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Determinants of pesticide use and food safety awareness in a dryland vegetable system in Burao Somaliland using an exploratory value chain approach

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Abstract

The intensification of vegetable production under rising pest pressure has increased reliance on pesticides, raising health concerns in settings with limited regulatory oversight such as Somaliland. Empirical evidence linking determinants of pesticide use with consumer food safety awareness within the same food system remains limited. This exploratory cross-sectional study surveyed 100 vegetable farmers and 50 consumers in Burao using structured interviews. Pesticide use was analysed using logistic regression and Bayesian modelling, while consumer data were analysed descriptively. Higher education showed a weak negative association with pesticide use (posterior mean = –0.84; 95% CrI: –1.74 to 0.07), and access to agricultural extension showed a negative association (posterior mean = –1.74; 95% CrI: –3.93 to –0.00), with estimates characterised by imprecision consistent with the limited number of pesticide-use cases. Consumers demonstrated moderate knowledge of pesticide-related risks (mean = 3.08/5) but relatively high concern (mean VAS = 5.38 cm). Education and income were associated with variation in knowledge and concern. Most consumers relied on informal markets (74%) and reported limited access to food safety information (86%). These findings highlight a gap between perceived risk and actionable understanding and underscore the role of informational and structural conditions across the value chain. Strengthening extension services, improving pesticide safety communication, and enhancing food safety

awareness represent key entry points, although evidence remains preliminary given the small, exploratory sample. Future research should expand sample sizes, incorporate broader safety indicators, integrate WHO hazard classifications, and examine the feasibility of integrated pest management in semi-arid smallholder systems.

Keywords: Pesticide use, food safety awareness, vegetable value chain, dryland systems, Somaliland

1. Introduction

Ensuring access to safe and nutritious food remains a critical global challenge, especially in developing countries where agricultural intensification increasingly relies on chemical inputs. Vegetable production enhances food security, dietary diversity, and rural livelihoods. It also contributes to climate-resilient food systems through short production cycles and income diversification under environmental uncertainty [12]. Their importance is reflected in the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 3 (Good Health).

Despite these benefits, global vegetable consumption remains below the World Health Organization (WHO) recommended intake of 240 g per capita per day. In sub-Saharan Africa, average intake is only about 70 g per day, less than one-third of the recommendation [3]. Addressing this production–consumption gap has become a central priority in agri-food system transformation.

In response to this demand, efforts to intensify vegetable production have increased reliance on chemical pesticides, as pest pressure is particularly high in horticultural systems [4]. While these inputs protect yields, their use varies widely in terms of user knowledge, safety practices, and regulatory oversight. This variability is compounded by differences in pesticide properties, including WHO hazard classifications, ranging from Class Ia (extremely hazardous) to Class U (unlikely to present acute hazard) [5].

At the global level, vegetable pesticide consumption exceeds 3.5 million tonnes annually, with widespread reliance on moderately hazardous (Class II) compounds, particularly organophosphates and pyrethroids, which pose significant risks when misused [6, 7]. These patterns highlight the need for assessments that account for exposure pathways, usage practices, and context-specific risks.

African agriculture offers a critical context for examining pesticide dynamics. Vegetable production across the continent faces structural constraints, including high pest pressure, climate variability, postharvest losses, and food safety concerns [2, 8]. These pressures reinforce pesticide dependence, especially where agricultural extension services are weak, regulatory systems limited, and farmer capacity constrained [9]. As a result, an estimated 20–40% of food produced in Africa is lost to pests and diseases [10], making chemical control a common and immediate response for many smallholders.

Evidence from East Africa illustrates how these constraints translate into farm-level practices. In Ethiopia, smallholder farmers often apply pesticides with limited adherence to safety practices [11]. In Tanzania, intensive pesticide use persists under weak regulatory enforcement and limited oversight of input markets [12]. In Uganda, consumers express high concern about residues, yet this does not consistently translate into safer purchasing behaviour [13]. Collectively, these studies highlight how farmer practices, institutional capacity, and consumer awareness interact to shape pesticide-related risks across the value chain.

Beyond East Africa, other semi-arid and arid regions offer instructive parallels. In Saudi Arabia, intensive vegetable production under dryland conditions has led to widespread pesticide use, with limited training on safe application and pre-harvest intervals resulting in detectable residues in marketed produce [14]. Similarly, in Iran, despite existing regulations, farmers continue to rely heavily on chemical control due to limited access to agricultural extension services and alternative pest management, contributing to documented poisonings and environmental contamination [15]. These patterns illustrate how high pest pressure, combined with weak institutional support, sustains pesticide dependence in dryland systems, reinforcing their relevance for understanding similar dryland contexts.

From a public health perspective, these production and institutional dynamics extend beyond farm-level practices to broader exposure risks. Chronic pesticide exposure has been associated with adverse health outcomes, including neurological and endocrine effects, and certain cancers [16]. However, these risks are not uniform, as they vary with differences in exposure intensity, duration, and regulatory conditions. In smallholder dryland systems, where safety practices may be constrained and monitoring limited, the potential for harmful exposure for both farmers and consumers can be elevated [17]. This positions pesticide use as a critical issue at the intersection of agricultural production and public health.

Within this broader context, Somaliland remains a critically under-researched setting where these challenges are pronounced. The dryland vegetable sector is expanding under pressures of urban demand, climate change, and food insecurity, while over 70% of households depend on climate-sensitive agriculture, heightening vulnerability to pest outbreaks and environmental variability [18]. Frequent pest incidence (aphids, caterpillars, and weevils) reinforces reliance on chemical control.

Despite national strategies to improve productivity and food security [19], institutional capacity for pesticide regulation and food safety oversight remains limited, with gaps across formal and informal markets. Food safety governance remains underdeveloped, with weak enforcement and monitoring [20], increasing the likelihood of pesticide residues entering the food chain. Although public concern is rising, behavioral responses remain constrained by limited access to affordable and safer alternatives.

Although a substantial body of literature examines pesticide use, farmer safety, and consumer exposure [7, 11, 17, 21], evidence from Africa remains limited and studies from Somaliland are absent. Furthermore, existing research often examines producers and consumers separately, limiting understanding of how production practices translate into downstream exposure and how consumer perceptions align with on-farm realities. This fragmentation constrains a systems-level understanding of pesticide-related risks, particularly in African dryland contexts where empirical evidence remains sparse and uneven.

Given this gap, the present study makes two contributions. First, it provides an exploratory assessment from Somaliland, addressing a key geographical and empirical evidence gap. Second, it provides a parallel assessment of determinants of pesticide use and consumer food safety awareness within the same geographic and market context, allowing for identification of potential mismatches between production practices and consumer risk perceptions.

To operationalise this contribution, this study aims to examine pesticide use and food safety awareness within a unified value chain framework in Burao, Somaliland. Specifically, the study addresses three research questions: (1) What is the prevalence and pattern of pesticide use among smallholder vegetable farmers? (2) Which socioeconomic and institutional factors are associated with pesticide use behaviour? and (3) How do consumers perceive pesticide-related risks in terms of knowledge and concern, and how do these perceptions vary across socioeconomic groups? By addressing these questions, the study seeks to provide an integrated understanding of how production practices and consumer responses interact within a data-constrained, dryland food system.

2. Methods

2.1 Theoretical framework

The study was guided by two complementary behavioural frameworks: the Theory of Planned Behavior (TPB) and the Health Belief Model (HBM). TPB posits that behavioural intentions are shaped by attitudes, subjective norms, and perceived behavioural control [22], and was used to conceptualise pesticide use among farmers as a behavioural outcome influenced by individual and institutional factors. In this context, variables such as education, farming experience, and access to agricultural extension services were treated as empirical proxies for behavioural capacity.

In contrast, HBM was applied to the consumer component to explain food safety awareness and risk-related behaviour, emphasising perceived susceptibility, severity, benefits, and barriers as determinants of protective action [23]. Variables such as food safety knowledge and income were used to capture variation in risk perception and associated behavioural responses under structural constraints.

The combined application of TPB and HBM reflects the study's value chain perspective, linking production-side decision-making with consumption-side risk perception. This integrated framework enabled a structured analysis of how behavioural determinants operate across different points in the system, supporting interpretation of how farmer practices and consumer responses relate within the same context without assuming direct measurement of all constructs.

Explanatory variables were selected based on their relevance to behavioural capacity and risk perception across both components. Due to data and sample size constraints, not all potential determinants (for example, crop characteristics and credit access) were included; thus, the specification was theoretically grounded but non-exhaustive.

To link theory with measurement, each theoretical construct was mapped to observable survey variables (Table 1). Where direct measurement of latent constructs was not possible, empirical proxies were used. Constructs that were not measured (subjective norms, perceived severity, self-efficacy) were acknowledged as limitations. Consistent with this operationalisation, TPB-related proxies (education, extension access, farmer organisation membership) were examined in relation to pesticide use, while HBM-related constructs (concern, barriers, knowledge) were used to characterise consumer risk perception and response patterns.

Table 1. Mapping of theoretical constructs to survey variables

Framework	Construct	Measured variable(s)	Operationalisation	Test/Analysis role
TPB (farmer)	Attitudes	Education level	Proxy: higher education assumed to increase awareness of health/environmental risks	Predictor in logistic regression
	Subjective norms	Not measured		Acknowledged limitation
	Perceived behavioural control	Access to agricultural extension services; membership in farmer organisation	Proxy: knowledge of alternatives and collective efficacy	Predictor in logistic regression
HBM (consumer)	Perceived susceptibility	Pesticide concern (Visual Analog Scale, 0–10 cm)	Direct measure of perceived risk	Descriptive (mean, range, by group)
	Perceived severity	Not measured separately	Combined with concern; limitation	-
	Perceived barriers	Reliance on informal markets; access to food safety information	Descriptive indicators	Cross-tabulation with concern/knowledge
	Self-efficacy	Not measured		Acknowledged limitation
	Cognitive understanding	Food safety knowledge (5-item Likert scale)	Not a formal HBM construct but informative	Descriptive (mean, by group)

2.2 Study area

The study was conducted in Burao district, Togdheer region, Somaliland, a semi-arid upper plateau zone with annual rainfall of 446–875 mm. Burao was purposively selected as a major urban–agricultural hub after Hargeisa, characterised by expanding vegetable production and a high concentration of consumers. Approximately 53% of the population is urban, creating strong demand for fresh horticultural produce [24]. This context provided a relevant setting for examining both production practices and food safety awareness within the same system.

Dominant horticultural crops are tomatoes, onions, cabbage, peppers, and leafy vegetables, widely grown in peri-urban and irrigated zones. Although no formal agricultural registry exists, vegetable farming is widely practised. Production is constrained by water scarcity, pest and disease pressure, and limited access to inputs such as certified seeds and reliable pesticide supplies. Common pests (aphids, caterpillars, whiteflies, beetles) often drive pesticide use. Farmers obtain pesticides from private agro-dealers and informal markets, with weak regulatory oversight. Formal farmer organisations are limited, and most producers operate independently, resulting in a heterogeneous production environment.

2.3 Study design and sampling procedure

A cross-sectional design with parallel farmer and consumer surveys was adopted, enabling concurrent assessment of production-side pesticide use and consumption-side food safety awareness within a single value chain. While this approach facilitates comparison across actors, it does not support direct linkage between individual production practices and consumer exposure pathways.

In the absence of a formal sampling frame for horticultural farmers, a multistage non-probability sampling approach was employed to prioritise variability across production systems rather than statistical representativeness. The target sample comprised 100 vegetable farmers and 50 consumers, with sizes determined by analytical objectives and logistical feasibility in a data-constrained context rather than formal power calculations, which consequently may limit statistical power for multivariable analysis, particularly where outcome events are relatively infrequent.

Sampling was implemented in two stages. Five villages (Suuqsade, Oodweyne, Beer, Calaacule, and Gatiitalay) were selected in consultation with local agricultural officers and community leaders to represent key vegetable production zones, from which approximately 20 farmers per village were recruited using purposive and snowball techniques, with quota controls to enhance sample diversity. In parallel, five major vegetable markets (Tawali, Nafaqo, Gaha, Central China, and Plaza) were selected based on sales volume and spatial distribution, with approximately 10 consumers sampled per market through systematic selection (every fifth buyer), and substitution applied where necessary to maintain continuity. This non-probability sampling design introduces potential selection bias and limits representativeness, particularly for population-level inference.

All study procedures were carried out in accordance with relevant guidelines and regulations for research involving human participants, including the principles of the Declaration of Helsinki. The study was reviewed by the Academic Research Committee of IGAD Sheikh Technical and Veterinary School (ISTVS), which determined that formal ethical approval was not required because the research involved minimal-risk survey interviews with adults. Verbal informed consent was obtained prior to each interview following explanation of the study objectives, confidentiality procedures, and the right to withdraw at any stage without consequence. No personally identifying information was recorded.

2.4 Data collection and variables

Data were collected through bilingual (Somali/English) face-to-face interviews using semi-structured questionnaires administered to farmers and consumers. The survey instrument comprised two modules (farmer and consumer). The instruments were pretested with 15 farmers and 10 consumers to assess clarity and contextual relevance, with feedback informing targeted revisions to wording and sequencing. Back-translation with local agricultural officers ensured linguistic consistency. Enumerators (graduate students from IGAD Sheikh Technical and Veterinary School) were trained in standardised interview procedures, including techniques for probing sensitive responses. The survey instruments are available from the corresponding author upon reasonable request.

Content validity was supported through a two-step process. First, items were adapted from published studies on pesticide use and food safety awareness in smallholder systems [7,13,17,21]. Subsequently, the draft questionnaire was reviewed by two local agricultural officers and one public health researcher familiar with the Burao context, who assessed clarity, relevance, and cultural appropriateness; further refinements were made based on their feedback. Formal content validity indices were not calculated, given the exploratory nature of the study.

Reliability testing such as Cronbach's alpha was not performed. The 5-item knowledge scale was designed as a formative index of conceptually distinct items (for example, awareness of residues and understanding of health effects) rather than a reflective scale; for such formative measures, internal consistency is not an appropriate reliability criterion [25]. Moreover, the small consumer sample (n = 50) would yield unstable reliability estimates. The single-item Visual Analog Scale for concern is not amenable to internal consistency testing by design.

All data collection procedures followed standardised field protocols. Given the exploratory and resource-constrained setting, these procedures provided adequate measurement consistency for the study context. Formal psychometric validation was therefore deferred to future studies with larger samples.

Following data collection and instrument validation, variables were defined and operationalised separately for the farmer and consumer modules. For the farmer module, the primary outcome was pesticide use, defined as application during the most recent growing season (0 = No, 1 = Yes; Table

2). This measure was selected to improve recall accuracy in the absence of farm records but did not capture application intensity or long-term use patterns. Explanatory variables included socioeconomic, farm, and institutional factors (Table 2), with market access operationalised as frequency of produce sales per week. The pre-harvest interval (PHI) was defined as the minimum time between the final pesticide application and harvest, allowing residues to decline below maximum residue limits [25], and compliance was self-reported. Consistent with the TPB framework, these variables were treated as empirical proxies for behavioural capacity influencing pesticide use decisions, rather than direct measures of attitudes or subjective norms.

The consumer module measured food safety knowledge using a 5-point Likert scale, operationalised as a composite score from five items (Table 2), and pesticide concern using a 10-cm Visual Analog Scale (0 = no concern; 10 = extreme concern). Concern responses were recorded in centimetres from the origin, consistent with the coding range in Table 2, yielding approximately continuous measurements. Visual Analog Scale (VAS) data are conventionally treated as continuous in exploratory health research [26]. While knowledge reflects ordered categorical responses, concern captures perceived risk on a continuous scale; both were analysed as complementary indicators of consumer food safety awareness. In line with the HBM framework, knowledge represented perceived understanding of pesticide-related risks, whereas concern reflected perceived susceptibility and severity.

A key limitation is reliance on self-reported data, which may introduce recall and social desirability bias; enumerator training and probing were used to mitigate this risk. Education levels were verified where documentation was available, while other variables were not independently validated (Table 2), consistent with field-based studies in data-constrained settings.

The study did not capture information on specific pesticide active ingredients, WHO hazard classifications, or alternative pest management strategies among non-users; pesticide use was therefore treated as a behavioural indicator, with toxicological context drawn from the literature [5, 6, 27](Supplementary Table S1). Due to survey length constraints, only two behavioural indicators (label reading and PHI adherence) were prioritised given their direct relevance to dosage, accuracy, application safety, and residue outcomes. Other recommended practices, including use of personal protective equipment, safe storage, and equipment calibration, were not assessed. Additionally, potentially important determinants such as crop diversity, credit access, pesticide availability, formal training, and regulatory enforcement were not included, which may introduce omitted variable bias.

Table 2. Variable operationalization

Variable	Type	Measurement	Coding/Range	Validation
Dependent variable				
Pesticide use	Binary	Self-reported pesticide application during most recent growing season	0 = No, 1 = Yes	Farm inventory verification where possible
Farmer predictors				
Age	Continuous	Self-reported years	20-75	Cross-checked where possible with national identity card (10%)
Education	Ordinal	Highest completed level	1=No formal education, 2=Primary, 3=Secondary, 4=Tertiary	
Farming experience	Continuous	Years of vegetable farming	1-40	Peer/local authority consistency checks

Farm size	Continuous	Total cultivable area (acres)	0.1–8.5	Self-reported
Income	Continuous	Estimated average monthly farm income (USD)	100–2000 USD	Self-reported sales over previous season (also reported categorically in Table 3 for descriptive purposes)
Extension access	Binary	Received agricultural extension advice in the past 12 months	0 = No, 1 = Yes	Self-reported
Market access	Ordinal	Frequency of selling produce per week	1 = ≤1 time/week, 2 = 2–3 times/week, 3 = ≥4 times/week	Self-reported
Consumer variables				
Pesticide concern	Continuous	Visual Analog Scale measuring perceived concern about pesticide residues (0 = no concern; 10 = extreme concern)	0–10 cm	Self-reported
Food safety knowledge	Scale	Composite score from 5 Likert-scale items assessing knowledge of pesticide use and risks	1–5 (sum score)	Self-reported
Income	Continuous	Monthly household income (USD)	100-2000 USD	Reported categorically in Table 4 for descriptive purposes

Education	Ordinal	Highest completed level	1=No formal education, 2=Primary, 3=Secondary, 4=Tertiary	Self-reported

2.5 Analytical approach

Given the non-probability sampling design, sample size constraints, and the limited number of outcome events, the analysis focused on identifying associations within the sample rather than supporting population-level inference. Statistical procedures were implemented in RStudio (version 4.4.3), applying logistic regression to examine factors associated with pesticide use among farmers, while consumer data were analysed descriptively to characterise patterns of food safety knowledge and concern based on standardised and pretested measurement instruments. Consistent with the operationalisation in Table 1, this approach captured TPB-related proxies through regression-based associations, while consumer indicators reflecting HBM constructs were examined descriptively.

Preliminary diagnostics included assessment of multicollinearity using variance inflation factors (VIF < 3) and checks for separation. Continuous variables were standardised to improve comparability across scales. With an events-per-variable (EPV) ratio of approximately 5 across 5–6 predictors, below the recommended minimum of 10–20, the multivariable analysis was susceptible to overfitting and unstable parameter estimates. Accordingly, results were interpreted with emphasis on the direction and magnitude of associations rather than statistical significance alone.

Bivariate associations between categorical predictors and pesticide use were evaluated using Pearson's chi-square test with Yates' continuity correction, or Fisher's exact test where expected cell counts were small, consistent with conservative approaches for handling sparse data and controlling Type I error [28].

Multivariable analysis was conducted using logistic regression, with predictor selection guided by theoretical relevance (TPB) and all conceptually relevant variables included in the initial model. To reduce overfitting under small-sample conditions, model refinement applied backward stepwise selection based on the Akaike Information Criterion ($\Delta AIC > 2$), resulting in a more parsimonious and interpretable specification. Stepwise selection carries risks of Type I error and model uncertainty, which were accounted for in interpretation.

To address small-sample bias and potential separation, the final model was estimated using Firth's penalised likelihood method, which reduces bias in maximum likelihood estimation under small-sample conditions [29]. Effect estimates were reported as profile likelihood confidence intervals, and model fit was assessed using the Hosmer–Lemeshow test.

To further characterise parameter uncertainty, a Bayesian logistic regression model was estimated in parallel. This framework provided posterior distributions and credible intervals, complementing frequentist inference under small-sample conditions. The model was estimated using 10,000 Markov chain Monte Carlo iterations with a 10% burn-in across four chains. Posterior means and 95% credible intervals were used to assess parameter direction and uncertainty, while Bayes factors were computed to evaluate evidence strength, particularly where frequentist results were inconclusive.

3. Results

3.1 Descriptive analysis of farmers

The mean age of vegetable farmers was 42.06 years, SD = 11.31 (Table 3). The average farm size was 2.74 acres (SD = 1.32). Farmers reported an average of 4.05 years of vegetable farming experience. Educational attainment was low: 82% had primary education or below. Access to agricultural extension services was limited, with 13% reporting contact within the past year. Agro-veterinary shops were the primary source of pesticide use information for 67% of farmers. Mean monthly income was USD

515 (SD = 370.51). Most farmers belonged to farmer organisations (71%) and reported access to markets (63%).

From a behavioural perspective, these characteristics reflect constraints in knowledge (education) and informational support (extension), alongside perceived behavioural control (access to market and collective structures), as conceptualised within the Theory of Planned Behavior.

Regarding pesticide use, 83% of farmers reported ever having used pesticides. However, only 30% applied pesticides during the most recent growing season (the operational definition of pesticide use in this study), resulting in a limited number of observed outcome events for subsequent analysis, while also pointing to possible seasonal variation or discontinuation among a subset of farmers. Table 3 presents the full socio-institutional characteristics of farmers.

Table 3. Socio-institutional characteristics of vegetable farmers (n = 100)

Characteristics	**Categories**	**N**	**Percentage (%)**	**Mean (SD)**
Age (years)	21-30	27	27	42.06 (11.31)
	31-40	46	46	
	41-50	16	16	
	>51	11	11	
Education levels	No formal school	34	34	
	Primary	48	48	
	Secondary	11	11	
	Tertiary	7	7	
Farm size (acres)	< 1	58	58	1.18 (0.93)
	1-2	25	25	
	> 2	17	17	
Access to extension services	Yes	13	13	
	No	87	87	
Farming experience	1-3 years	21	21	4.05 (1.35)
	3-5 years	54	54	
	Over 5 years	25	25	
Level of income (USD/month)	<500	62	62	515 (370.51)
	500-1000	23	23	
	> 1000	15	15	
Access to market	Yes	63	63	
	No	37	37	

Membership in farmer organisation	Yes	71	71
	No	29	29
Ever used pesticide for vegetable production	Yes	83	83
	No	17	17
Source of information on pesticide use	Agrovet	67	67
	Others	33	33

3.2 Descriptive analysis of consumers

The mean age of consumers was 42.76 years (SD = 11.87). Tertiary education was attained by 46%. Most consumers (82%) were aware of pesticide use in vegetable production, but only 14% reported access to food safety information. Vegetable consumption averaged 1.86 times per day (SD = 0.69), and the majority (74%) relied on open markets as their primary vegetable source. Consumer characteristics are summarised in Table 4. From a Health Belief Model (HBM) perspective, high awareness combined with limited access to food safety information may suggest potential gaps between risk recognition (susceptibility) and access to actionable guidance.

Table 4. Consumer characteristics (n = 50)

Characteristics	**Categories**	**N**	**Percentage (%)**	**Mean (SD)**
Age (years)	21-30	8	16	42.72 (11.87)
	31-40	12	24	
	41-50	20	40	
	>51	10	20	
Education levels	No formal school	7	14	
	Primary	9	18	
	Secondary	11	22	
	Tertiary	23	46	
Frequency of vegetable consumption (times/day)	Once	16	32	1.86 (0.69)
	Twice	25	50	
	Thrice	9	18	
Aware of pesticide use in vegetable farming	Yes	41	82	
	No	9	18	
Level of income (USD/month)	<500 (Low)	26	52	590 (390.94)
	500-1000 (Middle)	14	28	
	>1000 (High)	10	20	
Preferred source of vegetables	Open market	37	74	

	Supermarket	6	12	
	Own farm	7	14	
Access to vegetable safety information	Yes	7	14	
	No	43	86	
Food safety awareness	Knowledge: 5-point Likert		Concern: 10-cm VAS	Refer to Table 7 and Fig.2

3.3 Pesticide use and its determinants

3.3.1 Pesticide use

During the most recent growing season, 30% of farmers reported applying pesticides (Fig. 1). Among pesticide users, 22% reported reading and following label instructions. Application timing varied: 62% applied during flowering, 28% during the seedling stage, and 10% at crop maturity. To mitigate potential exposure, 66% of farmers reported waiting between one and four weeks before harvesting. These patterns indicate variation in behavioural execution and compliance, which may be influenced by differences in knowledge, attitudes, and perceived behavioural control within the TPB framework.

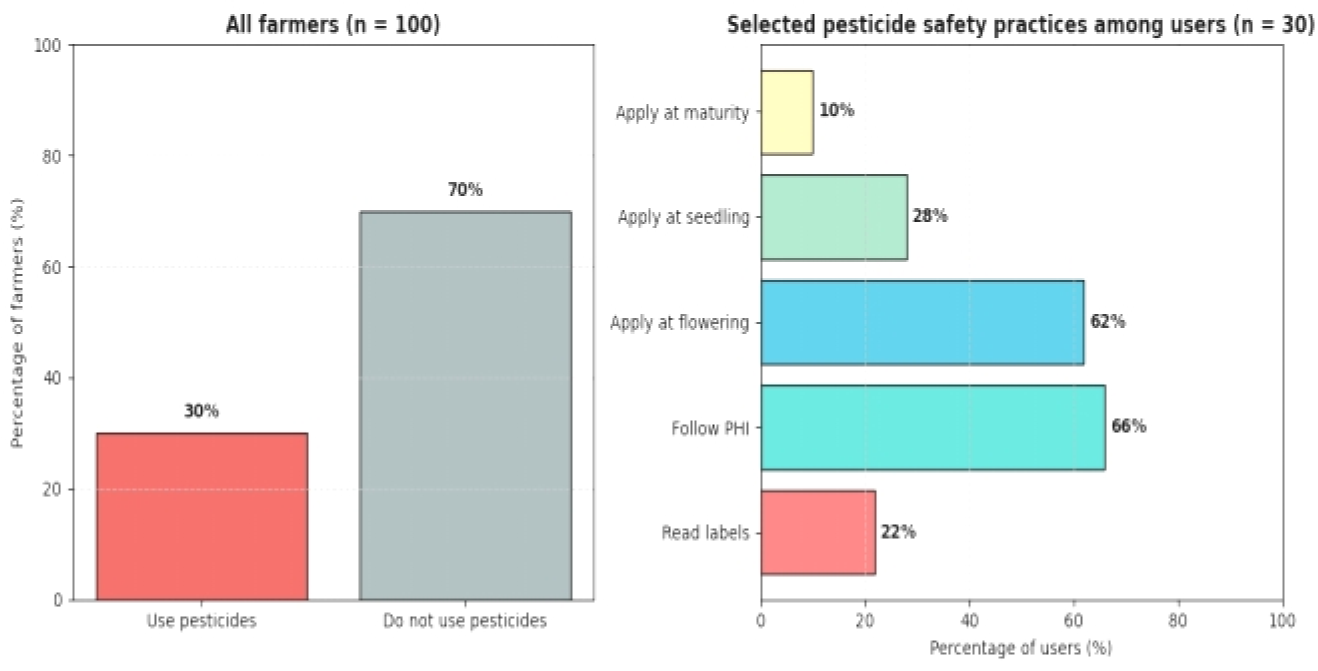

Fig. 1. Pesticide use and selected safety practices among vegetable farmers in Burao (n = 100)

Footnote: Safety practices are based on self-reported data from pesticide users only. The indicators presented (label reading and pre-harvest interval adherence) represent selected high-risk behaviours and do not capture the full range of FAO-recommended pesticide safety practices.

3.3.2 Determinants of pesticide use

Model diagnostics

Variance inflation factors (VIFs) ranged from 1.004 to 1.041, indicating no multicollinearity among the explanatory variables. No issues of complete or quasi-complete separation were detected.

Bivariate associations between categorical predictors and pesticide use were examined using Pearson's chi-square test with Yates' continuity correction or Fisher's exact test (Table 5). For this analysis, due to the small number of farmers with tertiary education (n = 7) (Table 3), secondary and tertiary levels were combined into a single "secondary or higher" category. Education level (secondary or higher vs. lower education) showed weak evidence of association within the sample (χ^2 = 3.92, p = 0.048). Access to agricultural extension services did not reach conventional statistical significance (Fisher's exact test: odds ratio = 0.17, 95% CI: 0.004–1.25, p = 0.101). Income level showed no evidence of association with pesticide use (χ^2 = 0.38, p = 0.828).

Table 5. Association between categorical variables and pesticide use

Predictor	**Test used**	**Test statistic**	**df**	**p value**
Education level (Secondary or higher)	Pearson's Chi-square (Yates)	3.92	1	0.048*
Access to extension	Fisher's Exact Test	Odds ratio: 0.17	-	0.101

Income level	Pearson’s Chi-square	0.38	2	0.828

Multivariable logistic regression

A Firth logistic regression model was fitted with pesticide use as the outcome. The Wald test indicated joint significance of the predictors (χ^2 = 17.96, p = 0.003); the likelihood ratio test gave χ^2 = 8.33 (p = 0.14). Coefficients, standard errors, 95% confidence intervals, Wald χ^2, and p-values are presented in Table 6. Education (secondary or higher) showed a negative, but not statistically significant, association with pesticide use (β = –0.78, 95% CI: –1.67 to 0.11, p = 0.084). Similarly, access to agricultural extension showed a negative, but not statistically significant, association (β = –1.31, 95% CI: –3.60 to 0.25, p = 0.106). Farm size, monthly income, and farming experience were not associated with pesticide use (p > 0.2). The breadth of the confidence intervals across model estimates is consistent with the limited number of observed outcome events.

Table 6. Firth logistic regression for predicting pesticide use

Predictor	**Coefficient (β)**	**SE (β)**	**95% CI (Lower–Upper)**	**Wald χ^2**	**p value**
Intercept	–0.982	1.048	–3.14 to 1.08	0.863	0.353
Education level (Secondary or higher)	–0.777	0.448	–1.67 to 0.11	2.98	0.084*
Access to extension (yes)	–1.313	0.896	–3.60 to 0.25	2.62	0.106
Farm size (acres)	–0.050	0.166	–0.39 to 0.28	0.088	0.766
Monthly income (USD)	0.00028	0.00045	–0.00087 to 0.00093	0.0038	0.951
Farming experience (years)	0.413	0.329	–0.23 to 1.10	1.571	0.210

Bayesian logistic regression

Bayesian logistic regression was used to examine associations with pesticide use. Model convergence was satisfactory (all $\hat{R}$ = 1.00; bulk and tail ESS > 7000). Posterior estimates are shown in Table 7. Access to extension had a posterior mean of –1.74 (95% credible interval: –3.93 to –0.00). Education (secondary or higher) had a posterior mean of –0.84 (95% CrI: –1.74 to 0.07). Farm size, income, and farming experience had credible intervals spanning zero.

Overall, both Bayesian and frequentist models indicate a negative association between extension access and education with pesticide use, although uncertainty remained substantial across estimates. These patterns suggest potential directional signals consistent with differences in knowledge and access to advisory support, but they do not provide definitive evidence of determinants.

Table 7. Posterior estimates from Bayesian logistic regression on pesticide use

Predictor	Estimate	Std. Error	95% Credible Interval	R hat	Bulk_ESS	Tail_ESS
Intercept	-1.10	1.13	[-3.34, 1.09]	1.00	9,692	9,427
Education level (Secondary or higher)	-0.84	0.47	[-1.74, 0.07]	1.00	9,728	8,056
Access to extension (yes)	-1.74	1.00	[-3.93, -0.00]	1.00	8,556	7,056
Farm size (acres)	-0.06	0.18	[-0.42, 0.30]	1.00	9,240	7,156
Monthly income (USD)	0.00	0.00	[-0.00, 0.00]	1.00	12,724	8,065
Farming experience (years)	0.46	0.35	[-0.22, 1.17]	1.00	9,386	8,161

3.3.3 Food safety awareness, knowledge, and concern

Awareness of pesticide use in vegetable production was reported by 82% of consumers (Table 4). Knowledge of pesticide-related risks, assessed using a

5-point Likert scale, had a mean score of 3.08/5, reflecting moderate levels on the ordinal knowledge scale (Table 8). Concern regarding pesticide residues, measured using a 10-cm visual analog scale, showed a mean score of 5.38 cm, indicating relatively elevated concern on the continuous scale (Fig. 2).

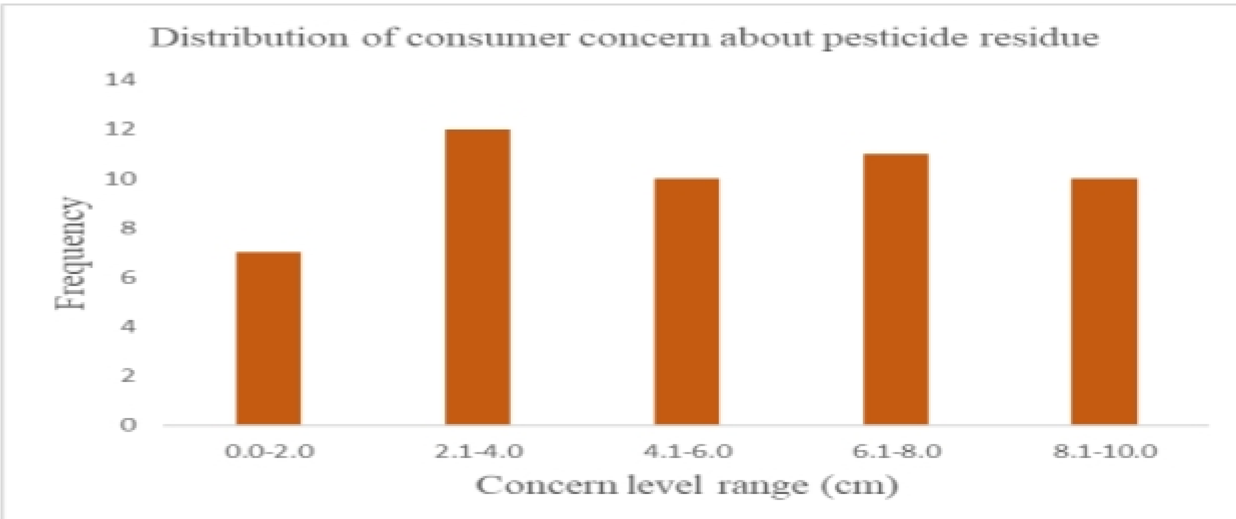

Fig. 2. Consumers' level of concern about pesticide residues measured using a 10-cm visual analog scale (0 = no concern; 10 = extreme concern), with values recorded in centimetres.

A disaggregated analysis by education level showed that consumers with tertiary education had a mean knowledge score of 3.25, whereas those without formal schooling scored 2.90. Concern about pesticide residues ranged from 3.97 to 5.79 on the 0–10 cm scale, across education groups. By income level, middle-income consumers reported the highest mean concern score (6.09 cm), followed by high-income (4.80 cm) and low-income (1.60 cm). However, the low-income category comprised three respondents (n = 3). Knowledge scores did not differ meaningfully across income groups (Table 8).

Regarding consumption behaviour, 50% of consumers reported consuming vegetables twice per day, and 74% relied on open markets as their primary source (Table 4). This pattern indicates continued reliance on potentially higher-risk supply channels despite moderate levels of awareness and concern, reflecting potential barriers to behavioural change as conceptualised in the Health Belief Model (HBM).

Table 8. Knowledge and concern by education level and income

Parameter	Average knowledge	Average concern(VAS, cm; 0–10)	Count
Education level			
No formal school	2.90	5.65	10
Primary	2.83	3.97	6
Secondary	3.00	5.79	10
Tertiary	3.25	5.45	24
Average	**3.08**	**5.38**	
Income			
Low	3.00	1.60	3
Middle	3.07	6.09	30
High	3.12	4.80	17

4. Discussion

Consistent with a value chain perspective, the findings provide insight into how production-side pesticide practices may shape downstream food safety risks, while examining how these risks are perceived within the same value chain context rather than through direct exposure pathways. In this study, 30% of farmers reported applying pesticides during the most recent growing season (Fig. 1), a level consistent with estimates from African smallholder systems (16–41%) [30]. However, it remains lower than that reported in more intensive vegetable systems in Southeast Asia, where smallholder vegetable production is more heavily reliant on synthetic pesticides as a primary pest management strategy [31], reflecting differences in production intensity, pest pressure, and institutional support.

Beyond prevalence, pesticide handling practices raise important food safety concerns. Only 22% of pesticide users reported reading and following label instructions, while 66% reported adherence to a pre-harvest interval (PHI) of one to four weeks (Fig. 1). While PHI adherence is essential for reducing residue risks, these estimates are subject to recall and social desirability bias. Evidence from similar smallholder contexts suggests that self-reported compliance may overestimate actual practice, with up to half of farmers not adhering to recommended PHI intervals and some harvesting on the same day of application [13, 32]. Given these patterns and data limitations, deviations from recommended PHI practices cannot be ruled out, although residue levels were not directly measured.

Across analytical approaches (bivariate, Firth logistic, and Bayesian), education (secondary or higher) and access to agricultural extension services showed negative associations with pesticide use (Table 5 and 6); however, statistical support was weak ($p = 0.084–0.106$; credible intervals overlapping zero). The combination of overlapping intervals and a limited number of outcome events reflects substantial estimation uncertainty within the exploratory design. Farm size, income, and farming experience were not associated with pesticide use, suggesting that economic capacity alone does not strongly predict behaviour in this setting. Within a TPB-informed interpretation, these associations reflect variation in behavioural capacity and perceived behavioural control, linking the observed patterns to the theoretical constructs.

These findings align with global evidence indicating that individual-level capacity factors, often proxied by education, are insufficient on their own to change pesticide practices without complementary structural and institutional support [33, 34]. At the regional level, similar patterns have been observed in East Africa, where the effectiveness of agricultural extension depends not only on access but also on the quality and relevance of advisory services [35, 36]. Empirical evidence remains mixed: access to agricultural extension has been associated with increased pesticide use in some contexts, no effect in others, and reduced overuse where services are effective [10, 30, 37]. Likewise, the influence of education varies across settings, reinforcing the context-dependence of pesticide use behaviour.

From a Theory of Planned Behavior (TPB) perspective, these patterns reflect associations between empirical proxies of behavioural capacity and pesticide use, rather than direct testing of latent constructs such as attitudes or subjective norms. Education may influence attitudes through increased awareness of health and environmental risks, while access to agricultural extension services may enhance perceived behavioural control by improving knowledge and access to alternatives such as integrated pest management (IPM), where pesticides are judiciously used alongside biological, cultural, and mechanical methods. The observed negative associations are consistent with these pathways, although the imprecision of the estimates and limited number of outcome events introduce substantial uncertainty.

Turning to the consumer side within the same value chain framework, and consistent with the Health Belief Model (HBM), the analysis extends to how production-related risks are perceived and responded to at the consumption level. At this level, 82% of respondents were aware of pesticide use (Table 4), yet knowledge of pesticide-related risks was only moderate (mean 3.08/5; Table 8), and concern was relatively high (mean 5.38 cm on a 10-cm VAS), reflecting elevated perceived risk on a continuous scale. While awareness denotes general recognition and knowledge reflects structured understanding, concern captures the intensity of perceived risk; together, these measures indicate a gap between perceived risk and actionable understanding.

This gap has observable behavioural implications. Despite elevated concern levels, 74% of consumers relied on open markets with limited regulatory oversight, and 50% consumed vegetables twice daily (Table 4). Moderate knowledge may reduce the perceived effectiveness of risk-mitigation strategies, such as washing produce or seeking certified alternatives, thereby constraining behavioural change even when concern is present. As a result, awareness alone appears insufficient without more actionable and context-specific knowledge.

From a HBM perspective, the analysis captures observable components of risk perception and behavioural response through knowledge and concern, rather than directly estimating all latent constructs. Higher concern values reflect elevated perceived susceptibility and severity, while moderate knowledge and continued reliance on informal markets indicate constraints in translating perceived risk into effective action. Structural factors, including limited availability, affordability, and access to safer alternatives, are likely to reinforce these constraints, such that concern operates more as an expression of perceived risk than as a consistent driver of protective behaviour. This pattern is well documented in food safety and health behaviour literature, where structural conditions constrain behavioural responses despite high perceived risk, particularly in African food systems characterised by informal markets and weak regulatory oversight [13, 38, 39].

Socioeconomic variation further reinforces this interpretation. Consumers with tertiary education had higher knowledge scores (3.25) than those without formal schooling (2.90), yet concern remained relatively high across all education levels (range 3.97–5.79 on the 0–10 scale). This indicates that variation in concern across the scale is not solely determined by knowledge, consistent with evidence that heightened public attention to food safety can elevate concern irrespective of education [39, 40].

By contrast, income appeared to shape the capacity to act on concern rather than the level of concern itself across the scale: middle-income consumers reported the highest concern (6.09 cm), while the low-income estimate (1.60 cm) is based on a very small sample (n = 3) and does not support strong inference (Table 8). Knowledge levels showed minimal variation across income groups. This pattern, high concern alongside continued reliance on informal markets supports the HBM's emphasis on perceived barriers as a critical determinant of behaviour, often outweighing perceived susceptibility when structural constraints are severe.

While these patterns clarify consumer-side responses, linking them directly to production practices remains methodologically constrained.

Producers and consumers were analysed in parallel rather than through direct behavioural or residue linkage, limiting causal inference. The value chain framing is therefore conceptual and descriptive. Within this design, linkage was interpreted indirectly by situating production indicators (pesticide use and safety practices) alongside consumer indicators (knowledge and concern) within the same market system. The results indicate analytical convergence, with both production practices and consumer responses shaped by shared informational and structural conditions, including limited access to agricultural extension services and reliance on informal markets. This system-level interpretation provides indicative, not causal evidence of alignment between upstream practices and downstream perceptions.

Taken together, these results distinguish awareness, knowledge, concern, and action as related but distinct dimensions of consumer food safety behaviour. Within this value chain context, higher levels of concern do not automatically translate into protective practices, as behavioural responses are mediated by structural constraints rather than driven solely by risk perception. This interpretation is consistent with the combined TPB–HBM framework applied throughout the analysis, particularly the role of behavioural capacity and perceived behavioural control on the production side and risk perception under structural constraints on the consumption side, and with broader evidence that consumers often prioritise price and convenience over safety[41, 42]. Accordingly, improving food safety outcomes requires not only targeted risk communication focused on practical mitigation strategies but also systemic interventions, including improved market regulation, increased access to certified produce, and enhanced affordability—echoing the structural needs identified on the production side.

Two key insights emerge from this analysis. First, pesticide use behaviour in this dryland, informal-market vegetable system does not appear to be strongly determined by resource endowments such as income or farm size. Second, the absence of data on alternative pest management practices among non-users renders “pesticide non-use” analytically ambiguous. Future research should explicitly capture biological, cultural, and mechanical control strategies alongside chemical use. In addition, objective validation such as residue testing and verification of pre-harvest interval (PHI) compliance is needed to better characterise exposure pathways and associated food safety risks. While the findings do not support strong policy conclusions, they highlight the importance of context-specific information systems and the need for further investigation into integrated pest management (IPM) adoption in similar dryland systems.

5. Conclusion

As vegetable production expands in Burao, pesticide-related food safety is likely to become an increasingly important challenge across the vegetable value chain. This study shows that pesticide use among smallholder farmers is present but not universal, with variation in safety practices, particularly in label comprehension and adherence to pre-harvest intervals. Education and access to agricultural extension services were associated with lower pesticide use, although estimates were imprecise and reflect patterns within an exploratory design rather than stable inferential relationships.

On the consumer side, awareness of pesticide use was widespread, yet knowledge remained moderate while concern was relatively elevated, indicating a gap between perceived risk and actionable understanding. Although education was associated with higher knowledge and income with variation in concern, reliance on informal markets appears to constrain the translation of concern into protective behaviour.

These findings are subject to several limitations, including the small non-probability sample, reliance on self-reported data, absence of formal reliability testing, and the limited number of pesticide-use cases, all of which constrain generalisability and causal inference. The findings therefore represent preliminary exploratory signals rather than definitive determinants. In addition, key theoretically relevant constructs, such as subjective norms (TPB) and perceived severity and self-efficacy (HBM), were not measured, limiting full empirical testing of the frameworks. The value chain analysis remains conceptual, as farmer and consumer data were analysed in parallel without individual-level linkage or direct exposure assessment. Furthermore, the absence of data on alternative pest management practices among non-users introduces ambiguity in interpreting pesticide non-use, which may reflect either deliberate adoption of safer strategies or constrained access to inputs. Despite these limitations, the findings indicate converging patterns in production practices and consumer perceptions shaped by shared informational and structural conditions within the same system.

Building on this, the findings highlight the role of these shared conditions in shaping both production practices and consumer responses. Interpreted through the combined TPB–HBM framework, the results suggest that behavioural capacity and perceived control on the production side, alongside perceived risk and structural constraints on the consumption side, jointly influence observed outcomes. Strengthening context-specific agricultural extension, improving pesticide safety communication, and enhancing food safety awareness in informal markets therefore represent key entry points for intervention in Somaliland’s horticultural sector.

Future research should expand sample sizes and establish direct linkages across the value chain through methods such as pesticide residue testing, traceability systems, or matched producer–consumer surveys. Additionally, future work should incorporate a broader set of pesticide safety indicators, including the use of personal protective equipment, storage practices, and container disposal, to enable more comprehensive risk assessment. Integrating WHO hazard classifications would strengthen the toxicological relevance of exposure assessment, while crop-specific analyses, for example tomatoes versus leafy greens, could capture variation in pesticide use and residue risk. Further investigation into the feasibility of biopesticides and integrated pest management (IPM) in semi-arid smallholder systems would provide critical insights for sustainable pest management transitions.

Declarations

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Ethics statement: Research involved human participants. Informed consent was obtained from all study participants, ensuring they were briefed on the research objectives and their rights as participants.

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