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RESEARCH PAPER

Environmental Literacy among Vegetable Farm Entrepreneurs and Its Influence on Green Agricultural Production in Ghana

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Abstract: A global surge in demand for vegetables such as lettuce, cabbage, tomatoes, onions, and eggplants has led to a significant increase in their production, particularly in Ghana. Consequently, many vegetable farm entrepreneurs (VFEs) have adopted farming practices that conflict with the principles of sustainable agriculture. This study investigates the role of environmental literacy in shaping green agricultural production (GAP) behaviour among 473 VFEs in Ghana. Environmental literacy is defined here as knowledge, responsibilities, and values related to the environment, as well as the skills required to translate these into practical action. Drawing on primary survey data, the study employs partial least squares structural equation modelling to examine the pathways through which environmental literacy influences GAP behaviour. The study's findings indicate a generally low level of environmental literacy among participants; however, it significantly influenced GAP behaviour across the pre-production, production, and post-production phases. The study also identifies GAP willingness as a partial mediator between environmental literacy and GAP behaviour. These insights highlight the crucial role of environmental education in promoting sustainable agricultural practices in emerging economies.

Keywords: Sustainable Agriculture, Environmental Literacy, Clean Production, Environmental Responsibility, Environmental Knowledge, Ghana

1. INTRODUCTION

Consuming vegetables can improve human health and help prevent chronic diseases. The globally increasing demand for vegetables such as lettuce, cabbage, tomatoes, onions, and eggplants can be attributed to this perceived

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causality. However, to increase vegetable production and preservation, some vegetable farm entrepreneurs (VFEs) are engaging in unsustainable farming practices that pose risks to human health, particularly in developing countries in Africa (Kumah *et al.* 2023; Mohammed *et al.* 2019; Adu *et al.* 2019). These practices include the unnecessary and wasteful application of highly toxic agrochemicals that accumulate in water, air, and land (Zhou *et al.* 2023), causing significant environmental pollution and negatively impacting human health (Aniah *et al.* 2021).

Recent studies in Ghana have reported that VFEs use non-recommended insecticides, such as Polytrine, Delphos, Thiodan, Thionex, Cypercal, Dursban, and Fastac; their excessive application appears to be increasing (Adu *et al.* 2019; Adesuyi *et al.* 2018). As a result, major vegetable products in Ghana, including tomatoes, cabbage, carrots, and lettuce, contain pesticide residues above the recommended thresholds (Kumah *et al.* 2023; Mohammed *et al.* 2019). The impact on human health is severe; for instance, a study revealed that the breast milk and blood of some vegetable farmers in Ghana were contaminated with highly toxic agrochemicals such as dichlorodiphenyltrichloroethane (Afari-Sefa *et al.* 2015).

To address unsafe agrochemical applications by farmers, governments and development practitioners in both developed and developing countries advocate for investing in green agricultural production (GAP) (Li *et al.* 2020, 2021). Green agricultural production refers to agricultural practices that minimize environmental pollution and conserve energy through the use of environmentally friendly technologies (Li *et al.* 2020, 2021; Tian, Sun, and Li 2023). Examples include the use of organic fertilizers and manure, organic pesticides, intercropping, zero-tillage methods, and crop rotation (Niu *et al.* 2022). GAP has tremendous potential to improve healthy crop yield, promote sustainable livelihoods, augment farmers' incomes, and ensure healthy food consumption while protecting the environment (Li and Shen 2021). It can also enhance farmers' capacity to adapt to climate change, particularly in contexts where coping strategies have become reactive, focusing primarily on reducing agricultural losses from climate change effects (Mehta 2024).

To support this shift, governments and other stakeholders in African countries are encouraging farmers to invest in GAP (Asiedu-Ayeh *et al.* 2022; Dapaah Opoku *et al.* 2020). However, despite numerous efforts to promote GAP, its adoption, particularly among VFEs in sub-Saharan African countries such as Ghana, remains low. Conversely, studies suggest an increase in the application of inorganic agrochemicals (Aniah *et al.* 2021; Mohammed *et al.* 2019).

Well-established literature highlights a persistent knowledge gap among VFEs in Ghana regarding the adoption of GAP behaviour, which can be linked to a lack of environmental literacy (EL) (Aniah *et al.* 2021; Adesuyi *et al.* 2018; Kumah *et al.* 2023; Dapaah Opoku *et al.* 2020). Environmental literacy refers to farmers' knowledge, values, motivations, skills, and ability to analyse environmental challenges and understand how to conserve and protect the environment (Roth *et al.* 1992). Theoretically and conceptually, EL is believed to play a crucial role in shaping farmers' willingness (and, ultimately, their behaviour) to act in a way that benefits the environment. For instance, inadequate EL and limited knowledge of safety precautions regarding agrochemical use among farmers may result in their unsafe application (Adesuyi *et al.* 2018).

This study aims to examine how GAP behaviour develops among VFEs at different stages of the production process. Specifically, it explores the processes and mechanisms through which EL influences GAP behaviour among VFEs in Ghana. For this purpose, VFEs are assumed to perceive farming as an entrepreneurial venture—aiming to scale up, maximize profits, take calculated risks, and drive business innovation (Osei *et al.* 2024). Consequently, farm entrepreneurs are assumed to pursue farm business opportunities, innovation, and entrepreneurial activities (Osei and Zhuang 2024). This paper seeks to answer the following two research questions:

(1) How does environmental literacy, conceptualized as knowledge, values, motivations, skills, and the ability to analyse environmental issues and understand how to conserve and protect the environment, contribute to GAP behaviour among VFEs in developing countries, particularly Ghana?

(2) Through what mechanisms does environmental literacy influence GAP behaviour among these entrepreneurs?

The study also examines the mediating effect of the willingness to engage in GAP on the relationship between EL and *actual* GAP behaviour. The findings contribute to a deeper understanding of the cognitive and motivational factors that drive GAP practices in the context of developing economies such as Ghana. This study's unique approach to assessing EL and its influence on GAP behaviour among VFEs in Ghana advances existing theoretical frameworks of EL and clean production practices among VFEs in developing countries. The following section outlines the theoretical background and the process of developing the hypotheses. Section 3 describes the methodology, followed by the results (Section 4) and discussion (Section 5). The final section presents some key insights.

2. THEORY AND HYPOTHESES DEVELOPMENT

The value–belief–norm (VBN) theory explains how individuals' values, beliefs, norms, awareness of consequences, and sense of responsibility interact in the development of pro-environmental behaviour (Stern 2000). Here, belief refers to individuals' acceptance of specific environmental protection values and practices as normal. Those with strong beliefs regarding environmental protection are more likely to develop significant conservation behaviours (Tuncer *et al.* 2009; Zhao *et al.* 2022) and attitudes towards environmental protection (Goulgouti *et al.* 2019; Tuncer *et al.* 2009). Environmental values serve as moral frameworks that determine whether actions are beneficial or harmful to the environment. The study proposes that VFEs develop GAP behaviour based on their beliefs and values regarding the environment. It also suggests that EL plays a bi-directional role. On the one hand, EL is influenced by awareness, value systems, and a sense of responsibility; on the other, it leads to the acquisition of skills necessary for implementing sustainable farming practices.

The study uses the theory of planned behaviour (TPB) to examine the mechanisms by which EL influences GAP behaviour. Proposed by Ajzen (1991), TPB posits that individual behaviours are determined by behavioural intentions, which are shaped by three core components: attitude towards the behaviour, subjective norms, and perceived behavioural control. According to TPB, an individual's willingness to act influences their behaviour (Ajzen 2011). In the context of VFEs adopting GAP behaviours, TPB provides a robust framework for understanding how EL can translate to actual behavioural change. For VFEs, a positive attitude towards environmental conservation and sustainable farming enhances their likelihood of adopting GAP. Further, their subjective norms, such as environmental values and awareness, significantly contribute to forming behavioural intentions towards practices that promote food safety, environmental protection, and resource efficiency. Environmental knowledge and practical skills are key components of EL, strengthening farmers' confidence in their ability to implement GAP effectively.

2.1. Environmental Literacy and Green Agricultural Production Behaviour

Environmental literacy encompasses several dimensions, including environmental cognition (McBride *et al.* 2013), environmental skills and responsibility (Srbinovski *et al.* 2010), as well as environmental knowledge and values (Maurer and Bogner 2020; Yu *et al.* 2022). Over time, the concept of EL has emerged as a key driving force in policies and research aimed at achieving sustainable communities (Shri and Tiwari 2021). In line with the existing literature, this study defines EL as comprising the following key dimensions: environmental knowledge and skills, a sense of responsibility, and values regarding the protection and conservation of the environment (Yu *et al.* 2022).

Environmental knowledge and skills refer to the ability to recognize environmental issues, analyse problems, and devise effective solutions to protect the environment. Such knowledge enables individuals to develop a deeper understanding of environmental challenges and enhances their awareness of the need for environmental protection (Chi 2022). For instance, farmers' knowledge and skills training in environmental protection practices significantly improved the safe application of pesticides in China (Pan *et al.* 2021). Similarly, equipping farmers with knowledge and skills related to GAP enabled them to implement GAP practices such as green pest control (Qiao *et al.* 2022a).

Environmental responsibility refers to individuals' views and beliefs that protecting the environment is a personal duty. Such individuals are more likely to dedicate their time and resources to improving environmental quality (Yang *et al.* 2021). Studies suggest that individuals and organizations with higher levels of environmental responsibility are more likely to engage in environmentally friendly practices, safeguard natural resources, and adopt green initiatives (Lee *et al.* 2018). Environmental responsibility has also been shown to positively influence the adoption of innovative green technologies (Wang *et al.* 2021). Hence, enhancing environmental literacy can have a substantial impact on fostering environmental responsibility.

Environmental values represent the beliefs and ethics individuals hold regarding environmental protection (Kurniawan 2021). These values significantly shape how individuals assess the importance of the environment. Pro-environmental behaviour is often driven by a sense of responsibility (Kurniawan 2021; Tamar *et al.* 2021) and the adoption of environmentally sustainable practices, which are closely linked to individuals' level of environmental education (Cincera *et al.* 2022; Qiao *et al.* 2022b). Based on this, we hypothesize that:

H1: Environment literacy has a significant direct effect on GAP behaviour among VFEs.

2.2. Environmental Literacy, GAP Willingness, and GAP Behaviour

Recent studies indicate that EL is a precursor to environmental awareness, a sense of responsibility, and the willingness and readiness to engage in environmental protection, which are directly associated with pro-environmental behaviour (Ramdas and Mohamed 2014; Clayton *et al.* 2019; Cincera *et al.* 2022). TPB highlights the strong positive association between individuals' intentions and their behavioural patterns. A farmer's decision to adopt GAP practices is strongly influenced by their environmental knowledge and skills, which increase their awareness of green agricultural practices (Liu *et al.* 2023). Consequently, we hypothesize that:

H2: EL significantly influences GAP willingness.

Several studies have found that behavioural willingness is directly related to actual behaviour (Chalak *et al.* 2017; Li *et al.* 2020). For example, farmers' willingness to engage in green agricultural waste disposal strongly influences their actual green waste disposal behaviour (Li *et al.* 2020). Zhu *et al.* (2022) demonstrated that the willingness of cooperative farmers in China to adopt GAP practices had a significant positive impact on their eventual adoption. Other studies have also confirmed a strong positive relationship between farmers' willingness and their subsequent adoption of organic agricultural practices (Zhou and Ding 2022). Based on this evidence, we hypothesize that:

H3: GAP willingness significantly influences GAP behaviour among farm entrepreneurs.

The willingness to adopt GAP also serves as a crucial mediator between EL and the actual adoption of sustainable farming behaviours. Using mediation analysis models, Yu *et al.* (2022) demonstrate that farmers' willingness to practise green agriculture fully mediates the relationship between their EL and GAP behaviour. This implies that increased knowledge and understanding of environmental issues motivate farmers to take action, provided they also have a willingness to act. Supporting this, Liu *et al.* (2024) show that while digital literacy positively influences green production behaviour, ecological cognition plays a critical bridging role, reinforcing the significance of intermediary cognitive factors such as willingness.

H4: The willingness to adopt green agriculture significantly mediates the relationship between EL and the GAP behaviour of VFEs.

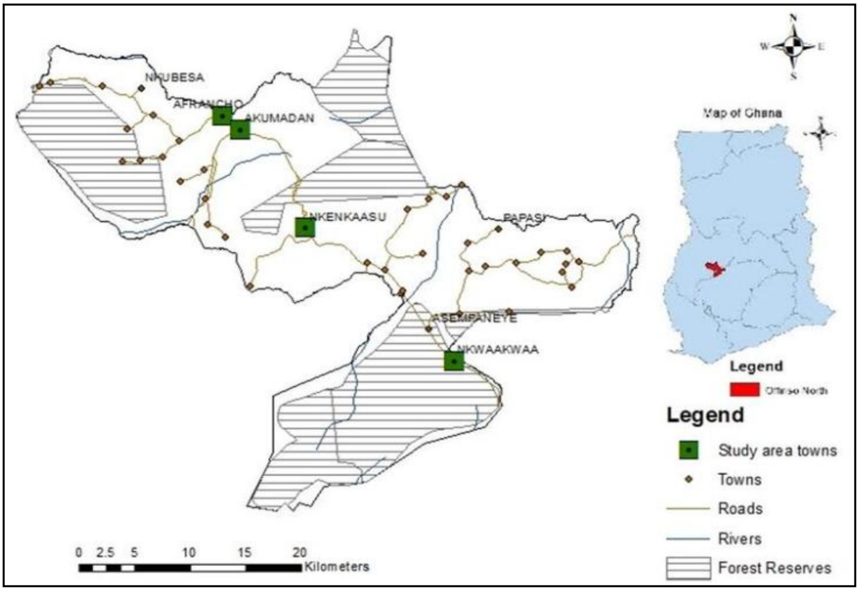
3. METHODS

This section presents the methodology adopted to examine the factors influencing the development of GAP among VFEs in Ghana. It outlines the research design, sampling strategy, data collection procedures, and analytical tools employed in the study.

3.1. Sample and Data Collection

A cross-sectional survey design was employed to investigate the factors driving the development of GAP in Ghana. The Offinso North District of the Ashanti region was purposively selected as the survey location, as Ministry of Food and Agriculture data identifies it as a geographical region in Ghana where vegetable farming activities are predominant. The study population encompassed all VFEs operating in the Offinso North District. The map showing the study area (Figure 1) has been sourced from Acheampong and Danso-Wiredu (2024). The district receives an average annual rainfall of 1250–1800 mm. It has approximately 30,000 farmers who primarily cultivate maize, yams, cashews, tomatoes, and okra. Vegetable farmers constitute the majority of the farming population in the study area.

Figure 1: Map of Offinso North District



Source*:* Acheampong and Danso-Wiredu (2024)

Given the homogenous nature of vegetable farming activities in the area, we used convenience sampling to select 473 VFEs based on their readiness to participate, availability, and relevant characteristics. The questionnaire aimed to assess VFEs' EL, willingness to adopt GAP, and actual GAP behaviour. The VFEs surveyed operate under the supervision of agricultural extension officers, who regularly educate them on GAP methods. Hence, most participants had already received some training on the practices, benefits, and consequences of GAP, including organic farming practices. During data collection, researchers personally visited the VFEs and administered a structured questionnaire to them.

3.2. Measurement of Variables

Dependent Variable: We measured green agricultural production behaviour (GAPB) as a latent construct based on VFEs' decision to adopt GAP and implement it across the pre-production, production, and post-production stages. At these three stages of production, VFEs engage in the procurement of green farming inputs (pre-production), the application of green farming inputs and agronomic practices (production), and the green packaging of farm outputs and waste disposal (post-production). A five-point Likert scale, ranging from 1 (never) to 5 (always), was used to measure the three dimensions of the GAPB construct. The observable items used to measure the GAPB dimensions were adapted and modified from Zhou *et al.* (2019) and Yu *et al.* (2022). The individual items used to measure the GAPB construct are presented in Table 2.

Independent Variable: Environmental literacy was measured based on three dimensions: environmental knowledge and skills, environmental values, and environmental responsibility, as proposed by previous scholars (Tuncer *et al.* 2009). The items used to measure these dimensions were adapted and modified from previous studies, including Yu *et al.* (2022). A five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), was used to assess each item.

Mediating Variable: Green agricultural production willingness (GAPW) was measured on a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The items used to measure GAPW were adapted and modified from previous studies, including Li *et al.* (2020). They captured the VFEs' willingness to invest time and resources in the practice of GAP (see Table 2). GAPW was utilized as a mediating variable to test the indirect effect of EL on GAPB.

Control Variables: We included a few control variables in the measurement model. Demographic factors such as age and education level were incorporated to control for farmer characteristics, while perceived soil quality was included to control for farm characteristics. Previous studies have confirmed the significant influence of farmers' profiles and farm characteristics on the adoption of green agricultural practices and behaviours (Zhang *et al.* 2021; Cui *et al.* 2022; Li *et al.* 2021).

3.3. Analytical Strategy

We used the partial least squares structural equation modelling (PLS-SEM) approach to test the study's hypotheses. PLS-SEM, a multivariate analysis technique, offers several advantages over other regression methods. Notably, it produces robust results even with small sample sizes, in contrast to other estimation techniques, such as analysis of moment structures–structural equation modelling (AMOS-SEM), which typically require larger samples (Manley *et al.* 2020). PLS-SEM can also handle issues associated with non-normal data. Initially, we used SPSS to assess data normality using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Common method bias was checked prior to the analysis. The results showed that all factors had eigenvalues greater than 1, with the maximum variance explained by a single factor at 24.625%, confirming the absence of common method bias.

We applied the PLS-SEM analysis technique in two iterative steps. The first involved assessing the measurement model, which yielded the factor loadings of the constructs' indicators and their reliability and validity. Scholars such as Manley *et al.* (2020) and Sarstedt *et al.* (2020) propose specific thresholds for assessing the measurement model based on indicator loadings, composite reliability (CR > 0.6), Cronbach's alpha (CA > 0.70), and average variance extracted (AVE > 0.5). The second step entailed evaluating the structural model to test the relationships between the latent variables. We employed the bootstrapping approach, with 5,000 resamplings, to estimate the significance levels of the direct and indirect path coefficients (Manley *et al.* 2020).

The structural model was further evaluated based on its predictive power (R^2), effect size (f^2), predictive relevance (Q^2), *t*-statistic, and *p*-values. The bootstrapping approach in PLS-SEM was applied to simulate the unknown data distribution. This method transforms the original small sample data into a larger sample with minimized standard error. The approach provides consistent and accurate estimates of path coefficients, even when the data is not normally distributed.

The structural equations used for the analysis are as follows:

$$Y = \alpha X + e_1 \quad (1)$$

$$M = \beta X + e_2 \quad (2)$$

$$Y = C'X + \delta M + e_3 \quad (3)$$

In these equations, Y denotes the main dependent variable, green agricultural production behaviour (GAPB), X represents the independent variable, environmental literacy (EL), and M denotes the mediating variable, green agricultural production willingness (GAPW). Equation (1) estimates the direct effect of EL on GAPB, where α is the coefficient of EL. Equation (2) further estimates the direct effect of EL on the mediator (GAPW); hence, β represents the coefficient of EL. Equation (3) also estimates the overall outcome effect with the mediator. Hence, C' is the direct effect of EL on GAPB after accounting for the mediating effect, while δ denotes the effect of the mediator (GAPW) on GAPB. The expressions e_1, e_2, and e_3 are the respective error terms.

4. RESULTS

In this section, the results of the study are presented and interpreted in detail. The analysis begins with the demographic profile of participants, the reliability and validity of the study's measurement model, as well as the structural model examined. Results from the study further demonstrate that EL significantly influences GAPB, both directly and through GAPW. GAPW partially mediates the effects of EL, age, education, and land quality on GAPB, confirming the study's core hypotheses.

4.1. Demographic Characteristics of Respondents

Table 1 presents the demographic characteristics of the respondents. Among the 473 VFEs who participated in the study, a significant majority (86.7%) were male, while 13.3% were female. Regarding age distribution, 75.7% of the respondents were above 36 years old, whereas 24.3% were aged between 18 and 35 years (categorized as young VFEs). The results show that 73.6% of the respondents had some level of formal education, including primary, secondary, and tertiary education, whereas 26.4% had no formal education. In terms of farm characteristics, most respondents (41.4%) operated farms smaller than 1 hectare, 36.2% operated on 1–2 hectares of land, and only 10.6% had farms of approximately 5 hectares or more. The farmers' annual income from farming activities varied, with the majority (28.5%) earning between GH₵ 20,001 and GH₵ 25,000, followed by 18.6% earning between GH₵ 15,001 and GH₵ 20,000. Additionally, 15.6% reported annual incomes below GH₵ 5,000, while 12.5% earned above GH₵ 25,000 annually. Household size also varied among respondents, with 31.5% having household sizes of 1–2 persons, 37.6% having 3–5 members, and 30.8% having 6 or more household members.

Table 1: Demographic Characteristics of Respondents

Variables	Frequency	Percentage (%)
Gender		
Male	410	86.7
Female	63	13.3
Age distribution		
18–25	37	7.8
26–35	78	16.5
36–45	114	24.1
46–55	136	28.8
Above 55	108	22.8
Educational background		
No formal education	125	26.4
Primary education	158	33.4
JHS/O' level education	91	19.2
SHS/VOC/TECH/A' level Education	76	16.1
Tertiary education	23	4.9
Farm size		
>1 ha	196	41.4
1–2 ha	171	36.2
3–4 ha	55	11.6
5–6 ha	32	6.8
6 ha and above	19	4.0
Annual income level (GH₵)		
Less than 5,000	74	15.6
5,000–10,000	56	11.8
10,001–15,000	61	12.9
15,001–20,000	88	18.6
20,001–25,000	135	28.5
Above 25,000	59	12.5
Household size		
1–2	149	31.5
3–5	178	37.6
6–8	72	15.2
9–10	48	10.1
Above 10	26	5.5

Source*:* Author's analysis

4.2. Reliability and Validity of the Measurement Model

Following the recommendations of previous studies, we evaluated the measurement models based on item loadings, Cronbach's alpha, composite reliability, and convergent validity (Hair *et al.* 2021). In the present study, all individual observed indicator loadings exceeded 0.50, as shown in Table 2, which satisfies the recommended criteria (Hair *et al.* 2021). The results further reveal high item loadings ranging from 0.828 to 0.955, as shown in Table 2.

Table 2: Factor Loadings, Construct Reliability, and Validity

Constructs/indicators	Loadings	Mean	Std dev.	Construct reliability
Environmental literacy (EL)				CA = 0.876 CR = 0.900 AVE = 0.502
Environmental knowledge and skills (EK)				CA = 0.926 CR = 0.953 AVE = 0.871
EK1 → I have an adequate level of knowledge on how to protect the environment	0.933	3.6110	0.009	
EK2 → I possess an adequate level of knowledge on how to detect environmental problems as early as possible before they emerge	0.940	3.6025	0.008	
EK3 → I have sufficient skills to solve environmental problems caused by agricultural activities	0.928	3.7632	0.012	
Environmental responsibility (ER)				CA = 0.912 CR = 0.945 AVE = 0.851
ER1 → I have the responsibility to practise green agricultural production to conserve the environment sustainably	0.884	3.9112	0.018	
ER2 → I have the responsibility to protect the ecological environment from pollution by adopting green agricultural practices	0.942	3.7928	0.009	
ER3 → If I do not adopt green farming practices to protect the environment, I will feel guilty since I believe I have that responsibility	0.941	3.7970	0.009	
Environmental values (EVALS)				CA = 0.930 CR = 0.955 AVE = 0.877
EVALS1 → I believe that a safe environment free from pollution is most important for sustainable development	0.922	3.4778	0.009	

EVALS2 → I believe that the environment belongs to nature and man is not the master of nature	0.948	2.3425	0.007	
EVALS3 → I believe that humans must coexist harmoniously with nature and not harm it.	0.939	2.3805	0.008	
Green agricultural production willingness (GAPW)				CA = 0.944 CR = 0.964 AVE = 0.900
GAPW1 → I am willing to invest some labour in the practice of green agricultural production technologies	0.940	2.6258	0.009	
GAPW2 → I am willing to invest my time in the adoption of green agricultural production technologies	0.955	2.7019	0.007	
GAPW3 → I am willing to invest some money in the adoption and practice of green agricultural production technologies	0.951	2.7040	0.007	
Green agricultural production behaviour (GAPB)				CA = 0.884 CR = 0.910 AVE = 0.592
Pre-production (PREP)				CA = 0.851 CR = 0.931 AVE = 0.870
PREP1 → The degree to which I purchase low-toxic and low-residue pesticides	0.937	2.6660	0.006	
PREP2 → The degree to which I purchase organic fertilizers and insecticides	0.929	2.4313	0.007	
Production (PRODUCT)				CA = 0.810 CR = 0.887 AVE = 0.724
PRODUCT1 → The extent to which I apply low-toxic and low-residue pesticides in my vegetable farming activities	0.843	3.2981	0.014	
PRODUCT2 → The extent to which I apply organic fertilizers and pesticides in my vegetable farming activities	0.828	2.0846	0.023	
PRODUCT3 → The degree to which I use the technology of formula fertilization in my vegetable farming activities	0.882	3.2727	0.013	

Post-production (POSTP)				
POSTP1 → The extent to which I reuse agricultural waste products from my vegetable farm	0.950	2.8985	0.007	CA = 0.898 CR = 0.951 AVE = 0.907
POSTP2 → The degree to which I apply environmentally friendly packaging activities for agricultural products	0.955	2.9345	0.005	

Source*:* Author's analysis

Note: CA, CR, and AVE denote Cronbach's alpha, composite reliability, and average variance extracted, respectively.

The reliability of the measurement constructs was determined using Cronbach's alpha and the composite reliability scores. Following the thresholds recommended by prior studies (Manley *et al.* 2020; Sarstedt *et al.* 2020), thresholds of 0.70 or higher were considered acceptable. As seen in Table 2, the CA reliability scores for this study ranged between 0.810 and 0.944, while the CR values of all constructs fell between 0.887 and 0.964. The results indicate that the study achieved sufficient reliability of all constructs. Additionally, the average variance extracted for all constructs exceeded the recommended threshold of 0.50.

To assess discriminant validity, the Fornell-Larcker criterion was applied to further evaluate the convergent validity of the latent constructs used in the measurement model. As per the criterion, the square root of the AVE of the latent variables should be greater than the coefficients of the correlation with the latent variables. Table 3 shows that the model meets this criterion. These results demonstrate a strong positive relationship between the latent variables, indicating the adequate discriminant validity of the model.

Table 3: Discriminant Validity

Constructs	1	2	3	4	5	6	7	8	9
1. Agricultural green production behaviour	0.769								
2. Agricultural green production willingness	0.647	0.949							
3. Environ-mental knowledge and	0.484	0.489	0.934						

skills									
4. Environ-mental literacy	0.728	0.703	0.818	0.709					
5. Environ-mental respon-sibility	0.347	0.311	0.451	0.683	0.923				
6. Environ-mental values	0.569	0.741	0.412	0.576	0.250	0.936			
7. Post-production	0.687	0.621	0.482	0.603	0.397	0.488	0.952		
8. Pre-production	0.729	0.903	0.490	0.413	0.316	0.757	0.605	0.933	
9. Production	0.565	0.637	0.289	0.551	0.198	0.698	0.471	0.685	0.851

Source: Author's analysis

We further utilized the Heterotrait–Monotrait ratio (HTMT) to assess the discriminant validity of the constructs. As recommended by scholars, to meet the acceptance threshold for discriminant validity, the HTMT values should not exceed 0.90 (Sarstedt, Ringle *et al.* 2020; Ali *et al.* 2018). Table 4 indicates that all the HTMT values are less than 0.90; hence, the results satisfy the sufficient condition of discriminant validity.

Table 4: Heterotrait–Monotrait Ratio

Constructs	1	2	3	4	5	6	7	8
1. Agricultural green production behaviour								
2. Agricultural green production willingness	0.808							
3. Environmental knowledge and skills	0.525	0.522						
4. Environmental literacy	0.788	0.742	0.805					
5. Environmental responsibility	0.382	0.335	0.492	0.829				
6. Environmental values	0.843	0.791	0.442	0.807	0.270			
7. Post-production	0.882	0.673	0.528	0.674	0.439	0.533		
8. Pre-production	0.801	0.705	0.551	0.793	0.358	0.850	0.689	
9. Production	0.603	0.715	0.327	0.608	0.226	0.796	0.546	0.811

Source*:* Author's analysis

4.3. Assessment of the Structural Model

As suggested by prior studies, the coefficient of determination (R^2), predictive relevance (Q^2), and effect size (f^2) were used to evaluate the structural model in the present study (Manley *et al.* 2020; Sarstedt, Hair *et al.* 2020). Regarding effect size, it is recommended that f^2 exceed 0.02. As indicated in Table 5, all values of f^2 exceed 0.02, confirming that the model has a meaningful effect on the dependent variables. Furthermore, the model's coefficient of determination ($R^2 = 0.781$) was substantial, as the model, including EL and GAPW, explains up to 78.1% of the variation in GAPB, the dependent variable. This indicates that EL, GAPW, and the control variables—such as age, perceived soil quality, and education have a significant impact on GAPB. Similarly, the R^2 value of 0.539 (Table 4) demonstrates that EL and the control variables explain up to 53.9% of the changes in GAPW. These results further affirm that the model has an appreciable explanatory power. Cross-validated redundancy (Q^2) measures the predictive relevance of the model. The Q^2 value is above zero, implying that the model has predictive relevance. The results from Table 5 show the Q^2 values for GAPW (0.457) and GAPB (0.429), further confirming that the model has adequate predictive relevance. We verified the structural equation model fit index using standardized root mean square (SRMR = 0.075) and normed fit index (NFI = 0.837) values. The results confirm that the SRMR and NFI values were within acceptable and satisfactory limits (see Table 5).

Table 5: Quality Criteria of Structural Model

Constructs	GAPB	GAPW	SSO	SSE	Q^2 (= 1 – SSE/SSO)	R^2
GAPW	0.747		1,419.000	770.629	0.457	0.539
EL	0.127	0.314				
GAPB			3,311.000	1,890.733	0.429	0.781

Note: Goodness of fit index: SRMR = 0.161. NFI = 0.837
Source*:* Author's analysis

4.4. Direct Path Effects of EL on GAPW and GAPB

The standard PLS-SEM bootstrapping method, employing 5,000 resamplings, was used to estimate the significance of the path effect coefficients in the structural model. The results presented in Table 6 demonstrate the direct effect of EL and the mediating effect of GAPW. They demonstrate that EL has a positive and statistically significant effect on GAPB ($\beta = 0.290$, $t = 8.22$, $p < 0.01$). The results further suggest that EL has a statistically significant and positive effect on GAPW ($\beta = 0.579$, $t = 11.178$, $p < 0.01$). In addition, GAPW was found to have a positive and statistically significant effect on GAPB ($\beta = 0.595$, $t = 22.74$, $p < 0.01$). The analysis of the control variables reveals that educational level and land quality statistically affect GAPB and GAPW. In contrast, age shows a significant but negative influence on both variables.

Table 6: Direct Structural Path Effects

Hypothesized direct structural relationships	**β**	**Std dev.**	***t***	***p*-value**
EL > GAPB	0.290***	0.035	8.222	0.000
EL > GAPW	0.579***	0.052	11.178	0.000
GAPW > GAPB	0.595***	0.026	22.740	0.000
Control variables				
Age > GAPB	−0.172***	0.027	6.483	0.000
Age > GAPW	−0.139***	0.034	4.099	0.000
Education > GAPB	0.035*	0.024	1.443	0.075
Education > GAPW	0.094**	0.046	2.065	0.020
Land quality > GAPB	0.121***	0.029	4.135	0.000
Land quality > GAPW	0.212***	0.039	5.423	0.000

Source*:* Author's analysis

Note: ***, **,* denote $p < 0.01$, $p < 0.05$, and $p < 0.10$ levels of significance

4.5. Mediating Effect of GAPW on the Relationship Between EL and GAPB

This study further examines the mediating role of GAPW in the relationship between EL and GAPB. As shown in Table 7, GAPW exhibited a positive and significant partial mediating effect in the relationship between EL and GAPB ($\beta = 0.345$, $t = 10.442$, $p < 0.01$). The results indicate that GAPW also partially mediates the relationships between age, education, and land quality and GAPB. The results presented in Table 7, however, show that age has a negative indirect effect on GAPB ($\beta = -0.083$, $t = 3.96$, $p < 0.10$).

Table 7: Mediating Effects

Mediating effects	**β**	**Std dev.**	***t***	***p*-value**
EL > GAPW > GAPW	0.345***	0.033	10.442	0.000
Control variables				
Age > GAPW > GAPB	−0.083***	0.021	3.961	0.000
Education > GAPW > GAPB	0.056**	0.027	2.055	0.020
Land quality > GAPW> GAPB	0.126***	0.024	5.228	0.000

Note: ***, **,* denote $p < 0.01$, $p < 0.05$, and $p < 0.10$ levels of significance

Source*:* Author's analysis

The results in Table 8 present the decisions made on the various hypotheses tested in the study. The results support hypotheses H1 and H2, which test the direct effect of EL on GAPW. The results further demonstrate that hypothesis H3, which tests the significant influence of GAPW on actual GAPB, is also supported. Similarly, GAPW was found to have a partial mediating effect in the relationship between EL and GAPB (H4).

Table 8: Hypotheses Testing

Hypothesized direct structural relationships	**β**	**Std dev.**	**Decision hypothesis supported / hypothesis not supported**
H1: EL > GAPB	0.290***	0.035	Hypothesis supported
H2: EL > GAPW	0.579***	0.052	Hypothesis supported
H3: GAPW > GAPB	0.595***	0.026	Hypothesis supported
H4: EL > GAPW > GAPW	0.345***	0.033	Hypothesis supported

Note: *** denotes $p < 0.01$ level of significance
Source: Author's analysis

5. DISCUSSION

The results indicate that EL has a positive and significant effect on GAPW and GAPB. This suggests that VFEs with higher levels of EL are better equipped to analyse farming practices and incorporate environmentally friendly technologies in their production and post-production activities. Moreover, the findings highlight that EL has a statistically significant and positive effect on farmers' willingness to implement GAP technologies.

Environmental literacy is rooted in VFEs' knowledge, skills, values, and sense of responsibility, which influence their willingness and intentions to implement GAP technologies (Zhu *et al.* 2022). VFEs with higher EL tend to exhibit strong environmental values and a greater sense of responsibility, which cultivates a positive attitude towards protecting the environment. These findings align with previous studies that argue that pro-environmental behaviour is associated with increased environmental knowledge and skills (Amoah and Addoah 2021; Kurniawan 2021; Tamar *et al.* 2021).

During the pre-production, production, and post-production stages, VFEs with greater EL are more likely to adopt GAP practices, such as using organic fertilizers or minimizing the use of inorganic pesticides (Yu *et al.* 2022). The findings indicate that VFEs are willing to adopt GAP activities and technologies when equipped with the necessary knowledge and skills. Moreover, they reveal that the willingness to implement GAP technologies partially mediates the association between EL and GAPB. These findings align with previous studies, such as those by Liu *et al.* (2024) and Yu *et al.* (2022), which identify willingness as the cognitive pathway mechanism through which EL translates into actual behavioural outcomes. The results confirm that farmers' willingness to implement GAP is significantly dependent on their environmental knowledge, skills, awareness, and readiness to implement GAP activities.

Strengthening farmers' EL is, therefore, essential to facilitate the transition to sustainable farming behaviours. These findings are consistent with prior research, including that by Zhu *et al.* (2022), who found that farmer willingness has a significant impact on GAPB due to the influence of environmental knowledge and skills. This study also makes an important theoretical contribution to both the extended value–belief–norm (VBN) theory and the theory of planned behaviour (TPB) by demonstrating how EL influences GAPB among VFEs. In the context of the VBN theory, the research shows that EL—encompassing knowledge, skills, and ethical responsibility—shapes environmental values and beliefs, which in turn help create personal norms that encourage pro-environmental behaviour. The introduction of "willingness" as a mediator between norms and behaviour adds depth to the VBN framework, highlighting that behavioural change not only arises from internal values but also from a conscious readiness to act.

Furthermore, concerning TPB, the study demonstrates that EL has a positive influence on farmers' attitudes towards sustainable farming and enhances their perceived locus of control by equipping them with the necessary knowledge and skills to implement green practices. Although subjective norms are not directly examined, the emphasis on ethical responsibility implies a social dimension that may influence behaviour. The findings confirm that EL strengthens key TPB components—attitude, perceived control, and intention—thereby encouraging the adoption of GAP practices. Overall, the study highlights the pivotal role of EL in driving sustainable behaviour through both normative and cognitive behavioural pathways.

6. CONCLUSIONS

This study assessed environmental literacy (measured through environmental knowledge and skills, environmental responsibility, and environmental values) as a key factor influencing the adoption of green agricultural practices across the pre-production, production, and post-production stages among VFEs in Ghana. It expands our understanding of the critical factors driving GAPB during pre-production decision-making, production, and post-production activities, contrary to previous studies that focus only on non-farm production. In line with trends in agricultural modernization and the Sustainable Development Goals, GAP is promoted as a strategic approach to simultaneously protect the environment and ensure food security in Africa and globally. The findings from the present paper reveal that while some VFEs are already engaged in GAP, others demonstrate a willingness to adopt GAP technologies to achieve sustainable agriculture in Ghana. Promoting GAP among VFEs is thus a key strategy for conserving the environment, improving productivity, and safeguarding human health through the production of safe agricultural products.

Central to this effort is the dissemination of information on green agricultural practices and the strengthening of environmental literacy through strong policies. Empirical evidence suggests that EL among the respondents remains low. Respondents lack sufficient environmental knowledge, skills, a sense of responsibility, and values to fully implement GAP. This limited EL can potentially undermine ongoing government and stakeholder efforts. The provision of adequate environmental education and comprehensive information on green agriculture must be prioritized. Therefore, agricultural extension officers and the Environmental Protection Agency in Ghana should play an active role in enhancing the EL of VFEs. Additionally, stronger policies and legal frameworks should be developed and implemented to promote adherence to sustainable agricultural practices.

To further support VFEs' willingness and readiness to adopt GAP, practical tools, resources, and incentives should be provided. Since willingness only partially mediates the relationship between EL and green behaviour, interventions must extend beyond the dissemination of information and include motivational support, peer-learning opportunities, and demonstration farms showcasing successful GAP adoption. Strengthening farmers' perceived behavioural control through hands-on training, access to sustainable inputs, and technical assistance will further empower them to transition from intention to action. Encouraging collaboration among government agencies, NGOs, and private-sector actors will ensure a holistic approach that reinforces the capacity and motivation of VFEs to adopt sustainable agriculture practices.

Although the present study focuses on Ghana, the findings and policy implications hold broader relevance for other regions and developing countries with similar agricultural conditions, particularly in sub-Saharan Africa. Many of these areas face shared or comparable challenges, including low levels of EL among VFEs, limited access to sustainable farming inputs, and inadequate extension support for GAP activities. Therefore, the insights gained from this study, especially regarding the role of EL in shaping GAP behaviour, can inform sustainable agriculture initiatives in similar socioeconomic and agroecological contexts. Lessons on enhancing EL, strengthening institutional support, and promoting farmer willingness can serve as a model for other developing countries striving to balance food security with environmental conservation.

Despite the rigorous analysis and empirical findings, this study has certain limitations. It relies on cross-sectional empirical data collected from VFEs in only the Ashanti region of Ghana. Future studies could benefit from employing panels or time series to assess how EL and participation in GAP evolve over time. The adoption of GAP in different regions can be compared. While this study examines only the perspectives of VFEs, future studies may extend the analysis to other agricultural enterprises, such as livestock farming, pisciculture, and staple crop production (e.g., rice, maize, and cocoa). Additionally, future investigations may focus on the decision-making processes underlying farmers' participation in GAP using either qualitative or quantitative research approaches.

Ethics Statement: We hereby confirm that this study complies with requirements of ethical approvals from the institutional ethics committee for the conduct of this research.

Data Availability Statement: All data used in this study are not publicly available due to privacy concerns. However, they may be obtained from the corresponding author upon reasonable request and with appropriate ethical clearance.

Conflict of Interest Statement: The author declares no conflicts of interest.

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