Research Article

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Knowledge and perception of cereal farmers and extension agents on fungicide use in northern Ghana

James Otoo,[a,b] Ramat Musah,[c] Toto Olita,[a] Kylie B. Ireland[a,d] and Ayalsew Zerihun[a*]

Abstract

BACKGROUND: Agricultural pesticide use in sub-Saharan Africa has doubled over the past three decades, with a greater relative increase for fungicides. As pesticide inputs continue to rise, so does the potential for the development of resistance. Here, we report on a survey conducted to understand pesticide resistance awareness, pesticide-use knowledge and practices of growers and agricultural extension officers (AEOs) in the cereals growing-belt of northern Ghana, with emphasis on fungicides. The results may inform development of strategies for improving pesticide literacy including resistance awareness, extension services and crop protection outcomes.

RESULTS: The survey revealed a low level of pesticide-use knowledge for AEOs and growers. This was more so for growers with low education, predominantly women. Education level (and indirectly gender) influenced perceived effectiveness of fungicides and levels of adoption of cultural and agrochemical best practices. Only 28% of growers and 11% of AEOs practiced crop and fungicide rotations, respectively. More than half (53%) of the respondents indicated that fungicides used in northern Ghana are not effective.

CONCLUSION: Given the low level of pesticide literacy of AEOs and growers, training programs on best practice for the use of pesticides, with targeted initiatives for female growers, would improve crop protection outcomes and safety. The limited adoptions of crop rotation and repeated use of fungicides with the same active ingredients, along with >50% of respondents reporting 'fungicides not working' suggest the potential presence of fungicide resistance cases in growers' fields in the Northern region of Ghana. Further work is needed to determine the incidence of resistance in the region. It is recommended that a key policy priority should focus on understanding broader agrochemical-use practices, crop losses and household-level food security in the presence of resistance risks.

Supporting information may be found in the online version of this article.

Keywords: crop and fungicide rotations; extension officers; Ghana; gender; perception of fungicide efficacy; pesticide-use literacy

1 INTRODUCTION

Pesticides are important tools used in crop production globally to manage pests and diseases, thereby reducing yield loss. Globally, ≈US$40 billion is spent annually on pesticides to manage different kinds of pests.[1] This magnitude of expenditure on crop protection measures indicates that biotic stressors such as insect pests,[2] weeds[3] and plant pathogens[4] remain significant limitations to the production of crops globally. In spite of such a significant investment in crop protection chemicals, it is estimated that ≈45% of annual global food production is lost owing to infestation of pests.[5] While the foregoing is the picture globally, in developing countries there is an indication that high crop losses have led to an increasing use of pesticides,[6,7] currently accounting for some 30% of global consumption.[8]

In Sub-Saharan Africa including Ghana, most cereal growers have adopted the use of pesticides as one of the measures to manage pest infestations.[9] In Ghana, for example, over the past decade, the import of pesticides (insecticides, herbicides and fungicides) for agricultural use have increased substantially, albeit starting from a relatively low base.[8] The increasing demand for

* *Correspondence to: A Zerihun, Centre for Crop and Disease Management, School of Molecular and Life Sciences, Curtin University, Bentley, WA 6102, Australia. E-mail: a.zerihun@curtin.edu.au*

a *Centre for Crop and Disease Management, School of Molecular and Life Sciences, Curtin University, Bentley, WA, Australia*

b *Regional Department of Agriculture, Extension Unit, Tamale, Ghana*

c *Regional Department of Agriculture, Engineering Unit, Tamale, Ghana*

d *Department of Biodiversity, Conservation and Attractions, Perth, WA, Australia*

pesticides indicates Ghanaian growers' interest in adopting strategies to minimize yield losses from pest damage. For instance, women growers in Ghana have adopted spraying of pesticides on their own crops, a task that was formerly reserved for men.[10]

Although fungicides can and do protect crops against fungal diseases, their use may come with associated risks, notably the risk of pathogens developing resistance, and reduced return on investment when not used appropriately. Inappropriate uses are likely to pose safety risk when growers lack appropriate training and have inadequate knowledge of pesticide management.[11] Inadequate knowledge of pesticide use is more often seen in women growers than in men in most developing countries.[12] An empirical study by Wumbei *et al.*[13] found low knowledge levels of pesticide use and application techniques among most growers in Ghana, including the Northern region where most of the country's cereal crops are produced. This is despite a network of District Agricultural Extension Officers (AEOs) providing growers with guidance and advice on pesticide use, including application times and doses, rotation of pesticide molecules as well as fundamental cultural practices such as the importance of rotating crop sequences to break pest cycles and build-up. There is thus a need for a greater effort to improve the understanding and knowledge of pesticide use and good practices adopted by growers. This is necessary because pesticide resistance in agricultural fields has become a global concern for several years now.[14–19] Consequently, the use of pesticides such as insecticides, fungicides and herbicides has led to increasing cases of resistance in target organisms.[20] This increasing level of resistance globally is partly driven by inappropriate pesticide-use practices to control pests.[21]

In developing countries, including Ghana, some of the factors that drive inappropriate pesticide use and decision-making by growers are the education level of growers,[22,23] financial status[24,25] and access to agricultural extension services.[26] For example, most growers in Ghana are not educated;[27] hence, they may have less understanding of label rates, pesticide active ingredients and modes-of-action (MoAs), and effective application times for pesticides. Additionally, if growers do not have the financial resources to purchase the most effective product, which may be more expensive, they may compromise by buying cheaper, but less efficacious products. The accumulation of these pesticides could lead to greater risk of pesticide resistance development. Further compounding this, in the absence of good extension services and advice, growers may lack the technical know-how in the proper and effective use of pesticides. Additionally, if AEOs themselves are not knowledgeable enough, they may give incorrect advice and propose inappropriate practices for growers to adopt. To solve current challenges in the agricultural sector and better contribute to innovation, extension officers require new capacities.[28] It is also important to ensure that AEOs are well-equipped with the appropriate logistics to deliver correct and up-to-date information to growers.

This study seeks to understand the perceptions, common practices and knowledge levels of the growers and AEOs in the use of fungicide in the Northern region of Ghana. This was achieved by (i) assessing growers and AEO's awareness and knowledge level of fungicide use, (ii) exploring the respondents' perspectives on fungicide efficacy, and (iii) assessing the knowledge of AEOs and the perceptions and practices of growers with regards to fungicide use in northern Ghana. Results of the survey will help in designing appropriate training on effective fungicide use and best management practices in northern Ghana to maximize return on investment and reduce the risk associated with pesticide use.

2 MATERIALS AND METHODS

2.1 Survey design and location

The survey questions were structured using a mix of open- and close-ended questions. Discrete and nonweighted questions

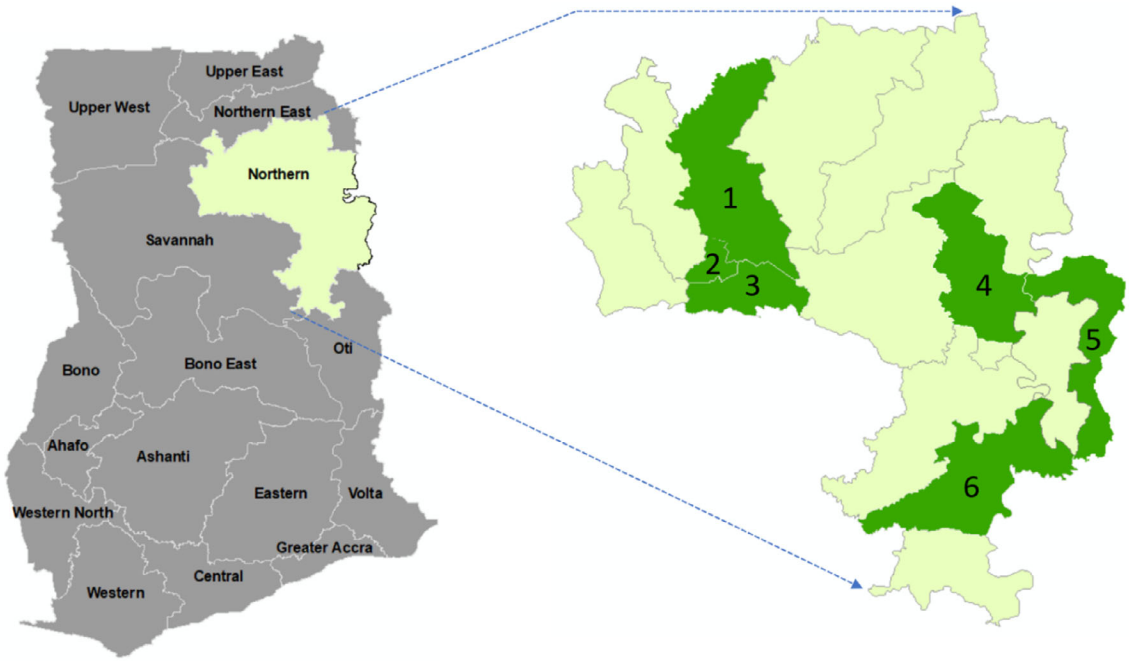

Figure 1. Map of Ghana (left) showing the position of the Northern region (yellow). Zoomed-in view of the Northern region (right), with the six surveyed districts highlighted in green, including Nanton (1), Sagnerigu (2) and Tamale metro (3) in the northwestern part of the region, Yendi (4) and Tatale (5) in the eastern part, and Nanumba-South (6) in the southern part of the Northern region.

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('select all that are applicable', or 'yes' or 'no', or 'choose only one response') were added to reduce bias in responses. We administered the survey using Qualtrics XM (Qualtrics, Provo, UT, USA) between August and September 2021 in six district assemblies in the Northern region of Ghana. The districts included Tatale-Sanguli, Yendi, Nanumba South, Nanton, Sagnerigu and Tamale metropolitan assembly (Fig. 1).

2.2 Participant recruitment and survey administration

Respondents targeted for the survey were cereal growers and AEOs in the Northern region of Ghana. Before the administration of the survey, the study's aim and the confidentiality of information were clearly explained to each respondent. The survey questionnaire was administered to 26 AEOs and 297 growers. In Ghana, most advisors (AEOs) are growers themselves, so there was no need to alter the survey between the respondent groups. These respondents were randomly selected from the database of growers and agricultural extension staff in each district assembly.

An advertisement was made through e-mails and social media platforms for respondents who were recruited to express their interest to be part of the survey. Later, the survey questionnaire was sent to interested respondents. All selected respondents voluntarily agreed to participate in the study without being offered any incentives. It was not mandatory for respondents to answer every question; hence, there are differences in the number of responses. The survey was administered to respondents either via an online survey (using the Qualtrics platform, or via face-to-face interviews for those growers who did not have internet connectivity in their communities or may have challenges understanding the English language). The survey was administered after obtaining ethics approval from Curtin University Human Research Ethics Committee (HREC no. HRE2021-0484).

2.3 Data analysis

Descriptive and statistical analysis were conducted in the R statistical environment, v4.1.0.[29] A scale ranging from 0 to 4 was assigned to responses such as perception, practices and knowledge level (Table S1). It was established through Shapiro–Wilks test that frequency data for some responses were not normally distributed ($P < 0.05$). Consequently, nonparametric tests (χ^2-test of difference) were used to analyze the survey responses.

3 RESULTS

3.1 General characteristics of survey respondents

A total of 323 respondents (consisting of both growers and AEOs) participated in the survey. Of the 323 respondents, 26 were AEOs. The median age of the respondents across the six districts was 42 years old; however, the median age of respondents in Tamale Metro and Sagnerigu districts was 50 years. On average, 21% of the respondents were females, with Nanumba South having the highest proportion of female respondents (43%), followed by Tatale district (31%), whereas Sagnerigu district had no female respondents (Table 1). The average farm size across the six districts was 4 ha. More than half of the respondents (57%) had not accessed formal education, whereas only 14% had attained tertiary education. Greater proportions of the respondents from Tatale and Nanton districts (77% and 63%, respectively) had no prior access to formal education (Table 1). The education levels among growers differed by gender. Specifically, 72% of female respondents had no formal education compared to 55% of their male counterparts. Furthermore, 9% of male growers reported having attained tertiary education, whereas no female growers reported reaching the tertiary level of education (Table 2). This comparison was not made for the AEOs owing to the limited number of female respondents. However, a χ^2-test for association revealed a significant difference ($\chi^2 = 40.3$, $df = 9$, $P < 0.001$) between educational level and pesticide knowledge of respondents. This suggests that AEOs who have attained higher educational level may have higher knowledge in pesticide use.

Educational differences among growers were observed across the six surveyed areas in the Northern region of Ghana (Table 2). These differences were distinct between gender groups, ranging from individuals with no formal education to those who have attained tertiary education.

Table 1. Demographic characteristics, farm size and educational level of respondents from the six districts in the Northern region of Ghana

Variable		District/Municipal assembly					
		Tatale	Nanton	Tamale Metro	Nanumba South	Yendi	Sagnerigu
Respondents	*n*	35	85	46	68	24	65
Demographic characteristics							
Median age	Years	37	45	50	30	38	50
Gender	M (%)	69	85	85	57	84	100
	F (%)	31	15	15	43	16	0
Cereal production							
Average farm size	Ha	4.4	4.1	4.1	3	4.4	6.2
Educational level							
No education	*n*	27	54	15	39	11	35
	%	77	63	33	57	46	53
Primary	*n*	2	0	3	14	0	12
	%	6	0	7	21	0	19
High school	*n*	1	21	17	10	6	10
	%	3	25	36	15	25	15
Tertiary	*n*	5	10	11	5	7	8
	%	14	12	24	7	29	13

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Table 2. Gender-based differences in educational attainment among growers

	Male (n = 236)		Female (n = 61)	
Educational level	n	%	n	%
No education	130	55	44	72
Primary	22	9	10	16
High school	63	27	7	12
Tertiary	21	9	0	0

Table 3. Rank of the major pest infestation problem faced by growers in the Northern region of Ghana

	Ranking			
Pest Infestation	1st	2nd	3rd	Respondents (n)
Weeds	249 (79%)	54 (17%)	15 (4%)	318
Disease	59 (19%)	177 (55%)	83 (26%)	319
Insect	44 (14%)	119 (37%)	155 (49%)	318

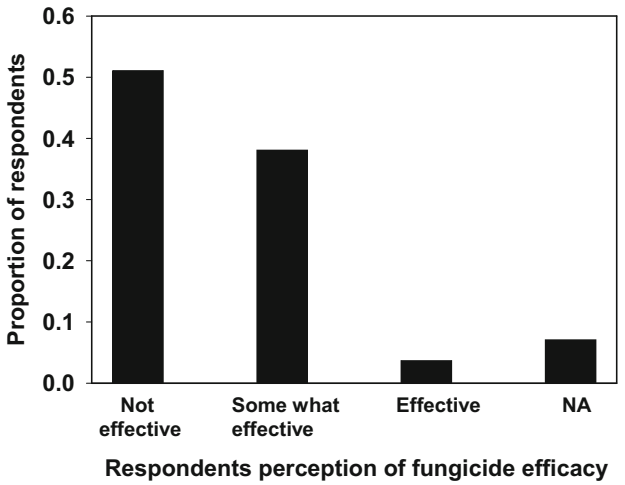

Figure 2. Perceptions of respondents on the efficacy of the fungicides they use in cereals in the Northern region of Ghana.

3.2 Key problems faced by cereal growers in northern Ghana

Weeds were identified as the most problematic pest by 79% of the growers across all of the surveyed districts (Table 3). Respondents ranked diseases (55%) and insects (49%) as the second and third most problematic pests, respectively.

Most respondents (58%) identified financial constraints as the greatest limitation to pesticide use. This was followed by a lack of knowledge about the correct product to use (28%), of how to use the product (13.3%) and of where to get the product (0.6%) (Table S2).

3.3 Perception, knowledge levels and fungicides use practices between agricultural extension officers and growers

There was a significant difference ($\chi^2 = 231.71$, $df = 3$, $P < 0.001$) in respondents' perceptions concerning fungicide effectiveness. More than half of the respondents (53%) thought that fungicides used in the Northern region of Ghana are not effective at all. Conversely, only 3.5% believed that fungicides are effective (Fig. 2). Among the 53% who considered fungicides to be ineffective, a greater proportion (29%) of the respondents were from Nanumba South district (Table 4).

In terms of the awareness and knowledge levels of fungicide use, the study found that the overall awareness of fungicide use was comparable between the gender groups. However, there was a significant difference ($\chi^2 = 595.56$, $df = 7$, $P < 0.001$) in fungicide knowledge levels between male and female respondents, with women more likely to have lower levels of knowledge (Fig. 3).

The survey revealed that both male and female farmers utilize pesticides in each season. However, the survey findings suggest that pesticide-use practices among gender groups differed depending on their knowledge levels. Nevertheless, regarding the use of fungicides with the same MoA, the survey revealed that both genders tend to adopt similar practices every season. For example, a significant proportion (78%) of male and female respondents used the same fungicide with the same MoA multiple times without switching to a different chemical activity group (Table S3).

Regarding the timing of fungicide application on crops during each season, a greater proportion of both gender groups opted to apply fungicides at the first sign of disease infestation. Specifically, 77% of male and 48% of female growers followed this practice (Table S3). Only a small proportion, comprising 3% of male and 2% of female growers, chose to apply fungicides before disease infestation. Notably, ≈15% of female growers applied fungicides when the damage caused by the disease had already become well-established, in comparison to 4% of male growers (Table S3).

Furthermore, when examining the rotation of crops and fungicides, both similarities and differences emerged between gender groups. In some districts, a similar proportion of male and female growers adopted crop and fungicide rotations as part of their management practices. However, in other districts, significant differences existed between the proportions of male and female growers adopting crop and fungicide rotations. Nevertheless, in Tatale-Sanguli district, regardless of gender, a similar proportion

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Table 4. Percentage of respondents reporting fungicides efficacy issues across the districts

District	Not effective	Somewhat effective	Effective	NA
Tatale-Sanguli	13	5	8	28
Nanton	24	32	25	17
Sagnerigu	15	26	25	11
Nanumba South	29	9	25	39
Yendi	10	4	0	5
Tamale Metro	9	24	17	0

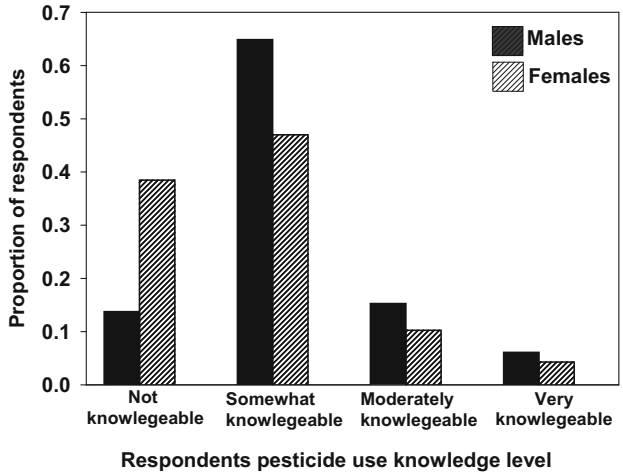

Figure 3. Knowledge levels of pesticides use between gender groups in northern Ghana.

of male and female growers adopted crop and fungicide rotations (Table 5).

First, ≈62 and 82% of AEOs and growers, respectively, did not practice crop rotation in cereal production (Table 6), a practice which may favor pest build-up and pose difficulties in controlling pest infestations. Moreover, we also see that 81% of AEOs and 77% of growers repeatedly used the same fungicides with the same MoA without alternations. This limited adoption of crop rotations which together with repetitive use of fungicides could potentially increase the risk of developing resistance.

In terms of fungicide application timing, half of the AEOs and a majority of growers (68%) applied fungicides at the first signs of disease infestation. However, there is a discrepancy when it comes to the timing of application in relation to crop growth stages. While 46% of AEOs apply fungicides during the active vegetative stage, most of the growers (80%) applied fungicides during the reproductive stage (Table 6), highlighting a discord between the practices of the advisors and the growers. The precise reason for this variation in practice (whether it is reflective of low adoption by growers or knowledge differences between AEOs and growers) is unclear. However, given that both the AEOs and growers have similar practices with respect to crop and fungicide rotations as well as fungicide application timing, it appears that the difference in practices with respect to growth stage timing may indicate knowledge differences in differentiating crop growth stages. A follow-up survey to understand why most growers apply fungicides at reproductive growth stages is warranted to devise appropriate extension to improve crop protection outcomes as well as product safety.

The results also indicate that 46% of AEOs and 26% of growers found it difficult to control crop diseases because the fungicide used no longer effectively controls the diseases. Only a small percentage, 4% of AEOs and 2% of growers, believed that fungicides provide effective control. However, a larger proportion of growers (68%) perceived that they achieve partial control of diseases in their fields each season (Table 6).

4 DISCUSSION

Our survey findings indicate that both growers and AEOs are aware of using pesticides to manage common pests in cereals production in the Northern region of Ghana. However, their level of knowledge is generally low. Additionally, growers and AEOs have similar pesticide-use perceptions and practices. The survey also revealed that ≈53% of the respondents perceive that fungicides used in northern Ghana are not effective. These findings provide a rationale for stakeholders in the agricultural sector to design appropriate training on pesticide use, and crop management for both growers and AEOs.

4.1 Pesticide awareness, knowledge and educational levels of respondents

Agricultural pesticide use in Ghana has increased over the years.[30] This study aimed to determine whether the growers in northern Ghana are aware of pesticides use and their knowledge of how these products are used. We found that nearly all respondents (98.7%) in the surveyed districts of the Northern Ghana are aware of pesticides/fungicides as pest control measures (Table S5). Given that they are aware of pesticides, it is expected that most growers are likely to use pesticides to control pest infestation. However, several constraints prevented a significant proportion of the respondents from using pesticides. The predominant factor identified in this survey is financial constraint which has also been reported in some sub-Saharan African countries.[31,32] Over 50% of the respondents surveyed were unable to buy the correct pesticide at the right time, or apply it when needed, and at the appropriate dose. Consequently, they compromised by buying cheaper and less effective products, thereby getting a lower return on investment. A low level of knowledge of the appropriate product to use was identified as the second constraint preventing respondents from purchasing or using pesticides. This is consistent with the findings of Ntow *et al.*[11] who observed that most vegetable growers in Ghana practice inappropriate methods in pesticides application as a consequence of their low knowledge levels. Therefore, it was recommended by Ntow *et al.*[11] that training programs should be organized for such a category of growers.

Even though women growers in most developing countries play a vital role in agriculture, they typically go through less training regarding pesticide management than their male counterparts.[12]

Table 5. Percentage of males and females adopting good management practices in the surveyed district

	Change of fungicide MoA				Adoption of crop rotation			
	Male		Female		Male		Female	
District	*n*	%	*n*	%	*n*	%	*n*	%
Tatale-Sanguli	23	57	12	58	23	26	12	25
Nanton	72	7	13	0	66	5	9	0
Sagnerigu	63	23	0	0	63	2	0	0
Nanumba South	41	5	29	7	39	59	31	29
Yendi	20	45	4	25	20	85	5	20
Tamale Metro	39	28	7	43	39	5	7	14

Abbreviation: MoA, mode of action.

Table 6. Responses of agricultural extension officers (AEOs) and growers regarding their practices of crop rotations, fungicide use and perceptions of efficacy of the fungicide products they use in their cereal crop production

		AEOs growers			
Variable	Practice	*n*	%	*n*	%
Crop rotation	Rotation	10	38	53	18
	No rotation	16	62	244	82
Fungicide same/change chemical group	Same	21	81	229	77
	Change	5	9	68	13
	Before infestation	5	19	4	1.5
Fungicide application time	First sign of infestation	13	50	203	68
	When I see damage	6	23	74	25
	When damage is established	2	8	16	5.5
	Seedling stage	6	23	2	1
Fungicide application at crop growth stages	Active vegetative stage	12	46	22	7
	Reproductive stage	8	31	240	80.5
	A week before harvest	0	0	34	11.5
Disease control difficulty	No control	12	46	77	26
	Partial	8	31	203	68
	Good	5	19	10	3.5
	Effective	1	4	7	2.5

Note: Total number of respondents = 323.

Furthermore, in the districts surveyed here, female growers had a lower level of education than their male counterparts. This creates a disparity in knowledge level about pesticide use between the gender groups. Consequently, female growers are more likely to record a reduction in productivity resultign from their limited technical expertise in implementing recommended practices. These findings align with the research conducted by Wang *et al.*[33] in China, where male growers demonstrated significantly greater knowledge about pesticide use compared to their female counterparts. Likewise, in Nepal, Atreya[34] observed that male growers tend to have better educational backgrounds than female growers within each household. Atreya[34] attributes this disparity to male growers often receiving a larger share of limited household resources, enabling them to attain a higher level of education and consequently possess more knowledge about pesticide use than female growers.

The limited knowledge among female growers on pesticide use can pose health risks to themselves and consumers because they actively participate in food crop production and utilize pesticides throughout each season. Often, they may participate in activities such as planting, weeding and harvesting as farm hands.[35] When they enter fields that have already been sprayed with pesticides while the restricted-entry interval is still in effect, as has been practiced by some growers in Ghana,[11,36] they come into direct contact with pesticides when performing the aforementioned tasks, owing to their low knowledge levels. If female growers lack knowledge on pesticide application, they may apply pesticides at the wrong time, and this could result in residues remaining on harvested food crops, posing a potential health risk to consumers.

The low levels of knowledge on pesticide use observed in this survey can be partially reflective of the educational level of respondents. For example, this survey has shown that ≈62% (Table S6) of growers had no formal education, which compares to the 67% reported by Imoro *et al.*[27] also from northern Ghana. In such regions, where most of the growers lack formal education,

it is important that guidance on fungicide use practices (e.g. label rates, application times) is available in ways that can be readily understood by growers. This approach reduces the potential for exposure of consumers to long-term health effects from product misapplication. There are further benefits of delivering fungicide-use guidance in ways growers who are not able to read can understand it. For example, if growers with low knowledge levels invest in pesticides for managing crop diseases, the possibility of having a lower return on their fungicide investment is high. This is because they may face challenges in understanding product label rates, correct application timings, FRAC codes, and which product to use. Consequently, there could be yield losses, which will affect household income, nutrition and food security. By contrast, when growers have higher levels of education, they are more likely to be knowledgeable about pesticide use, and hence, enabling them to make informed decisions regarding the adoption of recommended practices.[37]

4.2 Perspective of respondents on fungicide efficacy

Smallholder growers in Ghana are usually identified with lower farm yields and high poverty levels.[38] As they allocate the limited funds available in the household to buy fungicides to manage diseases in their farms, they expect that these fungicides will reduce disease infestation and improve their yield. If their expectations are not met, it tends to discourage them from further use of these fungicides. Our survey revealed variations in growers' perceptions regarding the effectiveness of fungicides used, with the majority of respondents indicating that the fungicides used are ineffective in controlling fungal diseases. We found that ≈53% of the respondents perceived that the fungicides available in the Ghanaian market have lost their efficacy and are therefore ineffective for managing common fungal diseases such as rice blast and maize rust. Some of the respondents reported that after using the fungicides, they had partial or no control of disease in their fields. These are consistent with reports of Nuwamanya *et al.*[39] that the majority of growers (81%) surveyed in Kenya perceive a decline in the efficacy of some fungicide applied to control early blight in tomato. Likewise, some vegetable growers in Ghana expressed concern about the ineffectiveness of some pesticides.[11] Factors that could contribute to the ineffectiveness of some pesticides include the use of expired products, inappropriate doses, nonoptimal spray coverage, and wrong application timing. For example, our survey results indicated that 73% of growers and 1% of AEOs did not check the expiration dates of products before usage (Table S4). This may impact growers' return on investments, subsequently discouraging many from using fungicides. Consequently, the resulting crop losses exacerbate the food insecurity situation in the country.

The fungicide ineffectiveness reported by respondents in this research can also be indirectly linked to growers' management practices, such as mono-cropping, and potentially directly to their repeated use of fungicides with the same active ingredients year after year which may contribute to fungicide resistance development.[40,41] For example, the survey revealed that ≈62% of AEOs and 82% of growers did not practice crop rotation while >75% the respondents (growers and AEOs alike) did not rotate fungicides. The combination of poor practices (no crop rotations plus use of the same fungicides) that most of the surveyed growers and AEOs follow creates increased risk for pathogen (disease) load build-up and potential for resistance selection. The challenges related to fungicide efficacy, regardless of their underlying causes, can significantly influence and/or potentially limit the use of fungicides by growers. Therefore, these concerns may be realistic reflections of disease control failures, and thus have broader implications for food security.

4.3 Perception and practices between agricultural extension officers and growers on fungicide use

The goal of agricultural extension, a type of informal education, is aimed at raising the living standards of smallholder growers;[42] hence, AEOs, by virtue of their roles, are responsible for providing guidance to growers on adopting agronomic practices geared towards enhancing their productivity. Consequently, growers are expected to adopt the practices recommended by their advisors. However, if AEOs lack adequate knowledge of disease management, it can hinder their ability to offer appropriate advice on crop protection issues. As a result, growers may be exposed to risks when it comes to protecting their crops, ultimately impacting productivity and income levels. For example, one AEO in Ghana sometimes provides services to as many as 706 growers[43] in a season, although the recommended extension officer to farmer ratio is 1: 200–500.[44] If this AEO, who lacks adequate knowledge of disease management, gives incorrect advice or recommends inappropriate pesticide application method to 706 growers, one could imagine the negative impact it would have on the income, productivity and health of smallholder growers, and subsequently the cascading effect on the region and the country as a whole.

Our survey revealed similar practices between AEOs and growers in regard to perceptions and practices that could contribute to fungicide resistance in northern Ghana. For example, most AEOs and growers (81% and 77%, respectively) use fungicides with the same MoA multiple times year after year. Also, they are unable to determine the FRAC code or chemical activity group of the fungicides they are using, which is critical for resistance management. Such repeated use of the same active ingredients from the same MoA fungicide, particularly single site active ingredients, can lead to selection of a resistant pathogen population[45] that results in difficulties in controlling disease and subsequent yield loss.

The findings from this research have shown that factors such as incorrect timing of fungicide application (e.g. after the disease has already advanced), repeatedly using the same MoA, using incorrect label rate or dose, and using incorrect products, are being practiced in northern Ghana, and could render fungicides ineffective and make it challenging to manage diseases in the future. As a result, growers who invest their limited household income in pesticides that fail to control pest infestations in their fields may experience a considerable financial burden. Consequently, this situation may lead to severe negative impact, including hunger, poverty and food insecurity within communities, potentially extending to the state or national level.

5 CONCLUSION AND POLICY IMPLICATIONS

This research aimed to examine the perceptions, common practices and knowledge levels of growers and AEOs regarding pesticide use, specifically focusing on fungicide use and potential resistance cases in the cereal belt of northern Ghana. The study revealed similarities in perceptions and practices among growers and AEOs. Low levels of knowledge regarding pesticide use were observed among both groups, primarily influenced by their limited educational background. Therefore, an in-depth training program for AEOs and growers to enhance their knowledge on best

pesticide-use practices and the introduction of cultural and biological means of managing pests, with targeted initiatives for female growers, would be very beneficial. Some indicators, such as the absence of crop rotation and the repeated use of fungicides with the same MoA, suggest the potential existence of fungicide resistance cases in growers' fields in the Northern region of Ghana. Further research is needed to determine the incidence of pesticide resistance in the region. Additionally, in some cases, late pesticide application practices may result in high concentrations of pesticide residues in end-products, necessitating careful monitoring to safeguard the impact of produce on the health and safety of consumers. Therefore, a key policy priority should focus on understanding broader agrochemical use, crop losses and household-level food security in the presence of resistance risks.

AUTHOR CONTRIBUTIONS

JO, writing-original draft, investigation, methodology, formal analyses; RM, investigation; TO, data curation, writing-review and editing; KI, conceptualization, methodology, supervision, writing-review and editing; AZ, conceptualization, methodology, visualization, supervision, project administration, writing-review and editing.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

REFERENCES

1 Popp J, Pető K and Nagy J, Pesticide productivity and food security. A review. *Agron Sustain Dev* **33**:243–255 (2013). https://doi.org/10.1007/s13593-012-0105-x.
2 Agrawal AA, Current trends in the evolutionary ecology of plant defence. *Functional Ecol* **25**:420–432 (2011). https://doi.org/10.1111/j.1365-2435.2010.01796.x.
3 Milberg P and Hallgren E, Yield loss due to weeds in cereals and its large-scale variability in Sweden. *Field Crop Res* **86**:199–209 (2004).
4 Oerke EC, Crop losses to pests. *J Agric Sci* **144**:31–43 (2006). https://doi.org/10.1007/S00003-011-0677-4.
5 Abhilash PC and Singh N, Pesticide use and application: an Indian scenario. *J Hazard Mater* **165**:1–12 (2009). https://doi.org/10.1016/j.jhazmat.2008.10.061.
6 Ecobichon DJ, Pesticide use in developing countries. *Toxicology* **160**:27–33 (2001). https://doi.org/10.1016/S0300-483X(00)00452-2.
7 Sarkar S, Gil JDB, Keeley J and Jansen K, The use of pesticides in developing countries and their impact on health and the right to food Technical report, Policy Department for External Relations, EP/-EXPO/DEVE/FWC/2019-01/LOT3/R/06, PE 653.622, European Union (2021).
8 FAOSTAT, Database collection of the Food and Agriculture Organization of the United Nations Technical-nical report, Food and Agriculture Organization (FAO) (2022). https://www.fao.org/faostat/en/#data/RP.
9 Mattah MM, Mattah PA and Futagbi G, Pesticide application among farmers in the catchment of ashaiman irrigation scheme of Ghana: health implications. *J Environ Public Health* **2015**:1–7 (2015). https://doi.org/10.1155/2015/547272.
10 Zseleczky L, Christie ME and Haleegoah J, Embodied livelihoods and tomato farmers' gendered experience of pesticides in tuobodom, Ghana. *Gender Technol Dev* **18**:249–274 (2014). https://doi.org/10.1177/0971852414529483.
11 Ntow WJ, Gijzen HJ, Kelderman P and Drechsel P, Farmer perceptions and pesticide use practices in vegetable production in Ghana. *Pest Manag Sci* **62**:356–365 (2006). https://doi.org/10.1002/ps.1178.
12 London L, De Grosbois S, Wesseling C, Kisting S, Rother HA and Mergler D, Pesticide usage and health consequences for women in developing countries: out of sight out of mind? *Int J Occup Environ Health* **8**:46–59 (2002). https://doi.org/10.1179/oeh.2002.8.1.46.
13 Wumbei A, Houbraken M and Spanoghe P, Pesticides use and exposure among yam farmers in the Nanumba traditional area of Ghana. *Environ Monit Assess* **191**:307 (2019). https://doi.org/10.1007/s10661-019-7449-5.
14 Beckie HJ, Busi R, Lopez-Ruiz FJ and Umina PA, Herbicide resistance management strategies: how do they compare with those for insecticides, fungicides, and antibiotics? *Pest Manag Sci* **77**:3049–3056 (2021). https://doi.org/10.1002/ps.6395.
15 Fisher MC, Hawkins NJ, Sanglard D and Gurr SJ, Worldwide emergence of resistance to antifungal drugs challenges human health and food security. *Science* **360**:739–742 (2018). https://doi.org/10.1126/science.aap7999.
16 FRAC, Resistance overview Technical report, Fungicide Resistance Action Committee (FRAC) (2015). https://www.frac.info/resistance-overview.
17 HRAC, Management of resistance Technical report, Herbicide Resistance Action Committee (FRAC) (2015). https://hracglobal.com/index.php.
18 IRAC, Resistance. Technical report, Insecticide Resistance Action Committee (IRAC) (2015). https://irac-online.org/about/resistance/.
19 Mian LS, Global pesticide resistance in arthropods. *J Am Mosq Control Assoc* **24**:620–621 (2008). https://doi.org/10.2987/8756-971X-24.4.620.
20 Hahn M, The rising threat of fungicide resistance in plant pathogenic fungi: botrytis as a case study. *J Chem Biol* **7**:133–141 (2014). https://doi.org/10.1007/s12154-014-0113-1.
21 Carroll SP, Jorgensen PS, Kinnison MT, Bergstrom CT, Gluckman FDRP and Tabashnik BE, Applying evolutionary biology to address global challenges. *Science* **346**:93 (2014). https://doi.org/10.1126/science.1245993.
22 Appleton S and Balihuta A, Education and agricultural productivity: evidence from Uganda. *J Int Dev* **8**:415–444 (1996).
23 Asadullah MN and Rahman S, Farm productivity and efficiency in rural Bangladesh: the role of education revisited. *Appl Econ* **41**:17–33 (2009). https://doi.org/10.1080/00036840601019125.
24 Kelly V, Adesina AA and Gordon A, Expanding access to agricultural inputs in Africa: a review of recent market development experience. *Food Policy* **28**:379–404 (2003). https://doi.org/10.1016/j.foodpol.2003.08.006.

25 Poulton C, Kydd J and Dorward A, Overcoming market constraints on pro-poor agricultural growth in sub-saharan Africa. *Dev Policy Rev* **24**:243–278 (2006). https://doi.org/10.1111/j.1467-7679.2006.00324.x.

26 Alemu AE, Mathijs E, Bauer H, Deckers J and Maertens M, Impact of supply chain coordination on honey farmers' income in Tigray, northern Ethiopia. *Agric Food Econ* **4**:9 (2016). https://doi.org/10.1186/s40100-016-0053-x.

27 Imoro ZA, Larbi J and Duwiejuah AB, Pesticide availability and usage by farmers in the northern region of Ghana. *J Health Pollution* **9**:190906 (2019). https://doi.org/10.5696/2156-9614-9.23.190906.

28 Sulaiman RV and Davis K, The New Extensionist: Roles, Strategies, and Capacities to Strengthen ex-Tension and Advisory Services. Technical report, Global Forum for Rural Advisory Services (GFRAS) Position Paper Lindau (2012).

29 R Core Team, *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria (2021) https://www.R-project.org/.

30 Horna D, Smale M, Al-Hassan R, Falck-Zepeda J and Timpo SE, Insecticide use on vegetables in Ghana: would GM seed benefit farmers? in *American Agricultural Economics Association Annual Meeting, Orlando, FL, July 27-29, 2008*. International Food Policy Research Institute, Washington DC (2008) https://ageconsearch.umn.edu/record/6506.

31 Myeni L, Moeletsi M, Thavhana M, Randela M and Mokoena L, Barriers affecting sustainable agricultural productivity of smallholder farmers in the eastern Free State of South Africa. *Sustainability* **11**:3003 (2019). https://doi.org/10.3390/su11113003.

32 Tambo JA, Kansiime MK, Mugambi I, Rwomushana I, Kenis M, Day RK *et al*., Understanding smallholders' responses to fall armyworm (*Spodoptera frugiperda*) invasion: evidence from five African countries. *Sci Total Environ* **740**:140015 (2020). https://doi.org/10.1016/j.scitotenv.2020.140015.

33 Wang W, Jin J, He R and Gong H, Gender differences in pesticide use knowledge, risk awareness and practices in Chinese farmers. *Sci Total Environ* **590**:22–28 (2017). https://doi.org/10.1016/j.scitotenv.2017.03.053.

34 Atreya K, Pesticide use knowledge and practices: a gender differences in Nepal. *Environ Res* **104**:305–311 (2007). https://doi.org/10.1016/j.envres.2007.01.001.

35 Christie ME, Van Houweling E and Zseleczky L, Mapping gendered pest management knowledge, practices, and pesticide exposure pathways in Ghana and Mali. *Agric Human Values* **32**:761–775 (2015). https://doi.org/10.1007/s10460-015-9590-2.

36 Afari-Sefa V, Asare-Bediako E, Kenyon L and Micah JA, Pesticide use practices and perceptions of vegetable farmers in the cocoa belts of the Ashanti and Western regions of Ghana. *Adv Crop Sci Technol* **3**:3 (2015). https://doi.org/10.4172/2329-8863.1000174.

37 Lekei EE, Ngowi AV and London L, Farmers' knowledge, practices and injuries associated with pesticide exposure in rural farming villages in Tanzania. *BMC Public Health* **14**:389 (2014). https://doi.org/10.1186/1471-2458-14-389.

38 Donkor E, Owusu V, Owusu-Sekyere E and Ogundeji AA, The adoption of farm innovations among Rice producers in northern Ghana: implications for sustainable Rice supply. *Agri* **8**:121 (2018). https://doi.org/10.3390/agriculture8080121.

39 Nuwamanya AM, Runo S and Mwangi M, Farmers' perceptions on tomato early blight, fungicide use factors and awareness of fungicide resistance: insights from a field survey in Kenya. *PLoS ONE* **18**:e0269035 (2023). https://doi.org/10.1371/journal.pone.0269035.

40 Angelini RMDM, Rotolo C, Masiello M, Gerin D, Pollastro S and Faretra F, Occurrence of fungicide resistance in populations of *Botryotinia fuckeliana* (*Botrytis cinerea*) on table grape and strawberry in southern Italy. *Pest Manag Sci* **70**:1785–1796 (2014). https://doi.org/10.1002/ps.3711.

41 Hollomon DW, Fungicide resistance: facing the challenge-a review. *Plant Protect Sci* **51**:170–176 (2015). https://doi.org/10.17221/42/2015-PPS.

42 Ibrahim H, Zhou J, Li M and Chen Q, Perception of farmers on extension Services in Northwestern Part of Nigeria: the case of farming households in Kano state. *J Service Sci Manag* **7**:57–62 (2014). https://doi.org/10.4236/jssm.2014.72006.

43 MoFA, Medium term expenditure framework (MTEF) for 2020–2023. Programme based budget estimates for 2020 Technical report, Ministry of Food and Agriculture (MoFA) (2019). https://mofep.gov.gh/sites/default/files/pbb-estimates/2020/2020-PBB-MoFA.pdf.

44 Swanson BE and Rajalahti R, Strengthening Agricultural Extension and Advisory Systems: Procedures for Assessing, Transforming, and Evaluating Extension Systems, in *Agriculture and Rural Development Discussion Paper*, Vol. **45**, The International Bank for Reconstruction and Development/The World Bank, Washington DC, p. 206 (2010).

45 Brent KJ and Hollomon D, *Fungicide Resistance in Crop Pathogens: How Can it be Managed? Technical Report, FRAC Monograph No.1*. Brussels, GIFAP (1995).

