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FARMERS' PERCEPTIONS ABOUT MYCOTOXIN CONTAMINATION IN MAIZE AND PEANUTS AND ASSOCIATED HEALTH RISKS IN SOUTHERN MOZAMBIQUE

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ABSTRACT

Fungal spoilage severely impacts food and feed systems, with certain species producing mycotoxins that endanger human and animal health. These toxins contaminate crops like maize and peanuts, thriving pre- and post-harvest in warm, humid climates such as those in sub-Saharan Africa. Mycotoxin contamination presents significant public health and economic challenges, particularly in developing countries where poor production, harvesting, and storage practices heighten risks. This study surveyed 384 smallholder farmers in Southern Mozambique (Maputo, Gaza and Inhambane provinces) storing maize and peanuts, assessing their perceptions of insect, fungal and mycotoxin contamination and its links to human diseases. Data were gathered via structured interviews and storage observations. Findings showed most farmers used traditional wood and straw granaries, which promote air circulation but elevate humidity and pest presence. Perceptions of pest infestations varied across storage types, reflecting diverse awareness. A strong correlation between fungal growth and mycotoxin contamination highlighted environmental influences. However, most farmers, including those affected by liver cancer, showed limited understanding of the connection between mycotoxin-contaminated food and health issues like liver cancer, cirrhosis, or food poisoning, with no reported knowledge of liver cancer prevention strategies, a critical knowledge gap. Food poisoning impacted 4.2% of the interviews, suggesting broader underreported effects. Commercial farmers demonstrated greater awareness of contamination risks and their association with food poisoning and liver cancer, likely due to market quality demands, while subsistence farmers with limited market access lacked such knowledge. These results underscore the need for advanced storage solutions, such as sealed granaries, and targeted farmer education to reduce mycotoxin risks in Southern Mozambique. Although this study emphasized liver cancer generally linked to aflatoxins, other mycotoxins (for example fumonisins, deoxynivalenol, ochratoxins) also threaten regional crops. Future research quantifying these contaminants and their ties to additional diseases could refine risk assessments and bolster food safety strategies. Investments in education and infrastructure are vital to safeguard public health and economic stability in this vulnerable region.

Key words: Food safety, smallholder farmers, mycotoxins, aflatoxins, sub-Saharan Africa

INTRODUCTION

Mycotoxin contamination poses a substantial threat to food safety and economic stability in Mozambique. Despite the importance of this issue, research on mycotoxins in the country remains scarce. Most studies target aflatoxins, a group of mycotoxins produced by *Aspergillus* species, which are linked to serious health issues in humans and animals, including liver cancer, cirrhosis and acute necrosis [1-3]. Beyond aflatoxins, other mycotoxins also contaminate food and pose health risks, yet research on these remains limited. Mozambique is notably affected by diseases associated with mycotoxin ingestion, particularly liver cancer, though data are sparse [4-6].

As in Mozambique, mycotoxin contamination is a widespread challenge across sub-Saharan Africa. Maize, a staple crop in the region, is frequently contaminated with multiple mycotoxins, including aflatoxins, deoxynivalenol, fumonisins, ochratoxins and zearalenone [7-9]. Aflatoxin levels in maize, peanuts and peanut oil often exceed safe limits established by international bodies such as the European Union and Codex Alimentarius [8]. Contamination occurs throughout the food production chain, from cultivation to storage. Traditional storage methods in sub-Saharan Africa, often lacking adequate ventilation and sanitation, create optimal conditions for insect pests and fungal growth [10-12], exacerbating mycotoxin proliferation in stored grains [13, 14].

Socioeconomic factors in Southern Mozambique further compound the prevalence of mycotoxin contamination [15]. Limited access to agricultural support, inadequate transportation, informal market practices, and insufficient knowledge of proper grain handling and storage impede farmers' ability to mitigate contamination risks [15-17]. Current pest and mycotoxin control methods in the region are largely ineffective, underscoring the need for dietary diversification to reduce reliance on highly contaminated crops like maize and peanuts [18-22].

Smallholder farmers, critical to food production and storage, significantly influence product quality. However, many in developing countries lack the knowledge and skills for effective post-harvest grain management. Limited access to public extension services further restricts the adoption of necessary technologies [23-25]. This study therefore assessed: (1) farmers' perceptions of maize and peanut contamination by insects, fungi, and mycotoxins, and (2) their awareness of the link between mycotoxin contamination and related diseases in rural areas of Southern Mozambique.

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MATERIALS AND METHODS

Description of the area of study

This study was conducted in rural areas of Maputo, Gaza and Inhambane provinces in Mozambique, a tropical nation in sub-Saharan Africa (Figure 1). These regions experience a tropical dry climate, with higher precipitation and temperatures from November to March [26].

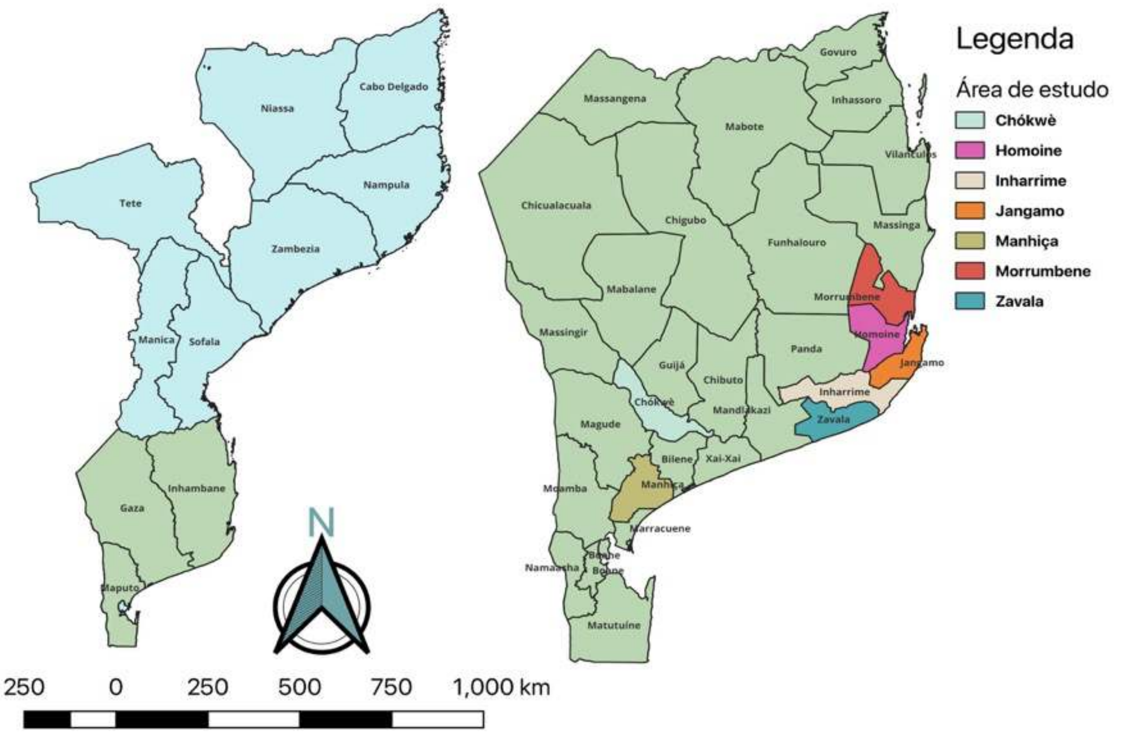

Figure 1: Map of Mozambique illustrating the target area of the study

Survey design

Before data collection, the research team established contacts with local public administrations and community leaders to facilitate farmer engagement. Data were collected through daily interviews with farmers using structured questionnaires. Participants were shown photographs of insects and fungi to evaluate their ability to identify common pests and moldy grains observed in storage units. Additionally, grain storage structures for maize and peanuts were observed and documented.

Sampling

Data collection involved interviewing 384 maize and peanut farmers from a total population of 241,530 in the study area. The sample size was determined using a standard statistical equation [27], where Z represents the standard deviation, p denotes the proportion of favorable responses, q indicates the proportion of unfavorable responses, d is the margin of error, N is the total population, and n is the calculated sample size. The number of respondents per location was proportional to the population size of that area, as detailed in Table 1.

$$n = \frac{Z^2 pqN}{d^2(N-1) + Z^2 pq}$$

The sample size for each location adhered to the principle of equivalence, ensuring that the ratio of respondents to the sample size (n) mirrored the ratio of the local population to the total population (N). Farmers were randomly selected using RStudio software. Interviewers visited the selected households to conduct interviews and assess maize and peanut storage conditions. If a household was unavailable, visits were rescheduled for a more suitable time. All participants provided informed consent after being briefed on the study's academic purpose.

Sociodemographic data were collected, including the gender of the head of the interview's family, family size, marital status, education level, engagement in agricultural and non-agricultural activities, and alternative income sources. Interviews were conducted in local languages (Cicopi, Changana, Ronga, Gitonga, Xitswa) to ensure comprehension of the term "mycotoxin." Participants were shown photographs of maize and peanut grains exhibiting fungal contamination, followed by images of stored-product insect pests. They were then asked to connect these visuals to their own storage experiences.

Farmers demonstrating awareness of fungal contamination were further questioned about mycotoxin-related issues, including food poisoning incidents within their families, foods most prone to contamination, cancer prevalence and its suspected causes. They also described their fungal and pest control practices.

To assess knowledge levels, a four-point scale was adapted [28], classifying understanding as poor (1), medium (2), good (3), or very good (4). This evaluation focused on four key areas: (1) recognition of fungal and mycotoxin contamination in food, (2) understanding the connection between mycotoxin ingestion and food poisoning, (3) awareness of diseases linked to mycotoxin exposure and (4) knowledge of preventive measures. The assessment provided a robust measure of farmers' comprehension and practices related to mycotoxin risks.

Data analysis

Data were analyzed using International Business Machines Statistical Package for the Social Sciences (IBM SPSS) Statistics, Version 25. Frequency analyses and chi-square tests were conducted to evaluate farmers' perceptions of maize and peanut contamination by insects, fungi and mycotoxins. Binary logistic regression was employed to examine the association between farmers' knowledge of mycotoxin contamination and the incidence of mycotoxin-related diseases. Statistical significance was assessed at the 1% and 5% levels for all analysis.

RESULTS AND DISCUSSION

Farmers' Socioeconomic Description

Approximately 73% of the interviews were conducted with male-headed households, while 27% involved female-headed households. On average, families comprised five members. Most participants were aged between 36 and 60 years, suggesting a lower involvement of younger individuals in agricultural activities. Furthermore, women, who are the primary contributors to Mozambican agriculture, accounted for 57.3% of the participants (Table 2).

Concerning marital status, approximately 60% of the interviewees were either married or cohabiting, indicating that marriage retains considerable importance within the study's target region. A significant portion of respondents (59.6%) lacked formal education, having not completed primary schooling and thus being unable to read or write. Only 35.9% of the interviewees had attained primary education. Regarding access to formal education, women faced a notable disadvantage, with 66.4% lacking any formal schooling compared to 50.6% of men. The data further indicated that most male participants had completed primary or basic education. Strikingly, only one female interviewee had achieved secondary education ($p<0.01$), as detailed in Table 2.

The predominant activity among most participants was agriculture (73.2%), followed by a mix of agriculture and livestock (6.5%) and other income-generating pursuits (3.6%). Notably, only 6.1% of the interviewed men reported having at least one family member engaged in paid activities, compared to just 1.8% of interviewed women, highlighting women's limited involvement in remunerated work. Agricultural practices were heavily influenced by climatic conditions. A substantial portion of farmers worked plots smaller than 1 hectare, though some cultivated larger areas. Key crops included maize, cowpea, peanuts and vegetables. Approximately 64.6% of the yield was destined for household consumption, while 32.6% served both consumption and trade, indicating that farmers encountered significant barriers to market access for selling their goods, as evidenced in Table 2.

Farmers perceptions of grain sanity and exposure to related human diseases

Although traditional granaries continue to be widely used in developing countries, documented advancements in granary design emphasizing enhanced durability, improved pest resistance, and minimized post-harvest losses underscore the increasing significance of modernized storage solutions for maize and peanuts [29,30].

The surveyed farmers reported storing maize and peanut grains in both traditional and enhanced granaries. Traditional granaries, built from locally available materials like wood and straw, promote air circulation, which may exacerbate humidity, insect infestations and microbial proliferation. Conversely, improved granaries, constructed from materials such as cement, clay, or plastic, provide superior sealing, thereby reducing air circulation, humidity, insect presence and microbial activity compared to their traditional counterparts.

The findings reveal distinct perceptions of pest infestation among farmers utilizing traditional versus improved granaries for maize and peanut storage. Of the 98.7% of farmers reporting pest infestations in stored grains, 90.9% relied on traditional granaries, whereas only 6.5% used improved granaries ($p<0.05$). Furthermore, data showed that 93.2% of farmers who observed fungal contamination in their grains employed traditional granaries. Likewise, of the 82.8% of farmers noting deterioration in stored maize and peanuts, 76% used traditional granaries. Notably, among the 40.9% of farmers applying chemical control, 38% stored grains in traditional granaries, while 35.7% of the 38% using non-chemical methods also relied on traditional storage (Table 3).

Farmers employing chemical control methods used solid formulations with pirimiphos-methyl as the active ingredient, with Actellic being the most common brand in the study area. In contrast, those opting for non-chemical approaches depended on plant extracts and ashes. A particularly distinctive traditional method involves building granaries above kitchen spaces. The smoke produced from burning firewood during cooking permeates the stored grain, aiding in the reduction of pest infestations.

Regarding food contamination**,** no statistically significant difference ($p > 0.05$) was observed between the perceptions of farmers who stored maize and peanuts in traditional granaries and those who used improved granaries. Overall, 4.2% of farmers reported instances of food poisoning. Additionally, 2.6% of participants reported a perception of liver cancer occurrence within their families and access to hospital treatment for the condition.

In terms of conservation methods**,** 1.6% of participants directly or indirectly affected by liver cancer confirmed the use of traditional granaries, compared to only 0.5% who reported using improved granaries ($p < 0.05$). Furthermore, none of the participants indicated any knowledge of liver cancer prevention measures, as summarized in Table 3.

Factors influencing farmers' perceptions of fungal and mycotoxin food contamination and the occurrence of liver cancer

The first group (a) consisted of farmers with business-oriented production practices (32,6%) (Table 2). These farmers demonstrated a higher likelihood of being knowledgeable about insect pest and fungal contamination in food, the association between food contamination and food poisoning, and the risks related to liver cancer, as detailed in Table 4.

The second group (b) included farmers who were knowledgeable about insect pests (98.7%) and fungal (93.2%) contamination in food, as well as the link between fungal contamination and food poisoning. The likelihood of such knowledge was higher among participants who had observed cases of food poisoning within their families, those with prior experience of liver cancer cases in their families, and particularly among participants from Morrumbene aged between 36 and 60 years. A similar trend was observed among participants from Chókwè and farmers who did not implement measures to control insect pests and fungi, as illustrated in Table 4.

Lastly, the third group (c) consisted of farmers well-informed about maize and peanut contamination by insect pests and fungi. Within this group, those employing chemical control methods exhibited a higher probability of possessing such knowledge. This likelihood was reduced among married farmers, those cultivating areas larger than 3 hectares, individuals storing maize and peanuts for over 4 months, and participants living in Homoíne, as detailed in Table 4.

The findings highlight the need to reconsider the provision of basic academic training in rural areas. Education is widely acknowledged as a critical tool for disseminating information and knowledge, as demonstrated by its positive influence on farmers' understanding of pests and control methods [31]. The prevalence of low educational levels among farmers identified in this study may hinder their capacity to make informed decisions regarding aflatoxin management, despite the availability of scientific advancements.

Regarding the types of granaries used, neither traditional nor improved granaries appear to provide adequate conditions for fully controlling the environmental and biological factors that influence fungal development and aflatoxin production. As a result, investments in more advanced and sophisticated storage systems are critically needed.

A study evaluating the effectiveness of traditional and improved granaries in protecting maize against *Prostephanus truncates* reported poor performance, with grain infestation occurring after 3 and 4.5 months, respectively [32]. Furthermore, the limited involvement of families in remunerated activities restricts their capacity to generate sufficient income for investing in more efficient storage systems. Similar financial constraints have been identified as a barrier to the adoption of hermetic technologies for maize conservation in Ethiopia [29].

Despite the adoption of various methods by many farmers to control insect pest infestations and fungal contamination, stored maize and peanuts in traditional granaries continue to show significant deterioration. This may be attributed to the comparatively lower efficiency of traditional granaries relative to modern storage systems, as supported by several studies [30, 33].

The efficacy of chemical pest control methods for stored products, particularly those employing pirimiphos-methyl-based formulations, is well-documented [34, 35]. However, the absence of active ingredient rotation in less efficient local storage systems may promote the emergence of resistant pest populations, diminishing control effectiveness and requiring higher doses. This escalation increases both control costs and risks to human and animal health. Alternatively, resource constraints often lead farmers to rely on non-chemical methods, such as plant-based materials, ash and granaries positioned above kitchens. Nonetheless, these approaches have been shown to offer limited effectiveness against insect pests [36].

Access to healthcare services in rural areas remains limited compared to urban areas [37], primarily due to factors such as long distances to the nearest hospitals and poor road infrastructure. In this study, fewer than 5% of participants reported cases of food poisoning and liver cancer within their families, despite having access to hospital care. These findings suggest that the incidence of such diseases may be underestimated, largely due to challenges in accessing healthcare for diagnosis and treatment. Rural populations often rely on traditional medicine to address family health issues, which may further reduce the likelihood of disease diagnosis [38].

Smallholder farmers benefit minimally from market opportunities due to their limited ability to access diverse markets, particularly in regions where food security is a growing concern [39]. The findings of this study reveal that farmers engaged in business activities are the most informed group regarding grain safety, its association with food poisoning, and liver cancer. Although they do not participate in large associations, their involvement in business, where product quality standards such as appearance are critical, requires them to classify their produce and set prices in accordance with market requirements. These practices provide them with a competitive advantage over smallholder farmers not involved in business activities.

Mycotoxins, which are colorless, odorless and invisible [40], often lead to the perception that contaminated food is safe for consumption. While most interviewees could visibly identify grains contaminated by fungi, a correlation between contamination and health risks such as food poisoning or liver cancer was only recognized by families with direct experience of such issues. These findings suggest that learning occurs primarily through exposure, underscoring the need to re-evaluate the content of interventions in rural areas, including those led by extension services and other stakeholders involved in information and technology transfer to farmers. Concurrently, it is crucial to reconsider the integration of food security concepts into primary education curricula, particularly in rural communities where agriculture is the predominant livelihood activity.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

Farmers are generally aware of insect pest and fungal contamination in their stored maize and peanuts. However, knowledge about mycotoxin contamination remains limited. Furthermore, the application of available alternatives for effective pest management is minimal.

Few farmers established a connection between food contamination, the occurrence of related diseases, and the consumption of contaminated food within their families. Knowledge and awareness of mycotoxins, food poisoning and liver cancer were primarily influenced by two factors: the business-oriented status of farmers and direct family exposure to cases of food poisoning or liver cancer. Notably, knowledge about liver cancer prevention was virtually absent among the participants.

The target group of this study comprised smallholder maize and peanut farmers, and the findings may not necessarily reflect the level of knowledge among medium- and large-scale farmers or the general public. Therefore, further research involving both the public and private sectors, as well as the media, is essential to enhance awareness of food security, aflatoxin contamination, and its implications for public health. Additionally, mycotoxin testing would provide a more precise evaluation of food contamination risks.

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DECLARATION OF CONFLICT OF INTEREST

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We have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

Table 1: Places of data collection, population (N) and sample size (n)

Place of	Population[1]		Sample Size
Sample collection	FA (N)	FA (%)	FA (n)
Inharrime	21043	9%	33
Jangamo	25458	11%	40
Morrumbene	34576	14%	55
Homoíne	28425	12%	45
Zavala	35024	15%	56
Chókwè	46873	19%	75
Manhiça	50131	21%	80
Total	241530	100%	384

[1]FA – Family Aggregate

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Table 2: Description of socioeconomic activities of farmers interviewed in some rural areas of southern Mozambique

Variables	Gender	N=384 (%)		X^2
	Male	**Female**	**Total**	
Age (years)				NS
18-35	55 (33,5)	70 (31,8)	125 (32,6)	
36-60	78 (47,6)	120 (54,5)	198 (51,6)	
More than 60	31 (18,9)	30 (13,6)	61 (15,9)	
Level of education (%)				a
None	83 (50,6)	146 (66,4)	229 (59,6)	
Primary	71 (43,3)	67 (30,5)	138 (35,9)	
Basic	10 (6,1)	6 (2,7)	16 (4,2)	
Secondary	0 (0,0)	1 (0,5)	1 (0,3)	
Occupation (%)				b
Agriculture	120 (73,2)	161 (73,2)	281 (73,2)	
Agriculture and livestock	13 (7,9)	12 (5,5)	25 (6,5)	
Remunerated workers	10 (6,1)	4 (1,8)	14 (3,6)	
Agriculture and other activities	21 (12,8)	43 (19,5)	64 (16,7)	
Land Size				NS
Less than 1 ha	105 (64)	125 (56,8)	230 (59,9)	
1-2 ha	42 (25,6)	69 (31,4)	111 (28,9)	
2-3 ha	7 (4,3)	18 (8,2)	25 (6,5)	
More than 3 ha	10 (6,1)	8 (3,6)	18 (4,7)	
Purpose of the production (%)				NS
Consumption	109 (66,5)	139 (63,2)	248 (64,6)	
Consumption and trade	53 (32,3)	72 (32,7)	125 (32,6)	
Other	2 (1,2)	9 (4,1)	11 (2,9)	
Total	164 (42.7)	220 (57.3)		

[NS] – not significant; [a] – significant at 1% and, b – significant at 5%; x^2- Chi square test

Table 3: Perceptions on the contamination and control of insect pests and fungi in stored maize and peanuts, and about the occurrence and control of food intoxication and liver cancer

Variables	**Storage**	**facilities**	**n=384 (%)**	**Total**	**X^2**
	Traditional	Modern	Do not use		
Occurrence of stored grain infested by insect pest (yes)	349 (90,9)	25 (6,5)	5 (1,3)	379 (98,7)	a
Occurrence of stored grain fungi contamination (yes)	330 (85,9)	23 (6,0)	5 (1,3)	358 (93,2)	ns
Occurrence of stored grain deterioration (yes)	292 (76,0)	22 (5,7)	4 (1,0)	318 (82,8)	ns
Pest control methods					ns
Chemical	146 (38)	11 (2,9)	0 (0,0)	157 (40,9)	
Nonchemical	137 (35,7)	7 (1,8)	3 (0,8)	147 (38)	
Do not control	69 (18)	7 (1,8)	4 (1,0)	80 (20,8)	
Occurrence of food poisoning in the family (yes)	14 (3,7)	1 (0,3)	1 (0,3)	16 (4,2)	ns
Occurrence of liver cancer cases in the family (yes)	6 (1,6)	2 (0,5)	2 (0,5)	10 (2,6)	a
Access to liver cancer medical treatment (yes)	6 (1,6)	2 (0,5)	2 (0,5)	10 (2,6)	a
Knowledge about liver cancer prevention (yes)	0 (0)	0 (0)	0 (0)	0 (0)	ns

[ns] – not significant; [a] – significant at 1%, X^2 Chi square test.

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Table 4: Determinants of perception about maize and peanut sanity, methods of pest control, food poisoning and liver cancer occurrence in some rural areas of southern Mozambique

Variables	ß Coefficient	Std. Err.	ODDS	knowledge
Gender (1=Male, 2=Female)	0,083	0,326	1,087ns	-
Married (1=Yes, 2=No)	-2,107	0,833	0,122**	Weak
Area of production > 3ha (1=Yes, 2=No)	-1,171	0,553	0,310**	Weak
Is maize stored for more than 4 months? (1=Yes, 2=No)	-0,827	0,325	0,437**	Weak
Resident in Chókwè (1=Yes, 2=No)	1,124	0,511	3,078*	Medium
Resident in Morrumbene (1=Yes, 2=No)	2,325	0,518	10,222*	Medium
Resident in Homoíne (1=Yes, 2=No)	-1,250	0,385	0,287*	Weak
Age: 36-60 years old (1=Yes, 2=No)	1,173	0,581	3,232**	Medium
The production is for business purposes (1=Yes, 2=No)	5,948	1,001	383*	Good
Chemical control of pests and fungi (1=Yes, 2=No)	0,952	0,376	2,590**	Weak
No control of pests and fungi (1=Yes, 2=No)	1,036	0,510	2,819*	Medium
Cases of food intoxication in the family (1=Yes, 2=No)	7,918	1,253	27,45*	Medium
Cases of liver cancer in the family (1=Yes, 2=No)	3,888	1,253	48,800*	Medium

*Significant at 1% and **5%; NS Not significant; Std. Err. – Standard error; ODDS – Odds ratio

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