

RESEARCH ARTICLE

IMPACT OF EXTENSION AND PEER LEARNING ON KNOWLEDGE OF FOOD QUALITY AND SAFETY: EVIDENCE FROM BLACK PEPPER FARMERS IN SRI LANKA

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ABSTRACT

Food quality and safety standards have become critical as agricultural development increasingly targets high-value crops and markets. These standards govern physical characteristics, purity, and contaminant levels to meet high-value market requirements. However, limited access to relevant information and post-harvest technologies constrains farmers' ability to acquire the knowledge necessary to maintain these standards. While prior research has largely focused on staple crops, evidence on knowledge enhancement in high-value crops such as black pepper remains limited. This study examines the effect of information provision on knowledge enhancement and retention among black pepper farmers in Sri Lanka, utilising a randomised controlled trial involving 660 farmers in the Matale District. Two interventions were compared: a government extension program on quality and safety standards, and farmer-to-farmer belief and experience sharing. Knowledge was assessed immediately after the interventions and six months later to capture retention. Results indicate that the government extension program significantly increased immediate knowledge and sustained these gains over six months, demonstrating strong retention. In contrast, farmer-to-farmer experience sharing showed no immediate effect but improved knowledge over time, suggesting gradual shifts in beliefs as farmers observed peers' practices. Heterogeneity analysis reveals that participant characteristics, including age, gender, education, occupation, and baseline postharvest knowledge, influence intervention effectiveness, highlighting the need to tailor approaches for specific subgroups. Overall, the findings emphasise the importance of structured, expert-led extension programs in strengthening farmers' knowledge on food quality and safety standards, while supporting knowledge retention through farmer learning.

Keywords: Black pepper, Food quality and safety, Information provision, Knowledge enhancement

INTRODUCTION

Black pepper, referred to as the 'King of Spices,' is one of the most prized and widely consumed spices globally, and plays a dominant role in the multi-billion-dollar spice industry (Kumari *et al.*, 2019; Spence, 2024). It is used for culinary and medicinal purposes. Its active compound, piperine, exhibits antioxidant, digestive, and potential anti-tumour effects (Balasubramanian *et al.*, 2016; Srinivasan, 2007).

In 2018, global black pepper production reached a peak of 752,000 tonnes, with an estimated value of USD 4.1 billion, and is

projected to continue expanding in response to rising global demand (Khew *et al.*, 2022). However, despite its economic significance, black pepper production in many developing countries is constrained by quality and safety challenges (Yogendrarajah *et al.*, 2014). Sri Lanka, ranked as the sixth-largest black pepper producer with an annual production of 46,600 metric tons (FAO, 2023), also experiences comparable quality and safety challenges.

Food quality and safety standards have become critical as agricultural development increasingly targets high-value crops and markets. Black pepper quality standards

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involve physical, chemical, and microbiological parameters (Supplementary Table S1), with a primary focus on post-harvest practices (Supplementary Table S2). However, limited access to relevant information and post-harvest technologies remains a major constraint for farmers in developing countries (Magnan *et al.*, 2021). Providing targeted information is therefore essential for enhancing farmers' knowledge of improved post-harvest practices.

Previous studies on information provision have mainly examined its effects on reducing quantity losses in yield (Manda *et al.*, 2024; Chegere & Söderbom, 2020; Amadu & McNamara, 2024), though the impact on quality losses in yield remains critical, as quality deterioration has a greater influence on food safety outcomes (Ricker-Gilbert *et al.*, 2024). Only limited research has examined the impact of information provision on quality outcomes (Magnan *et al.*, 2021; Bauchet *et al.*, 2021). Most of these studies focused on the adoption of quality improvement practices or the reduction of quality and safety deterioration, while comparatively few investigated effects on knowledge enhancement. For example, Anitha *et al.* (2019) documented significant knowledge gains among groundnut, maize, and sorghum farmers in Malawi following training on aflatoxin contamination. Tambo *et al.* (2019) showed that extension programs delivered through information and communication technologies (ICT) significantly enhanced Ugandan farmers' knowledge of fall armyworm in maize. Even where research has addressed knowledge enhancement, existing studies have largely focused on cereal and legume crops, leaving a clear gap in understanding how information provision influences knowledge related to quality and safety management in spices such as black pepper.

To address this gap, this study examines the impact of information provision on knowledge enhancement for improving the quality and safety of spices, particularly black pepper, through two information provision approaches: a government extension program and farmer-to-

-farmer belief and experience sharing. The government extension program offers formal, structured training designed to educate farmers on quality. This training was delivered by Extension Officers (EOs) from the Department of Export Agriculture, the authorised government agency responsible for promoting spice crop production, including pepper, in Sri Lanka. The training covered identification of optimal maturity stages, recommended threshing methods, fresh and dry grading procedures, blanching techniques, improved drying practices, and proper storage methods, emphasising how these practices directly contribute to achieving the required high quality and safety standards.

In contrast, farmer-to-farmer belief and experience sharing relies on informal knowledge exchange, where farmers communicate their own beliefs and practical insights among themselves. Although this session was conducted based on the provided guidelines on quality and safety standards and recommended practices in black pepper production, it relied exclusively on farmer-led discussions without formal technical instructions.

The study was conducted in the Matale District of Sri Lanka using a randomized controlled trial (RCT) involving 660 black pepper farmers. By experimentally comparing a formal extension program and farmer-to-farmer discussions, this study provides causal evidence on how different information delivery mechanisms shape knowledge dynamics in black pepper value chains.

MATERIALS AND METHODS

Study site

The study was conducted in seven EO divisions, Pallepola, Palapathwala, Yatawattha, Wahakotte, Alugolla, Raththota, and Hunuketaela, within the Matale District of Sri Lanka. The district is a pioneering region for commercial black pepper cultivation in the country (Figure. 1) and the second-largest pepper-producing district, with 5,862 hectares under cultivation and an annual production of 3,576 metric tons (DEA, 2023).

Sampling method and experimental design

A total of 660 farmers were randomly selected from 1,027 registered black pepper farmers in Matale district. They were then randomly assigned to one of three groups: two treatment groups and one control group, with 220 farmers in each group.

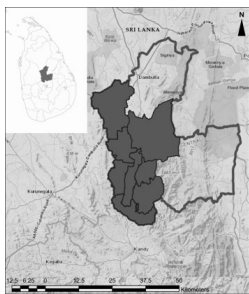


Figure 1: Map of the study site

As per Table 1, Treatment 1 involved a government extension program delivered by the Department of Export Agriculture, covering quality and safety standards and recommended practices in black pepper production.

Table 1: Experimental groups

Program content	C	T1	T2
Basic training on Agronomic practices of Pepper cultivation from planting to harvesting (45 min)	✓	✓	✓
Government extension program on quality and safety standards and recommended practices in black pepper production (45 min)		✓	
Farmer-to-farmer belief and experience sharing based on the provided guidelines for discussion on quality and safety standards and recommended practices in black pepper production (45 min)			✓
Documentary movie on the Department of Export Agriculture as a placebo (15 min)	✓		

The experimental design was pre-registered in the American Economic Association's RCT Registry (AEARCTR-0012674).

Treatment 2 consisted of a farmer-to-farmer belief and experience sharing session, facilitated by an EO, where farmers discussed and exchanged their existing knowledge, experiences, and beliefs on quality and safety standards and recommended practices in black pepper production. The control group

participated in a placebo activity, which involved watching a documentary movie about the Department of Export Agriculture. Importantly, all groups received the same basic training on agronomic practices for pepper cultivation, covering all stages from planting to harvesting.

Research implementation and data collection

Baseline data were collected through a survey conducted between 28th November and 28th December 2023, before the intervention (Figure 2). Farmers in all three groups were invited to their assigned interventions ahead of program implementation, between 28th December 2023 and 2nd February 2024. All invitees were offered a lottery ticket as an incentive for their contribution to the study. The government extension program, the farmer-to-farmer belief and experience sharing sessions, and the control intervention were implemented by EOs from the Department of Export Agriculture between 5th January and 9th February 2024.

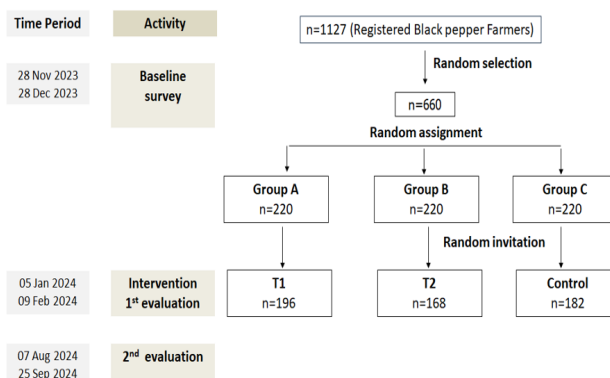


Figure 2: Experimental timeline and design

Out of 220 farmers assigned to each group (660 in total), 196 (89.1%) participated in Treatment 1 (T1), 168 (76.4%) in Treatment 2 (T2), and 182 (82.7%) in the control group, resulting in a total of 546 participants and indicating partial compliance with assignment.

Knowledge enhancement was assessed using test scores that measured participants' understanding of quality and safety standards and recommended post-harvest practices in black pepper production immediately after

training and again six months later, coinciding with the harvesting season.

Knowledge data were collected at three time points through two evaluation rounds: baseline, immediate post-intervention, and a six-month follow-up. The first evaluation assessed immediate knowledge changes using surveys administered immediately before and immediately after the intervention, conducted between 5th January and 9th February 2024 during program implementation. The second evaluation was conducted between 7th August and 25th September 2024 and aimed to assess knowledge retention six months after the interventions, coinciding with the harvesting

period. Knowledge scores were measured using a quiz consisting of 25 multiple-choice questions, covering black pepper cultivation (10 questions) and quality and safety standards and recommended practices (15 questions). The internal consistency reliability of the knowledge scale was assessed using Cronbach's alpha, yielding $\alpha = 0.82$, indicating high internal consistency.

Descriptive statistics

Balance tests were conducted on participant characteristics and information facts to assess the success of randomization across assigned groups. Table 2 presents summary statistics.

Table 2: Descriptive statistics for the potential covariates

Variable	C (n=182)		T1 (n=196)		T2 (n=168)	
	Mean	SD	Mean	SD	Mean	SD
Participant Characteristics						
Age	48.80	15.43	50.51	13.46	52.00	12.85
Sex (female dummy)	0.40	0.49	0.45	0.50	0.37	0.49
Secondary education dummy (yes=1)	0.50	0.50	0.58	0.50	0.58	0.50
Doing farming as an occupation (yes=1)	0.20	0.40	0.24	0.43	0.18	0.39
Information facts						
Distance to ASC (km)	7.48	4.97	8.54	6.94	7.98	6.30
Number of visits to the ASC during the last 12 months	2.23	1.13	2.23	1.21	2.20	1.36
Main information source EO dummy (yes=1)	0.45	0.50	0.50	0.50	0.51	0.50
Prior knowledge dummy (yes=1)	0.056	0.23	0.05	0.22	0.04	0.20

'n' indicates the number of observations (Farmers). SD: Standard Deviation, ASC: Agrarian Service Centre in Sri Lanka and EO: Extension Officer of the Department of Export Agriculture (DEA), Sri Lanka, who is authorised to conduct extension activities for black pepper and other export spices. For dummy variables, the mean values represent the proportion of observations that take the value of 1.

Table 3 reports baseline comparisons among the groups. Participant characteristics and information facts were generally well-balanced across groups. However, participant age slightly differed between Treatment 2 and the control group. While these minor imbalances are likely due to random variation and do not compromise the validity of randomization, the relevant covariates are incorporated into the regression models to improve estimation accuracy.

Empirical framework

We employed a linear regression model to estimate the causal effects of government extension programs and farmer-to-farmer belief and experience sharing on knowledge enhancement. We first estimate intention-to-treat (ITT) effects, capturing the impacts of assignment to treatment, relative to assignment to the control group. The ITT is policy-relevant and remains unbiased under non-compliance. Given partial non-compliance, ITT estimates may understate the

effect of receiving the intervention. To estimate the causal effect for compliers, we

Table 3: Baseline comparison among the groups

Variable	Diff (T1-C)		Diff (T2-C)		Diff (T1-T2)	
	Mean	SE	Mean	SE	Mean	SE
Participant Characteristics						
Age	1.71	1.62	3.20*	1.67	-1.49	1.47
Sex (female dummy)	0.06	0.06	-0.02	0.06	0.08	0.06
Secondary education dummy (yes=1)	0.08	0.06	0.08	0.06	0.01	0.06
Doing farming as an occupation (yes=1)	0.04	0.05	-0.02	0.05	0.02	0.05
Information facts						
Distance to ASC (km)	1.05	0.69	0.50	0.67	0.55	0.74
Number of visits to the ASC during the last 12 months	0.01	0.13	-0.03	0.15	0.03	0.14
Main information source EO dummy (yes=1)	0.04	0.06	0.06	0.06	-0.01	0.06
Prior knowledge dummy (yes=1)	-0.01	0.03	-0.02	0.03	0.01	0.02

'n' indicates the number of observations (Farmers). SD: Standard Deviation, ASC: Agrarian Service Centre in Sri Lanka and EO: Extension Officer of the Department of Export Agriculture (DEA), Sri Lanka, who is authorised to conduct extension activities for black pepper and other export spices. For dummy variables, the mean values represent the proportion of observations that take the value of 1.

employ two-stage least squares (2SLS), using randomized invitations to the interventions as instruments. This approach allows us to estimate the local average treatment effects (LATEs) of the two interventions, addressing endogeneity in actual participation (Cawley *et al.*, 2018; Kubitza & Krishna, 2020).

Equation 1 specifies the ITT estimation model.

Where; Y_{it} : knowledge score of farmers i at time t , where $t = 1$: immediate post-intervention time and $t = 2$: six months after the intervention time, T_{1i} and T_{2i} respectively represents the assignment in government

$$Y_{it} = \alpha_0 + \beta_1 T_{1i} + \beta_2 T_{2i} + \gamma_0 Y_{i,t=0} + X_{i\sigma_0} + u_{it} \quad \text{Eq. 1}$$

extension program (T1) and farmer-to-farmer belief experience sharing (T2). β_1 and β_2 : average treatment effects on the treated (ITT), for T1 and T2, respectively, $Y_{i,t=0}$: baseline knowledge score before the intervention, X_i : a vector of other household-level covariates at the baseline, and we estimate three model specifications: (a) without covariates, (b) including only covariates that were imbalanced at baseline,

$$T_{ji} = \alpha_1 + \pi_1 Z_{1i} + \pi_2 Z_{2i} + \gamma_1 Y_{i,t=0} + X_{i\sigma_1} + v_{it} \quad \text{Eq. 2}$$

experience sharing. Z_{1i} and Z_{2i} are instruments indicating random invitation to each respective treatment. The second stage of the

and (c) including all covariates, u : error term. Equation 2 shows the first stage of the 2SLS model, which estimates the effects of random invitation to treatment on actual participation.

Where T_{ji} is an indicator for the actual participation of farmers i in *treatment j*. $j = 1$ denotes participation in the government extension program, and $j = 2$ denotes participation in farmer-to-farmer belief and

2SLS model used to estimate the LATE of interventions is presented in Equation 3.

$\widehat{T}_{1i}$ and $\widehat{T}_{2i}$ are predicted values for

$$Y_{it} = \beta_0 + \delta_1 \widehat{T}_{1i} + \delta_2 \widehat{T}_{2i} + \gamma_2 Y_{i,t=0} + X_i \sigma_2 + \varepsilon_2$$

(Equation 2). δ_1 and δ_2 are the coefficients of interest, representing the LATEs of participation in government extension program and farmer-to-farmer belief and experience sharing, respectively, on the knowledge enhancement. Estimates from the IV-2SLS procedure capture the effects of the information interventions on households who comply with the randomized invitations and thus mitigate the endogeneity in the actual participation decision.

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

RESULTS AND DISCUSSION

This study employs a randomized controlled trial (RCT) design to identify the causal effects of government extension training and farmer-to-farmer experience sharing on black pepper quality and safety knowledge, ensuring strong internal validity by minimising selection bias.

We report both intention-to-treat (ITT) and local average treatment effect (LATE) models for impact estimation, which strengthens the credibility and policy relevance of our findings. ITT estimates capture the effect of assignment to treatment and therefore reflect real-world program effectiveness under actual participation conditions, including non-compliance. Since not all farmers complied with their assigned treatment, ITT may underestimate true effects. Therefore, LATE using IV-2SLS is applied to estimate the causal impact among compliers and correct for non-compliance bias (Cawley *et al.*, 2018; Kubitz & Krishna, 2020). Together, presenting both ITT and LATE balances policy realism with causal precision and enhances the robustness of the conclusions.

The results were consistent across all three model specifications: (a) without covariates,

participation in the respective training sessions obtained from the first stage

Eq. 3

(b) including only covariates that were imbalanced at baseline, and (c) including all covariates, indicating robustness of the estimated effects (Tables 4 and 5). The estimated impacts under LATE are consistently larger than the ITT estimates, highlighting that actual receipt of the interventions has a stronger effect on knowledge enhancement. Therefore, our discussion focuses on the IV-2SLS (LATE) estimates from model (c), which include all covariates (Table 4).

Impact of information intervention on knowledge enhancement and retention

Table 4 presents the impacts of the government extension program (T1) and the farmer-to-farmer belief and experience-sharing (T2) on farmers' knowledge, measured immediately after the intervention. The government extension program improved farmers' knowledge scores immediately after the training, increasing the total test score by 1.56 points out of 15 compared to the control. This is consistent with prior evidence showing that expert-led training programs generate rapid knowledge gains (Anitha *et al.*, 2019; Tambo *et al.*, 2019). However, extension interventions differ considerably in their design and delivery mechanisms, ranging from ICT-based advisory services and brief workshops to demonstration plots and field days. Such variations influence not only the intensity of engagement but also the depth of cognitive processing.

In contrast, the farmer-to-farmer experience-sharing intervention (T2) had no immediate effect, which may be due to initial exposure to peer practices introducing uncertainty or conflicting information, causing a slight drop in immediate test scores.

Our results extend beyond immediate knowledge enhancement and examine knowledge retention six months after training,

an outcome less frequently examined in the extension literature, which often focuses on short-term post-training effects.

Table 5 reports the impacts six months later, and the positive impact of the government extension program persisted over time, with

Table 4: Treatment effect on immediate knowledge enhancement

	ITT			LATE		
	(a)	(b)	(c)	(a)	(b)	(c)
Government extension program (T1)	1.30*** (0.18)	1.30*** (0.18)	1.33*** (0.18)	1.51*** (0.22)	1.51*** (0.22)	1.56*** (0.21)
Farmer-to-farmer belief and experience sharing (T2)	-0.36** (0.17)	-0.38** (0.18)	-0.34* (0.18)	-0.31 (0.20)	-0.32 (0.21)	-0.28 (0.21)
Control mean	8.27	8.27	8.27	8.32	8.32	8.32
Ho: T1=T2 (p-value)	0.00	0.00	0.00	0.00	0.00	0.00
Baseline test score	Yes	Yes	Yes	Yes	Yes	Yes
Imbalance covariates	No	Yes	No	No	Yes	No
All covariates	No	No	Yes	No	No	Yes
N (farmers)	546	546	546	546	546	546

Robust standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1 Imbalanced covariates (1): participant age
All covariates (8): Participant characteristics (age, gender female dummy, secondary education dummy, farmer dummy), information facts (distance to the ASC, number of ASC visits in the last year, EO as the main information source dummy, prior knowledge dummy)

test scores remaining 2.14 points higher relative to the control group, six months after the intervention. Moreover, the farmer-to-farmer experience-sharing intervention had a positive effect on knowledge measured six months after the intervention, increasing the total test score by 0.52 points out of 15

compared to the control. This may, possibly reflecting gradual belief changes as farmers observed the practices and outcomes of their peers. Social reinforcement and repeated interactions within farmer networks may further strengthen confidence and support the gather knowledge. This pattern suggests that

Table 5: Treatment effect on knowledge retention (six months after the intervention)

	ITT			LATE		
	(a)	(b)	(c)	(a)	(b)	(c)
Government extension program (T1)	1.77*** (0.19)	1.77*** (0.19)	1.80*** (0.19)	2.09*** (0.24)	2.09*** (0.24)	2.14*** (0.24)
Farmer-to-farmer belief and experience sharing (T2)	0.35* (0.19)	0.34* (0.20)	0.37* (0.20)	0.49** (0.23)	0.48** (0.23)	0.52** (0.23)
Control mean	6.09	6.09	6.09	7.46	7.46	7.46
Ho: T1=T2 (p-value)	0.00	0.00	0.00	0.00	0.00	0.00
Baseline test score	Yes	Yes	Yes	Yes	Yes	Yes
Imbalance covariates	No	Yes	No	No	Yes	No
All covariates	No	No	Yes	No	No	Yes
N (farmers)	546	546	546	546	546	546

Robust standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1 Imbalanced covariates (1): participant age
All covariates (8): Participant characteristics (age, gender female dummy, secondary education dummy, farmer dummy), information facts (distance to the ASC, number of ASC visits in the last year, EO as the main information source dummy, prior knowledge dummy)

informal farmer discussions drive differently from formal extension programs. This delayed but strengthening retention effect highlights that experiential learning can play

a critical role in reinforcing knowledge over time, even when immediate gains are not significant.

These results are visually summarised in Figure 3 using a coefficient plot, which illustrates the magnitude and significance of the treatment effects on knowledge scores immediately after the intervention and six months later.

Overall, these findings underscore the complementary roles of formal and informal information provision. The government extension program provides strong and sustained knowledge improvements, while farmer-to-farmer belief and experience sharing reinforce and consolidate knowledge over time. For policy and practice, the results

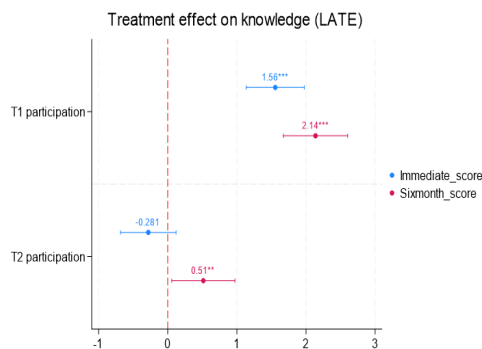


Figure 3: Treatment effects on farmers' knowledge scores immediately after the intervention and six months later

highlight the importance of continuing structured extension programs while strategically integrating social learning mechanisms to support long-term knowledge

retention, with targeted adjustments to address heterogeneity among farmer groups. In practice, this could involve integrating group discussions, farmer field schools, or facilitated peer exchanges into formal training programs to enhance both immediate learning and sustained adoption.

Heterogeneity

Table 6 illustrates the heterogeneous impacts of the government extension program and farmer-to-farmer belief and experience sharing on immediate knowledge enhancement across age, gender, education, occupation, and baseline post-harvest knowledge. Immediate knowledge gains were smaller for older participants, those with secondary education, and for farmers who received the government extension program. For farmer-to-farmer experience sharing, immediate knowledge enhancement showed lower impacts for older participants and farmers, while participants with higher baseline knowledge on pepper processing benefitted more.

Table 7 presents the heterogeneous impacts measured six months after the intervention. In terms of knowledge retention, the effects were smaller across all characteristics, older age, female gender, secondary education, being a farmer, and higher baseline post-harvest knowledge, as indicated by negative and significant interaction coefficients in T1.

Table 6: Heterogeneous impacts on immediate knowledge enhancement

	>=M.P. age	P. Female	S.E. Co. P.	P. Farmer	Know. P.P.
Government extension program (T1)	2.17*** (0.36)	1.81*** (0.33)	2.27*** (0.41)	1.79*** (0.05)	1.56*** (0.22)
Farmer-to-farmer experience sharing (T2)	0.20 (0.31)	-0.48 (0.30)	-0.22 (0.36)	-0.10 (0.24)	-0.32 (0.21)
Interaction terms					
T1* Characteristics	-1.27*** (0.44)	-0.58 (0.46)	-1.32*** (0.47)	-1.23*** (0.41)	0.03 (0.70)
T2* Characteristics	-0.92** (0.44)	0.52 (0.44)	-0.18 (0.44)	-0.94** (0.43)	1.16* (0.69)

Robust standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1

Where: MP age: Mean Participant age; P. Female: Participant is a female; SE. Com. P.: Secondary Education Completed Participant; P. Farmer: Participant is a farmer; Know. PP.: Knowledge of Pepper Processing

Similarly, T2 effects remained lower for older participants and farmers.

Overall, these results highlight that the effectiveness of interventions varies systematically across participant characteristics. In other words, the findings indicate that while the government extension

program is effective at transmitting technical knowledge, its impact may vary across demographic and socio-economic groups, suggesting that certain farmers may require more targeted or tailored training approaches. Factors such as age, education level, occupation, and prior knowledge appear to influence how participants absorb and retain

Table 7: Heterogeneous impacts on knowledge retention

	>=M.P. age	P. Female	S.E. Co. P.	P. Farmer	Know. P.P.
Government training (T1)	2.84*** (0.42)	2.68*** (0.37)	2.93*** (0.45)	2.38*** (0.28)	2.21*** (0.25)
Farmer-to-farmer experience sharing (T2)	1.20*** (0.40)	0.61* (0.34)	0.78* (0.41)	0.74** (0.27)	0.55** (0.24)
Interaction terms					
T1* Characteristics	-1.44*** (0.53)	-1.26** (0.53)	-1.48** (0.53)	-1.28** (0.48)	-1.18* (0.59)
T2* Characteristics	-1.29** (0.51)	-0.20 (0.49)	-0.57 (0.48)	-1.19** (0.49)	-0.39 (0.63)

Robust standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1

Where: MP age: Mean Participant age; P. Female: Participant is a female; SE. Com. P.: Secondary Education Completed Participant; P. Farmer: Participant is a farmer; Know. PP.: Knowledge of Pepper Processing

information. Similarly, the effects of farmer-to-farmer experience sharing are not uniform across participants. While peer-based interactions can support gradual learning and reinforcement of knowledge, their effectiveness depends on participants' existing knowledge and engagement in the production process. These findings highlight the importance of considering farmer heterogeneity when designing information interventions, as tailoring extension approaches to different farmer groups may enhance learning outcomes and improve the effectiveness of knowledge dissemination.

The main limitation of this study is the lack of structured peer-farmer interventions, highlighting the need for future research to compare their effectiveness and cost efficiency with formal government training. Integrating structured training with deliberate peer-based learning could enhance information provision and promote sustained improvements in quality and safety in high-value crop value chains.

CONCLUSION

The role of information provision in enhancing knowledge to improve quality and safety in high-value crop value chains remains underexplored, despite its critical importance. This study addresses this gap by examining the impact of information provision through government extension programs, which focuses quality and safety standards in black pepper production, and through farmer-to-farmer experience sharing. Overall, the findings highlight the stronger role of formal government extension programs in effectively transmitting technical knowledge related to the quality and safety practices of black pepper. Their structured and systematic approach enables more reliable knowledge acquisition and retention among farmers. While farmer-to-farmer belief and experience sharing can contribute to learning through social interactions and gradual belief adjustments, its role appears more complementary rather than a substitute for formal training. The variation in outcomes across farmer characteristics further suggests that the effectiveness of information interventions depends on participant

attributes, emphasising the importance of designing extension strategies that consider the needs of different farmer groups.

Accordingly, extension services should prioritise structured training, integrate peer-to-peer learning to reinforce adoption, and tailor strategies to farmers' characteristics to maximise knowledge acquisition, retention, and practical application.

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CONFLICTS OF INTEREST

The authors declare no potential conflict of interest.

Ethics approval and consent to participate

This study received ethical approval from the institutional review board of Hiroshima University (approval no. HR-LPES-001384).

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Supplementary Table S1: Quality and safety standards of black pepper

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			
<i>Escherichia coli</i> (MPN/g)	Negative	Negative	Negative
Salmonella, per 25 g	Absent	Absent	Absent

Based on SLS 105: Part 1 (2008), Sri Lanka Standards Institution (SLSI, 2008)

Supplementary Table S2: Key post-harvest practices of black pepper

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