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Farmers' Knowledge, Practices, Attitudes and Experiences on Pesticide Use on Cabbage (*Brassica oleracea* var. capitata) Across the Four Agro-Ecological Zones of Eswatini

Gelane Dlamini[1], Siphephile Msibi[2], Bonokwakhe Hezekiel Sukati[3], Nike Lewu[4] and Yoseph Assefa[3*]

[1]*Department of Agriculture and Extension, Ministry of Agriculture, Hhohho region, Mayiwane RDA, Kingdom of Eswatini*
[2]*Regional Plant Protection Officer, Ministry of Agriculture, Department of Agriculture Research and specialist services, Malkerns research station, kingdom of Eswatini*
[3]*Department of Crop Production, Faculty of Agriculture, University of Eswatini, Luyengo Campus Luyengo, Kingdom of Eswatini*
[4]*The ARC-Institute for Fruit, Vine and Wine (ARC Infruitec-Nietvoorbij), Stellenbosch, South Africa*
**Corresponding Author Y. Assefa, Department of Crop Production Faculty of Agriculture, University of Eswatini, Luyengo Campus Luyengo, Kingdom of Eswatini. E-mail: yosepharm@yahoo.com*

Abstract: In Eswatini, chemical pesticides are widely utilized by vegetable growers to manage persistent pest pressures. However, unsafe handling, inadequate protective protocols, and hazardous disposal methods are frequently reported, leading to occupational health risks, environmental contamination, and potential pesticide residues in food systems. This study evaluated the baseline knowledge, attitudes, and practices (KAP) regarding pesticide use among smallholder cabbage (Brassica oleracea var. capitata) farmers across the four distinct agro-ecological zones of Eswatini to assess occupational safety and environmental risks. Primary data were gathered through structured, face-to-face interviews with 93 randomly selected cabbage growers, supplemented by direct field observations, and analyzed using descriptive statistics. The results demonstrate an overwhelming reliance on chemical pest control across all zones, with minimal adoption of alternative cultural practices, despite insect pests being identified as the primary production constraint. While a majority of respondents were educated and maintained awareness regarding basic safety protocols like pre-entry intervals, critical behavioral gaps remain. The vast majority of farmers failed to utilize full Personal Protective Equipment (PPE), and a significant proportion engaged in hazardous disposal methods, including re-applying leftover chemicals onto crops, burning empty containers, or discarding waste directly into fields. These unsafe practices are highly correlated with a lack of formal agricultural training and remarkably low institutional participation in farmers' associations. Notably, distinct demographic variations occurred across zones; for instance, while male farmers dominated the national average, female household heads constituted the majority in the Lubombo Plateau. The study concludes that there is an urgent, mandatory need for targeted educational and practical extension programs to bridge the gap between awareness and behavior. Interventions must focus on the correct, full deployment of PPE, uniform safety protocols, and safe waste-disposal management. Furthermore, agricultural policies should aggressively promote Integrated Pest Management (IPM) frameworks and strengthen local farmer cooperatives to facilitate peer-to-peer knowledge transfer, reduce chemical dependency, and build sustainable, resilient vegetable supply chains in Eswatini.

Keywords: Cabbage, Eswatini, Farmers, Health-risk, Knowledge, Pesticides

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INTRODUCTION

Cabbage (*Brassica oleracea* var. capitata) is an important vegetable cultivated in tropical and subtropical regions of Africa (Muleke *et al.*, 2013). This species, along with oriental varieties, plays a significant role in human nutrition, as it is rich in vitamins and compounds that may help prevent cancer. Additionally, cabbages provide essential fiber, which supports healthy digestion, and its vibrant color also enhances salads (Masarirambi *et al.*, 2020). Beyond its nutritional value, cabbage has substantial economic importance. Its production, post-harvest handling, storage, and processing create jobs and generate revenue, thereby contributing to the gross domestic product (Masarirambi *et al.*, 2020). In Eswatini, cabbage is one of the most important vegetables (Kibirige, 2022), with an annual production estimated at 1,402.72 metric tonnes per year, 60% of which is sold in formal markets while informal markets absorb the remaining 40% (Singh *et al.*, 2020). It is mostly grown by smallholder farmers in rural areas (Kibirige, 2022). Pesticides are heavily used by cabbage farmers in Eswatini to control pathogens, weeds, and insect pests (Msibi *et al.*, 2023), and remarkable increases in agricultural products due to these inputs have been reported globally (Tudi *et al.*, 2021).

The application of pesticides, however, also results in various externalities, including adverse effects on human health and the environment (Ahmed *et al.*, 2024). The use of chemical pesticides carries profound toxicological and environmental risks, such as harmful residues in food, soil, and water, negative impacts on non-target insects and beneficial organisms, and the rapid emergence of resistant pest strains (Akhtar *et al.*, 2024). Consequently, exposure to chemical pesticides has become one of the most critical occupational risks among farmers in developing countries (Wesseling *et al.*, 2001; Konradsen *et al.*, 2003; Coronado *et al.*, 2004). While all individuals can encounter some kinds of dietary or environmental pesticide exposure, rural farmers confront a particularly high risk of acute poisoning because of added, direct occupational exposure. Misuse or unsafe use of highly hazardous pesticides, coupled with a weak or totally absent legislative and monitoring framework in the use of pesticides, remains a major driver for the high incidence of pesticide poisoning in developing nations (Konradsen *et al.*, 2003). Furthermore, low education levels of rural populations, a stark lack of information and training on pesticide safety issues, poor spraying technology, and deficient personal protection during pesticide handling play significant roles in worsening these intoxication scenarios (Hurtig *et al.*, 2003; Atreya, 2008).

There have been numerous studies examining pesticide use on vegetables and risk exposure in developing countries across Africa (Fuhrimann *et al.*, 2021; Ssemugabo *et al.*, 2022; Chilipweli *et al.*, 2021). Similarly, vegetable production dynamics and commercial marketing arrangements in Eswatini have been studied over the last decade (Dlamini *et al.*, 2022; Masarirambi *et al.*, 2020); however, little remains empirically known about localized pesticide utilization, knowledge levels, and farmer behavior within the country. The purpose of this study was to systematically investigate the knowledge, attitudes, and practices of Eswatini cabbage growers regarding pesticide use across different agro-ecological settings. The study examined current management practices in vegetable production and assessed the extent of pesticide use. A cross-sectional survey assessed the knowledge and perceptions of local farmers regarding the safe use of pesticides to understand the farmers' views on potential pesticide poisoning and environmental damage. This structural field baseline information will be highly useful in the development of more appropriate, localized, and sustainable pest management options and tools, as well as providing empirical data for better national pesticide regulatory policies.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out across the four distinct, sequential agro-ecological zones (AEZs) of the Kingdom of Eswatini, which transition geographically from west to east. The westernmost zone is the Highveld, characterized by a humid climate and an annual rainfall range of 1000 to 1500 mm. This zone transitions eastward into the Middleveld, a subtropical region receiving an average annual rainfall of 762 to 1193 mm. Further east lies the Lowveld, a gently undulating, semi-arid ecological zone situated at an altitude of 60 to 730 m above sea level; this region is highly prone to seasonal droughts and receives an average annual rainfall of 508 to 890 mm. The easternmost zone is the Lubombo Plateau, which features a climate comparable to the Middleveld and maintains an average altitude of approximately 700 m (Tfwala *et al.,* 2020).

Survey Design and Sampling Procedure

A cross-sectional field survey was executed between September and November 2024 across all four administrative regions of Eswatini. The specific target survey areas within these regions were selected based on localized official cabbage production statistics in close consultation with regional agricultural extension officers. To ensure precise geographical tracking, the spatial coordinates (latitude and longitude) of each participating farm household were recorded on-site using a GARMIN 12X portable Geographic Positioning System (GPS) receiver.

A total of 93 smallholder cabbage farmers were selected using a stratified random sampling technique across the four agro-ecological zones. To accommodate the structural variations in the density of the cabbage-producing population across the country, the number of individual smallholders interviewed per zone was varied proportionally. The final sample distribution comprised 23 farmers from the Highveld, 32 farmers from the Middleveld, 26 farmers from the Lowveld, and 12 farmers from the Lubombo Plateau. Participation in the study was entirely voluntary, and individual face-to-face interviews were conducted with each randomly selected farmer who expressed explicit consent to participate.

Data Collection and Enumeration

Primary data collection was performed using a pre-tested, comprehensive structured questionnaire administered by trained survey personnel. The thematic framework of the questionnaire was adapted from established agricultural survey protocols (Lewu and Assefa, 2009) and was carefully presented to the household heads to capture nuanced behavioral details. The instrument gathered detailed empirical data on the personal socio-demographic profiles of the household heads, total household size, and smallholder awareness regarding major cabbage insect pests, plant pathogens, and structural pest management practices. To cross-validate the verbal responses and obtain direct, first-hand information regarding real-time cabbage cultivation and chemical application habits, systematic field observations were conducted simultaneously by the survey personnel on the active cropping plots of the visited rural communities.

Statistical Data Analysis

The primary data gathered from the field questionnaires were coded, cleaned, and compiled into an Excel spreadsheet format for processing. Descriptive statistical analysis techniques were utilized to compute frequencies and percentage distributions for the measured variables across each zone. For every categorical question, the percentage of farmers sharing identical practices, knowledge gaps, or attitudes was calculated on a regional and national basis. The percentages were calculated based strictly on the total number of actual respondents per specific question, and any missing data or non-responses were mathematically excluded from the final percentage calculations. In instances where farmers cited multiple reasons or strategies for a single pest management action, percentages were calculated independently for each category of response. The analytical model evaluated the influence of key demographic traits, educational backgrounds, and farm sizes against the distribution of the farming population according to their operational handling and risk perceptions regarding synthetic pesticides.

RESULTS

Household Demographics and Farm Characteristic

The baseline socio-demographic profiles and structural farm characteristics of the interviewed smallholder cabbage growers across the four agro-ecological zones (AEZs) are summarized in Table 1. The descriptive data reveal that a majority of the cabbage-producing households nationally (60.2%) were headed by males. However, a striking geographic inversion was observed in the Lubombo Plateau, where female household heads constituted the dominant demographic at 66.7% of respondents. In terms of age distribution, 44.0% of the nationwide sample fell into the middle-aged category (35 to 49 years), while older farmers (over 50 years) made up 31.2%, and younger individuals (18 to 34 years) represented 25.8% of the total population (Table 1).

The formal educational status of the respondents varied noticeably by ecological zone. Cumulatively, 86.0% of the cabbage growers possessed formal schooling, with 55.9% completing secondary high school, 19.3% completing primary school, and 10.8% attaining tertiary qualifications. Conversely, 14.0% of the countrywide sample was completely uneducated (illiterate). The highest concentration of illiterate farmers occurred in the Lubombo Plateau at 25.0%, whereas the lowest baseline level of illiteracy was recorded in the Middleveld at 9.4% (Table 1).

A critical gap was identified in specialized agricultural training: only 52.7% of the total surveyed farmers had received formal training in vegetable production and pesticide application protocols. The remaining population relied on informal training via general community agricultural meetings (21.5%) or possessed no training whatsoever (25.8%). Large family structures were highly prevalent, with 68.8% of households maintaining more than five family members. While 59.1% of these households received operational assistance from family members, agricultural labor shortages were widespread, forcing 74.2% of the smallholders to hire external labor. Furthermore, 62.4% of the respondents exhibited a total financial reliance on cabbage and vegetable sales as their sole household income stream (Table 1).

Land Tenure, Inputs, and Institutional Involvement

The structural farm characteristics show that land ownership was highly decentralized, with an average of 56.5% of the countrywide sample operating on self-owned farms (Table 2). Leased or borrowed land was most prevalent in the Middleveld zone (42.4%), while community-association land land accounted for a national average of 16.6%. Cabbage farming in Eswatini was intensely dominated by smallholdings, with 67.7% of the total sample cultivating fields smaller than 1 hectare (<1ha), and only 8.6% managing plots exceeding 3 hectares (3ha).

Irrigation water procurement patterns revealed that 44.2% of the smallholders relied entirely on purchasing water, particularly in the Middleveld (63.6%) and Lowveld

(57.7%). On-farm water infrastructure (such as boreholes) served as the primary source in the Highveld (56.5%), while communal river or dam extraction averaged 19.2% nationally. Seedlings were the overwhelmingly preferred planting material across all four AEZs, averaging 88.9%. Regarding soil fertility management, 52.7% of the growers applied inorganic synthetic fertilizers exclusively, 28.6% applied an integrated combination of organic and inorganic fertilizers, and 18.7% relied solely on organic matter (Table 2).

Crucially, institutional support through local farmers' associations was weak. As shown in Figure 1, the vast majority of smallholder cabbage growers across Eswatini were entirely unaffiliated with any professional agricultural association, reflecting a national non-involvement average of 80.6% compared to a low involvement rate of only 19.4%.

Smallholder Perceptions of Pest Pressures and Management Strategies

Insect pests were identified as the primary biotic threat damaging cabbage fields across all surveyed zones. As shown in Table 3, the perceived pressure from insect pests peaked in the semi-arid Lowveld at 61.9%, followed by the Highveld (42.8%) and Middleveld (42.3%), leading to a high national average of 47.4%. Crop diseases caused by pathogens were reported by 17.9% of farmers nationally, while localized gastropod (slug) pressures averaged 10.2%. A considerable proportion of growers (19.2% nationally) reported facing simultaneous multi-taxa infestations containing insects, plant pathogens, and slugs concurrently (Table 3).

To suppress these severe pest pressures, chemical interventions were overwhelmingly favored over alternative agronomic tactics. As illustrated in Figure 2, the national average for chemical pesticide reliance stood at 94.8%, while alternative cultural control practices were nearly non-existent across the four agro-ecological zones.

Pesticide Profiles and Field Safety Behaviors

The field survey documented a broad array of chemical formulations utilized by smallholders, ranging across multiple toxicological spectrums according to the World Health Organization (WHO) classification system (Table 4). Alarmingly, the extremely hazardous organophosphate and carbamate derivatives, such as Methomyl (Masta 900 SP; Class IA) and Acetamiprid (Alice; Class IB), were routinely applied by growers to control insect pests. Moderately toxic Class II synthetic pyrethroids and organophosphates, including Deltamethrin, Cypermethrin, and Chlorpyrifos-ethyl, were also widely used. Water-soluble powders (SP) and emulsifiable concentrates (EC) represented the dominant physical formulations handled by the smallholders in their storage facilities (Table 4).

The operational handling, risk perception, and waste mitigation strategies executed by farmers are presented in Table 5. Regarding harvesting security protocols, a national average of 67.2% of respondents claimed to actively observe the designated post-application pre-entry field intervals. However, a combined 32.9% of the countrywide sample failed to observe or only inconsistently followed these mandated withholding periods.

Farmers' awareness of the health impacts of pesticide exposure was highly fragmented. Chronic ailments (34.6%) and direct dermatological disorders/skin sickness (33.6%) were the most widely cited health risks, whereas the risk of acute lethal toxicity (death) was recognized by only 23.5% of the total sample. Environmental risk literacy was similarly narrow: 47.2% of farmers identified the risk of water body contamination, and 22.8% recognized soil contamination risks, but only 6.4% were aware of potential pest resurgence secondary to pesticide abuse (Table 5).

Compliance with Personal Protective Equipment (PPE) mandates was critically deficient. Over half of the surveyed population (56.8%) wore only partial, fragmented PPE during chemical preparation and spraying operations, while 12.0% executed applications completely unprotected without any PPE items. Only 20.5% of smallholders utilized full PPE as instructed by chemical manufacturer labels.

Post-application hygiene habits also varied extensively: 32.0% bathed and washed contaminated clothes immediately, 28.6% changed clothes but delayed bathing, and 13.5% limited their hygiene routine to washing hands and putting away gear (Table 5).

The management of chemical leftovers and product waste presented severe environmental contamination risks. To clear tank leftovers, 40.5% of growers re-applied the excess concentrated chemical mix back onto standing crops, and 49.7% discarded the toxic leftovers directly onto the soil or surrounding boundaries. Open atmospheric burning was the primary method used to dispose of empty pesticide containers, averaging 58.4% nationally and peaking at 69.0% in the Middleveld. Alternative disposal methods included burying containers in shallow farm pits (23.7%), throwing them directly into adjacent forests or active fields (8.0%), or discarding them in unmanaged pit areas (9.8%; Table 5).

DISCUSSION

Socioeconomic Determinants and Demographic Realities

The socio-demographic characteristics of smallholder farmers function as critical determinants of their agricultural knowledge, operational attitudes, and safety practices regarding chemical handling (Assefa *et al.*, 2008). Within rural farming communities, household dynamics heavily influence the adoption threshold of modern agricultural inputs and adherence to recommended safety protocols (Kabir and Rainis, 2015; Kabir *et al.*, 2017). The concentration of cabbage growers within the middle-aged (44.0%) and older (≥50 years) brackets suggests a seasoned demographic, which can play a major role in determining collective family knowledge and their willingness to adopt new pest management tools or modify traditional chemical habits (Balasha, 2019). This maturity is often positively associated with increased field experience, which can be leveraged to integrate safer pest interventions.

A notable structural finding is the high baseline of formal literacy, with 86.0% of the surveyed cabbage growers possessing some level of formal education. In rural ecosystems, formal education is widely believed to complement indigenous knowledge, effectively enhancing the structural capacity of smallholders to decode technical product instructions, process extension materials, and internalize complex toxicity warnings (Stilwell, 2010). However, the high literacy documented in this study stands in stark contrast to the persistent behavioral safety gaps observed in the field. This disconnect implies that formal general education alone is insufficient to guarantee safe field practices unless coupled with targeted, practical training.

The low formal training coverage (52.7%) and the remarkably low institutional involvement in local farmers' associations (19.4%) represent critical systemic bottlenecks. When farmers operate outside organized cooperatives or associations, they face severely restricted access to diverse, verified sources of technical knowledge and modern pest management tools (Mishuk *et al.*, 2021). These institutional limitations leave growers isolated, forcing them to rely heavily on informal advice or aggressive commercial marketing from chemical vendors rather than unbiased extension services (García *et al.*, 2012).

Pest Pressures and the Driving Forces of Chemical Over-Reliance

Consistent with structural baseline evaluations from neighboring sub-Saharan African nations, insect pests represent the most disruptive biotic constraint impeding cabbage production across Eswatini's agro-ecological zones, particularly in the hot, semi-arid Lowveld (Fuhrimann *et al.*, 2021; Ssemugabo *et al.*, 2022). This heavy and concentrated pest pressure serves as the primary driver for local management decisions. The overwhelming national reliance on chemical pesticides (94.8%) indicates that smallholders perceive fast-acting synthetic inputs as the only effective, dependable, and readily accessible mechanism to safeguard their investments against catastrophic yield losses.

This lopsided behavioral trend occurs at the expense of cultural or biological control methods, which remain almost completely unadopted across the country. Such deep chemical dependency aligns closely with regional observations by Msibi *et al.* (2023) in Eswatini and related smallholder vegetable assessments across Africa (Chilipweli *et al.*, 2021; Mergia *et al.*, 2021). The systemic neglect of non-chemical cultural control strategies is frequently tied to a general lack of practical awareness, constrained technical skills, or an enduring perception among rural growers that alternative practices are inadequate under high pest pressure (Khan *et al.*, 2021).

Compounding this chemical over-reliance is the routine application of extremely hazardous formulations, such as Methomyl (Class IA) and Acetamiprid (Class IB). The field presence of such highly toxic chemical groups introduces profound occupational risks for the rural workforce and severe toxicological threats to surrounding ecological matrices (Van Scoy *et al.*, 2012). For example, compounds like Methomyl exhibit intense, non-target toxicity to mammals, aquatic invertebrates, and local fish populations, meaning their unrestricted use carries serious systemic risk (Farré *et al.*, 2002). This alarming reality underscores the immediate need to introduce structural Integrated Pest Management (IPM) frameworks to actively substitute or phase out highly hazardous chemicals.

Gaps in Health Literacy and Occupational Safety Practices

Despite their extensive handling of toxic chemical formulations, smallholder cabbage growers display fragmented risk literacy and poor behavioral safety compliance. Compared to global baseline studies evaluating pesticide practices among farmworkers, the holistic hazard awareness documented in this cohort was significantly lower (Zyoud *et al.*, 2010; Recena *et al.*, 2006; Jallow *et al.*, 2017). While regional growers demonstrated a high awareness of visible or familiar conditions, such as chronic illnesses and dermatological skin sicknesses, their recognition of acute, life-threatening lethal toxicity was dangerously low. This selective awareness indicates a clear educational gap regarding the full toxicological spectrum of exposure risks.

The widespread failure to deploy adequate Personal Protective Equipment (PPE) represents a major threat to occupational health. More than half of the surveyed smallholders applied these hazardous compounds using only partial, fragmented protective gear, while 12.0% operated completely unprotected. This dangerous behavioral pattern stands in sharp contrast to comparative data from alternative developing regions; for instance, certain smallholder cohorts in East Africa achieve near-universal protective compliance due to rigorous regulatory and institutional enforcement (Henry and Feola, 2013).

Operating without appropriate physical protection dramatically escalates the incidence of dermal and respiratory absorption, driving the high rates of occupational poisoning frequently documented across developing

Table 1: Household and farm characteristics of the interviewed cabbage farmers in the four AEZs of Eswatini

Regions	*Number of respondents*				
	Lowveld	*Middleveld*	*Highveld*	*Lubombo*	*Country average*
Household Head					
Male	15 (57.7%)	23 (71.9%)	14 (60.9%)	4 (33.3%)	56 (60.2%)
Females	11 (42.3%)	9 (28.1%)	9 (39.1%)	8 (66.7%)	37 (39.8%)
Age					
young (18-34)	9 (34.6%)	5 (15.6%)	6 (26.1%)	4 (33.3%)	4 (25.8%)
Middle age (35-49)	9 (34.6%)	18 (56.3%)	7 (30.4%)	6 (50%)	40 (44%)
. Old age (50+)	8 (30.8%)	9 (28.1%)	10 (43.5%)	2 (16.7%)	29 (31.2%)
Education					
1. Primary	6 (23.1%)	5 (15.6%)	6 (26.1%)	1 (8.3%)	18 (19.3%)
2. High school	15 (57.7%)	20 (62.5%)	10 (43.5%)	7 (58.3%)	52 (55.9%)
3. Tertiary	2 (7.7%)	4 (12.5%)	3 (13%)	1 (8.3%)	10 (10.8%)
4.un-educated	3 (11.5%)	3 (9.4%)	4 (17.4%)	3 (25%)	13 (14%)
Training on vegetable farming					
1.Formal	13 (50%)	18 (56.2%)	12 (52.2%)	6 (50%)	49 (52.7%)
2.Informal	6 (23.1%)	3 (9.4%)	8 (34.8%)	3 (25%)	20 (21.5%)
3.None	7 (26.9%)	11 (34.4%)	3 (13%)	3 (25%)	24 (25.8%)
Family members					
1. Less than 5	11 (42.3%)	9 (28.1%)	5 (21.7%)	4 (33.3%)	29 (31.2%)
2. More than 5	15 (57.7%)	23 (71.9%)	18 (78.3%)	8 (66.7%)	64 (68.8%)
Family members assisting in farming					
1. None	8 (30.8%)	19 (59.4%)	8 (34.8%)	3 (25%)	38 (40.9%)
2. Available	18 (69.2%)	13 (40.6%)	15 (65.2%)	9 (75%)	55 (59.1%)
Labor source					
Hire	21 (80.8%)	25 (78.1%)	5 (21.7%)	10 (83.3%)	69 (74.2%)
Family labor	5 (19.2%)	7 (21.9%)	18 (78.8%)	2 (16.7%)	24 (25.8%)
Main source of income for the family.					
1. Vegetables (fully dependent)	17 (65.4%)	21 (65.6%)	13 (56.52%)	7 (58.33%)	58 (62.4%)
2. Vegetables and other sources	9 (34.6%)	11 (34.4%)	10 (43.48%)	5 (41.67%)	35 (37.6)

Table 2: Farm characteristics and access to farm inputs by cabbage farmers in the four AEZ of Eswatini

% of respondents						
Variables	*Factors*	*Lowveld*	*Middleveld*	*Lubombo*	*Highveld*	*Average for the country*
Farm/land ownership	Own farm	14(53.85)	16(48.48%)	7(58.33%	15(65.22%)	**56.5%**
	Borrowed land (Leased)	7 (26.92%)	14(42.42%)	2(16.67%	5(21.74%)	**26.9%**
	Association land	5 (19.23%)	3(9.09%)	3(25%)	3(13.04%)	**16.6%**
Total farm size (ha)	Small scale (less than 1ha)	24(92.31%)	19(59.38%)	7(58.33%	14(60.87%)	**67.7%**
	Medium (1-2 ha)	2 (7.69%)	6(18.75%)	4(33.33%	8(34.78%)	**23.6%**
	Large scale (>3ha)		7(21.88%)	1(8.33%	1(4.35%	**8.6%**
Irrigation water availability	1.Purchased	15(57.69%)	21(63.64%)	3(25.00%	7(30.43%)	**44.19%**
	2.Available on farm	7 (26.92%)	7(21.21%)	5(41.67%	13(56.52%)	**36.58%**
	3.Nearby river/dam	4 (15.38%)	5(15.15%)	4(33.33%	3(13.04%)	**19.23%**
Planting materials	Seedlings	23 (88.46%)	27(84.38%)	11 (91.67%)	21 (91.30%)	**88.95%**
	Seeds	3 (11.54%)	5 (15.63%)	1 (8.33%)	2 (8.70%)	**11.05%**
Type of fertilizers used	Organic	7 (26.92%)	3 (9.38%)	2 (16.67%)	5 (21.74%)	**18.68%**
	Inorganic	13 (50.00%)	19 (59.38%)	8 (66.67%)	8 (34.78%)	**52.71%**
	Both	6 (23.08%)	10 (31.25%)	2 (16.67%)	10 (43.48%)	28.62%

Table 3: Pest problems in the cabbage farms in the four AEZ of Eswatini

	Number of respondents				
Variables	*Highveld*	*Middleveld*	*Lowveld*	*Lubombo*	*Country average*
Insect pests	9 (42.8%)	11(42.3%)	13(61.9%)	4(40%)	**37(47.4%)**
Pathogens	4(19%)	6(23.1%)	2(9.5%)	2(20%)	**14(17.9%)**
Slugs	3(14.3%)	2(7.7%)	1(4.8%)	2(20%)	**8(10.2%)**
Mammals	0	0	3(14.3%)	1(10%)	**4(5.1%)**
Insect pest +pathogens+slugs	5(23.8%)	7(26.9%)	2(9.5%)	1(10%)	15(19.2%)

Table 4: *Pesticides used by* cabbage farmers in the four AEZs of Eswatini

Common Name (Trade Name)	*Active Ingredients*	*Formulation type*	*Toxicity class (WHO classification)*
MASTA 900 SP	Methomyl - 900g/kg	Water-soluble powder	Class 1A
Decis 100 EC	Deltamethrin - 100g/l	Emulsifiable concentrate	Class II
Avi-Sipermetrin	Cypermethrin- 200g/kg	Emulsifiable concentrate	Class II
Efekto Malasol®	Mercaptothion -500 g/ℓ		Class III
WARLOCK® 19.2 EC	Emamectin Benzoate 19.2 g/L	Emulsifiable concentrate	Class II
Chlorpyrifos-ethyl	Chlorpyrifos/Chlorpyrifos - 480 g/ℓ		Class II
ABAMECTINE 0.15 EC/ Avermectine	Abamectin - 6.0%	Emulsifiable concentrate	Class IV
Alice	acetamiprid (neonicotinoid)……200 g/ kg		Class Ib
Bravo	Chlorothalonil -720g/L	A suspension concentrate fungicide	Class II
Copper oxychloride	Copper oxychloride (85%)	Wettable powder fungicide	Class Iv
Dithane	Mancozeb (Dihiocarbamate) - 800g/kg	Wettable powder Fungicide	Class U

Table 5: Farmers practices on health hazards related to use of pesticides

Variables	*Respondents*				
	Highveld	*Middleveld*	*Lowveld*	*Lubombo*	*Country average*
Pre-entry interval observation					
1.Yes	13 (61.9 %)	17 (58.6 %)	19 (73.1 %)	9 (75.0%)	**58(67.2%)**
2.No	6 (28.6 %)	8 (27.6 %)	1 (3.8 %)	2 (16.7%)	**17(19.2%)**
3.Sometimes	2 (9.5 %)	4 (13.8 %)	6 (23.1 %)	1 (8.3%)	**13(13.7%)**
Knowledge on the effects of pesticides on health					
1.Death	7 (33.3 %)	7 (24.1 %)	3 (11.5 %)	3 (25.0%)	**20(23.5%)**
2. skin Sickness	3 (14.3 %)	9 (31.0 %)	21 (80.8 %)	1 (8.3%)	**34(33.6%)**
3.Chronic problems	11 (52.4 %)	13 (44.8 %)	2 (7.7 %)	4 (33.3%)	**30(34.6%)**
4.Other sicknesses	-	-	-	4 (33.3%)	**4 (8.3%)**
Knowledge on the effects of pesticides on the environment					
1.Pest resurgence	1 (4.8 %)	2 (6.9 %)	1 (3.8 %)	1 (10.0%)	**5(6.4%)**
2.Loss of biodiversity	2 (9.5 %)	5 (17.2 %)	7 (26.9 %)	1 (10.0%)	**15(15.9%)**
3.Contamination of water bodies	16 (76.2 %)	17 (58.6 %)	1 (3.8 %)	5 (50.0%)	**39(47.2%)**
4.Soil contamination	1 (5.6 %)	3 (10.3 %)	17 (65.4 %)	1 (10.0%)	**22 (22.8%)**
5.None	1 (5.0 %)	2 (6.9 %)		2 (20.0%)	**5 (8.0%)**
Protective clothing					
1.Part of the required PPE	10 (47.6 %)	19 (65.5 %)	15 (55.6 %)	7 (58.3%)	**51 (56.8%**
2.Full PPE (as per the label)	6 (28.6 %)	5 (17.2 %)	3 (11.1 %)	3 (25.0%)	**17 (20.5%**
3.No PPE	3 (14.3 %)	2 (6.9 %)	5 (18.5 %)	1 (8.3 %)	**11 (12.0%**
4.Sometimes wear PPE	2 (9.5 %)	3 (10.3 %)	4 (14.8 %)	1 (8.3 %)	**10 (10.8%)**

Variables	*Respondents*				
	Highveld	*Middleveld*	*Lowveld*	*Lubombo*	*Country average*
Protective measures after pesticide use					
1.Take a bath and wash clothes immediately after using pesticides	11 (50.0 %)	4 (13.8 %)	8 (30.8 %)	4 (33.3%)	**27 (32.0%)**
2.Wash clothes immediately and wash clothes later	3 (13.6 %)	6 (20.7 %)	5 (19.2 %)	6 (50.0%)	**20 (25.9%)**
3.Change clothes and bath later	5 (22.7 %)	13 (44.8 %)	10 (38.5 %)	1 (8.3%)	**29 (28.6%)**
4.Wash hands and put away PPE	3 (13.6 %)	6 (20.7 %)	3 (11.5 %)	1 (8.3%)	**13 (13.5%)**
Management of leftover pesticides					
1.Store for next use	4 (19.0 %)	6 (20.7 %)	7 (26.9 %)	1 (9.1 %)	**18 (18.9%)**
2.Discard them	7 (33.3 %)	5 (45.5 %)	3 (30.0 %)	9 (90.0%)	**24 (49.7%)**
3.Re-apply on plants	10 (47.6 %)	18 (43.9 %)	16 (61.5 %)	1 (9.1%)	**45 (40.5%)**
Disposal of containers					
1.Burn	11 (52.4 %)	20 (69.0 %)	14 (53.8 %)	7 (58.3%)	**52 (58.4%)**
2.Bury	7 (33.3 %)	3 (10.3 %)	9 (34.6 %)	2 (16.7%)	**21 (23.7%)**
3.Dispose in the forest or fields	1 (4.8 %)	2 (6.9 %)	1 (3.8 %)	2 (16.7%)	**6 (8.0%)**
4.Throw in pits	2 (9.5 %)	4 (13.8 %)	2 (7.7 %)	1 (8.3%)	9 (9.8%)

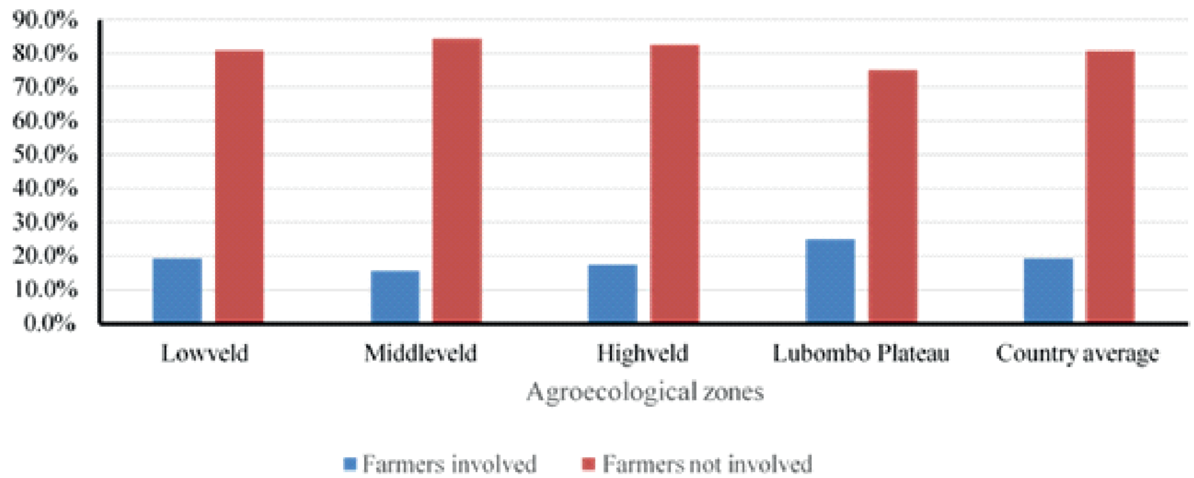

Figure 1: Percentage representation of cabbage farmers' direct involvement within agricultural associations across the four distinct agro-ecological zones of Eswatini.

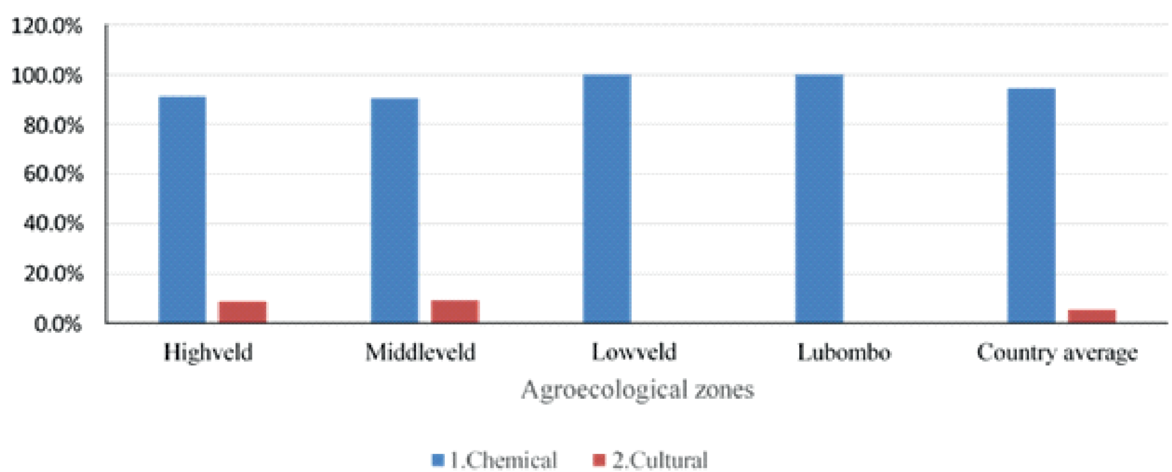

Figure 2: Distribution of active pest management approaches (chemical vs. cultural interventions) preferred by surveyed cabbage farmers across agro-ecological boundaries.

countries (Wesseling *et al.*, 2001; Konradsen *et al.*, 2003). Because many smallholder families reside in close proximity to their active cropping plots, the threat of passive, non-occupational exposure extends directly to vulnerable household members (Yassin *et al.*, 2002; Jallow *et al.*, 2017). Consequently, improving safety compliance must be prioritized by integrating occupational health and safety protocols directly into local primary and agricultural healthcare frameworks.

Environmental Degradation via Hazardous Leftover and Waste Disposal

The operational habits associated with managing chemical leftovers and empty containers present severe long-term environmental hazards. Consistent with behavioral trends documented by Damalas *et al.* (2008), the common practice of re-applying excess, concentrated tank mixtures directly back onto standing cabbage plants is highly problematic. This practice routinely drives localized chemical over-application, drastically increasing the likelihood of unacceptably high pesticide residue concentrations in the final food supply chain (Mohafrash and Mossa, 2024). Furthermore, the high proportion of growers who discard liquid chemical leftovers directly into field boundaries or open soils is deeply concerning. This behavior leads to direct environmental contamination of local soil matrices and neighboring aquatic systems—a serious eco-toxicological threat that many smallholders recognize conceptually but fail to actively mitigate due to a lack of practical disposal alternatives (Damalas *et al.*, 2008).

Similarly, the dominant method for processing empty chemical containers, open atmospheric burning (58.4%), presents significant atmospheric and localized pollution risks. When empty plastic containers are subjected to low-temperature open burning, they release highly toxic, persistent organic pollutants, including dioxins and furans, which compromise local air quality and human respiratory health (Mohafrash and Mossa, 2024).

These unsafe waste management behaviors are reinforced by the institutional isolation of the farmers. Because the vast majority of these growers operate independently outside the structural framework of institutional farmers' associations, they are effectively cut off from collective waste collection programs, triple-rinsing workshops, and formal environmental stewardship networks. To mitigate these issues, agricultural extension frameworks must move beyond teaching basic chemical application mechanics; they must actively implement community-led container recycling programs, provide concrete training on non-chemical pest alternatives, and leverage local cooperative networks to drive safe, sustainable field behaviors.

CONCLUSION

This study reveals a critical over-reliance on synthetic chemical pesticides, including highly hazardous Class IA and IB formulations, as the primary pest management strategy among smallholder cabbage growers in Eswatini. Despite possessing high levels of formal literacy and a general awareness of basic health and environmental risks, farmers consistently demonstrate a severe disconnect between knowledge and behavior. This gap is manifested in deficient Personal Protective Equipment (PPE) deployment, non-compliant field pre-entry intervals, and hazardous waste disposal practices, such as the open burning of chemical containers and the re-application of toxic leftovers onto crops. These behaviors are significantly exacerbated by a lack of formal training and low institutional engagement with farmers' associations.

To achieve a safe and resilient agricultural sector, Eswatini must implement a multi-faceted intervention strategy. Agricultural extension services should transition from basic application instructions to practical, behavior-oriented training that enforces mandatory PPE usage and uniform triple-rinsing and disposal protocols. Furthermore, policy frameworks must prioritize the integration of Integrated Pest Management (IPM) practices to offer viable non-chemical alternatives and actively strengthen local farmer cooperatives to serve as essential hubs for peer-to-peer risk education, collective waste stewardship, and sustainable crop protection.

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