38

Note: Within parentheses are standard errors. GRW=Gujranwala, SKP=Sheikhupura. The total yield gap accounts for both basmati and non-basmati varieties.

Significant yield gaps exist at the tehsil as well as the district levels. Tehsil Sheikhupura (SKP) has the highest total yield gaps (1679.33 kg/ha), with Kamoke (KMK) and Nowshera Virkan (NV) also showing significant gaps. Tehsil Muridke (MDK) has

the highest basmati yield gaps of 1954.11 kg/ha, against an economic yield of 4630.75 kg/ha (Table 5).

Overall, significant basmati rice yield gaps, combined with spatial variation, reveal critical opportunities to increase yields by making farmers adopt improved technologies through extension services, particularly in high-yield gap areas such as Sheikhpura and Muridke tehsils.

Table 5

Tehsil-wise Total Yield Gaps and Basmati Yield Gaps during 2023-24

	Total Yield Gap			
	MDK	SKP	KMK	NV
Actual Yield	3834.08 (7.23)	2762.63 (8.05)	3576.10 (6.85)	3411.04 (6.49)
Economic Yield	5078.50 (0.86)	4441.96 (3.91)	5031.06 (3.19)	4799.77 (1.58)
Total Yield Gap (Kg/Hectare)	1244.42	1679.33	1454.95	1388.73
	Basmati Yield Gap			
	MDK	SKP	KMK	NV
Actual Yield	2676.64 (7.95)	3877.57 (7.28)	2872.35 (7.66)	3304.29 (7.20)
Economic Yield	4630.75 (4.06)	5081.47 (0.86)	4704.88 (0.97)	4942.1 (1.87)
Basmati Yield Gap (Kg/Hectare)	1954.11	1203.90	1832.53	1637.81

Note: Within Brackets are standard deviations. MDK=Muridke, SKP=Sheikhpura, KMK=Kamoke, NV=Nowshera Virkan. Actual yield and economic yields are measured in maunds per acre.

6. DISCUSSION

The results imply that to effectively limit yield gaps in rice production, the agricultural extension department needs to enhance and expand its services. This can be realized by maintaining a strong and continuous connection with rice farmers that may require regular training sessions, technical support, and access to the training of the trainers of the latest agricultural research and innovations. Through this enhanced connectivity with farmers, the extension staff would gain strategic insights into field-level constraints, demands, and contextual factors, thereby delivering more context- and region-specific solutions that can considerably increase rice yield.

Tehsil-wise yield gap analysis reveals that Muridke is not ideally fit for Basmati cultivation, with significant yield gaps, though it exhibits satisfactory performance in overall rice production. On the contrary, Sheikhpura is more regionally adapted for Basmati cultivation but it faces wider gaps in total rice yield, suggesting that farmers in this area should be incentivized to cultivate Basmati varieties rather than adopting non-basmati varieties.

The survey data indicate that many farmers experience challenges while incorporating improved rice cultivation techniques. In particular, the rising production cost and limited access to fertilizers made it difficult for them to comply with the suggested protocols. The lack of awareness in farmers also discourages them from adopting new technologies, such as the mechanical rice transplanter. Although the extension department encouraged its adoption in the last rice cropping season, most

farmers utilized leased machinery. Because they lacked training and experience, the results were marginal, thereby many growers reverted to conventional hand transplanting this season.

While our findings do not directly quantify the causes of rice yield gaps, previous research provides several plausible explanations. For instance, Niazi & Farooq (2019) found that higher fertilizer prices significantly reduce Basmati rice production, with a 1 percent increase in fertilizer prices leading to a 0.7 percent decrease in yield. High transportation costs, limited market size, and poor dealer networks further contribute to elevated input prices, which in turn widen yield gaps (Morris, et al. 2007; Van Dijk, et al. 2017). Fertiliser management practices are particularly influential, accounting for approximately 65 percent of yield variability in rice production (Saberali & Darzi-Naftchali, 2024). On the whole, a suboptimal use of agricultural inputs remains a significant factor contributing to rice yield gaps (Silva, et al. 2017). Climate change also poses a significant threat, with projected scenarios indicating that the most severe conditions could reduce rice yields by nearly 50 percent. In comparison, even the least severe scenarios may result in a decline of approximately 20-25 percent (Gaydon, et al. 2023). Therefore, implementing effective adaptation strategies is essential to mitigate the negative impacts on rice production (Ahmad, et al. 2015; Shabbir, et al. 2020; Gaydon, et al. 2023).

This study provides a precise estimate of yield gaps among the farmers in different districts, it has certain limitations. For instance, it does not account for weather shocks or breakdown inefficiencies within specific sources. Additionally, the analysis focuses on yield gap estimates without examining their underlying determinants. More research needs to investigate the underlying factors driving these gaps, such as input use, technology adoption, and institutional influences, to inform more effective strategies for closing these gaps and improving rice productivity.

7. CONCLUSION AND IMPLICATIONS

This study provides evidence of yield volatility among medium to small-scale rice growers in Gujranwala and Sheikhpura districts using the top-decile approach. The findings highlight significant gaps and, consequently, massive potential to improve productivity among rice growers. Although Basmati rice is a premium export-quality cereal, its yield in the selected districts remains suboptimal due to asymmetric agronomic information, biotic and environmental stressors, and resource constraints. The empirical evidence indicates that high-performing growers mostly benefit from crop-related information provided by the agricultural extension services, which frequently and effectively engage with farmers in some tehsils, whereas the less productive farmers receive limited institutional support.

Therefore, targeted collaboration between the extension department and Basmati rice growers is imperative to bridge the yield gaps. This integrated effort should enhance farmer-inclusive strategies that engage both large-scale and small-scale farmers, ensuring equitable access to information, training, and resources. The farmers consistently report that knowledge alone is insufficient without logistical assistance. Furthermore, addressing yield gaps across districts and tehsils through region-specific interventions will encourage equitable rural development and livelihood improvement.

Therefore, public institutions must interact synergistically with the extension department to facilitate farmers with targeted financial interventions, including subsidies on inputs such as seeds, fertilizers, electricity, and agricultural machinery, specifically

designed to Basmati rice cultivation. By reducing cost barriers and enhancing institutional responsiveness, the government can reinforce the economic sustainability of Basmati rice farming, improve farmer wellbeing, and strengthen Pakistan's competitiveness in global rice markets. Thus, a systematic approach that integrates field-level recommendations with institutional backing will be essential to minimize yield gaps and encourage sustainable Basmati rice production.

Appendix

Table 1

Rice Production and Yield of Rice in Pakistan in 2021-22

Province	Area (000 hectares)	Production (000 tonnes)	Yield per Hectare (kgs/ha)
Punjab	2555.1	5779.0	2262
Sindh	756.6	2566.2	3392
Balochistan	161.4	524.7	3251
Khyber Pakhtunkhwa	64.2	157.6	2453

Source: GOP (2021-22).

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