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Seed Distribution Factors and Rice Productivity: The Mediating Role of Technology Adoption

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Abstract

Purpose: This study examines the mediating role of seed technology adoption in linking seed distribution quality, distribution accessibility, agricultural extension support, and distribution program effectiveness with rice farmers' productivity at UPT Pengembangan Benih Padi dan Palawija, Dinas Pertanian dan Ketahanan Pangan Provinsi Jawa Timur.

Research Methodology: A quantitative causal design was applied using data from 100 rice farmers selected from 800 certified high-yielding seed recipients through purposive sampling. Data were collected using a five-point Likert-scale questionnaire and analyzed through regression analysis, partial and simultaneous tests, and the Sobel test to evaluate direct and indirect effects.

Results: The results show that seed technology adoption is the strongest predictor of rice farmers' productivity and is significantly influenced by seed distribution quality, accessibility, agricultural extension support, and program effectiveness. Distribution accessibility is the strongest determinant of adoption. The mediation analysis confirms that adoption fully mediates the effect of accessibility on productivity, while partially mediating the effects of seed quality, extension support, and program effectiveness.

Conclusions: Seed technology adoption is a key mechanism that transforms distribution efforts into productivity improvements. Distribution accessibility alone does not improve productivity unless it encourages actual adoption.

Limitations: This study is limited by its cross-sectional design, single research setting, and the use of the Sobel test for mediation analysis.

Contributions: This study contributes by demonstrating distinct full and partial mediation pathways, highlighting adoption as a strategic factor in improving agricultural productivity.

Keywords: *Intervening Variable, Mediation, Rice Farmer Productivity, Seed Distribution, Seed Technology Adoption*

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1. Introduction

Agricultural productivity improvement remains a central concern in achieving food security and strengthening the sustainability of farming systems. Among various agricultural interventions, the provision and dissemination of improved seed technology represents one of the most important strategies for increasing crop productivity. Certified and high-yielding seeds are developed to provide better genetic potential, improved resistance, and higher production capacity compared with

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conventional seed varieties (Sindhuja, Singh, Raj, Sahu, Singh, & Srivastava, 2024). Consequently, many government agricultural programs emphasize seed distribution as a strategic instrument to enhance farmers' production performance. However, the effectiveness of seed distribution programs is often evaluated primarily from a supply-side perspective, such as the quantity of seeds distributed, distribution coverage, seed quality assurance, and the availability of agricultural extension activities. Such assessments may overlook an essential behavioral process, namely whether farmers actually adopt and utilize the distributed seed technology in their farming practices (Mulesa, Dalle, Makate, Haug, & Westengen, 2021; Louwaars, & Manicad, 2022).

The availability of high-quality seeds does not automatically guarantee increased agricultural productivity. Farmers must first recognize the benefits, develop confidence in the technology, and integrate the innovation into their cultivation practices. Therefore, the success of seed technology programs depends not only on the effectiveness of distribution mechanisms but also on farmers' adoption decisions (Louwaars & Manicad, 2022). A seed distribution system may achieve high levels of coverage, yet its contribution to productivity improvement remains limited if farmers do not adopt the technology appropriately. This condition indicates that adoption serves as a critical bridge between agricultural intervention and productivity outcomes (Takahashi, Muraoka, & Otsuka, 2020; Sudjaniah, Ismaliyanto, Utami, & Arita, 2026; Nasihin, Feryani, Dwiyanti, Azahrotussholikha, Sundari, Syaikudin, & Rozi, 2025).

This phenomenon can be observed at UPT Pengembangan Benih Padi dan Palawija, Dinas Pertanian dan Ketahanan Pangan Provinsi Jawa Timur. Although East Java produced more than 9.6 million tons of dry unhusked grain in 2023, the adoption rate of certified high-yielding seeds reached only 54%, which remained below the national target of 75%. Meanwhile, the realization of seed distribution by the Unit reached 78%. The difference between distribution achievement and adoption performance demonstrates that successful delivery of seed technology does not necessarily result in its effective utilization by farmers. This discrepancy represents an important empirical issue, suggesting that understanding the factors that encourage adoption is essential for ensuring that seed distribution programs generate meaningful productivity improvements.

The role of adoption in agricultural innovation can be explained through Rogers (1983) Diffusion of Innovations theory, which conceptualizes adoption as a process consisting of knowledge, persuasion, decision, implementation, and confirmation stages. According to this perspective, farmers do not immediately accept technological innovations after receiving them; instead, adoption is influenced by the perceived advantages of the innovation, communication channels, social influence, and supporting environmental conditions. Therefore, seed distribution quality, accessibility, agricultural extension support, and program effectiveness may function as important factors that influence farmers' adoption decisions before contributing to productivity improvement.

Previous studies have provided evidence regarding the importance of these factors in agricultural technology adoption. Puspitasari (2017) demonstrated that farmers using certified seeds achieved better production efficiency than farmers using non-certified seeds, indicating that access to quality seed technology is relevant for improving farming outcomes. Gunawan, Hubeis, Fatchiya, and Susanto (2019) found that extension support and external agricultural conditions play significant roles in encouraging innovation adoption among farmers. Koesrini et al. (2019) further showed that the utilization of superior rice varieties contributes to improved yield performance. Other studies have also emphasized that adoption decisions are influenced not only by the availability of technology but also by farmers' knowledge, perceptions, experience, and communication with extension agents (Mayalibit, Suwarto, Rusdiyana, & Wijianto, 2018; Ridwan, Maulina, & Fahrimal, 2022).

Despite these findings, previous research has generally focused on examining direct relationships between agricultural inputs, institutional support, and productivity outcomes. Limited attention has been given to the mechanism through which distribution-related factors are transformed into productivity improvements through farmer adoption behavior. In particular, it remains unclear whether seed distribution quality, accessibility, extension support, and program effectiveness influence

productivity independently or whether their effects occur primarily because they encourage farmers to adopt seed technology. This distinction is important because agricultural institutions require a clear understanding of whether improving distribution systems alone is sufficient or whether additional adoption-oriented interventions are necessary (Foray, 2019). Previous research suggests that technological interventions may not directly improve farmer performance but require behavioral mechanisms that translate technological availability into actual utilization. For example, (Putri, Hadiwijaya, & Aprizal, 2026) demonstrated that technology-related factors influence farmer performance through an intervening mechanism, highlighting the importance of behavioral transformation in achieving agricultural outcomes.

Furthermore, different distribution factors may not operate through the same mechanism. Some factors may directly influence productivity because they improve cultivation conditions, while others may contribute mainly by increasing farmers' willingness to adopt new technologies. Without identifying these differences, policy interventions may allocate resources toward distribution improvements without fully understanding which factors generate actual productivity gains (Ehrlich & Overman, 2020). Therefore, examining adoption as an intervening variable provides a more comprehensive explanation of how agricultural programs achieve their intended outcomes.

Based on this research gap, this study examines the mediating role of seed technology adoption in the relationship between seed distribution quality, distribution accessibility, agricultural extension support, distribution program effectiveness, and rice farmers' productivity. Specifically, this study investigates how these four antecedents influence adoption, how adoption affects productivity, and whether adoption fully or partially mediates the relationship between each antecedent and productivity. The novelty of this research lies in its explicit identification of different mediation pathways by simultaneously testing four distribution-related factors. This approach extends the application of Diffusion of Innovations theory by demonstrating that adoption is not merely a consequence of technology availability but a strategic mechanism that determines whether agricultural innovations produce measurable productivity outcomes. The findings are expected to provide both theoretical and practical contributions by enriching the literature on agricultural technology adoption and offering insights for policymakers and agricultural institutions in designing more effective seed distribution strategies.

2. Literature Review and Hypothesis/es Development

2.1 Diffusion of Innovations Theory

Diffusion of Innovations theory developed by Rogers (1983) provides a comprehensive framework for explaining how new technologies, ideas, or practices are introduced, accepted, and implemented within a social system. The theory explains that innovation adoption does not occur immediately after individuals receive information about a new technology but develops through a sequential process consisting of knowledge, persuasion, decision, implementation, and confirmation stages. In the agricultural sector, this theory is particularly relevant because farmers often evaluate technological innovations based on perceived benefits, compatibility with existing farming practices, complexity, and observable outcomes (Nasriddinovich, 2025; Ofulue, Okike, Nworie, & Nworie, 2025). The adoption of improved seed technology therefore depends not only on the availability of superior seeds but also on farmers' understanding, acceptance, and confidence in applying the technology. Consequently, agricultural institutions need to consider both technological and behavioral aspects when designing programs aimed at improving farming productivity (Klerkx, Jakku, & Labarthe, 2019).

The Diffusion of Innovations theory also emphasizes that the success of technological dissemination is influenced by communication channels, social systems, and supporting environments surrounding potential adopters. In agricultural development programs, seed distribution systems, extension services, and institutional support represent important channels that facilitate the movement of innovation from providers to farmers (Chete, 2021). The theory suggests that farmers are more likely

to adopt new technologies when they receive adequate information, experience direct benefits, and obtain continuous support during implementation. Therefore, seed distribution quality, accessibility, extension support, and program effectiveness can be considered important antecedents that influence farmers' adoption decisions. In this study, the theory is used to explain the role of seed technology adoption as an intervening mechanism that connects distribution-related factors with rice farmers' productivity outcomes.

2.2 Seed Technology Adoption

Seed technology adoption refers to farmers' decision to accept, utilize, and continuously apply improved seed technologies in their agricultural production activities. According to Rogers (1983), adoption represents the final stage of the innovation diffusion process where individuals decide to implement an innovation after evaluating its advantages and suitability. In rice farming, the adoption of certified high-yielding seeds is an important determinant because the potential benefits of improved seed varieties can only be achieved when farmers actually use and manage them properly. Although improved seeds may provide higher yield potential, better resistance, and improved production efficiency, these advantages cannot be realized if farmers continue using conventional seeds. Therefore, adoption represents a critical behavioral process that determines whether agricultural innovations produce meaningful improvements in farming performance (Hermans, Whitfield, Dougill, & Thierfelder, 2021).

Previous studies indicate that farmers' adoption decisions are influenced by various technical, economic, and institutional factors. Mayalibit, Suwarto, Rusdiyana, and Wijianto (2018) found that farmers' attitudes toward certified superior seeds are influenced by knowledge, experience, and perceptions regarding the benefits of seed technology. This finding indicates that adoption is not merely determined by the physical availability of seeds but also by farmers' understanding and acceptance of technological innovations. Ridwan, Maulina, and Fahrimal (2022) emphasized that effective communication between extension agents and farmer groups plays an important role in transforming agricultural innovations into actual field practices. Thus, seed technology adoption should be viewed as an active decision-making process that determines the effectiveness of seed distribution programs in improving agricultural productivity.

2.3 Seed Distribution Quality and Seed Technology Adoption

Seed distribution quality represents the extent to which farmers receive planting materials that meet established standards regarding genetic characteristics, physical quality, purity, and suitability for agricultural conditions. High-quality seed distribution is essential because the performance of agricultural production is strongly influenced by the quality of inputs used during cultivation. Farmers who receive seeds with consistent quality are more likely to perceive the technology as reliable and beneficial for improving production outcomes. Therefore, seed quality becomes an important factor influencing farmers' confidence and willingness to adopt improved seed technologies. From the perspective of innovation diffusion, perceived advantages of an innovation represent one of the main factors determining whether individuals accept and implement new technologies (Yuen, Cai, Qi, & Wang, 2021).

Previous empirical studies have demonstrated the relationship between seed quality and agricultural performance. Mulsanti et al. (2014) showed that differences in seed classes affect rice production outcomes, indicating that seed quality contributes significantly to cultivation performance. The availability of high-quality seeds may increase farmers' expectations regarding productivity improvement and encourage them to replace traditional seed varieties with improved alternatives. Furthermore, when farmers observe positive results from using superior seeds, their trust in the technology increases and strengthens future adoption intentions. Therefore, higher seed distribution quality is expected to encourage greater acceptance and utilization of seed technology among rice farmers.

Seed distribution quality has a positive effect on seed technology adoption.

2.4 Distribution Accessibility and Seed Technology Adoption

Distribution accessibility refers to the extent to which farmers can obtain improved seed technology through adequate availability, appropriate distribution channels, affordable access, and convenient procedures. Accessibility represents an important prerequisite in the adoption process because farmers cannot utilize technological innovations that are difficult to obtain or unavailable within their production environment. In agricultural systems, the effectiveness of seed distribution programs is not only determined by the quantity of seeds delivered but also by whether farmers can access and utilize these resources when needed. Limited accessibility may create barriers that prevent farmers from experiencing the benefits of improved seed technology, thereby reducing their willingness to adopt innovation. Therefore, improving accessibility becomes an essential strategy to ensure that seed technology reaches farmers and creates opportunities for adoption (Okori, Munthali, Msere, Charlie, Chitaya, Sichali, & Chirwa, 2022).

From the perspective of Diffusion of Innovations theory, accessibility increases farmers' exposure to new technologies and provides opportunities to evaluate the potential benefits of innovation. Puspitasari (2017) demonstrated that farmers who used certified seeds achieved higher production efficiency compared with those using non-certified seeds, indicating the importance of access to quality seed technology in improving farming outcomes. However, accessibility alone may not directly generate productivity improvements because farmers must first decide to adopt and implement the available technology. The availability of certified seeds through accessible distribution channels can reduce adoption barriers by increasing farmers' opportunities to obtain and test improved seed varieties. Therefore, better distribution accessibility is expected to strengthen farmers' adoption decisions toward seed technology.

H_2: Distribution accessibility has a positive effect on seed technology adoption.

2.5 Agricultural Extension Support and Seed Technology Adoption

Agricultural extension support represents the role of extension institutions and agents in providing farmers with knowledge, technical guidance, and information related to agricultural innovations. Extension services serve as an important communication mechanism that connects technology providers with farmers by explaining the advantages, application procedures, and expected outcomes of new technologies. In the context of seed technology adoption, farmers often require additional knowledge regarding seed selection, planting methods, cultivation practices, and risk management before deciding to adopt improved seeds. Therefore, extension support helps reduce uncertainty and increases farmers' confidence in adopting agricultural innovations. The presence of effective extension services can accelerate the transition from awareness of technology to actual implementation in farming activities (Mapiye, Makombe, Molotsi, Dzama, & Mapiye, 2021) .

Previous studies have emphasized the significant contribution of extension support in encouraging agricultural innovation adoption. Gunawan et al. (2019) found that extension support and external agricultural conditions influence farmers' willingness to adopt innovations and improve the sustainability of farming practices. Extension agents not only provide technical information but also facilitate learning processes through demonstrations, discussions, and continuous assistance. Through these activities, farmers can better understand the benefits of improved seed technology and develop the capability to apply it effectively. Therefore, agricultural extension support is considered an important factor that strengthens farmers' adoption behavior and increases the likelihood that seed distribution programs achieve their intended outcomes.

H_3: Agricultural extension support has a positive effect on seed technology adoption.

2.6 Distribution Program Effectiveness and Seed Technology Adoption

Distribution program effectiveness refers to the extent to which seed distribution programs are successfully implemented according to their objectives, including proper targeting, timely delivery, appropriate management, and achievement of expected outcomes. An effective distribution program

requires coordination among agricultural institutions, seed providers, extension agents, and farmer groups to ensure that distributed technologies are properly received and utilized. Program effectiveness is not only reflected by the amount of seed distributed but also by the extent to which the program supports farmers in adopting and applying the technology. When programs are implemented effectively, farmers are more likely to perceive the intervention as reliable and beneficial for improving their agricultural performance. Therefore, effective program management becomes an important foundation for encouraging technology adoption (Uduji & Okolo-Obasi, 2018).

The relationship between program effectiveness and adoption can also be explained through institutional trust and perceived usefulness. Farmers who experience well-managed distribution programs are more likely to develop confidence in the agricultural institutions providing the technology. Anwarudin et al. (2020) emphasized that institutional support and agricultural facilitation contribute to strengthening farmers' capacity to adopt innovations and maintain sustainable agricultural practices. Furthermore, effective programs can provide complementary support, such as information dissemination, monitoring, and technical assistance, which facilitates the adoption process. Therefore, distribution program effectiveness is expected to positively influence farmers' decisions to adopt seed technology.

H_4: Distribution program effectiveness has a positive effect on seed technology adoption.

2.7 Seed Technology Adoption and Rice Farmers' Productivity

Rice farmers' productivity reflects the ability of farmers to generate agricultural output through the effective utilization of production inputs, cultivation practices, and technological innovations. Among various agricultural technologies, improved seed technology plays an important role because seeds determine the genetic potential, growth performance, and yield capacity of rice plants. However, the productivity advantages of improved seeds cannot be achieved solely through their availability because farmers must adopt and apply the technology appropriately during the cultivation process. When farmers adopt certified high-yielding seeds, they gain access to improved genetic characteristics that may contribute to better plant performance, higher yields, and more efficient production processes. Therefore, seed technology adoption represents an essential factor that determines whether technological innovations can produce measurable improvements in agricultural productivity (Obianefo, Mzyece, Masasi, Obiekwe, & Anumudu, 2021).

Previous studies have provided empirical evidence regarding the relationship between improved seed adoption and farming productivity. Puspitasari (2017) found that the utilization of certified seeds was associated with better production efficiency among rice farmers compared with the use of non-certified seeds. Similarly, Nayak, Habib, Das, Islam, Hossain, Karmakar, and Hassan (2022) demonstrated that the adoption of superior rice varieties contributed to improved yield performance under different agricultural conditions. These findings indicate that adoption functions as a mechanism through which the potential advantages of seed technology are translated into actual production outcomes. Furthermore, adoption reflects farmers' capability and willingness to integrate innovation into their farming practices, which ultimately determines the effectiveness of agricultural technology interventions. Therefore, farmers who actively adopt seed technology are expected to achieve higher productivity compared with farmers who do not utilize improved seeds.

H_5: Seed technology adoption has a positive effect on rice farmers' productivity.

2.8 The Mediating Role of Seed Technology Adoption

The relationship between agricultural interventions and productivity improvement is not always explained through direct effects alone. In many cases, technological inputs and institutional support influence productivity through behavioral mechanisms that determine whether farmers actually utilize the provided resources. In the context of seed distribution programs, seed quality, accessibility, extension support, and program effectiveness may create favorable conditions for adoption, but productivity improvements occur only when farmers implement the technology in their farming

activities (Macours, 2019). Therefore, seed technology adoption can be conceptualized as an intervening variable that explains how distribution-related factors are transformed into productivity outcomes. This mediation perspective provides a more comprehensive understanding of the process through which agricultural programs generate benefits for farmers.

The mediating role of adoption is particularly important because different distribution factors may influence productivity through different pathways. Distribution accessibility, for example, may primarily affect productivity by increasing farmers' opportunities to obtain and use improved seeds, meaning that its effect may depend strongly on adoption behavior. Meanwhile, seed quality, extension support, and program effectiveness may influence productivity through both direct mechanisms and indirect mechanisms involving adoption. Examining these different pathways allows researchers and policymakers to identify whether productivity improvements require greater emphasis on distribution improvements, adoption facilitation, or a combination of both approaches. Consequently, this study extends previous research by explicitly testing whether seed technology adoption provides full or partial mediation between distribution-related antecedents and rice farmers' productivity. The identification of these mediation patterns contributes to a deeper understanding of agricultural innovation diffusion and provides practical insights for designing more effective seed distribution strategies.

H_6: Seed technology adoption mediates the relationship between seed distribution quality, distribution accessibility, agricultural extension support, distribution program effectiveness, and rice farmers' productivity.

3. Research Methodology

3.1 Research Design and Data Collection

This study employed a quantitative research approach with a causal explanatory design to examine the mediating role of seed technology adoption in the relationship between seed distribution factors and rice farmers' productivity. The causal design was selected because this study aims to identify the direct and indirect relationships among variables, particularly how seed distribution quality, distribution accessibility, agricultural extension support, and distribution program effectiveness influence productivity through seed technology adoption. The research framework was developed based on the Diffusion of Innovations theory, which emphasizes that technology adoption serves as an important mechanism through which innovation-related factors influence performance outcomes (Sugiyono, 2019).

The research was conducted at UPT Pengembangan Benih Padi dan Palawija, Dinas Pertanian dan Ketahanan Pangan Provinsi Jawa Timur, which serves as an institution responsible for supporting the distribution of certified high-yielding rice seeds. The study population consisted of 800 rice farmers who had received certified high-yielding seeds distributed by the institution during the 2023–2025 period. The respondents were selected using purposive sampling based on specific criteria, including farmers who had used the distributed seeds for at least one planting season, were members of partner farmer groups, cultivated a minimum of 0.25 hectares of rice farmland, and were willing to participate in the research. These criteria were applied to ensure that respondents had sufficient experience to evaluate seed distribution services and adoption behavior.

The sample size was determined using the Slovin formula with a 10% margin of error, resulting in a minimum requirement of 89 respondents. However, to improve data reliability and representation, this study collected responses from 100 rice farmers. Data collection was conducted through a structured questionnaire using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The questionnaire was designed to measure six main constructs consisting of seed distribution quality, distribution accessibility, agricultural extension support, distribution program effectiveness, seed technology adoption, and rice farmers' productivity.

3.2 Measurement of Variables

Seed distribution quality refers to farmers' perceptions regarding the quality, reliability, and suitability of distributed certified seeds for rice cultivation. Distribution accessibility represents farmers' ease of obtaining improved seed technology, including availability, distribution channels, and convenience of access. Agricultural extension support measures the extent to which farmers receive information, technical guidance, and assistance from agricultural extension agents regarding seed utilization and cultivation practices. Distribution program effectiveness reflects farmers' evaluation of program implementation, including targeting accuracy, management quality, and achievement of program objectives.

Seed technology adoption is positioned as an intervening variable representing farmers' decision and willingness to apply improved seed technology in their farming activities. This construct reflects the extent to which farmers accept, utilize, and continuously implement certified high-yielding seeds. Rice farmers' productivity represents the outcome variable, reflecting improvements in agricultural production achieved through effective utilization of seed technology and farming practices.

3.3 Data Analysis

The collected data were analyzed using regression-based mediation analysis to examine the direct and indirect relationships among the research variables. Before hypothesis testing, instrument validity and reliability tests were conducted to ensure that the measurement instruments adequately represented each construct. In addition, classical assumption tests, including normality, multicollinearity, heteroscedasticity, linearity, and autocorrelation tests, were performed to confirm the suitability of the regression model.

The mediation analysis was conducted using two regression sub-structures. The first sub-structure examined the effects of the four antecedents, namely seed distribution quality, distribution accessibility, agricultural extension support, and distribution program effectiveness, on seed technology adoption (a-path). The second sub-structure analyzed the effects of seed technology adoption and the four antecedents on rice farmers' productivity (b-path and c′-path). Partial (t) tests and simultaneous (F) tests were used to evaluate the significance of individual and collective effects at a significance level of 5%.

Furthermore, the Sobel test was applied to examine the significance of indirect effects through seed technology adoption. The mediation effect was determined based on the significance of the indirect pathway and the remaining direct effect. A mediation relationship was categorized as full mediation when the indirect effect was significant while the direct effect became insignificant. Meanwhile, partial mediation occurred when both direct and indirect effects remained significant.

The Sobel test statistic was calculated using the following Formula 1:

$$z = \frac{a \times b}{\sqrt{b^2 S_a^2 + a^2 S_b^2}} \tag{1}$$

where a represents the regression coefficient of the antecedent variable on seed technology adoption, b represents the coefficient of seed technology adoption on productivity, and Sa and Sb represent the standard errors of the respective coefficients. A z-value greater than 1.96 indicates a statistically significant mediation effect.

4. Results and Discussions

4.1 Results

Table 1. The a-path effects of the four antecedents on seed technology adoption

Antecedent	*B*	Beta	*t*	Sig.	Rank
Distribution Accessibility (X_2)	0.449	0.454	9.052	0.000	1st
Seed Distribution Quality (X_1)	0.417	0.338	6.602	0.000	2nd
Distribution Program Effectiveness (X_4)	0.337	0.277	5.303	0.000	3rd
Agricultural Extension Support (X_3)	0.268	0.245	4.595	0.000	4th

Table 1 presents the effects of the four antecedents on seed technology adoption. The results indicate that all four antecedents have a positive and significant influence on seed technology adoption, with significance values below 0.05. Among these factors, distribution accessibility (X_2) demonstrates the strongest effect, with the highest standardized coefficient (β=0.454; t=9.052; p<0.001), ranking first among the predictors. This finding suggests that farmers' ability to obtain and access improved seed technology represents the most influential factor in encouraging adoption behavior.

Seed distribution quality (X_1) shows the second strongest effect (β=0.338; t=6.602; p<0.001), indicating that the availability of reliable and high-quality seeds contributes significantly to farmers' willingness to adopt improved seed technology. Distribution program effectiveness (X_4) ranks third (β=0.277; t=5.303; p<0.001), demonstrating that effective implementation and management of seed distribution programs support farmers' adoption decisions. Meanwhile, agricultural extension support (X_3) also has a positive and significant effect (β=0.245; t=4.595; p<0.001), although its relative contribution is lower compared with the other antecedents.

The model explains a substantial proportion of variance in seed technology adoption, as indicated by an R^2 value of 0.787 and an adjusted R^2 value of 0.778. The simultaneous test confirms that the four antecedents jointly provide a significant contribution to explaining variations in seed technology adoption (F=87.939; p<0.001). These findings indicate that seed technology adoption is not merely an individual farmer decision but is strongly influenced by the effectiveness of the overall seed distribution system, particularly accessibility, which emerges as the most dominant determinant.

Table 2. The b- and c′-paths effects of adoption and the four antecedents on productivity

Variable	*B*	Beta	*t*	Sig.
Seed Technology Adoption (Z) b-path	0.393	0.379	3.516	0.001
Distribution Program Effectiveness (X_4)	0.408	0.324	5.179	0.000
Agricultural Extension Support (X_3)	0.204	0.181	2.915	0.004
Seed Distribution Quality (X_1)	0.204	0.159	2.453	0.016
Distribution Accessibility (X_2)	0.099	0.097	1.345	0.182

Table 2 presents the direct effects of seed technology adoption and the four antecedents on rice farmers' productivity. The results indicate that seed technology adoption has a positive and significant effect on productivity, with the highest standardized coefficient among all predictors (β=0.379; t=3.516; p=0.001). This finding demonstrates that farmers' adoption of improved seed technology represents an important mechanism in enhancing productivity outcomes.

Among the four antecedents, distribution program effectiveness (X_4) shows the strongest direct effect on productivity after adoption is included in the model (β=0.324; t=5.179; p<0.001). Agricultural extension support (X_3) also has a positive and significant effect (β=0.181; t=2.915; p=0.004), indicating that knowledge transfer and technical assistance contribute to improved farming performance. Similarly, seed distribution quality (X_1) demonstrates a significant positive effect on productivity (β=0.159; t=2.453; p=0.016), suggesting that the quality of distributed seeds remains an important factor in supporting production outcomes.

In contrast, distribution accessibility (X_2) does not show a statistically significant direct effect on productivity after seed technology adoption is incorporated into the model (β=0.097; t=1.345; p=0.182). This result indicates that the contribution of accessibility to productivity may primarily occur through farmers' adoption of seed technology rather than through a direct pathway. The model demonstrates strong explanatory capability, with an R^2 value of 0.767 and an adjusted R^2 value of 0.755, while the simultaneous test confirms that the variables included in the model significantly explain variations in rice farmers' productivity (F=62.035; p<0.001).

Table 3. Sobel test mediating role of seed technology adoption

Path	*a*	*b*	a×b	Sobel *z*	Sig.	Mediation Type
$X_2 \rightarrow Z \rightarrow Y$	0.449	0.393	0.177	3.268	0.001	Full
$X_1 \rightarrow Z \rightarrow Y$	0.417	0.393	0.164	3.100	0.002	Partial
$X_4 \rightarrow Z \rightarrow Y$	0.337	0.393	0.132	2.920	0.003	Partial
$X_3 \rightarrow Z \rightarrow Y$	0.268	0.393	0.105	2.794	0.005	Partial

Table 3 confirms that all four indirect paths through adoption are statistically significant (z>1.96). The accessibility path (X_2) stands out as the only full-mediation case: its effect on productivity exists solely because it first builds adoption. The remaining three antecedents show partial mediation, exerting influence on productivity both directly and through the adoption channel, with the strength of each indirect effect (a×b) tracking closely with that antecedent's strength in building adoption in Table 1.

4.2 Discussion

The dominance of distribution accessibility in shaping adoption (Table 1), coupled with its complete dependence on adoption to affect productivity (Table 3), offers a distinctive empirical picture of how the diffusion process actually unfolds within a provincial seed agency. This full-mediation pattern refines the efficiency-oriented view of certified-seed accessibility (Puspitasari, 2017) in the present context, easy geographic and administrative access to certified seed raises productivity only insofar as it culminates in a farmer's actual decision to use that seed, consistent with the broader finding that low accessibility functions as a principal barrier specifically to adoption rather than to output directly. This finding refines Rogers (1983) diffusion logic by showing, quantitatively, that one antecedent among several can operate purely as an adoption-building input with no independent productivity effect of its own.

By contrast, seed distribution quality, extension support, and program effectiveness each retain an independent effect on productivity even after adoption is modeled, indicating that these three antecedents matter for reasons beyond merely triggering adoption, quality benefits any farmer who uses the seed regardless of behavioral change, extension support improves cultivation practice more broadly, and program effectiveness reflects institutional targeting that benefits productivity through channels other than the individual adoption decision. This distinction is consistent with Gunawan, Hubeis, Fatchiya, and Susanto (2019), both of whom framed technology uptake as one important, but not the only, bridge between agricultural inputs and productivity outcomes. The broader literature reinforces this reading from several angles, Mayalibit, Suwarto, Rusdiyana, and Wijianto (2018) showed farmer attitudes toward certified seed hinge on cumulative knowledge and experience rather than access alone; Ridwan, Maulina, and Fahrimal (2022) demonstrated that innovation communication between extension agents and farmers is the operational mechanism that converts availability into use; and Nuswardhani (2019) documented that national certified-seed uptake has lagged for years despite continuous distribution efforts, a pattern the present mediation results help explain: distribution alone is necessary but not sufficient, and its productivity payoff depends on whether it is converted into adoption.

Taken together, these findings argue for a shift in program design: rather than treating farmer adoption as an automatic downstream consequence of good distribution, the Unit should manage adoption as an explicit target in its own right, through demonstration plots, structured post-distribution mentoring,

and communication strategies of the kind emphasized by Ridwan et al. (2022), precisely because, for at least one key antecedent, accessibility, there is no productivity payoff without it.

5. Conclusions

Seed technology adoption is the strongest single predictor of rice farmers' productivity in this model and functions as a genuine intervening mechanism rather than a background formality. It is most strongly shaped by distribution accessibility, followed by seed distribution quality, program effectiveness, and extension support. Adoption fully mediates the effect of distribution accessibility on productivity, meaning accessibility improvements alone will not raise yields unless they translate into actual adoption, while it partially mediates the effects of seed quality, extension support, and program effectiveness, which retain productivity value independent of adoption. These results position adoption-facilitation, alongside continued attention to seed quality, extension, and program management, as an indispensable and directly manageable lever for UPT Pengembangan Benih Padi dan Palawija, Dinas Pertanian dan Ketahanan Pangan Provinsi Jawa Timur. Future studies could adopt a longitudinal, multi-season design and bootstrap-based mediation techniques such as the PROCESS macro to validate these mediation patterns beyond the Sobel test's normality assumption.

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Author Contributions

AS contributed to the conceptualization, research design, data collection, data analysis, interpretation of results, and preparation of the initial manuscript draft. SOP contributed to research supervision, validation of the research framework, critical revision of the manuscript, and refinement of the final version. Both authors reviewed and approved the final manuscript for publication.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article. The research was conducted independently, and all findings presented in this manuscript are based solely on the authors' analysis and interpretation of the collected data.

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