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ORIGINAL ARTICLE

Do Quality Practices Pay? Evidence from Post-Harvest Quality Adoption among Black Pepper Farmers in Matale District, Sri Lanka

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Abstract

Adoption of post-harvest quality improvement practices is critical for farmers to meet high-value market standards. However, evidence on their impact on producing graded, high-quality output and subsequent income remains limited, beyond studies showing that these practices can improve quality, reduce losses, or enhance income. This study addresses this gap by evaluating the impact of post-harvest technology adoption on the production of graded dry black pepper, subsequent income, and total income among black pepper farmers in the Matale District of Sri Lanka. The analysis used primary data from 810 farmers collected through a structured household survey. The main analysis focuses on a sample of 248 farmers to ensure clear group differentiation (84 high adopters and 164 low adopters), while robustness checks include 562 medium adopters. Propensity score matching is employed to address self-selection bias. The results show that adoption significantly increases total black pepper income by 0.19–0.21 million LKR/ha and graded dry black pepper income by 0.24–0.27 million LKR/ha. In addition, adoption leads to a significant increase in graded dry black pepper production by 132–144 kg, highlighting that quality upgrading drives economic gains. These findings suggest that promoting the adoption of post-harvest quality practices can enhance farmers' earnings and facilitate access to high-value markets.

Keywords: *Black pepper, High-value markets, Production, Quality adoption*

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1. Introduction

Black pepper, widely regarded as the "King of Spices," is among the extensively consumed spices worldwide and plays a substantial role in the high-value global spice trade (Kumari et al. 2019; Spence, 2024; Wimalarathna et al. 2024). It is valued for its bioactive compounds, particularly piperine, which contribute to its antioxidant, antimicrobial, and gastro-protective properties and support its widespread use in culinary and medicinal applications (Srinivasan, 2007; Butt et al. 2013; Balasubramanian et al. 2016). Global black pepper production reached about 0.75 million tonnes in 2018, with an estimated value of USD 4.1 billion, and has increased to approximately 0.93 million tonnes in 2024, reflecting rising global demand (FAO, 2024; Khew et al. 2022).

As agricultural development increasingly focuses on high-value crops and markets, food quality and safety standards have become increasingly important (Magnan et al. 2021). Achieving these standards requires the adoption of appropriate post-harvest quality practices (Manda et al. 2024). For black pepper, quality standards comprise a range of physical, chemical, and microbiological safety requirements, detailed in Table A1 (Sri Lanka Standards Institution, 2008). These standards primarily apply to post-harvest processing, emphasising key practices such as threshing, blanching, drying, grading, and storage (Balasubramanian et al. 2016; Table 1), rather than cultivation alone. The adoption of these practices is therefore essential to ensure compliance with international quality and safety standards and to enhance access to premium export markets.

Sri Lanka is one of the major global producers of black pepper, ranking seventh in the world with an annual production of approximately 44,467 tonnes valued at USD 249.46 million in 2024, according to the Food and Agriculture Organisation. The spice sector is a key component of the country's economy, and black pepper has been identified as a priority crop in the National Export Strategy (NES, 2018) to enhance export performance. However, significant export earnings can only be achieved by targeting high-value markets with premium-quality products. Currently, around 75% of Sri Lanka's black pepper exports are directed to India, while exports to the European Union and other high-value markets remain limited (Department of Export Agriculture, 2023), particularly due to challenges in meeting required quality and safety standards.

Despite the importance of post-harvest quality practices in accessing high-value markets, adoption among farmers remains limited, partly due to insufficient information about the economic benefits of adopting these technologies (Suri & Udry, 2024). Although information on economic returns is critical for technology adoption, existing studies on post-harvest technology adoption have predominantly focused on loss reduction and quality improvement rather than income enhancement. In particular, a large body of literature examines loss reduction (Ndegwa et al. 2016; Omotilewa et al. 2018; Stathers et al. 2020; Brander et al. 2021; Chegere et al. 2022; Amadu & McNamara, 2024; Manda et al. 2024), while another stream emphasises improvements in product quality (Pretari et al. 2019; Walker et al. 2018;Omotilewa et al. 2019; Bauchet et al. 2021; Leavens et al. 2021; Hoffmann et al.

2021; Magnan et al. 2021). Although reductions in quantity losses and improvements in product quality can ultimately lead to higher income and economic benefits for farmers, relatively few studies directly examine the economic impacts of post-harvest quality adoption on farmers' income.

Existing studies on the economic impacts of post-harvest technologies focus primarily on maize and storage interventions, showing that adoption can significantly increase farmers' income (Benimana et al., 2023; Adams et al. 2024). Similarly, evidence from cocoa farmers shows that improved post-harvest practices significantly increase farmers' income (Olutumise et al. 2025). However, there is limited evidence on the impacts of post-harvest technology adoption in spice crops, including black pepper. Existing research on black pepper farmers in Sri Lanka shows that the adoption of post-harvest technologies, including the use of threshing machines, blanchers, and drying equipment, is associated with increased income and improved farmer well-being, as these practices can reduce post-harvest losses, improve product quality, and enable farmers to sell larger quantities of black pepper at higher prices, although causal evidence remains limited. (Adikaram et al. 2025). Moreover, the impact of post-harvest technology adoption on both the production of graded high-quality output and subsequent income gains remains unexplored.

This study aims to examine the impact of adopting post-harvest quality improvement practices, including threshing, fresh and dry berry grading, blanching, and storage, on both farmers' income and the production of graded dry black pepper (high-quality) among smallholder farmers in Sri Lanka. By jointly analysing quality upgrading and economic outcomes, the study provides novel evidence on whether these practices translate into tangible financial gains for farmers.

2. Materials and Methods

2.1 Study Site and Data

This study is based on a survey conducted in seven divisional secretariat divisions in the Matale District, Sri Lanka: Matale, Yatawaththa, Ambanganga Korale, Naula, Galewela, Raththota, and Pallepola, involving 810 black pepper farmers selected by simple random sampling from 1,127 registered black pepper farmers in the district. Matale is a pioneering region for commercial black pepper cultivation in the country. It ranks as the second-largest black pepper-producing district, covering 5,862 hectares with an annual production of 3,576 metric tonnes (Department of Export Agriculture, 2023). The district receives annual rainfall between 1,115.8 mm and 2,733.5 mm and annual average temperatures ranging from 24.64°C to 26.75°C (Subasinghe and Kulathilake, 2025), creating favourable agro-climatic conditions for black pepper production. Data were collected through face-to-face interviews using a structured questionnaire to gather information on farmers' socio-economic characteristics, adoption of post-harvest quality improvement practices, production and income.

2.2 Measurement of Adoption and Sample Classification

Farmers were categorised as high or low adopters based on an adoption quotient derived from their reported adoption of six key post-harvest quality improvement practices in black pepper. When multiple methods exist within a post-harvest practice, the adoption indicator reflects the specific behaviour most closely associated with achieving the required quality and safety standards. This may involve either the adoption of a recommended practice or the avoidance of a non-recommended practice, as presented in Table 1. Each adoption indicator was scored as 1 if the farmer adopted the recommended practice (or avoided the non-recommended practice) and 0 otherwise.

Table 1: Key post-harvest quality improvement practices in black pepper (Balasubramanian et al. 2016)

Post-harvest Practices	Definition	Adoption Indicator
Threshing	Separation of berries from spikes using hand, foot (inside sack), barefoot, or a mechanical thresher	Avoidance of barefoot threshing
Grading (fresh berry)	Sorting fresh berries to remove immature, lightweight berries (pinheads) using a winnowing fan or an electronic grader	Implementation of fresh berry grading
Blanching	Immersing fresh berries in 80°C hot water for 3 minutes before drying	Adoption of the blanching practice
Grading (dry berry)	Sorting dried black pepper based on size and bulk density using a mesh (5×8 mm) or an electronic grader	Implementation of dry berry grading
Drying	Reducing the moisture level of black pepper to up to 12% wet basis, using either sun drying (on bare floor, flooring material, elevated floor, or recommended elevated cement floor) or an artificial dryer	Avoidance of sun-drying on bare floors
Storage	Storing dried black pepper using appropriate materials such as poly sack bags (with or without an inner polythene liner)	Storage in a poly sack bag with an inner polythene liner

The adoption quotient was calculated following Haque et al. (2025) as:

Adoption Quotient = (Total score obtained by farmer / Maximum score) × 100

Each practice contributed equally to the index, yielding a maximum possible score of 6, which represents the adoption of all recommended practices. This approach is justified on three grounds. First, all selected practices represent critical components of post-harvest quality and safety, particularly in graded black pepper production. Second, there is no strong empirical or theoretical basis to assign differential weights in the absence of validated weighting schemes. Third, equal weighting enhances transparency and simplicity in index construction.

Based on the adoption quotient, farmers were grouped as high adopters (66.65–100) or low adopters (below 33.34). Farmers with medium adoption levels (33.35–66.64) were excluded from the main analysis to ensure clearer differentiation between high- and low-adopter groups. Medium adopters, on average, demonstrate transitional or mixed behaviour, combining both adoption and non-adoption of recommended practices, which may lighten differences between groups and lower the precision of estimated effects. Therefore, focusing on the two extremes enhances analytical clarity and strengthens internal validity when examining behavioural contrasts. As a result, the final sample of the main analysis consisted of 248 farmers, including 84 high adopters and 164 low adopters.

As a robustness check, additional analyses were conducted by including medium adopters (562 farmers) and examining differences between high vs. medium and medium vs. low groups.

2.3 Data Analysis and Impact Evaluation

Propensity Score Matching (PSM) was employed to estimate the impact of adopting post-harvest quality improvement practices on farmers' income and high-quality production. Since adoption is not randomly assigned, simple comparisons between high and low adopters may yield biased estimates due to self-selection.PSM addresses this issue by constructing a comparable control group based on observable characteristics using the estimated propensity scores (Rosenbaum and Rubin, 1983). Farmers classified as high adopters were considered the treatment group, while low adopters served as the control group.

The impact of adoption of post-harvest quality improvement practices was estimated using the Average Treatment Effect on the Treated (ATET), which measures the mean difference in outcomes between high adopters and their matched counterparts (Imbens, 2004; Hossain et al. 2025) as:

$$ATET = E[Y_1 \mid T = 1, p(X) = q] - E[Y_0 \mid T = 1, p(X) = q]$$

where $E[Y_1 \mid T = 1, p(X) = q]$ denotes the expected outcome for high adopters (treatment group) with a given propensity score, and $E[Y_0 \mid T = 1, p(X) = q]$ denotes the expected outcome for those same high adopters had they not adopted, the counterfactual. The term T is a binary variable indicating high adopters ($T = 1$) and low adopters ($T = 0$). $p(X) = q$ represents the time-invariant variables used for matching (Table 2). Under the Conditional Independence Assumption, the counterfactual $E[Y_0 \mid T = 1, p(X) = q]$ is identified by the observed outcomes of matched low adopters ($T = 0$) with similar propensity scores, i.e., $E[Y_0 \mid T = 0, p(X) = q]$.

Table 2: Description of matching variables

Variables	Description
Household head age	Age of the household head
Household head gender dummy	1 if household head is female,0 otherwise
Secondary education dummy	1 if the household head received a secondary education,0 otherwise
Household head occupation farmer dummy	1 if household head is a farmer,0 otherwise
Family size	Total number of members in the household
Land size	Total land size in acres (ac)
Variety local dummy	1 if the variety grown is local,0 otherwise

To assess the robustness of the results, we applied three PSM algorithms, including Nearest Neighbour Matching (NNM), Kernel Matching (KM), and Radius Matching (RM), each addressing different aspects of matching quality (Haque et al. 2025). NNM pairs each treated observation with the closest control(s) within a specified propensity score range, reducing the risk of poor matches. KM uses weighted averages of all control observations, giving more weight to controls with propensity scores closer to the treated unit, which improves efficiency. RM pairs treated units with all controls within a defined propensity score radius, ensuring that only comparable observations are included.

All data analyses were performed using Stata 18.0 (StataCorp LLC, College Station, TX, USA).

3. Results and Discussion

3.1 Descriptive Statistics

Table 3 presents the mean differences in both potential variables and outcome variables for the full sample of 248 farmers, as well as for the treatment group (84 high adopters) and the control group (164 low adopters) of post-harvest quality improvement practices. Across all groups, the average household head (HHH) age of farmers is around 60 years. Most farmers are male, and more than 50% have attained secondary education, with similar family sizes observed across groups. Overall, household demographic characteristics, such as age, education, and family size, are relatively comparable between the treatment and control groups. However, a higher proportion of farmers in the treatment group report farming as their primary occupation compared to the control group. Land size is larger among high adopters compared to low adopters, while nearly 90% of farmers across all groups cultivate local pepper varieties.

Outcome variables show substantial variation between the two groups before matching. High adopters report significantly higher total black pepper income (0.38 vs. 0.11 million LKR/ha), dry black pepper income (0.30 vs. 0.02 million LKR/ha), and production quantity (176.77 kg vs. 21.25 kg) compared to low adopters ($p < 0.01$). While these differences indicate a positive association between adoption and economic outcomes, they may also reflect selection bias, thereby justifying the use of PSM to obtain causal estimates.

Table 3: Descriptive statistics

	Total sample (n=248)		Treatment group (n=84)		Control group (n=164)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Potential variables						
Household head (HHH) age	60.21	13.01	60.08	12.70	60.27	13.21
HHH gender (female dummy)	0.13	0.34	0.06	0.24	0.16	0.37
Secondary education dummy (yes = 1)	0.56	0.50	0.58	0.50	0.55	0.50
HHH occupation farmer dummy (yes = 1)	0.42	0.50	0.57	0.50	0.35	0.48
Family size	3.69	1.24	3.58	1.26	3.75	1.23

Land size (ha)	0.49	0.42	0.66	0.48	0.41	0.36
Variety local dummy (yes = 1)	0.92	0.27	0.89	0.31	0.93	0.25
Outcome variables						
Total black pepper income (million LKR/ha)	0.12	0.22	0.30	0.30	0.02	0.06
Graded dry black pepper income (million LKR/ha)	0.20	0.22	0.38	0.29	0.11	0.10
Graded dry black pepper production (kg)	73.93	121.60	176.77	157.95	21.25	38.20

Note: All income and production outcomes are measured on an annual basis.

3.2 Balance Between Treated and Control Groups

Table 4 reports the comparison of key variables between high (Treatment) and low (control) adopters of post-harvest quality practices, both before and after matching. Before matching, household head gender (female) ($p = 0.02$), primary occupation (farmer) ($p < 0.01$), and land size ($p < 0.01$) show statistically significant differences between high and low adopters. However, after matching, none of the variables remains statistically significant, indicating that the matching procedure effectively reduces observable differences between the two groups. It highlights the credibility of the identification strategy and supports the validity of the estimated treatment effects, consistent with the methodological framework of PSM (Rosenbaum & Rubin, 1983).

Table 4: Balance between the treated and control groups

Variable	Before matching	Mean		% bias	
	After matching	Treated	Control	reduction	p>|t|
HHH age	U	60.08	60.27		0.91
	M	60.08	61.01	-382.30	0.63
HHH gender (female dummy)	U	0.06	0.16		0.02
	M	0.06	0.07	91.30	0.81
Secondary education dummy (yes = 1)	U	0.58	0.55		0.67
	M	0.58	0.62	-18.80	0.66
HHH occupation farmer dummy (yes = 1)	U	0.57	0.35		0.00
	M	0.57	0.60	89.30	0.75
Family size	U	3.58	3.75		0.32
	M	3.58	3.61	82.40	0.88
Land size (ha)	U	0.66	0.41		0.00
	M	0.66	0.62	82.80	0.58
Variety local dummy (yes = 1)	U	0.89	0.93		0.28
	M	0.89	0.88	64.00	0.77

Note: *U (unmatched) denotes the sample before matching; M (matched) denotes the sample after matching. The percentage bias reduction may exceed 100% for variables with very small initial imbalance.*

3.3 Impact of the Adoption of Quality Improvement Practices on Income and Production

Table 5 presents the impact of adopting post-harvest quality improvement practices on income and production outcomes using three matching procedures: NNM, KM, and RM. The estimates are consistent across all matching methods in terms of direction, magnitude, and statistical significance, confirming the robustness of the findings.

High adopters earn significantly higher total black pepper income, with increases ranging from 0.19 to 0.21 million LKR /ha ($p < 0.01$) compared to low adopters. Notably, income from graded dry black pepper shows a substantial increase, ranging from 0.24 to 0.27 million LKR/ha ($p < 0.01$). The increase in income from graded dried black pepper is higher than the increase in total black pepper income across all matching methods. This suggests that income gains are primarily driven by quality upgrading rather than increases in overall production alone, since graded dry black pepper reflects compliance with quality standards.

Consistent with this, adoption leads to a significant increase in graded dry black pepper output, with high adopters producing approximately 132 to 144 kg ($p < 0.01$) more than low adopters. This finding on increased production of high-quality output aligns with and extends previous studies that emphasise improvements in product quality following technology adoption (Pretari et al. 2019; Walker et al. 2018; Omotilewa et al. 2019; Bauchet et al. 2021; Leavens et al. 2021; Hoffmann et al. 2021; Magnan et al. 2021).

Overall, the results demonstrate a positive impact of adopting post-harvest quality improvement practices on both product quality and farmers' income, reinforcing existing evidence that such technologies enhance farmers' economic performance (Benimana et al. 2023; Adams et al. 2024; Olutumise et al. 2025). However, while prior studies have largely focused on staple crops such as maize, this study extends the literature by providing evidence on the economic benefits of technology adoption in a high-value crop, black pepper.

Importantly, within the Sri Lankan context, this study provides causal evidence in the black pepper sector, where prior research has largely been limited to associative findings that reveal correlations between the adoption of post-harvest technologies and outcomes such as income and farmer well-being (Adikaram et al. 2025). These gains are likely driven by improvements in product quality that enable farmers to access higher-value products, highlighting the critical role of quality upgrading in translating adoption into tangible economic benefits. This supports the argument that post-harvest quality improvement is a key pathway for smallholder farmers to access high-value markets and improve their livelihoods (Magnan et al. 2021; Suri & Udry, 2024).

Table 5: Impact of the adoption of quality improvement practices on income and production: High adopters vs. low adopters

Outcome variables	NNM	KM	RM
Total black pepper income (million LKR/ha)	0.19***	0.20***	0.21***
	(0.03)	(0.03)	(0.03)
Graded dry black pepper income (million LKR/ha)	0.24***	0.25***	0.27***
	(0.04)	(0.03)	(0.03)
Graded dry black pepper production (kg)	132.10***	136.70***	144.11***

	(18.84)	(17.83)	(17.55)

*Note: Bootstrap standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1. All income and production outcomes are measured on an annual basis.*

3.4 Robustness Analysis

As a robustness check, additional analyses were conducted by incorporating medium adopters and comparing outcomes across different adoption levels (Table 6). The results reveal a clear and consistent gradient pattern: high adopters achieve significantly higher income and production outcomes than medium adopters, while medium adopters outperform low adopters. Although the magnitude of the estimated effects for medium adopters is smaller than that for high adopters, the effects remain statistically significant across all matching methods.

This pattern indicates increasing levels of adoption are associated with progressively greater economic benefits. The smaller magnitude observed for medium adopters likely reflects their partial adoption behaviour, which yields improvements but at a lower scale compared to full adoption. Overall, these findings reinforce the robustness and validity of the main results.

Table 6. Impact of adoption of quality improvement practices on income and production: High adopters vs. medium adopters and medium adopters vs. low adopters

Outcome variables	NNM	KM	RM
Panel A: High adopters vs. medium adopters			
Total black pepper income (million LKR/ha)	0.16***	0.14***	0.16***
	(0.04)	(0.03)	(0.03)
Graded dry black pepper income (million LKR/ha)	0.22***	0.22***	0.23***
	(0.04)	(0.03)	(0.03)
Graded dry black pepper production (kg)	119.34***	117.33***	122.40***
	(20.55)	(16.73)	(16.57)
Panel B: Medium adopters vs. low adopters			
Total black pepper income (million LKR/ha)	0.04***	0.05***	0.05***
	(0.01)	(0.01)	(0.01)
Graded dry black pepper income (million LKR/ha)	0.03***	0.03***	0.03***
	(0.01)	(0.01)	(0.01)
Graded dry black pepper production (kg)	17.74***	17.47***	19.24***
	(5.12)	(4.46)	(4.43)

Note: Standard errors are in parentheses *** *p<0.01*, ** *p<0.05*, * *p<0.1*. *All income and production outcomes are measured on an annual basis.*

3.5 Heterogeneity

Heterogeneity analysis based on land size and occupation shows that the impact of adopting post-harvest quality improvement practices remains positive and statistically significant across all subgroups (Table 7). The magnitude of the effects is larger among farmers with above-median land size and those primarily engaged in farming, for all outcomes.

In contrast, the estimated effects for female farmers are not statistically significant, while male farmers exhibit significant positive impacts across all outcomes. This may suggest potential constraints faced by female farmers in fully realising the benefits of adoption.

However, formal t-tests indicate that differences in treatment effects across subgroups are not statistically significant. The estimated t-values fall below conventional thresholds, suggesting that the observed variations reflect differences in magnitude rather than statistically significant heterogeneity.

Overall, broadly consistent heterogeneity results of the positive impact of adopting post-harvest quality improvement practices across farmer subgroups specify the external validity of the finding.

Table 7: Heterogeneous treatment effects on income and production

Outcome variables	Land size		Occupation		Gender	
	> median	≤ median	Farmer	Non farmer	Female	Male
Total black pepper income (million LKR/ha)	0.16***	0.12***	0.17***	0.14***	0.18	0.14***
	(0.05)	(0.04)	(0.04)	(0.05)	(0.16)	(0.04)
Graded dry black pepper income (million LKR/ha)	0.28***	0.17***	0.28***	0.17***	0.01	0.27***
	(0.06)	(0.03)	(0.05)	(0.04)	(0.20)	(0.03)
Graded dry black pepper production (kg)	145.43***	96.55***	146.04***	98.30***	111	150.09***
	(33.28)	(178.73)	(26.67)	(26.97)	(179.02)	(19.70)

Note: Standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1. *All income and production outcomes are measured on an annual basis.*

3.6 Policy Implications and Recommendations

The findings demonstrate that the adoption of post-harvest quality improvement practices significantly enhances farmers' income and production, particularly through increasing the production and income from graded dry black pepper. This highlights the importance of quality upgrading as a pathway for smallholder farmers to access high-value markets, consistent with previous studies (Magnan et al. 2021; Suri & Udry, 2024).

A key contribution of this study is its focus on graded dry black pepper production and corresponding income, which more directly capture the effects of adopting post-harvest quality improvement practices. By emphasising these outcomes, the analysis provides a more policy-relevant assessment of adoption, highlighting quality upgrading rather than overall production increases.

To translate these gains into broader impact, several actionable policy measures are recommended. First, strengthening extension services is critical, with a focus on practical, hands-on training on post-harvest quality improvement practices, including threshing, grading, blanching, and storage. Targeted interventions should support farmers in progressing from partial to full adoption, for example, through successful farmer visits and structured peer-learning programs. Second, improving access to post-harvest infrastructure, such as drying facilities, grading equipment, and storage systems, can facilitate compliance with quality standards and reduce losses. Third, expanding access to credit and input subsidies can help resource-constrained farmers overcome upfront investment barriers. Finally, strengthening market linkages, including certification schemes and direct connections to exporters, can enable farmers to capture price premiums for higher-quality produce.

Overall, an integrated policy approach combining capacity building, infrastructure support, and market development is suggested to sustain adoption and enhance smallholder farmer participation in high-value agricultural markets.

3.7 Study Limitations

The main analysis of this study focuses on comparing high and low adopters to ensure a clear distinction between treatment groups and improve the quality of matching. While this enhances internal validity, it may limit external validity, as the findings may not fully generalise to farmers with medium levels of adoption. Although medium adopters are included in supplementary analyses, their exclusion from the main analysis may influence the overall representativeness of the results.

In addition, due to the absence of detailed cost data on post-harvest practices, the analysis is limited to income and production outcomes and does not capture net profit or overall profitability. As a result, the full economic returns to adoption may not be fully assessed. Future research should incorporate detailed cost information to provide a more comprehensive evaluation of the economic returns to adoption.

4. Conclusions

The role of adopting post-harvest quality improvement practices in enhancing both the production of graded, high-quality pepper and associated income remains underexplored, despite their importance for meeting quality standards to access high-value markets. This study addresses this gap by providing causal evidence on the impact of adoption, using Propensity Score Matching to control for self-selection and ensure credible comparisons between high and low adopters. The results show that adoption significantly increases total pepper income, graded dry pepper income, and graded dry pepper production, highlighting the role of quality upgrading in driving economic gains. By enabling farmers to meet required quality standards, these practices improve access to higher-value markets and generate substantial economic returns. These findings point to the need for policy interventions that promote post-harvest quality upgrading, particularly through training and extension, to support smallholder integration into high-value export markets.

Conflicts of interest: The authors have no conflicts of interest regarding this publication.

Appendix

Table A1: Quality and safety standards for black pepper (Sri Lanka Standards Institution, 2008)

Characteristics	Requirement		
	Grade 1	Grade 2	Grade 3
Physical requirements			
Extraneous Matter, (foreign materials like dust, twigs, stones, or other plant parts), per cent by mass, (Maximum)	1	2	2
Light berries and broken berries - per cent by mass, ((Maximum)	2	10	15
Pinheads - per cent by mass, (Maximum)	0.5	1	2
Bulk density, g/l Minimum	550	500	450
Chemical requirements			
Moisture content, per cent by mass, (Maximum)	12	14	14
Total ash, per cent by mass, on dry basis (Maximum)	7	7	7
Non-volatile ether extract, per cent by mass, dry basis (Minimum)	10	10	10
Volatile oils, ml/100g, on dry basis (Minimum)	3	3	3
Piperine content, per cent by mass, (Minimum)	6	6	6
Microbial limits			
Escherichia coli (MPN/g)	Negative	Negative	Negative
Salmonella, per 25 g	Absent	Absent	Absent

Note: *Based on SLS 105: Part 1 (2008), Sri Lanka Standards Institution.*

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