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Hybrid Seed Systems in Modern Agriculture: Adoption, Productivity, and Livelihood Outcomes among Smallholder Farmers in Pakistan

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ABSTRACT

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Hybrid maize seed technologies have the potential to enhance agricultural productivity and rural incomes; however, evidence from Pakistan remains fragmented across seed supply, adoption, agronomic performance, and farmer livelihoods. This quantitative, computer-based dry-lab research study synthesized official agricultural statistics for 2021–22 to 2025–26, certified maize seed availability for July 2025–March 2026, surveys of 822 farmers across four provinces and 400 hybrid growers in Punjab, and agronomic field-trial findings. Descriptive statistics, percentage differences, genotype comparisons, and econometric estimates were analyzed without pooling heterogeneous datasets or re-estimating farmer-level models. National maize production declined from 10.985 million tonnes in 2022–23 to a provisional 8.794 million tonnes in 2025–26. Certified maize seed availability met 62.6% of estimated requirements, with imports comprising 76.1% of recorded supply. In a Nowshera trial, the highest-yielding hybrid achieved 12.533 tonnes/ha, representing a 33.9% increase over the commercial hybrid check. Observational comparisons indicated 33.3% higher yields and 83.9% higher net farm profits among hybrid cultivators, despite increased production costs. Adoption correlated with education, land resources, and extension access; matching estimates also indicated higher household income among adopters. Hybrid seed systems demonstrate promising agronomic and economic associations, but variation among data sources, lack of microdata, and the inclusion of larger farms constrain causal inference and limit generalization to smallholders. Enhanced seed quality, extension services, and affordability require coordinated, targeted, and locally tailored policy interventions.

Introduction

Agricultural modernization plays a critical role in enhancing crop productivity, ensuring food security, and promoting rural economic development, especially in regions where agriculture is a primary source of household income. Among recent agricultural innovations, hybrid seed technology has received significant attention for its capacity to improve crop performance, increase yield potential, and boost agricultural profitability. However, the adoption of improved seed technologies varies considerably among farming communities, influenced by disparities in financial resources, education, farm size, institutional support, and access to agricultural information. Feder et al. (1985) identified these socioeconomic and institutional factors as key determinants of agricultural technology adoption, noting that the mere availability of technology does not ensure widespread use.

Hybrid maize (*Zea mays* L.) constitutes a significant advancement in modern plant breeding. These hybrid varieties are developed through controlled crosses between genetically distinct parental lines to harness heterosis and combine favorable agronomic traits. Progress in maize breeding has led to higher grain yields, improved stress tolerance, and more efficient crop development. Duvick (2005) demonstrated that genetic improvement, alongside advances in crop management, has made substantial contributions to maize productivity. Tollenaar and Lee (2002) similarly highlighted the importance of yield stability, environmental adaptability, and genotype-by-management interactions. Collectively, these findings indicate that the performance of hybrid seeds is determined not only by genetic potential but also by soil conditions, irrigation, fertilizer management, and other agricultural practices.

Pakistan serves as a significant case for examining hybrid maize cultivation, given the crop's contributions to cereal production, livestock feed, agro-industrial activities, and agricultural income. National agricultural statistics reveal notable fluctuations in maize production and productivity from the 2021–22 to 2025–26 agricultural years. These variations underscore the ongoing need for agricultural technologies that can enhance productivity. Nevertheless, access to certified seeds, production costs, and regional disparities in farming resources remain critical factors. The affordability of hybrid seeds is especially pertinent for resource-limited farmers, who must weigh the anticipated benefits of improved varieties against higher upfront costs and uncertainty in agricultural returns. Karlan et al. (2014) found that agricultural investment decisions are shaped by credit constraints and production risks, while Suri (2011) showed that technology adoption decisions depend on expected returns and farmers' comparative advantages.

Empirical studies from Pakistan have demonstrated significant associations between hybrid seed adoption and various socioeconomic characteristics of farmers. Ali et al. (2020), utilizing survey data from 822 maize growers across four provinces, found that education, land resources, agricultural assets, and institutional access were positively correlated with hybrid seed adoption. The study further reported that hybrid cultivators experienced higher productivity, greater farm profitability, and improved household economic outcomes. In a related study, Akhtar et al. (2024) examined 400 hybrid maize growers in Punjab and emphasized the roles of education, agricultural credit, farming experience, and extension services in influencing adoption decisions. Collectively, these findings suggest that hybrid seed utilization is shaped by both technological opportunities and farmers' ability to access and effectively manage improved agricultural inputs.

The agronomic performance of hybrid maize varieties constitutes a key aspect of agricultural modernization. Field experiments conducted in Pakistan have shown significant variation in grain yield and growth characteristics among different maize genotypes. Sardar et al. (2023) evaluated candidate maize hybrids under the agroclimatic conditions of Peshawar and observed differences in yield-related traits. More recently, Khshnood et al. (2025) assessed 34 candidate hybrids and two comparison varieties in Nowshera and reported notable variation in grain yield and plant development. These results highlight that hybrid performance is shaped by both genetic characteristics and local environmental conditions. Therefore, varietal suitability should be evaluated when assessing agricultural potential.

Wheat productivity is influenced by agronomic management, including sowing time, planting geometry, and nutrient application. Kalwar et al. (2018) examined sowing-date effects on the growth and yield of the wheat variety Benazir-2013 in Sindh, Pakistan, while Kaleri et al. (2026) investigated the interactive effects of planting geometry and nitrogen–phosphorus management on wheat growth, yield, and productivity.

The economic impact of hybrid cultivation encompasses more than increased grain production. While improved varieties can lead to higher agricultural output, overall profitability is also influenced by seed prices, fertilizer costs, irrigation, labor expenses, and prevailing market conditions. Khonje et al. (2015) identified positive associations between improved maize adoption, crop income, and household welfare in eastern Zambia. Similarly, Mendola (2007) found links between agricultural technology adoption and poverty reduction among rural households in Bangladesh. However, increases in productivity do not always result in proportional gains in household income, especially for farmers with small landholdings or limited access to complementary agricultural resources.

Methodological rigor is crucial when interpreting the relationships between hybrid seed adoption and livelihood outcomes. Farmers who adopt hybrid varieties may systematically differ from non-adopters in terms of education, financial resources, management skills, and land quality. Doss (2006) identified methodological challenges in observational technology adoption studies, including issues with variable definitions, sampling, and selection bias. Experimental studies, such as those by Carter et al. (2021), offer stronger identification of the effects of specific agricultural interventions. Nevertheless, results from observational surveys, agronomic experiments, and national agricultural statistics pertain to different analytical units and should not be interpreted as directly comparable causal estimates.

Despite the growing body of literature, research on hybrid seed systems in Pakistan remains dispersed across agricultural economics, plant sciences, and rural development disciplines. Most existing studies address adoption determinants, crop productivity, and household welfare in isolation, and national agricultural statistics offer limited insight into the economic outcomes for individual seed adopters. Additionally, published farmer samples frequently encompass a range of landholding sizes, limiting the ability to generalize findings to smallholder households. Consequently, an integrated assessment is required to synthesize the available evidence and differentiate reported associations from independently derived descriptive findings.

This study addresses the identified research gap by employing a quantitative, computer-based dry-lab methodology utilizing secondary agricultural and socioeconomic data. Official statistics on maize production and certified seed use are combined with published farmer surveys and agronomic field trial results from Pakistan. The analysis is structured around three objectives: investigating hybrid seed availability and socioeconomic adoption characteristics; evaluating comparative agronomic productivity; and assessing farm production costs, profitability, efficiency, and livelihood-related economic outcomes. By integrating these aspects within a descriptive and comparative framework, the study aims to generate evidence pertinent to agricultural modernization, seed system development, and economically sustainable maize production in Pakistan, while recognizing the limitations inherent in observational and heterogeneous secondary data sources.

Literature Review

Hybrid seed technology represents a key element of agricultural modernization due to its capacity to enhance crop productivity, improve genetic performance, and increase agricultural profitability. The effectiveness of improved seed technologies, however, is contingent upon seed availability, quality assurance, market infrastructure, and farmers' access to production resources. Louwaars and de Boef (2012) highlighted the necessity of integrating formal and informal seed systems to improve the distribution and accessibility of quality seeds. Their framework demonstrated that effective seed-sector development requires coordination among public institutions, private enterprises, and farming communities.

Similarly, McGuire and Sperling (2016) analyzed 9,660 seed-acquisition observations across six countries and found that approximately 90.2% of seed acquisitions occurred through informal channels. These findings underscore the significance of existing farmer seed networks and indicate that formal seed distribution policies should consider local purchasing practices. While the results are not specific to Pakistan's hybrid maize sector, they offer a relevant framework for examining certified seed availability and agricultural input accessibility.

Hybrid seed adoption is shaped by farmers' socioeconomic characteristics, financial capacity, institutional support, and perceptions of agricultural risk. Although hybrid varieties may provide higher yield potential, adoption is often constrained by seed prices, limited access to credit, insufficient agricultural extension services, and uncertainty about expected returns.

Ali et al. (2020) examined hybrid maize adoption among 822 farmers in Punjab, Sindh, Khyber Pakhtunkhwa, and Balochistan. Their findings showed that education, farm size, agricultural assets, market accessibility, and social networks were associated with adoption decisions. The study also reported favorable productivity and economic outcomes among hybrid maize cultivators, indicating that technological and socioeconomic factors jointly influence agricultural performance.

Akhtar et al. (2024) analyzed adoption patterns among 400 hybrid maize growers in Punjab and identified education, farming experience, agricultural credit, extension contact, and off-farm income as significant correlates of adoption timing. The findings reinforce the importance of financial and institutional resources in the dissemination of agricultural technology.

Collectively, these studies demonstrate that adoption is not determined solely by the productive characteristics of hybrid seeds. However, their observational designs limit causal inference, and differences in sampling and variable definitions restrict direct comparisons between the investigations.

Seed quality and market confidence affect farmers' willingness to invest in improved varieties. Commercial hybrid seed cultivation typically requires repeated seed purchases, making affordability and product authenticity critical considerations.

Gharib et al. (2021) examined willingness to pay for hybrid maize seed in Kenya and found that concerns about seed authenticity influenced purchasing decisions. Farmers were willing to pay approximately 15% more for seeds supplied directly by a seed company than for comparable seeds obtained from local retailers. These findings underscore the importance of trusted suppliers and credible quality-assurance systems.

Shee et al. (2020) analyzed farmers' willingness to pay for improved agricultural technologies in Tanzania. Their findings highlighted how information, perceived technological benefits, and purchasing capacity shape demand for improved seeds and complementary inputs.

These studies indicate that improving seed availability alone is insufficient to encourage adoption. Effective agricultural seed systems also require transparent certification, reliable distribution, and affordable prices. In Pakistan, this distinction is particularly relevant because certified maize seed availability and actual hybrid adoption are separate indicators that should not be interpreted interchangeably.

Hybrid maize productivity is determined by genetic characteristics, environmental conditions, and agricultural management. Although improved varieties may have high yield potential, their performance varies across locations and production environments.

Saleem et al. (2026) examined genotype-by-environment interactions among maize hybrids across multiple locations in Pakistan. Their findings revealed substantial variation in grain yield and stability, emphasizing the importance of selecting varieties based on environmental adaptability rather than maximum yield alone.

Similarly, Setimela et al. (2017) evaluated stress-tolerant maize varieties across eastern and southern Africa and reported yield advantages of approximately 4% to 19% for selected improved hybrids compared to commercial checks. The findings demonstrated that varietal performance depended on environmental stress and growing conditions. studies provide an agronomic foundation for evaluating Pakistan's published hybrid maize field trials. They also indicate that differences between experimental genotypes should be interpreted within their specific growing environments. Consequently, variety-level results from separate locations and seasons should not be treated as directly comparable estimates of overall hybrid seed superiority.

The economic value of hybrid seed cultivation depends on whether productivity improvements offset additional production costs. Hybrid varieties may require higher expenditures on seeds, fertilizer, irrigation, and complementary inputs, which can affect net farm returns.

Mason and Smale (2013) analyzed subsidized hybrid seed use among smallholder maize farmers in Zambia using household panel data. Their findings indicated that seed subsidies contributed to improvements in agricultural production and selected household welfare indicators, although the estimated benefits were modest during the initial years of the intervention. The study also emphasized that economic advantages were sensitive to seed prices and program administration costs.

Evidence from Pakistan similarly indicates that hybrid maize cultivation involves higher production costs alongside greater reported yields and profits (Ali et al., 2020). However, these differences may partly reflect variation in farm characteristics and management practices.

The literature supports evaluating hybrid seed systems using multiple economic indicators, including production costs, gross revenue, net profit, and revenue-to-cost ratios. Yield improvement alone is insufficient to establish economic profitability.

Improved agricultural technologies can influence household livelihoods by increasing agricultural income, consumption, asset accumulation, and reducing economic vulnerability. However, the distribution of these benefits depends on farm size, household resources, and access to agricultural markets.

Mathenge et al. (2014) analyzed hybrid maize adoption and household welfare in Kenya using panel data. Their findings indicated positive relationships between hybrid seed use, household income, asset values, and selected poverty indicators, although the magnitude of benefits varied across regions.

Bezu et al. (2014) examined improved maize adoption in Malawi and reported positive associations with household maize consumption, income, and asset holdings. Their analysis also indicated that welfare benefits differed across household wealth categories.

Similarly, Becerril and Abdulai (2010) analyzed improved maize varieties in Mexico using propensity score matching and identified positive associations with household expenditure and poverty reduction. However, observational matching estimates rely on assumptions regarding selection into adoption and cannot establish causality.

These findings indicate that improved seed technologies can contribute to household economic well-being, but productivity and livelihood outcomes should be evaluated separately. Specifically, evidence from farmers with different landholding sizes cannot be generalized to smallholder households without appropriate subgroup analysis.

Existing research demonstrates the potential agronomic and economic benefits of hybrid maize cultivation. However, evidence regarding seed accessibility, adoption determinants, varietal performance, profitability, and household livelihoods remains fragmented across agricultural and socioeconomic studies.

Pakistan-specific investigations have primarily examined farmer adoption characteristics, agronomic performance, or agricultural economics in isolation. Additionally, differences in study populations, observation periods, and analytical methods limit the direct integration of their findings.

The present study addresses this gap through a quantitative, computer-based dry-lab analysis of secondary agricultural data. Official production and certified seed statistics are analyzed alongside published farmer surveys and agronomic field-trial evidence. Descriptive and comparative analyses are employed to evaluate seed availability, adoption characteristics, crop productivity, profitability, and livelihood outcomes. provides an integrated assessment of hybrid maize systems in Pakistan while distinguishing newly calculated descriptive comparisons from econometric estimates reported in the original studies. This approach offers evidence relevant to agricultural development and identifies priorities for improving seed accessibility, varietal suitability, and farm-level economic performance.

Methodology

Research Design

A quantitative, computer-based dry-lab research approach was utilized, drawing on publicly available secondary agricultural and socioeconomic data. A descriptive and comparative analytical framework was implemented to assess hybrid maize seed availability, adoption characteristics, crop productivity, farm profitability, production efficiency, and livelihood outcomes in Pakistan. Official agricultural statistics were integrated with numerical findings from published farmer surveys and agronomic field experiments.

Maize (*Zea mays* L.) was selected due to its agricultural and economic significance, as well as the availability of published evidence on hybrid seed technologies. The analysis integrated national production trends, farmer-level findings, and genotype-specific crop performance measurements. All observations were sourced from existing data; no new farmer surveys, laboratory experiments, or field trials were undertaken.

Study Area and Data Sources

The geographical scope encompassed Pakistan, with a specific focus on Punjab, Sindh, Khyber Pakhtunkhwa, and Balochistan. National agricultural statistics were sourced from the Pakistan Economic Survey 2025–26. Hybrid adoption and economic outcomes were analyzed using published farmer surveys, while agronomic evidence was derived from maize-variety field trials conducted in Nowshera and Peshawar.

Source Selection and Data Extraction

Secondary sources were selected based on their relevance to hybrid maize adoption, agricultural productivity, production economics, and livelihood outcomes in Pakistan. Government publications were prioritized for national production and certified seed data, whereas empirical agricultural studies provided information on farmer characteristics, varietal performance, and economic indicators.

Eligible sources included extractable numerical information on at least one principal research dimension. Data were systematically organized by source, observation period, geographical coverage, variable definition, and measurement unit.

Extracted variables comprised maize cultivated area, production, seed availability, farmer age, education, farming experience, land resources, extension access, grain yield, production costs, gross revenue, net profit, household income, poverty estimates, and agricultural efficiency scores.

Published summary statistics and econometric estimates were documented separately from descriptive calculations conducted in this analysis. Individual farmer records were not reconstructed from published averages. Source selection was targeted rather than based on an exhaustive systematic literature search.

Measurement of Agricultural Production and Seed Availability

National maize productivity was determined using annual production and cultivated area statistics.

Equation 1. Average maize yield

$$Y_t = \frac{Q_t}{A_t} \times 1000$$

Where:

- Y_t = Average maize yield (kg/ha)
- Q_t = Total maize production (thousand tonnes)
- A_t = Total cultivated area (thousand hectares)
- t = Agricultural year

Annual changes in maize production and productivity were assessed by calculating the difference between initial and comparison values. Certified seed availability was evaluated using the estimated national maize seed requirement and reported availability from public-sector, private-sector, and imported sources.

Equation 2. Certified seed supply coverage

$$SC = \frac{S_A}{S_R} \times 100$$

Where:

- SC = Certified seed supply coverage (%)
- S_A = Total available certified maize seed (metric tonnes)
- S_R = Estimated national maize seed requirement (metric tonnes)

The percentage contribution of each seed source was calculated relative to total recorded availability. The difference between requirement and availability was determined by subtracting available seed from the estimated requirement. These indicators described national certified maize seed supply and were not interpreted as direct measures of hybrid seed adoption or actual farmer planting decisions.

Assessment of Hybrid Seed Adoption

Hybrid seed adoption was analyzed using previously published farmer surveys. Socioeconomic characteristics were extracted from Ali et al. (2020) and Akhtar et al. (2024), including education, farming experience, landholding characteristics, agricultural credit, extension access, and off-farm income. Selected adoption-model coefficients were sourced from the published probit regression by Ali et al. (2020). These estimates described observed associations between farmer characteristics and hybrid seed adoption. Adoption-timing evidence from Akhtar et al. (2024) was examined separately due to differences in sample and regression specification compared to the four-province survey.

Comparative Analysis of Agronomic Performance

Agronomic productivity was primarily assessed using published genotype-level results from a randomized complete block field trial conducted in Nowshera in autumn 2023. The experiment evaluated 34 candidate white maize hybrids, one commercial hybrid check (Pioneer 30-Ko8), and one open-pollinated comparison variety (Azam). Published grain yields were standardized to tonnes per hectare. Descriptive analysis included calculation of the mean, median, minimum, maximum, and ranking of candidate hybrid genotype means. The arithmetic mean was calculated across the 34 candidate genotype means. Absolute and relative yield differences were determined using the commercial hybrid check as the principal reference.

Equation 3. Relative difference

$$RD(\%) = \frac{X_C - X_R}{X_R} \times 100$$

Where:

- RD = Relative percentage difference
- X_C = Value for the comparison group or genotype
- X_R = Value for the reference group or genotype

The same percentage-difference procedure was applied for descriptive comparisons of productivity and farm economic indicators where appropriate. Supplementary evidence from a separate Peshawar maize field trial was examined independently, without pooling observations with the Nowshera experiment. The trials differed in location, season, genotype selection, and experimental conditions.

Farm Production Costs and Profitability

Farm-level economic comparisons were derived from hybrid and open-pollinated maize production data reported by Ali et al. (2020). The analysis included mean grain yields, production costs, gross revenue, net profit, and revenue-to-cost ratios. Monetary values were reported in Pakistani rupees per acre, and crop yield was expressed in tonnes per hectare. Net profit was defined as gross revenue minus total reported production costs, while the revenue-to-cost ratio was calculated as gross revenue divided by production costs. Absolute and percentage differences between hybrid and open-pollinated maize cultivators were calculated to describe variations in economic performance. As the underlying data were observational, profitability differences were interpreted as published group comparisons rather than independently established effects of hybrid seed technology.

Household Livelihood Outcomes and Production Efficiency

Livelihood outcomes were evaluated using propensity-score-matching estimates reported by Ali et al. (2020). Extracted measures included differences in maize productivity, household income, and poverty status between hybrid adopters and matched non-adopters. Four matching specifications were considered: nearest-neighbor, kernel-based, radius, and Mahalanobis metric matching. Where supported by the original documentation, yield effects expressed in maunds per hectare were converted to kg/ha using approximately 40 kg per maund. Poverty proportion differences were reported in percentage points. The matching procedures were not independently repeated due to unavailability of original respondent-level data. The four estimates were interpreted as alternative specifications from a single source sample rather than independent studies. Technical, allocative, and economic efficiency scores were also extracted from the published stochastic-frontier analysis. Differences between hybrid and open-pollinated maize growers were calculated by subtracting their reported mean efficiency scores. The original efficiency models were not re-estimated.

Statistical Analysis and Data Quality

Descriptive statistics, percentage calculations, comparative yield assessments, and farm-level economic comparison were employed in the analysis. Continuous indicators were summarized using reported means, medians, or ranges. Published regression coefficients, matching estimates, and efficiency scores were presented separately from newly calculated descriptive differences. Data were checked for consistency in measurement units, reporting periods, source definitions, and numerical calculations. Revised and provisional agricultural statistics were identified appropriately. Comparisons were limited to variables with sufficiently compatible definitions. No pooled econometric model or meta-analysis was conducted due to differences in source populations, data structures, and analytical methods. Missing values were not imputed, and no artificial farmer observations or experimental measurements were introduced.

Ethical Considerations and Study Limitations

The investigation relied on publicly accessible government statistics and aggregated findings from published academic research. No identifiable participant information, biological specimens, or new household responses were collected. Ethical clearance or exemption requirements for secondary-data research were subject to institutional policy. The study was limited by differences in source periods, geographical coverage, sample composition, and analytical techniques. Access to individual farmer records

and experimental plot-level measurements was unavailable, restricting independent replication of published inferential analyses.

Results

This data analysis investigated hybrid maize seed systems in Pakistan, with a focus on seed availability, adoption characteristics, agricultural productivity, farm profitability, and livelihood outcomes. The analysis incorporated national maize production statistics from 2021–22 to 2025–26, certified seed availability records for July 2025–March 2026, and published socioeconomic data from surveys of 822 maize farmers across four provinces and 400 hybrid maize growers in Punjab. Agronomic evidence was sourced from published maize field trials conducted in Nowshera and Peshawar. The results are summarized in eight tables that detail national production trends, seed availability, farmer characteristics, adoption determinants, varietal yield performance, production economics, household livelihood outcomes, and agricultural efficiency. Descriptive calculations are clearly separated from statistical estimates reported in the original studies to maintain alignment with the quantitative dry-lab research methodology.

National Maize Production and Productivity

Table 1; National maize cultivation, production, and productivity in Pakistan, 2021–2026

Agricultural year	Area (ooo ha)	Production (ooo tonnes)	Yield (kg/ha)
2021–22	1,653	9,525	5,762
2022–23	1,719	10,985	6,390
2023–24	1,641	9,739	5,935
2024–25 (revised)	1,588	9,037	5,691
2025–26 (provisional)	1,587	8,794	5,541

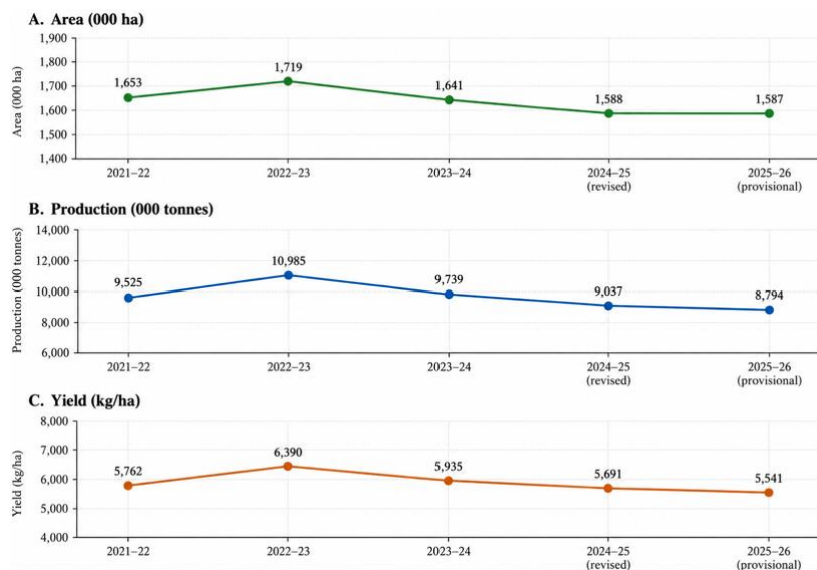


Figure 1 National Maize Production and Productivity

Interpretation: National maize production increased from 9.525 million tonnes in 2021–22 to 10.985 million tonnes in 2022–23, followed by a decline to 8.794 million tonnes in 2025–26. This represented a 19.9% decrease from the production peak.

Average yield also declined from 6,390 to 5,541 kg/ha during the same period, indicating reduced national productivity. These aggregate trends describe maize production generally and cannot be attributed specifically to hybrid seed adoption.

Certified Maize Seed Availability

Table 2; Certified maize seed requirements and availability, July 2025–March 2026

Indicator	Quantity (metric tonnes)	Share of available seed (%)
National seed requirement	36,581	—
Public-sector availability	1,979	8.6
Private-sector availability	3,492	15.2
Imported seed availability	17,435	76.1
Total seed availability	22,906	100.0
Requirement–availability difference	13,675	—
Requirement covered	62.6%	—

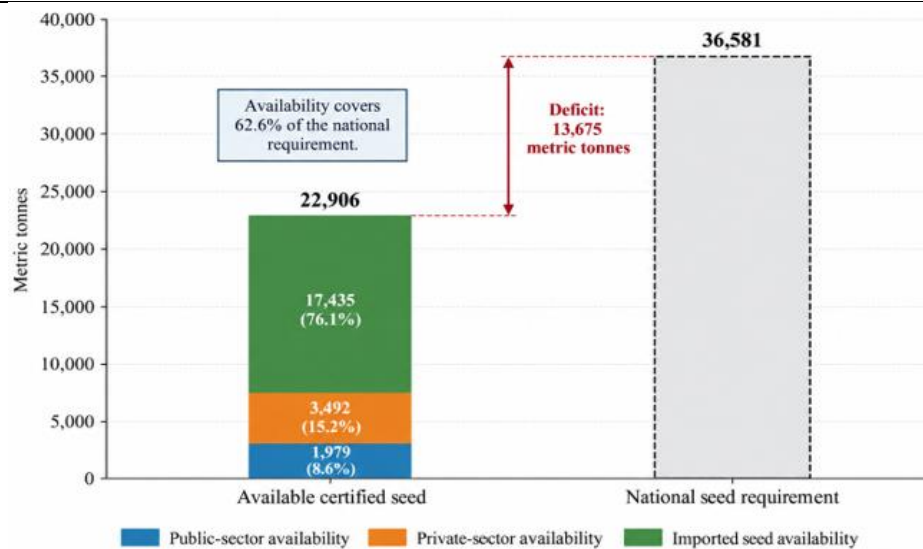


Figure 2 Certified Maize Seed Availability

Interpretation: Recorded certified maize seed availability was 22,906 metric tonnes against an estimated requirement of 36,581 metric tonnes, representing 62.6% coverage. Imported seed constituted 76.1% of available supply, compared with 15.2% from the domestic private sector and 8.6% from the public sector. The figures demonstrated substantial reliance on imported certified maize seed. However, they did not distinguish hybrid from non-hybrid seed or measure farmers' actual planting decisions.

Socioeconomic Characteristics of Maize Farmers

Table 3; Characteristics reported in two Pakistani maize-farmer surveys

Characteristic	Four-province survey	Punjab survey
Sample size	822	400
Mean age (years)	42.53	44.77
Mean education (years)	9.70	6.89
Maize-growing experience (years)	16.64	12.20
Mean land owned (acres)	14.23	—
Mean hybrid maize area (acres)	—	33.32
Agricultural extension access (%)	7	77
Credit access (%)	—	47

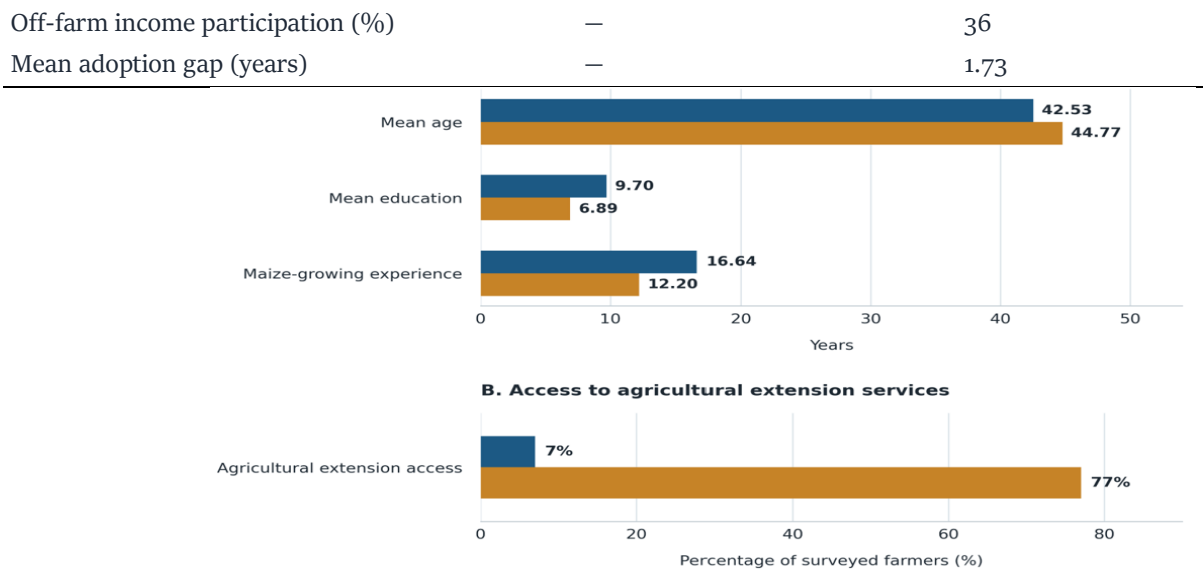


Figure 3 Characteristics reported in two Pakistani maize-farmer surveys

Interpretation: The four-province survey reported an average farmer age of 42.53 years and 16.64 years of maize-growing experience, while the Punjab survey recorded corresponding values of 44.77 and 12.20 years. Agricultural extension access varied considerably between the samples, at 7% and 77%, respectively. The Punjab survey additionally reported credit access among 47% of respondents and a mean hybrid-variety adoption gap of 1.73 years. Differences between surveys should be interpreted cautiously because their sampling frameworks and variable definitions were not identical.

Socioeconomic Determinants of Hybrid Seed Adoption

Table 4; Selected probit estimates of hybrid maize adoption

Explanatory variable	Coefficient	Reported t
Farmer age	−0.010	2.23
Education	+0.010	2.45
Landowner status	+0.020	2.56
Land owned (acres)	+0.020	2.86
Tractor ownership	+0.010	2.57
Agricultural extension access	+0.020	2.04
Punjab indicator	+0.050	2.71
Khyber Pakhtunkhwa indicator	+0.030	2.01

Figure 4 displays the selected probit estimates of hybrid maize adoption. The plot shows the coefficient and reported |t| for each variable. The x-axis represents the Probit coefficient (source-reported) ranging from -0.02 to +0.06. The y-axis lists the variables. Each variable has a blue dot representing the coefficient and a horizontal line representing the confidence interval.

Figure 4 Selected probit estimates of hybrid maize adoption

Interpretation: The published model indicated positive associations between hybrid maize adoption and education, landownership, agricultural assets, and extension-service access. The coefficient for farmer age was negative. These findings

suggested that access to productive resources and institutional support was associated with adoption decisions. The results were observational and did not establish causal effects of the explanatory variables.

The separate Punjab study examined the timing of replacement among existing hybrid maize growers using negative-binomial regression. Its source-reported results also identified socioeconomic and institutional correlates, although inconsistencies between some printed coefficient signs and narrative interpretations limited direct comparison.

Agronomic Performance of Hybrid Maize Varieties

Table 5; Grain-yield results from the Nowshera hybrid maize experiment, 2023

Genotype or group	Grain yield (tonnes/ha)	Difference from commercial check (tonnes/ha)
CHT-17	12.533	+3.172
CHT-23	11.861	+2.500
CHT-6	11.259	+1.898
CHT-20	11.089	+1.728
CHT-18	11.083	+1.722
Mean of 34 candidate hybrids	9.421	+0.060
Commercial check (P30-K08)	9.361	Reference
Open-pollinated check (Azam)	6.322	-3.039

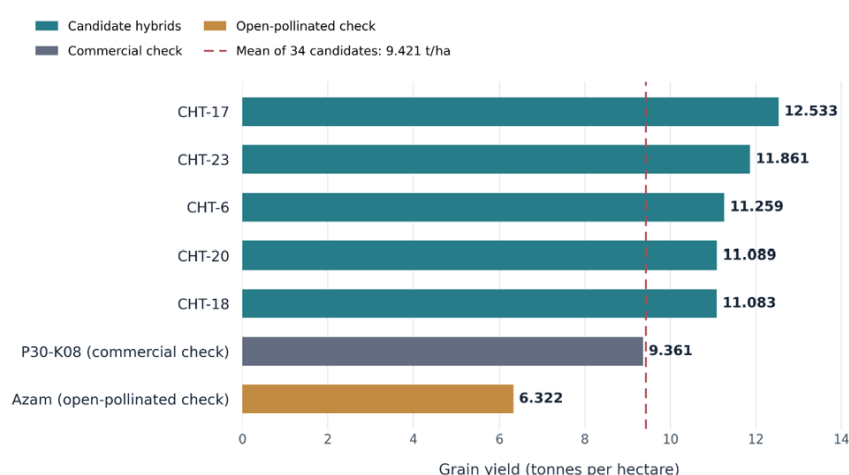


Figure 5 Grain-yield results from the Nowshera hybrid maize experiment, 2023

Interpretation: Grain yields among the 34 candidate hybrids ranged from 7.228 to 12.533 tonnes/ha, demonstrating considerable variation in agronomic performance. CHT-17 achieved the highest yield, exceeding the commercial hybrid check by approximately 33.9%. The mean across candidate hybrids was 9.421 tonnes/ha, only slightly higher than the commercial check. Seventeen candidate hybrids exceeded the commercial check, while all 34 exceeded the open-pollinated Azam check in reported mean yield. These findings described variety-specific performance within the original experiment; no new pairwise significance tests were calculated. A separate Peshawar field evaluation reported a maximum grain yield of 5,031.11 kg/ha for PSHW-201916. Because the two experiments differed in genotypes and experimental conditions, their results were not statistically pooled.

Production Costs and Farm Profitability

Table 6; Economic comparison of hybrid and open-pollinated maize cultivation

Indicator	Open-pollinated maize	Hybrid maize	Relative difference (%)
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Grain yield (tonnes/ha)	5.7	7.6	+33.3
Production cost (PKR/acre)	25,890	34,981	+35.1
Gross revenue (PKR/acre)	54,452	87,500	+60.7
Net profit (PKR/acre)	28,562	52,519	+83.9
Revenue-to-cost ratio	2.10	2.51	+19.5

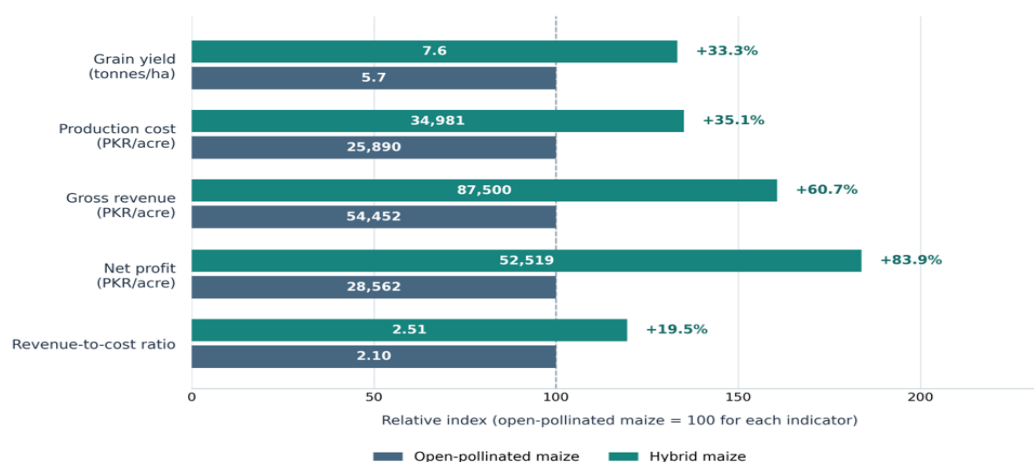


Figure 6 Economic comparison of hybrid and open-pollinated maize cultivation

Interpretation: Hybrid maize cultivators recorded 33.3% higher average grain yields than open-pollinated maize growers. Although production costs were 35.1% higher, gross revenue and net profit were approximately 60.7% and 83.9% higher, respectively. The revenue-to-cost ratio was also greater among hybrid cultivators (2.51 versus 2.10). These findings indicated favorable descriptive economic differences but did not isolate the independent effect of seed technology from other farmer and management characteristics.

Hybrid Adoption and Household Livelihood Outcomes

Table 7; Source-reported propensity-score-matching estimates of hybrid maize adoption

Matching method	Yield ATT (maunds/ha)	Household income ATT (PKR)	Poverty ATT (percentage points)
Nearest neighbor	+2.41**	+2,176*	-3**
Kernel-based	+2.35***	+3,122**	-2*
Radius	+3.11**	+3,518***	-3 (NS)
Mahalanobis metric	+2.62***	+2,936**	-3**

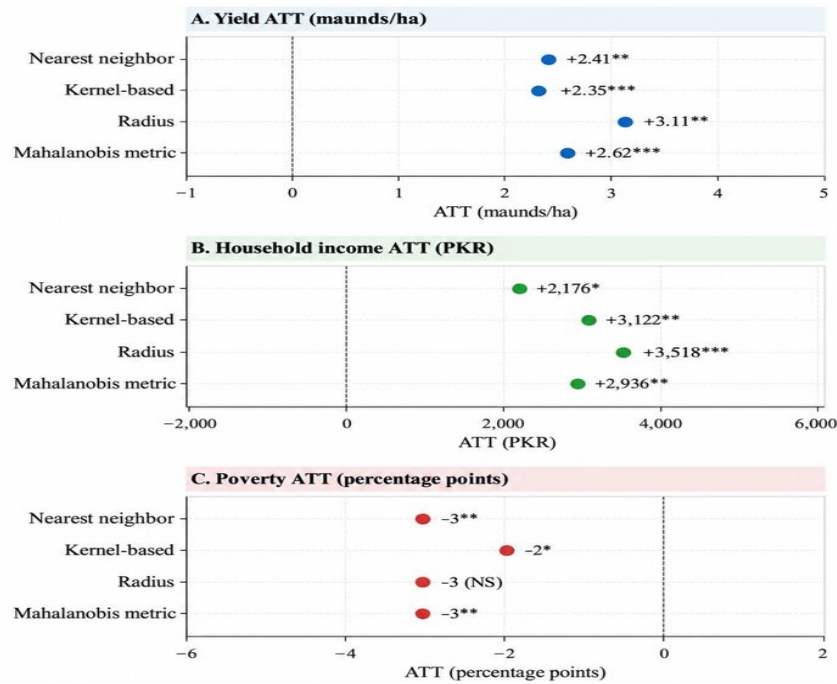


Figure 7 Source-reported propensity-score-matching estimates of hybrid maize adoption

Interpretation: The published matching estimates indicated positive yield and household income differences among hybrid maize adopters across all four methods. Estimated yield differences ranged from 2.35 to 3.11 maunds/ha, approximately 94–124 kg/ha, while household income differences ranged from PKR 2,176 to PKR 3,518. Poverty differences were negative across the specifications, although the radius-matching estimate was not statistically significant. These results were based on observational matching rather than randomized treatment assignment and were not independently re-estimated.

Technical, Allocative, and Economic Efficiency

Table 8; Source-reported production-efficiency scores

Efficiency indicator	Hybrid maize	Open-pollinated maize	Difference
Technical efficiency	0.87	0.75	+0.12
Allocative efficiency	0.84	0.71	+0.13
Economic efficiency	0.73	0.53	+0.20

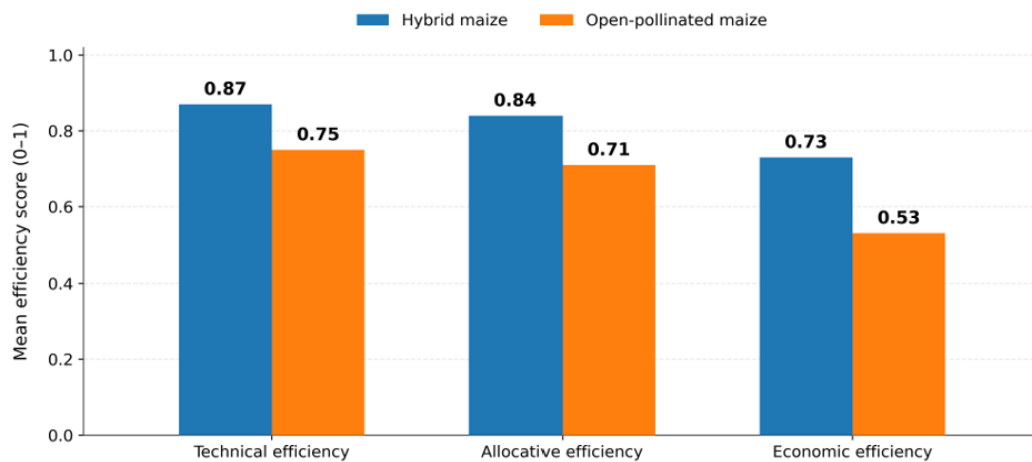


Figure 8 Source-reported production-efficiency scores

Interpretation: Hybrid maize growers exhibited higher reported mean efficiency scores across all three dimensions. Technical efficiency was 0.87 compared with 0.75 among open-pollinated maize growers, while allocative efficiency was 0.84 versus 0.71. The largest difference was recorded for economic efficiency (0.73 versus 0.53). These differences described the fitted efficiency estimates of the original farmer sample and did not establish that hybrid seed cultivation alone accounted for improved efficiency.

Discussion

This quantitative secondary-data analysis investigated hybrid maize seed systems in Pakistan by integrating national agricultural statistics, farmer surveys, and published agronomic experiments. The results revealed considerable variation in maize productivity, certified seed availability, adoption characteristics, and farm-level economic outcomes. While published comparisons typically favored hybrid maize cultivation regarding yield, profitability, and production efficiency, the evidence also underscored the significance of genetic variability, socioeconomic resources, and institutional support.

National maize production declined by approximately 19.9% between 2022–23 and 2025–26, while average productivity decreased from 6,390 to 5,541 kg/ha. These trends indicate that agricultural performance is shaped by broader production conditions, such as cultivated area, input availability, and environmental variability. Cairns et al. (2013) emphasized that sustained maize productivity requires improved germplasm in combination with effective management and adaptation to environmental stress. However, the national figures analyzed in this study did not differentiate between hybrid and conventional maize production, which precludes direct attribution of productivity changes to seed adoption.

Certified maize seed availability constituted approximately 62.6% of the estimated national requirement during July 2025–March 2026, with imported seed comprising 76.1% of recorded supplies. These results underscore the significance of seed-system accessibility and the reliance on imported planting materials. However, recorded seed availability does not equate to actual hybrid seed adoption, and the reported requirement–availability gap does not independently confirm a shortage experienced by farmers.

Blekking et al. (2021) demonstrated that formal seed certification and market expansion do not guarantee improved varietal performance or informed farmer decision-making. Similarly, Rutsaert and Donovan (2020) identified weaknesses in seed distribution and information systems that limited the diffusion of improved maize varieties in Kenya. These findings indicate that strengthening Pakistan's seed sector requires attention to availability, quality assurance, reliable distribution, and provision of locally appropriate varietal information.

Published Pakistani farmer surveys indicated that education, agricultural assets, landholding characteristics, and extension access were associated with hybrid seed adoption. Chavas and Nauges (2020) emphasized that agricultural technology adoption is shaped by uncertainty, expected returns, and learning processes. Pakistan-specific research by Akhtar et al. (2018) similarly demonstrated that hybrid maize farmers considered climatic, biological, price, and financial risks as significant factors. These findings suggest that improving adoption necessitates addressing financial and informational constraints in addition to seed accessibility.

The agronomic results demonstrated substantial variation among maize hybrids evaluated under Pakistani field conditions. In the Nowshera experiment, CHT-17 achieved the highest reported grain yield of 12.533 tonnes/ha, approximately 33.9% higher than the commercial hybrid check. However, the mean yield across the 34 candidate hybrids was only marginally greater than that of the commercial comparison variety.

This distinction indicates that hybrid seed performance is determined by genotype selection rather than hybrid classification alone. Although all candidate hybrids outperformed the open-pollinated check in published genotype means, only 17 surpassed the commercial hybrid check. These findings support the necessity of evaluating individual varieties under relevant growing conditions.

Variations between the Nowshera and Peshawar experiments further demonstrated the necessity for location-specific assessments. Differences in climatic conditions, genetic materials, and crop-management practices limited direct comparisons between trials. The results indicate that agricultural improvement programmes should prioritize varietal adaptability, yield stability, and performance under local production conditions rather than selecting hybrids solely based on maximum experimental yield.

Published economic comparisons indicated that hybrid maize cultivators achieved approximately 33.3% higher grain yields and 83.9% higher net farm profits than those cultivating open-pollinated varieties. However, hybrid production costs were also approximately 35.1% higher, indicating that increased productivity required additional investment.

These findings align with Khan et al. (2023), who reported favorable economic returns from hybrid maize cultivation compared to traditional varieties in Swabi, Pakistan. However, increased yields do not necessarily guarantee higher profitability, as financial returns depend on seed prices, fertilizer expenditure, irrigation requirements, labor costs, and output markets.

Ricker-Gilbert and Jayne (2017) demonstrated that agricultural input-support programmes can improve maize production in the short term without necessarily resulting in sustained productivity gains. Their findings underscore the importance of evaluating long-term economic returns rather than focusing solely on immediate input adoption.

Efficiency comparisons also favored hybrid maize growers, with reported technical, allocative, and economic efficiency scores of 0.87, 0.84, and 0.73, respectively. Akhtar et al. (2023) similarly identified socioeconomic and institutional factors associated with hybrid maize production efficiency in Pakistan. These findings reinforce the importance of management practices, extension contact, credit access, and productivity. However, the observed efficiency differences were derived from source-reported stochastic-frontier estimates and do not independently establish that hybrid seed technology alone improved production efficiency.

Published propensity-score-matching estimates indicated favorable associations between hybrid seed adoption and household livelihoods. Reported household income differences ranged from PKR 2,176 to PKR 3,518, while matched yield differences ranged from approximately 94 to 124 kg/ha. Poverty differences were generally negative, although statistical significance varied across matching specifications.

These findings are consistent with broader evidence from Ali et al. (2020), which associated hybrid maize adoption with favorable agricultural and socioeconomic outcomes in Pakistan. However, the matched estimates were substantially smaller than the unadjusted descriptive yield difference, highlighting the importance of accounting for differences between adopting and non-adopting farmers.

Paudel et al. (2023) demonstrated that the livelihood benefits of hybrid maize adoption in Nepal varied according to farm size and resource availability. Their findings suggest that productivity improvements per unit of land do not necessarily generate equivalent household-level economic benefits across different farming populations.

This distinction is particularly relevant for Pakistan because the available farmer surveys included medium and larger farms. Consequently, the present findings cannot be generalized to households operating only small landholdings. Improvements in agricultural profitability may improve livelihoods, but the magnitude of these benefits depends on cultivated area, household resources, and access to agricultural markets. This suggests that agricultural policy should prioritize access to and the quality of improved maize seeds, alongside investments in farmer support services. Strengthening domestic seed production, improving certification procedures, and developing locally suitable varieties may improve access to reliable planting materials.

Agricultural extension programmes should deliver practical information on varietal selection, fertilizer requirements, irrigation management, and production economics. Affordable agricultural credit and targeted input-support mechanisms may also assist resource-constrained farmers in managing the initial costs associated with improved seed technologies.

However, policies promoting hybrid seed adoption should be evaluated based on their effects on net farm returns rather than grain yield alone. Particular attention should be given to farmers with limited land resources, as higher productivity does not necessarily result in substantial household income improvements.

The principal limitation of this study is that national agricultural statistics, farmer surveys, and experimental field trials differed in observation periods, geographical coverage, sampling methods, and analytical procedures. Additionally, observational comparisons remain vulnerable to selection effects, while localized agronomic experiments cannot establish nationwide varietal performance. Future research should prioritize longitudinal farmer-level datasets, farm-size-specific analyses, and multi-location hybrid maize experiments. Integrating agronomic measurements with detailed production costs and household income observations would provide stronger evidence regarding the economic sustainability and livelihood implications of hybrid seed technologies.

Overall, the findings indicate that hybrid maize cultivation presents promising agricultural and economic opportunities in Pakistan. However, realizing these benefits requires coordinated improvements in seed quality, institutional accessibility, agronomic management, and farmers' financial capacity. The available evidence supports these priorities but does not independently establish causal effects of hybrid seed adoption on smallholder livelihoods.

Conclusion

This study examined hybrid maize seed adoption, agricultural productivity, farm profitability, and livelihood outcomes in Pakistan using a quantitative dry-lab approach based on secondary agricultural data. The findings highlighted the potential importance of hybrid seed technologies for agricultural modernization while identifying constraints associated with seed availability, socioeconomic resources, and varietal performance.

National maize production and productivity fluctuated considerably during 2021–2026, while certified seed availability covered approximately 62.6% of estimated requirements. Published agronomic evidence demonstrated substantial differences in grain yield among hybrid maize varieties. Observational comparisons indicated 33.3% higher grain yields and 83.9% higher net farm profits among hybrid cultivators than among conventional maize growers, despite greater production costs. Published household-level estimates also suggested favorable associations between hybrid adoption and agricultural income. However, these findings did not independently establish causal effects.

The results emphasize the importance of strengthening domestic seed production, improving certification and distribution systems, expanding agricultural extension services, and facilitating access to affordable agricultural inputs. Policies should prioritize locally suitable hybrid varieties and support resource-constrained farmers in translating productivity improvements into sustainable economic returns.

The analysis was limited by differences in secondary-data sources, the unavailability of individual farmer records, and restricted evidence specific to smallholder households. Future studies should integrate longitudinal farmer-level information with multi-location agronomic assessments to provide stronger evidence of productivity and livelihood effects.

Overall, hybrid maize technology offers promising opportunities for improving agricultural productivity and profitability in Pakistan. Its long-term contribution to rural development depends on reliable seed systems, appropriate crop management, and equitable access to agricultural resources.

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