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Assessment of farmer's knowledge and attitudes toward fungi and mycotoxin contamination in staple crops in southern Mozambique

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Introduction: In Mozambique, 80% of the population directly depends on agriculture as a source of food and income. However, some of the most produced food crops, such as maize, rice and peanuts, are easily contaminated by fungi and mycotoxins. The naturally high prevalence of mycotoxins can be aggravated by the high vulnerability and lack of knowledge of the farmers. The aims of this study were to assess the knowledge and perceptions of small-size and medium-size farmers in the provinces of Inhambane and Gaza, southern Mozambique, regarding awareness of fungi and mycotoxin contamination of food crops, losses of production and income, and the causes and consequences of this contamination.

Methods: A survey was conducted with 180 farmers in the two provinces. A multiple linear regression model was used to correlate the level of knowledge with the sociodemographic characteristics of the studied population.

Results: The results showed that 97.8% of the farmers have an insufficient level of knowledge about fungi and mycotoxins contamination of food crops. While 17.8% showed sufficient or good knowledge of the conditions that promote fungal contamination, only 3.9% knew what measures to apply to mitigate their occurrence. The level of knowledge was lower for the Inhambane farmers.

Discussion: According to the estimated model, province, gender, age (>45 years old), primary and secondary (1st cycle) education, another source of income other than agriculture and experience as a farmer (>10 years) are statistically significant predictors of the level of knowledge of the Mozambican farmers analyzed. These findings highlight the urgent need of tailored interventions to promote good agricultural and storage practices that allow the mitigation of mycotoxin contamination of food.

KEYWORDS

storage, maize, peanuts, grain loss, small-hold farmers, aflatoxins

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1 Introduction

On a worldwide scale, it is estimated that between 713 and 757 million people suffer from chronic malnutrition, and Africa remains the region with the largest estimated prevalence of undernourishment—20.4%—, against a worldwide average of 9.1% (FAO, IFAD, UNICEF, WFP, and WHO, 2024). Food loss is a worldwide and crop-wide phenomenon, and roughly one-third of the food produced in the world for human consumption gets wasted (AUC, 2018). For grains (cereals and pulses), which constitute the major food supply in many low and medium-income countries, the post-harvest losses are estimated at approximately USD 4 billion/year (at 2007 prices; Zorya et al., 2011). In Sub-Saharan Africa (SSA), poor post-harvest handling practices and inadequate storage and conservation conditions result in a rapid post-harvest crop deterioration, and most food products only last 3 months (Tivana et al., 2014). This situation reduces the ability of rural and urban populations, especially those on low incomes, to be provided with food throughout the year. This is aggravated by the fact that farmers tend to rapidly sell part of their crops at low prices (AUC, 2018). It is estimated that reducing the level of post-harvest losses of cereals in sub-Saharan Africa could contribute to meeting the minimum food needs of 48 million people, resulting in a huge contribution to eradicating hunger (AUC, 2018).

Due to the prevailing hot and humid climatic conditions of the SSA, fungal contamination of food crops is one of the major drivers of food loss in the region (Kortei et al., 2023). Not only do fungi deteriorate the crops, resulting in evident and measurable loss, but they also promote the accumulation of toxic metabolites, mycotoxins, that constitute major health challenges for the population, most of the time hidden. The consumption of food contaminated with mycotoxins leads to the accumulation of these toxins in animal and human organs, which are associated with many acute and chronic diseases due to their carcinogenic, mutagenic, genotoxic, teratogenic, neurotoxic and estrogenic effects. Filamentous fungi and associated mycotoxins can occur at different stages of the human food chain, from pre-harvest to storage in homes and warehouses (Tamele et al., 2022).

The economic impacts of fungi and mycotoxins on society can be thought of in two ways: (i) the direct market costs associated with lost trade or reduced revenues due to contaminated food or feed and (ii) the losses to human health from adverse effects associated with mycotoxin consumption. Market-related losses occur within systems where mycotoxins are monitored in the food and feed supply. A product that has mycotoxin levels above a certain maximum permitted level is immediately rejected for sale or sold at a lower price for a different use (Zain, 2011). Several studies have attempted to quantify the potential market losses associated with mycotoxins in crops. In the United States, Vardon et al. (2003) estimated the total annual losses due to three mycotoxins—aflatoxins, fumonisins and deoxynivalenol—to be as high as 1 billion US dollars. Almost all this loss was reported by corn, peanut and wheat producers. However, it was estimated that livestock producers suffered a small part of this loss due to adverse effects on animal health. In three Asian countries—Thailand, Indonesia and the Philippines—the total estimated annual loss due to aflatoxins was around 1 billion Australian dollars (Highley et al., 1994). This loss was a combination of market impacts, through the rejection of lots with excessively high levels of mycotoxins.

Mozambique has a chronic malnutrition rate that has positively evolved from around 30% of food-insecure households in 2019 to 16.5% in 2023 (INE, 2024). Nonetheless, 1.49 million people (13% of the population) still face acute levels of food insecurity (IPC, 2025). Agriculture plays a dominant role in the lives of the population of Mozambique and constitutes the main source of employment and family income for the majority of the population (80% of households are involved in the sector) in rural, peri-urban areas (MADER/DPP, 2024). Of these, 98% are smallhold farmers that produce mostly maize, peanuts, rice, beans and cassava for family subsistence (MADER/DPP, 2024). Some of these crops, in particular maize, rice and peanuts, are strongly contaminated by fungi and mycotoxins (Matusse et al., 2024).

Data on mycotoxins in Mozambique dates back to 1960 after a survey carried out in the province of Inhambane (1960–1974), which correlated the incidence of hepatocellular carcinoma and aflatoxin (AF) contamination in maize and peanuts (van Rensburg et al., 1985). Mycotoxin contamination has been reported for corn (van Rensburg et al., 1985; Warth et al., 2012; Augusto et al., 2014; Martinho et al., 2024), peanuts (van Wyk et al., 1999; Warth et al., 2012; Bila et al., 2022), and cashew nuts (Owusu and Bila, 2023). In a recent study developed in the provinces of Gaza and Inhambane, aflatoxins were detected in various agricultural products at alarming levels (Matusse et al., 2024). In all these studies, the content of aflatoxins was higher than recommended in many parts of the world, where the maximum permitted limit is between 4 μg/kg and 20 μg/kg for different food matrices for human consumption.

On a worldwide basis, the Codex Alimentarius Commission established by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) has adopted multiple food standards, guidelines and codes of practice applicable for mycotoxins in food and feed (FAO/WHO, 1995, with multiple revisions and amendments). Based on, but not limited to, this document, mycotoxin surveillance programs have been properly implemented in many countries by national food quality and safety agencies (Chilaka et al., 2022). On the other hand, while many countries in Africa follow the Codex Alimentarius, in particular for aflatoxins, the existing regulations are only considered for commodities with trade value (Chilaka et al., 2022), and lack appropriate strategies to address mycotoxin control and monitoring of the local food supplies.

As member of the Codex Alimentarius, Mozambique adhered to the guidelines for aflatoxin maximum tolerable limits, but there is still no established legislation or regular mycotoxin monitoring programs (Sineque et al., 2017, 2019). On the other hand, information on mycotoxins is, as noted, scarce, despite the knowledge that these toxins can contaminate the human food chain as well as animal feed, which can later contaminate other food products such as milk, eggs, meat, and other related products (Cambaza et al., 2018). In Mozambique, the players in the post-harvest management chain include the family sector and the formal and informal commercial sectors. However, the family sector and the informal commercial sector are predominant. Poor compliance with good post-harvest management practices in these sectors, either by lack of awareness or limited financial and technological capacity, are among the main causes of post-harvest losses (FAO, 2011; CEAGRE, 2021a).

Statistics on the levels of post-harvest losses in Mozambique are scarce (FAO, 2011; Chisvo and Jaka, 2017; MADER/DPP, 2024). The limited research into post-harvest management, coupled with the lack of appropriate tools for collecting data on post-harvest losses, the lack of systematization of information, and the lack of awareness about the importance of investing in post-harvest management are some of the factors that contribute to the limited information in the country. However, some estimates indicate that post-harvest losses of agricultural products are between 20 and 40% of total production (FAO, 2011). The vulnerability of producers and climate change aggravates the situation of post-harvest losses. It has been pointed out that high losses occur among families headed by women, the elderly and people living with HIV-AIDS due to the limited capacity to build local post-harvest management systems or technologies and the lack of financial capacity to acquire improved technologies (CEAGRE, 2021a). On the other hand, climate change, which manifests itself in the form of increasingly frequent and intense extreme weather events (floods, cyclones and droughts), has aggravated the situation of post-harvest losses because it causes the destruction of infrastructure that would facilitate the process of marketing production, causes the destruction of storage and conservation systems, destructs the development and investment plan and increases the vulnerability of post-harvest management actors (CEAGRE, 2021a). This situation leads to the detour of financial resources that would otherwise be dedicated to post-harvest management. Climate change also creates a favorable environment for the emergence and development of the agents that cause post-harvest losses and contribute to their increased aggressiveness (CEAGRE, 2021a).

The 2023 Integrated Agricultural Survey of Mozambique (MADER/DPP, 2024) reports that, at a national level, 13% of the small hold farms suffered post-harvest losses in the most prominent cereals (maize and rice) and up to 28% in beans, but there is no reference to the percentage of product loss or the cause of those losses. The provinces of Inhambane and Maputo had the highest post-harvest losses for maize, with 19.1 and 17.7%, respectively. As far as rice is concerned, Sofala lead with 30.6% losses, followed by Maputo province with 26.4%. Losses in nhemba beans were reported of up to 49% in the province of Tete.

The post-harvest chain consists of several stages which, in the case of cereals and pulses, include harvesting, transportation, pre-processing (threshing or shelling, grading, cleaning and drying), storage and conservation, processing, marketing and consumption. In the cereal value chain most post-harvest losses occur during storage, followed by pre-processing (drying, threshing and cleaning). The high losses during storage and pre-processing result from the use of inadequate storage and drying technologies (use of traditional technologies), poor pest control during storage, storage of grain with high levels of humidity, which is conducive to attack by pests and the development of fungi (FAO, 2011; Recha and Chiulele, 2017). From the high level of crop loss in Mozambique, even after several projects and reports assessing the causal factors and agents of such losses (e.g., FAO, 2011; CEAGRE, 2021a, 2021b), it becomes evident that there is still a poor understanding from the farmers and the general population of good post-harvest handling and management of food crops.

Taking this into consideration, post-harvest loss management requires an integrated approach bringing together a multiplicity of approaches across the entire crop value chain that together contribute to reducing the losses occurring during and post harvesting of food crops (AUC, 2018). This integrated approach includes understanding the production and storage methods of cereals, legumes and peanuts, in order to recognize the risk of contamination of these crops by fungi and mycotoxins, in the hope of helping to develop and establish agricultural practices that can reduce production losses and the negative consequences for people's health resulting from these contaminations. There is also a pressing need to determine the level of knowledge of producers on this subject, so that it is possible to develop technical training plans and rural extension activities that are appropriate to the reality of local farmers.

This study presents and discusses the results obtained in the survey carried out among smallhold farmers in the provinces of Inhambane and Gaza, two of the provinces with the highest rates of food insecurity and of crop post-harvest losses in Mozambique (INE, 2024; MADER/DPP, 2024), regarding the practices of production, storage and marketing of agricultural products, as well as the farmers' perception regarding losses of production and income resulting from contamination of agricultural products by fungi and mycotoxins. The final aim of this study was to determine the priority tools and actions for effective management of mycotoxins in agricultural products produced and consumed in the provinces under study.

2 Methods

2.1 Study site

Data collection (using questionnaires) was carried out in the months of October and November 2022, in three districts of the province of Gaza, namely, Chokwé, Chonguene and Manjakaze, and three from the province of Inhambane, namely Jangamo, Massinga and Inharrime (Figure 1). The criteria used to select the provinces of Gaza and Inhambane and their respective districts took into account the following factors: (i) according to the Integrated Agrarian Survey (MADER, 2020), they are two of the provinces in the southern region of the country with the highest production of crops prone to contamination by fungi and consequently the production of mycotoxins, such as corn, peanuts and beans; (ii) according to the Basic Agriculture and Food Indicators report 2015–2019 (INE, 2020), these are the provinces of Mozambique with the highest rate of households experiencing acute food insecurity; (iii) the lack of related studies from these provinces.

2.2 Elaboration of the questionnaire

The research was carried out in accordance with the study objectives, bibliographic review, local information and based on previously available models. Prior to application at the study site, the questionnaire was piloted on August 31, 2022 in the Mahubo, Boane district, Maputo province, where surveys were administered to five local farmers to improve the structure of the questions, adapt the language to the target audience, and define the time for applying the questionnaire, to avoid exhaustion of the producers as well as of the researcher.

2.3 Sampling plan

A non-probabilistic sampling was used for convenience or accessibility. According to Jorge (2013), non-probability sampling is a

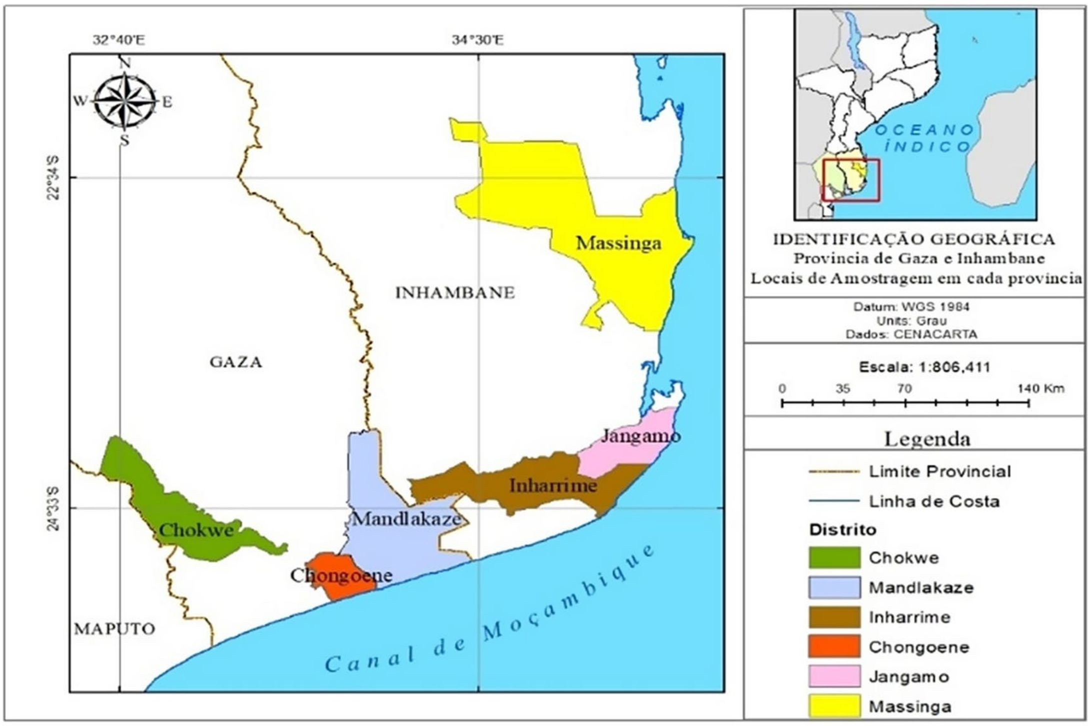

FIGURE 1
Geographic location of the provinces and districts covered in the study.

method in which individuals are chosen simply because they are more accessible or easier to evaluate, and constitutes the least rigorous of all types of sampling. In turn, Marconi and Lakatos (2002) argue that in this type of sampling the researcher is interested in the opinion of certain elements of the population, even if it may not be representative of the same, admitting that they may in some way represent the universe. To calculate the sample size, the Yamane (1967) formula was used:

$$n = \frac{N}{1 + Ne^2}$$

Where n is the sample size to be calculated; N is the relevant population; and e is the standard error (dependent on the desired degree of confidence).

A confidence level of 90% and an error of 10% (0.1) were adopted to draw the sample. According to the Integrated Agrarian Survey (MADER, 2020), the province of Gaza had a total of 365,593 farms, and the province of Inhambane had a total of 201,428 (Table 1). The sample size for each province is shown in Table 1. From the application of the formula, the recommended minimum sample size is 79 respondents from Gaza and 67 from Inhambane. A total of 90 surveys were carried out per province, in case there were invalid surveys. The definition of the confidence level and sample size considered what was proposed by Patton (1990) cited by Jorge (2013), according to which the size depends on the heterogeneity of the target group, time, available resources and the ease of obtaining the desired data.

The questionnaire was applied to small and medium-size farmers from the subsistence and commercial sectors in the provinces of Gaza and Inhambane, where 90 producers were interviewed per province, 30 per district. The total number of farmers interviewed was 180 (Table 2).

2.4 Data collection method

Given the aims of the study and the type of data required to respond to the surveys, the research was quantitative. The criteria for the selection of the interviewed farmers were defined based on the following: (i) The producers to be interviewed must be producers of cereals and legumes or have experience with the production and storage of cereals and legumes; (ii) They must be located in the districts under study; and (iii) They must be available to participate in the research. The questions covered information related to the production, storage and marketing processes of agricultural products, and the stages and conditions that can promote contamination during the production and storage of cereals and legumes in the provinces of Gaza and Inhambane. The questionnaire was divided into 7 sections: (i) general information, (ii) agricultural and livestock production, (iii) production factors, (iv) storage and marketing, (v) knowledge about fungi and mycotoxins, (vi) strategies used to reduce contamination and pre- and post-harvest losses, and (vii) training and education.

The questionnaires were administered personally by the researcher in the local language (Chichangana), or in Portuguese in the case of producers who could speak the language. In the district of Jangamo, province of Inhambane, the application of the questionnaires was assisted by a translator to the local language (Bitonga). Photographs were used to illustrate some cereals and legumes contaminated by fungi in some cases where the producer was unfamiliar with the term

TABLE 1 Definition of the sample size based on the population characteristics.

Province	Total	Small farms		Medium-size farms		Large farms	
		N	%	N	%	N	%
Gaza	365,593	348,878	95.43%	16,461	4.50%	254	0.07%
	79	75	96.00%	4	4.00%	0	0.00%
Inhambane	201,428	192,083	95.36%	9,288	4.61%	57	0.03%
	67	64	96.00%	3	4.00%	0	0.00%

TABLE 2 Number of questionnaires applied in the study sites.

Province	District	Administrative post	Number of questionnaires
Gaza	Chokwé	Macarretane	15
		Chokwé	15
	Mandjacaze	Chibondzane	15
		Chidenguele	15
	Chongoene	Chongoene	30
Sub-total			90
Inhambane	Jangamo	Jangamo	30
	Massinga	Massinga	15
		Chicomo	15
	Inharrime	Inharrime	15
		Mocumbi	15
Sub-total			90
Total			180

fungi and/or molds. All farmers were given an explanatory presentation of the survey objective, and written informed consent was obtained prior to administering the questionnaires.

2.5 Data analysis

Concerning the quantitative data analysis, the variables were categorized and coded following Gil (2008). Data was summarized and analyzed using Microsoft Excel—version 2010. The Chi-Square test or the Monte Carlo exact test were used to compare proportions. The conditions for applicability of the parametric tests, namely homogeneity of variances and normality of data, were tested using the Levene and Kolmogorov–Smirnov tests, respectively. Failure to verify these conditions implied the use of nonparametric tests. In this sense, the Mann–Whitney test was used to compare two independent variables. Finally, a multiple regression model was estimated to identify sociodemographic predictors of the level of knowledge about fungi and mycotoxins at the significance level of 5%.

The instrument used to collect data allowed to obtain information on knowledge of fungi and mycotoxins taking into account 4 dimensions of knowledge, namely, (1) Identification and definition of fungi and mycotoxins; (2) Knowledge of the consequences of consumption, by animals and humans, of food contaminated by fungi and mycotoxins (harmful effects); (3) Knowledge of the conditions that promote contamination by fungi before, during and after harvesting and/or during storage; (4) Measures adopted/recommended to prevent contamination by fungi at all stages of agricultural production.

To analyze the association between sociodemographic variables (gender, age, educational qualifications, type of farming, other source of income, experience as a farmer (>10 years); belonging to an association/cooperative and having technical support) and location (province) with the level of knowledge (quantitative variable), a multiple linear regression model was estimated which included only qualitative variables as independent variables. In this model, the methodology adapted from Kyei et al. (2021) was used to construct the dependent variable (Y). This variable was calculated considering the answers to the questions that form part of each dimension. Each correct answer was given a score of one, and each incorrect answer or 'no' answer was given a score of zero. The overall knowledge score was calculated by adding all answers in each dimension (Supplementary Table S1).

The maximum score was 51 points for overall knowledge of fungi and mycotoxins, 3 points for the dimension of identification of fungi and definition of mycotoxins, 4 points for knowledge of the consequences of consuming food contaminated by fungi and mycotoxins, 12 points for knowledge of the conditions that promote contamination by fungi and mycotoxins, and 32 points for preventive practices against contamination by fungi and mycotoxins. Subsequently, considering the maximum scores obtained in each dimension, the variables were recoded using a scale ranging from 0 to 100%. Regarding the qualitative independent variables, dummy variables were created (Supplementary Table S2), namely Province (D1); Gender (D2); Age: 26–35 years (D3); Age: 36–45 years (D4); Age: > 45 years (D5); Primary education (D6); Secondary (1st cycle; D7); Secondary (2st cycle; D8); University (D9); Type of farming (D10); Other source of income (D11); Experience as a farmer (>10 years; D12); Belongs to association/cooperative (D13); Technical support (D14). The model can be represented as follows:

$$Y = \beta 0 + \beta 1 \cdot D1 + \beta 2 \cdot D2 + \beta 3 \cdot D3 + \beta 4 \cdot D4 + \beta 5 \cdot D5 + \beta 6 \cdot D6 + \beta 7 \cdot D7 + \beta 8 \cdot D8 + \beta 9 \cdot D9 + \beta 10 \cdot D10 + \beta 11 \cdot D11 + \beta 12 \cdot D12 + \beta 13 \cdot D13 + \beta 14 \cdot D14 + \epsilon .$$

Where:

(1) Y: quantitative dependent variable (level of knowledge about fungi and mycotoxins);
(2) D1, D2, …, D14: independent variables (dummy variables:0 or 1);
(3) β0: intercept (reference category);
(4) βi (i = 1,2,..., 14) mean difference in Y between category i and the reference category;
(5) ε: random error.

To distribute respondents by level of knowledge, for descriptive analysis, the level of knowledge was classified as follows: 0–49%: Insufficient; 50–69%: Sufficient; 70–89%: Good; 90–100%: Very good.

3 Results and discussion

3.1 Socio-demographic characterization of the farmers

Farmers in the Gaza province are mainly male (53.3%), aged 36 or under (64.4%), have no education or only primary education (73.4%), have been farmers for more than 15 years (57.8%), have no source of income other than agriculture, the type of agriculture they practice is subsistence or family farming (67.8%), do not belong to an association or cooperative (67.8%) and, usually, have technical support from non-governmental entities (54.4%; Table 3). Regarding the province of Inhambane, the majority of farmers are female (67.8%), are over 36 years old (82.2%), have only primary education (54.4%), have been farmers for over 15 years (71.1%), have no source of income other than agriculture (74.4%) and the type of agriculture they practice is subsistence or family farming (85.6%), do not belong to any association or cooperative (83.3%) and have not had any technical support (51.1%).

Comparing the farmer's profile, differences were recorded in the number of farmers per province, considering gender ($p = 0.004$), age ($p = 0.004$), type of agriculture practiced ($p = 0.042$) and association and/or cooperative ($p = 0.015$). In Gaza, there are more male farmers, while in Inhambane women are the majority. Furthermore, in Gaza, farmers are older (>45 years) than in Inhambane (15–25 years). In Gaza, agriculture is more commercial, while in Inhambane province, agriculture is of subsistence and, finally, in Gaza, the number of farmers belonging to an association and/or cooperative is higher compared to Inhambane (Table 3).

TABLE 3 Socio-demographic characterization of the farmers.

Variable	Group	Gaza		Inhambane	
		n	%	n	%
Gender	Female	42	46.7	61	67.8
	Male	48	53.3	29	32.2
Age group (years)	15–25	2	2.2	13	14.4
	26–35	14	15.6	15	16.7
	36–45	31	34.4	30	33.3
	>45	43	47.8	32	35.6
Education level	None	23	25.6	30	33.3
	Primary	43	47.8	49	54.4
	Secondary (1st cycle)	13	14.4	7	7.8
	Secondary (2nd cycle)	10	11.1	4	4.4
	University	1	1.1	0	0
Time as farmer (years)	1–5	11	12.2	7	7.8
	6–10	11	12.2	7	7.8
	11–15	16	17.8	12	13.3
	>15	52	57.8	64	71.1
Other sources of income	No	61	67.8	67	74.4
	Yes	29	32.2	23	25.6
Type of agriculture	Subsistence/familiar	66	73.3	77	85.6
	Commercial	24	26.7	13	14.4
Belongs to association/ cooperative	No	61	67.8	75	83.3
	Yes	29	32.2	15	16.7
Technical support	No	41	45.6	46	51.1
	Yes(1)	49	54.4	44	48.9

(1)Non-governmental organization.

3.2 Characterization of the farming structure

3.2.1 Crop production

A survey of grown crops and their respective areas of occupation and annual production was carried out. Figure 2 shows that, regardless of the province, most farmers cultivate areas ranging from 1 to 5 hectares. In the province of Inhambane, the number of farmers who have areas of this size is higher (70%) than in the province of Gaza (55.6%), while the province of Gaza has a higher percentage of farms bigger than 6 ha.

Figure 3 shows the main crops produced in the provinces of Gaza and Inhambane and the percentage of farmers who say they produce these crops. Maize is grown in both provinces by most farmers (>90%), while rice and common beans are only produced in Gaza. In Inhambane, in addition to maize, the cowpeas (nhemba beans) stand out, which are produced by all farmers (100%), followed by peanuts (95.6%) and cassava (80%). None of the farmers inquired from this province reported the production of rice, sweet potatoes, or common beans. In comparative terms, considering the province, there are no statistically significant differences in the proportions of farmers who grow corn ($p > 0.05$). Regarding the other crops, the proportion of farmers is different by province ($p < 0.05$). For example, in Gaza the proportion of farmers is higher in rice ($p = 0.000$), sweet potato ($p = 0.019$), potato ($p = 0.007$) and common bean ($p = 0.000$). In Inhambane the number of farmers is higher in sorghum ($p = 0.000$), peanut ($p = 0.000$), cassava ($p = 0.000$) and cowpea ($p = 0.000$).

Considering the cultivated areas, the areas occupied by each crop, as stated by the farmers, are very heterogeneous, regardless of the crop. In Gaza, the three main crops that recorded the largest areas occupied were corn (average = 1.07 ha), cassava (average = 1.07 ha) and common beans (average = 0.87 ha). In the province of Inhambane, in addition to corn (average = 1.23 ha), cowpeas (0.998 ha) and sweet potatoes (average = 0.96 ha) stand out. Comparing the areas occupied by each crop (ha) by province, there are statistically significant differences in all crops except for sweet potatoes, where the area occupied is similar in both provinces. It is worth noting, once again, that in the province of Inhambane there is no production of rice, sweet potatoes and common beans. In Gaza the areas of corn, rice, sweet potatoes and common beans are larger, while in the province of Inhambane the areas with sorghum, peanuts, cassava and cowpea crops are larger.

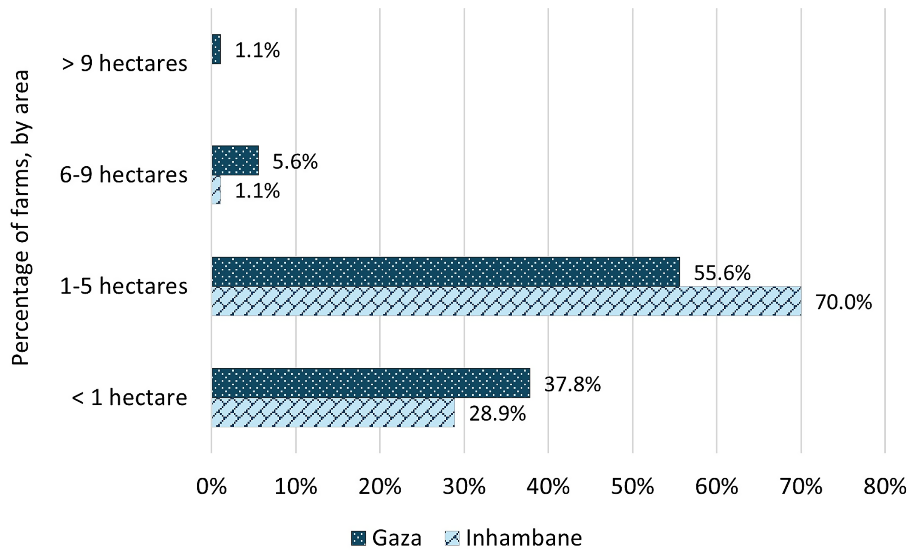

FIGURE 2
Average dimension of the farms in the provinces of Gaza and Inhambane.

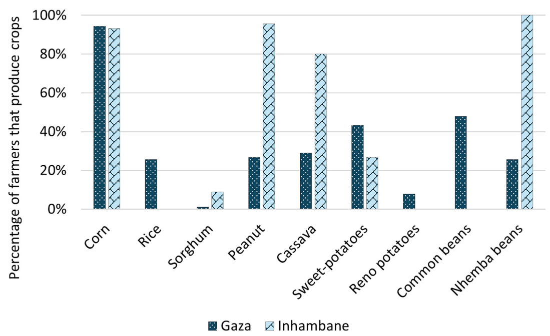

FIGURE 3
Percentage of farmers that produce the main crops.

In terms of production, there is also a large distance from the average for all crops. In Gaza, the three crops that recorded the highest average production were cassava (average = 3.53 tons), rice (average = 2.05 tons) and sweet potato (1.342 tons), while in Inhambane they were sweet potato (average = 2.67 tons), cassava (average = 0.792 tons) and corn (average = 0.49 tons). Considering the province, crop production differs significantly in all crops. It should be noted that, although the area occupied by corn is larger in the province of Inhambane, the average quantity produced is higher in the province of Gaza.

3.2.2 Storage and marketing

Among the stored crops in Inhambane, the most important are cowpeas (100% of producers store them), corn (94.4%) and peanuts (95.6%). In this province there is no storage of rice and common beans, since there is no production. In the province of Gaza, there is no storage of cassava and the storage of corn is carried out by most farmers (93.3%). The proportion of farmers who store peanuts ($p = 0.000$), cowpeas ($p = 0.000$), sorghum ($p = 0.000$) and cassava ($p = 0.000$) is different and higher in the province of Inhambane.

In Gaza, the containers used for storage by most farmers are bags for peanuts (92.6%) and rice (95%). Drums are used for sorghum (100%), but only one farmer carries out production and storage. In Inhambane province, most farmers choose drums for corn (63.5%) and cowpeas (56.7%) and bags for cassava and peanuts (Figure 4). The storage time is longer in Inhambane province, with an average duration of 11 months, compared to Gaza province, with a duration of 7.8 months. As for the remaining crops, no statistically significant differences were recorded in the storage duration. However, in Gaza the maximum storage times are longer than in Inhambane, with storage times reaching 36 months for corn and peanut, and 48 months for rice. Statistically significant differences between provinces were only found in the storage duration of peanuts.

These results are in line with the report by CEAGRE (2021b), which states that in Mozambique most small farmers store their grain in raffia/jute bags or in traditional barns. The same study states that these structures do not prevent the development and multiplication of insects and fungi, attacks by rodents, or the influence of climatic factors such as high temperatures and relative humidity. Therefore, traditional storage structures are not ideal for preserving grain for a period longer than 3 months, except in cases where pesticides are applied.

In both provinces, agricultural products are stored in a traditional way and for long periods, which in Gaza province can reach 36 months in the case of corn and peanuts, and 48 months in the case of rice. Presumably, cultural and educational differences in both provinces may influence storage methods and control practices for fungal storage diseases, due to their ability to identify and infer their presence in food and their consequences. Azaman et al. (2016) investigated the knowledge, attitude and practices of stakeholders from the Peninsular Malaysia regarding aflatoxin contamination in peanut-based products and concluded that knowledge influences awareness as well as farmers' conservation and management attitudes and behavior.

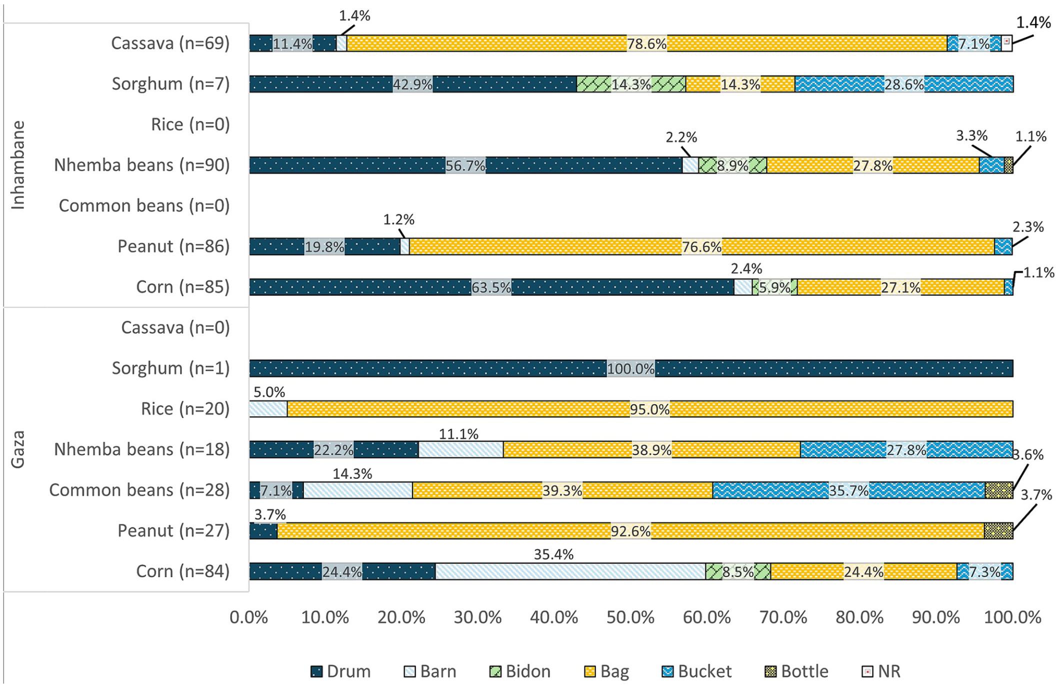

FIGURE 4
Types of storage systems used by farmers, by crop and by province (NR = no response).

According to most farmers, the primary destination of the production of the various crops is human consumption in both provinces (100%) but also animal feed and processing in the province of Inhambane, with 75.6 and 74.4%, respectively (Figure 5). Still in this same context, statistically significant differences were found in the proportions of farmers taking into account the destinations: animal feed ($p = 0.000$), processing ($p = 0.000$), sale to intermediaries/resellers ($p = 0.001$) and sale on the national market ($p = 0.029$), with the latter two production destinations being practiced in greater numbers by farmers in the province of Gaza, while the remaining destinations are chosen by a greater number of farmers in Inhambane. According to Grisa and Schneider (2008), production for family consumption largely meets dietary needs, but there are foods that cannot be produced by the family and that are indispensable. In this sense, meeting these and other needs requires the family to sell part of the production. This is the case of producers in the provinces of Gaza and Inhambane who, by diversifying production, satisfy part of the consumption demands, but also sell part of these products and transform them into flour for family food and animal feed.

3.3 Farmers' knowledge of crop contamination by fungi and mycotoxins

3.3.1 General knowledge of fungi and mycotoxins

The number of farmers who claim to know how to identify fungi/molds in agricultural products is relatively low in both provinces, 31.1% in Gaza and 20% in Inhambane, and no statistical differences are observed between provinces ($p = 0.087$). According to a study carried out by Magembe et al. (2016) in Kenya, respondents over 35 years of age had more knowledge about contamination by fungi and natural mycotoxins due to their field experience of more than 20 years as farmers, which is in line with the present study, since in the province of Gaza, where the largest number of producers knows how to identify contamination with molds/fungi in agricultural products, more than 80% of the interviewed producers were over 35 years of age, compared to the province of Inhambane, where only 69% of the producers are over 35 years of age. On the other hand, the results of the present study contrast with the results obtained in the study carried out by Kortei et al. (2023) in Ghana, in which most of the respondents were between 18 and 25 years of age and had adequate knowledge about food contamination by fungi. It also contrasts with the findings of Kortei et al. (2021), who showed knowledge of natural toxins in food by students aged between 21 and 25 years in tertiary institutions in Ghana.

This study also aimed to understand whether farmers who claimed to know how to identify fungi/mold in agricultural products were aware of how contamination by fungi/mold affected them. In this matter, only the change in the color of agricultural products was identified by the majority of farmers as being one of the consequences of contamination by mold/fungi, 82.1% in Gaza and 50% in Inhambane (Figure 6). The vast majority of farmers are unaware of the consequences of eating moldy food, and only 34.4% of farmers from Gaza say that it can cause disease in humans (Figure 7). Furthermore, a minority is aware of human or animal disease cases resulting from consuming contaminated food (2.2% in Gaza and 4.4 in Inhambane), and a significant proportion of farmers use contaminated products as human food (34.4% in Gaza and 66.7% in Inhambane) and animal feed (25.5% in Gaza and 6.7% in Inhambane). From these food crops, maize is the one where more farmers detect fungal contamination (73.3% of the farmers from Gaza and 90% from Inhambane), with the

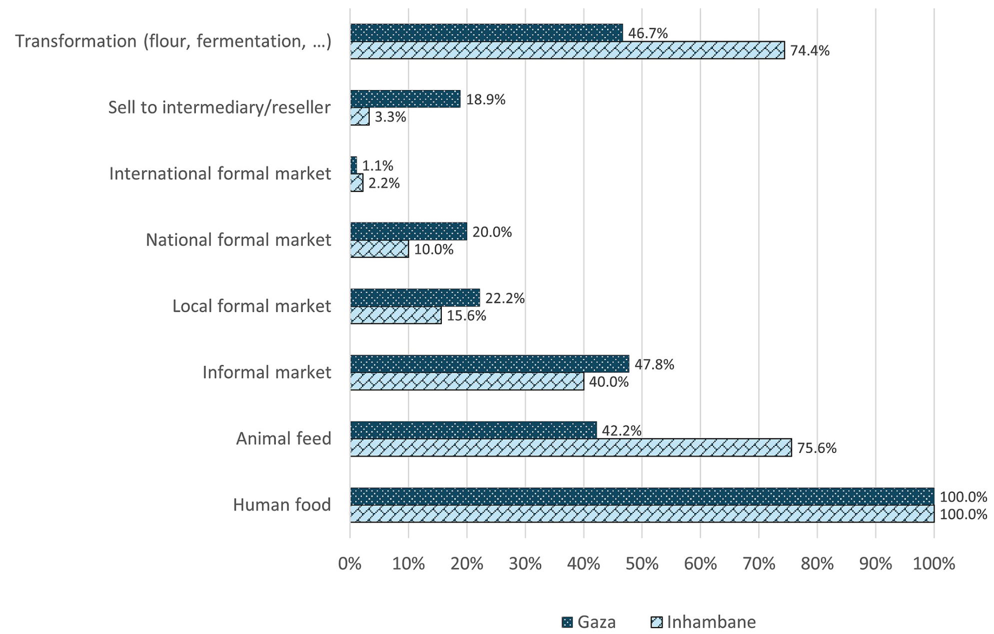

FIGURE 5
Destination of the produced crops.

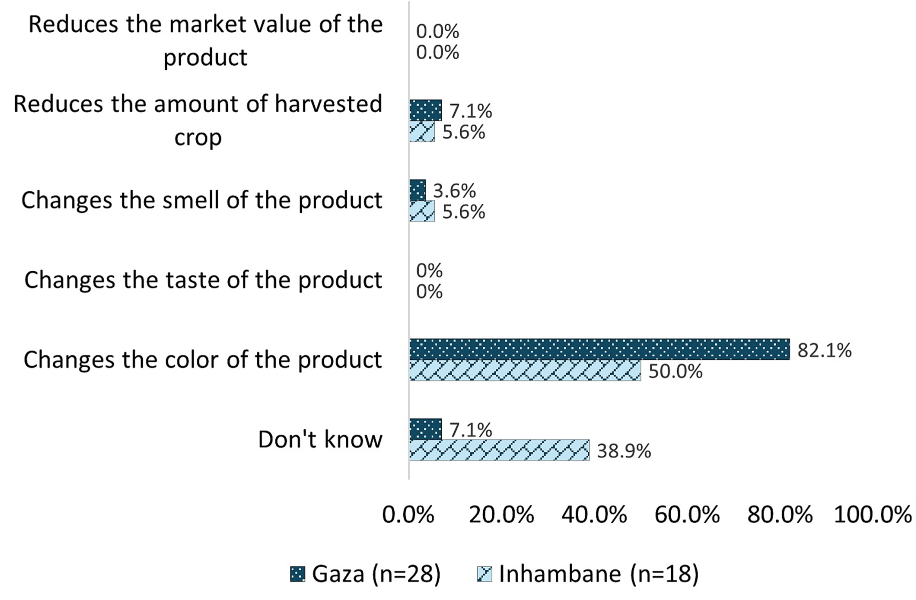

FIGURE 6
Effects of fungal contamination on crops as perceived by farmers.

other crops (beans, peanuts and dry cassava) showing very low contamination from the farmers' perspective (< 5%).

Considering the destination of contaminated agricultural products by province, Figure 8 shows that most farmers in Gaza report destroying these products, while in Inhambane, farmers claim to use these products for animal feed. A significant proportion of farmers choose to leave contaminated produce in the field, although some farmers separate the contaminated part and use the healthy part. Some farmers report using contaminated products for family food, to mix with healthy products and for processing. For many farmers, production losses due to mold contamination of agricultural products can reach 25%, as can income losses. Interestingly, regardless of the province, a considerable number of farmers do not know or have never accounted for production or income losses (Figure 9).

Regarding mycotoxins, the overwhelming majority of farmers (86.7% in Gaza, 98.9% in Inhambane) had never heard of these toxic substances produced by fungi. Among the 12 farmers from Gaza who claimed to know what mycotoxins are, 3 (25%)

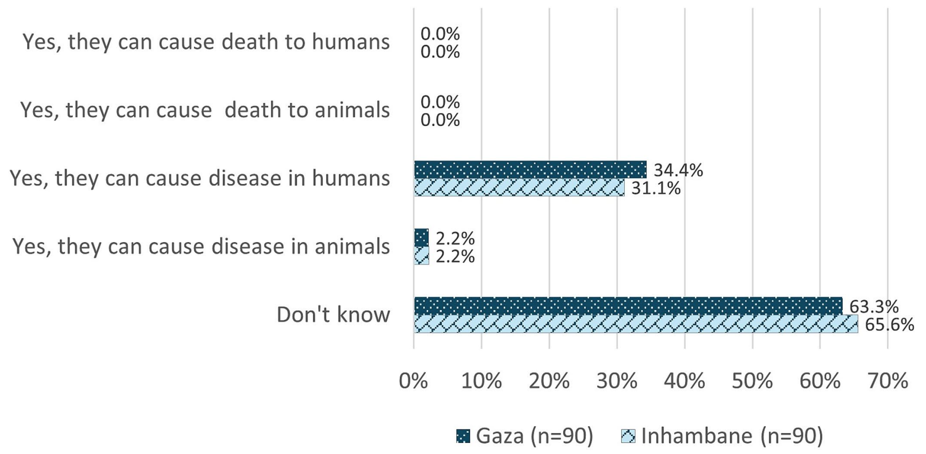

FIGURE 7
Knowledge of the consequences of consuming moldy foods.

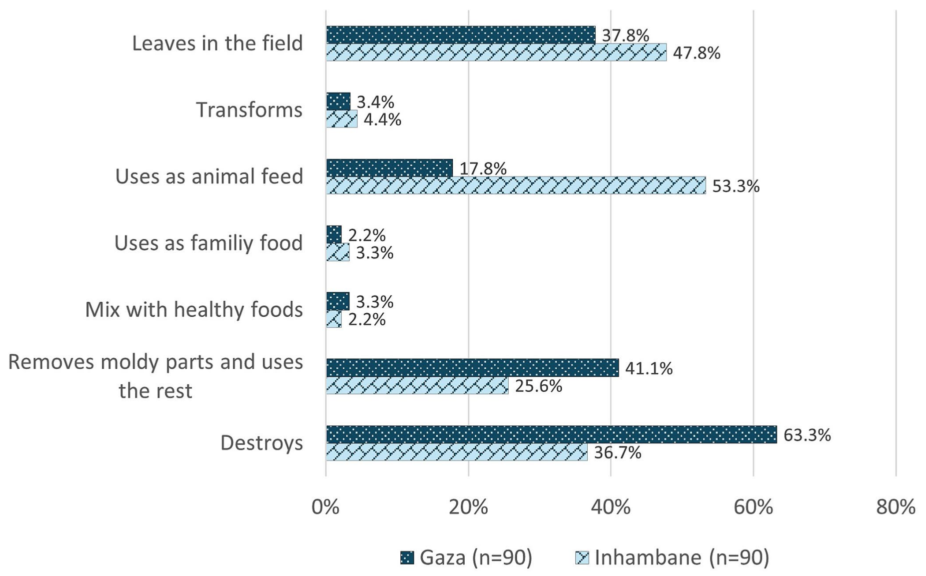

FIGURE 8
Destination given by the farmers to moldy crops.

considered them to be toxic substances that exist in the environment and that can contaminate agricultural products, 2 (16.7%) considered them to be natural substances that exist in crops, and only 2 (16.7%) knew that they were toxic metabolites produced by contaminating fungi. The farmer from Inhambane responded by defining them as natural substances that exist in agricultural products. In the present study, most respondents were uneducated or semi-literate with a low level of education, and few had ever heard of mycotoxins.

The one farmer from Inhambane who had heard of mycotoxins learned about them through training and believed they cause chronic disease. The 12 farmers from Gaza who had heard of mycotoxins learned from technicians of local authorities (50%), other farmers, neighbors or family (16.7%), technicians from farmers' cooperatives or associations (8.3%) or from the social media (8.3%), but they generally did not know of the consequences of consuming mycotoxin-contaminated foods. Only one farmer from Inhambane stated that he had carried out mycotoxin analyses on his agricultural products, namely on corn. However, he did not know or could not remember which mycotoxins were analyzed. None of the farmers from Gaza had ever tested their crops for mycotoxins. Table 4 shows the production stages, by crop, where the appearance of mold and mycotoxins is most frequent, according to the producers' perception. It should be noted that no farmers reported the appearance of mold and mycotoxins during the processing of agricultural products. Regarding the production stages, their appearance depends on the crop. For example, in corn, which is a crop grown by a significant number of farmers in both provinces, contamination appears, according to farmers, before and after harvest.

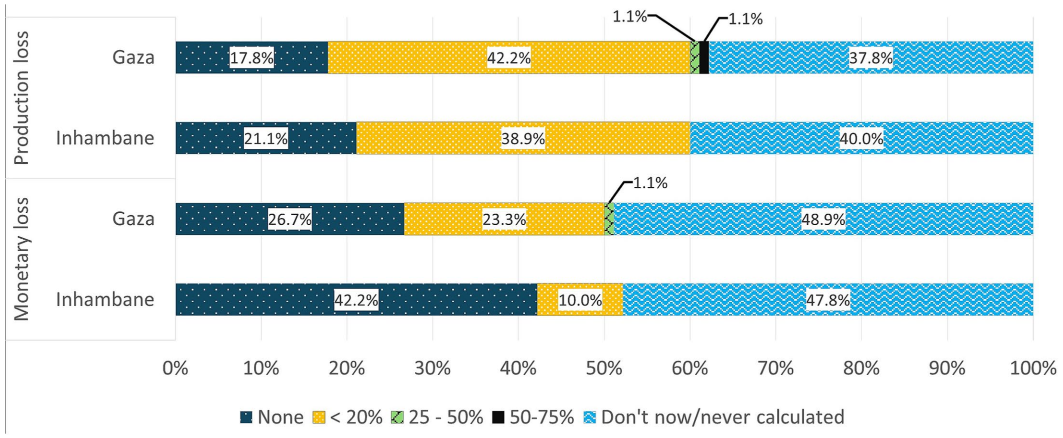

FIGURE 9
Production or income losses due to fungal contamination reported by farmers, by province.

3.3.2 Strategies used to reduce contamination and losses due to mold

According to farmers, several conditions can promote contamination, but rain stands out in both provinces, both before and during harvest (Figure 10). Regarding knowledge about the conditions that can promote contamination after harvest, 33.3 and 23.3% of farmers in Gaza and Inhambane, respectively, claim not to know. However, the majority admit to knowing, indicating humidity as the main cause, with the accumulation of wet or recently harvested crops for long periods and the presence of insects in the storage area. The presence of rodents, poultry or other birds in the storage area are also conditions that promote contamination, indicated by more than 40% of farmers in Gaza province (Figure 11). Measures to reduce crop loss are implemented by most farmers at all stages of the cultivation/production process, before (68 and 77% in Gaza and Inhambane, respectively), during (88 and 96%) and after (88 and 100%) harvest. There were differences in the number of farmers who implemented measures to reduce the risk of contamination during harvest ($p = 0.038$), with most farmers in Inhambane province doing so. There were no differences in the proportion of farmers implementing measures to reduce the risk of contamination before and after harvest ($p > 0.05$). As mentioned, the vast majority of farmers take measures to reduce contamination, even if they are not fully aware of the objective of those measures. Before harvesting, the three practices most used by farmers in Gaza were: preparing the land by plowing the soil and removing debris (65.6%), applying chemical treatments (pesticides, fungicides, herbicides; 39.3%) and crop rotation (32.8%; Figure 12). In the province of Inhambane, the following practices stand out: preparing the land by plowing the soil and removing debris (91.3%), manipulating planting dates (20.3%) and selecting healthy seeds (10.1%). Comparing the practices used by farmers, statistically significant differences were found in the number of farmers who perform crop rotation ($p = 0.000$), maintain the recommended spacing between rows and between plants ($p = 0.002$) and apply chemical treatments ($p = 0.000$). These practices are used by a greater number of farmers in Gaza province. In Inhambane province, the percentage of farmers who prepare the land by plowing the soil and removing debris is higher compared to Gaza ($p = 0.000$).

During harvest, the three measures implemented by the largest number of farmers were: not keeping freshly harvested produce in piles for long periods before drying or threshing (Gaza: 43%; Inhambane: 65.1%), measuring moisture content (Gaza: 58.2%; Inhambane: 46.5%), and cleaning freshly harvested produce to remove damaged grains/pods/produce and other foreign matter (Gaza: 36.7%; Inhambane: 59.3%; Figure 13). In addition, there were differences in the proportions of farmers implementing the following measures during harvest: (1) Gaza: storing produce protected from rain ($p = 0.000$); (2) Inhambane: do not keep freshly harvested produce in piles for long periods before drying or threshing ($p = 0.004$), clean freshly harvested agricultural produce to remove damaged grains/pods/produce and other foreign materials ($p = 0.004$). After harvest, the main measures implemented by the largest proportion of farmers were: drying grains immediately after harvest ($p = 0.000$); not keeping freshly harvested products in piles for more than a few hours before drying or threshing (Gaza: 87.3%; Inhambane: 100%), separating damaged grains/pods/products and other foreign matter present (94.4%; Inhambane: 58.2%) and storing grains/pods/agricultural products in a dry and well-ventilated place (Gaza: 53.2%%; Inhambane: 94.4%; Figure 14).

Several measures implemented after harvesting were identified, where the number of farmers implementing them differs with the province. For example, in Gaza, more farmers implement the following measures to reduce the risk of contamination: not keeping freshly harvested produce in piles for more than a few hours before drying or threshing ($p = 0.000$); storing agricultural produce in areas with water drainage ($p = 0.009$); and using fungicides ($p = 0.021$). In the province of Inhambane, the following measures are implemented by a greater number of farmers: drying grains immediately after harvesting ($p = 0.000$); storing grains/pods/produce in a dry and well-ventilated place ($p = 0.000$); storing agricultural produce protected from rain ($p = 0.000$); clean newly harvested agricultural products to remove damaged grains/pods/products and other foreign matter present ($p = 0.000$); separate damaged/attacked/contaminated grains/pods/products from undamaged/attacked/contaminated ones ($p = 0.000$), store agricultural products protected from birds and rodents ($p = 0.000$), store agricultural products protected from the ground by an impermeable material ($p = 0.000$) and regularly clean the agricultural product storage area ($p = 0.000$).

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TABLE 4 Stages of mycotoxin contamination, by crop, according to farmer's perception.

Crop	Stage	Frequency		Frequency	
		n	%	n	%
Corn		Gaza (n = 83)		Inhambane (n = 85)	
	Before harvest	35	42.2	33	38.8
	During harvest	6	7.2	12	14.1
	After harvest	37	44.6	40	47.1
	NR	5	6		–
Rice		Gaza (n = 17)		Inhambane (n = 0)	
	Before harvest	–	–	–	–
	During harvest	2	11.8	–	–
	After harvest	4	23.5	–	–
	NR	11	64.7	–	–
Sorghum		Gaza (n = 4)		Inhambane (n = 8)	
	Before harvest	1	25	1	12.5
	During harvest	–	–	4	–
	After harvest	1	25	–	50
	NR	2	50	3	37.5
Peanut		Gaza (n = 24)		Inhambane (n = 86)	
	Before harvest	2	8.3	7	8.1
	During harvest	1	4.2	1	1.2
	After harvest	13	54.2	25	29.1
	NR	8	33.3	53	61.6
Cassava		Gaza (n = 23)		Inhambane (n = 64)	
	Before harvest	6	26.1	3	4.7
	During harvest	7	30.4	–	–
	After harvest	2	8.7	1	1.6
	NR	8	34.8	60	93.8
Sweet-potato		Gaza (n = 30)		Inhambane (n = 48)	
	Before harvest	8	26.7	–	–
	During harvest	3	10	–	–
	After harvest	3	10	1	2.1
	NR	16	53.3	47	97.9
Beans		Gaza (n = 35)		Inhambane (n = 0)	
	Before harvest	10	28.6	–	–
	During harvest	5	14.3	–	–
	After harvest	10	28.6	–	–
	NR	10	28.6	–	–
Nhemba beans (cowpea)		Gaza (n = 11)		Inhambane (n = 90)	
	Before harvest	5	45.5	46	51.1
	During harvest	1	9.1	5	5.6
	After harvest	3	27.3	27	30
	NR	2	18.2	12	13.3

NR, no response.

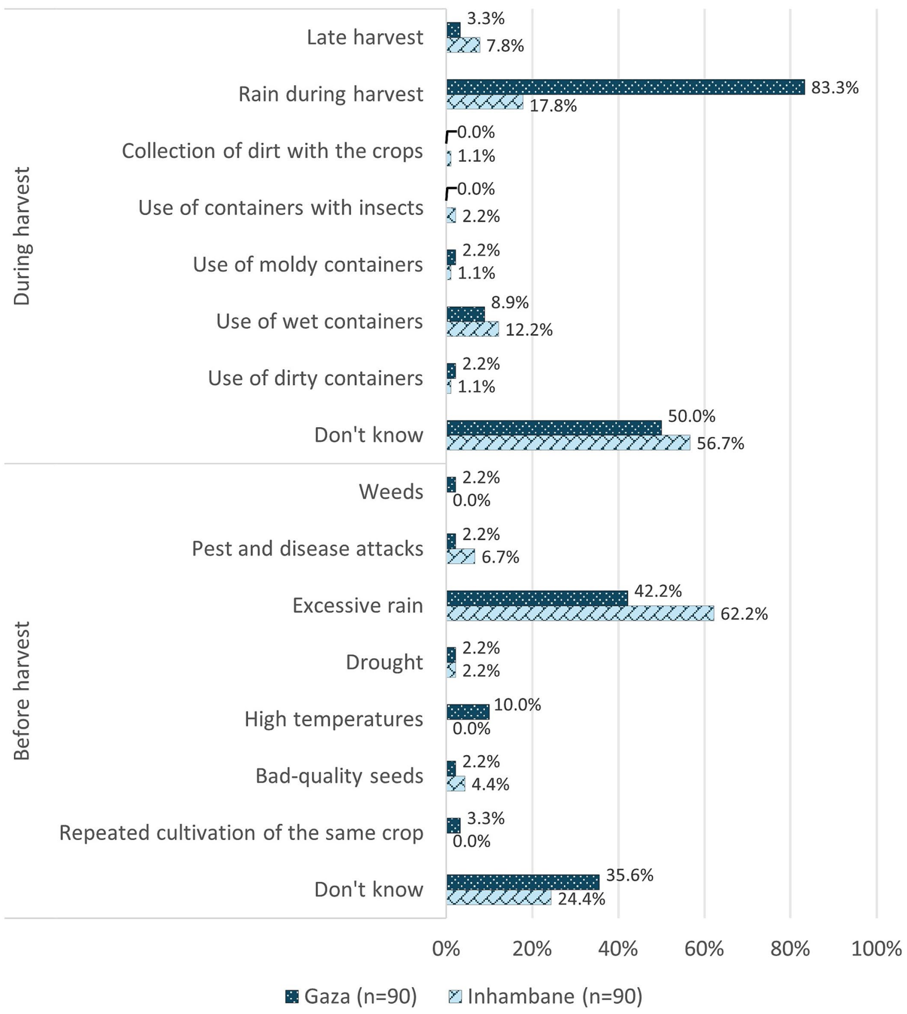

FIGURE 10
Knowledge about conditions that promote crop contamination by fungi before and during harvest.

3.3.3 Education and training in good agricultural and management practices

Thirty percent (27 of 90) and 10% (9 of 90) of farmers in Gaza and Inhambane provinces, respectively, claim to have received training in good agricultural and management practices. Of those who received training, the overwhelming majority, 92.6% in Gaza and 88.9% in Inhambane, consider it necessary to reinforce and update their knowledge. Among those who did not receive any type of training (63 in Gaza and 81 in Inhambane), most farmers, 88.9% in Gaza and 97.5% in Inhambane, consider it necessary to attend training. The largest number of farmers with training/education is from Gaza province ($p = 0.001$), while the province of Inhambane has the largest number of farmers who, perhaps because they have not had training, consider it necessary to obtain such training ($p = 0.032 < 0.05$), especially in the management of production factors ($p = 0.001$) and in post-harvest management ($p = 0.001$).

3.3.4 Level of knowledge of producers about fungi and mycotoxins

According to Figure 15, the vast majority of farmers have an insufficient level of knowledge (97.8%) and only 2.2% showed a sufficient level of knowledge. The implementation of preventive measures against contamination and the identification of fungi or definition of mycotoxins register the highest number of producers with insufficient levels of knowledge, 96.1 and 94.4%, respectively. On the other hand, knowledge of the conditions that promote contamination registers the highest number of farmers with a positive level of knowledge (sufficient: 16.7%, or good: 1.1%), followed by knowledge of the consequences of consuming contaminated food (sufficient: 9.4%, or good: 3.3%). Overall, Gaza farmers seem to be better informed than the ones from Inhambane.

Sociodemographic and geographic variables were studied as predictors of the level of knowledge. The regression model was estimated after removing outliers (standard deviation = 2) and confirming the absence of multicollinearity (tolerance >0.1 and VIF < 10; Pallant, 2021). The estimated model can be represented as follows (Table 5):

$$\hat{Y} = 19.789 + 6.025D1 + 3.339D2 + 3.230D5 + 2.182D6 + 7.269D7 - 2.911D11 + 2.916D13.$$

Table 5 shows that, despite the moderate adjusted R^2 value, the Z test presents a statistically significant value ($p < 0.001$), confirming the

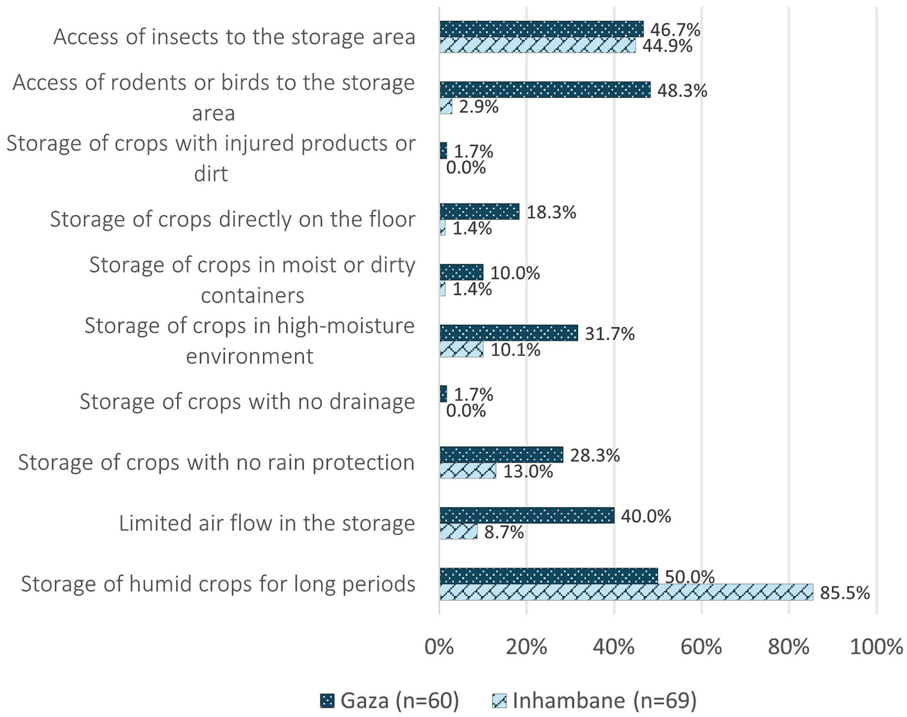

FIGURE 11
Knowledge about conditions that promote post-harvest crop contamination by fungi.

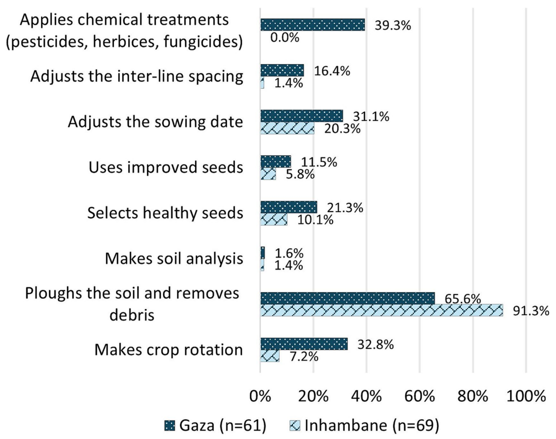

FIGURE 12
Measures adopted by farmers to reduce fungal contamination of crops before harvest.

suitability of the model to describe part of the relationship between the independent variables and the dependent variable (Pestana and Gageiro, 2014). The set of independent variables selected through the Stepwise method explains 38.9% of the level of knowledge about fungi and mycotoxins. The findings show that province (D1), gender (D2), age (>45 years old; D5), educational qualifications, namely, primary (D6) and secondary (1st cycle; D7), other sources of income (D11), and experience as a farmer (>10 years; D13) are statistically significant predictors of the level of knowledge about fungi and mycotoxins. All the other variables were removed as they were not statistically significant at a 5% significance level, namely, age (26–35 years old; D3), age (36–45 years old; D4), secondary (2nd cycle; D8), university (D9), type of farming (D10), belonging to association/cooperative (D12) and having technical support (D14). In addition, the level of knowledge was found to be higher among respondents from Gaza province compared to Inhambane (mean difference = 6.025), among male respondents compared to female (mean difference = 3.339), among farmers aged over 45 compared to farmers aged between 15 and 25 (mean difference = 3.230) and among farmers with primary and secondary (1st cycle) education compared to those with no education, with mean differences of 2.182 and 7.269, respectively (Table 5). Furthermore, the farmers with another source of income had less knowledge when compared to those who are dedicated exclusively to agriculture (mean difference = −2.911). Finally, the results showed that individuals who have been involved in agriculture for more than 10 years have higher level of knowledge compared to farmers who have been in agriculture for fewer years (mean difference = 2.916).

4 Discussion

In this study, the farmers interviewed were mostly smallhold farmers, with farming areas below 5 hectares, with more than 35 years old and with low educational level. The majority practiced subsistence agriculture and had no other source of income. These characteristics show the typical farmers from the studied provinces, which, although close to the city of Maputo, are particularly rural and with very low income. Our results show that educational qualifications as well as age

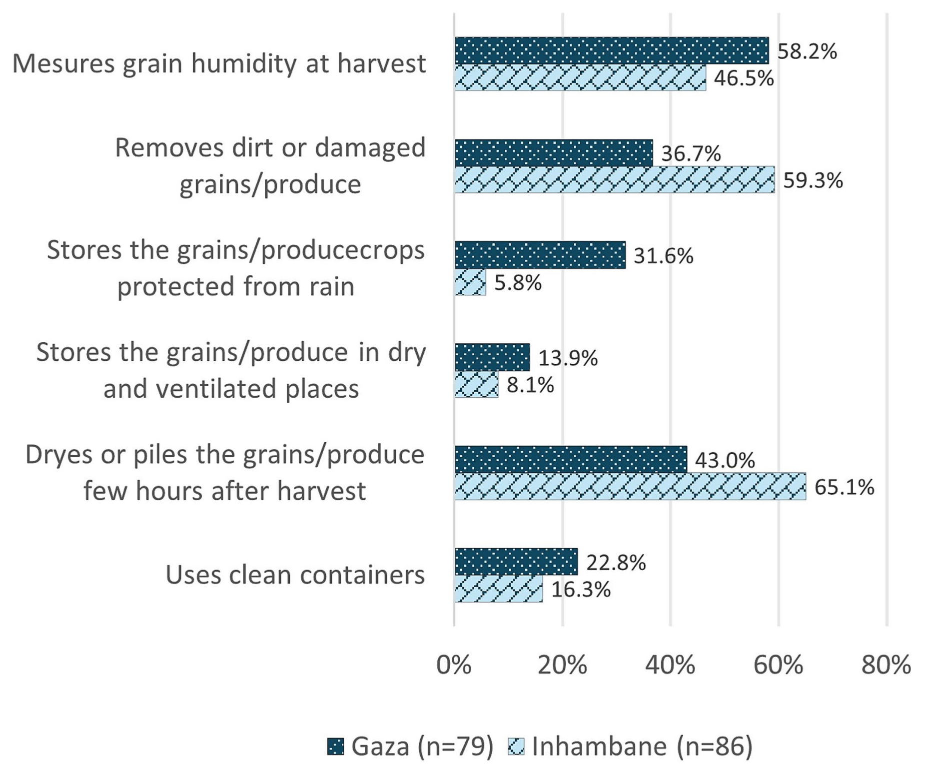

FIGURE 13
Measures adopted by farmers to reduce fungal contamination of crops during harvest.

and gender are factors that contribute to the level of knowledge, as older, male and more educated farmers showed higher level of knowledge. The province of Gaza showed more male farmers, older and with higher education than Inhambane, and the general level of knowledge was higher in Gaza. Respondents with primary and secondary education levels (1st cycle) recorded higher levels of knowledge when compared to those with no education. The results are consistent with those reported in the literature. Several studies refer to the influence of the education level on the probability of adopting new agricultural practices and technologies. Mwangi and Kariuki (2015) point out that education influences decision-making on issues related to agriculture, and Come et al. (2022) consider that low levels of education can have serious implications on the agricultural production system, with individuals without education being less informed and more resistant to technological changes.

Biru and Gemta (2022) found that, although knowledge about fungi and mycotoxin contamination was generally very low among Ethiopian farmers, there was a better understanding of fungal infection and mycotoxins as the educational level increased. Udomkun et al. (2018) also reported that farming families in the Republic of Congo (Central Africa) with higher levels of education had higher level of knowledge about aflatoxins. A cross-sectional survey involving 642 respondents from 12 regions of Ghana showed that age and educational level were related to knowledge about the occurrence of fungi and mycotoxins in food (Kortei et al., 2023). This study demonstrated that higher education directly influenced knowledge about mycotoxicosis and the management of stored foods to present poisoning by fungal metabolites. Melesse (2018) and Kortei et al. (2023) also stated that younger farmers are more likely to have better knowledge of good agricultural practices and adopt agricultural technologies because they have better education and more access to information. In relation to this variable, the province of Gaza has a higher level of education than Inhambane, with a higher percentage of the population having completed secondary education. It should be noted that none of the producers interviewed in the province of Inhambane attended higher education. However, it may also be the case that older farmers have acquired extensive experience and resources for adopting new technologies. A study from Kenya (Gachara et al., 2022) demonstrated that older farmers tended to be more knowledgeable of crop loss mitigation strategies and were more open to the use of innovative and more technological agricultural practices that reduce the risk of crop contamination.

Regarding gender, Matumba et al. (2016) conducted a survey involving 805 respondents from seven districts in Malawi (East Africa). The researchers found that women had significantly lower knowledge scores on issues related to fungi in food. Similar results were found in the present study. Kortei et al. (2023) also reported that female farmers in Ghana were less knowledgeable of mycotoxin contamination than men, while Magembe et al. (2016) reported the opposite in Tanzania.

In the present study the level of knowledge in Gaza province was on average higher when compared to Inhambane province, maybe because there are more commercial farmers in Gaza than in Inhambane. In a study by Matumba et al. (2016), the location had a significant effect. However, the education of the respondent had a subtle effect on the knowledge score. This suggests that location is a predictor of the level of knowledge. Also, farmers with another source of income dedicate less time to agriculture and therefore have

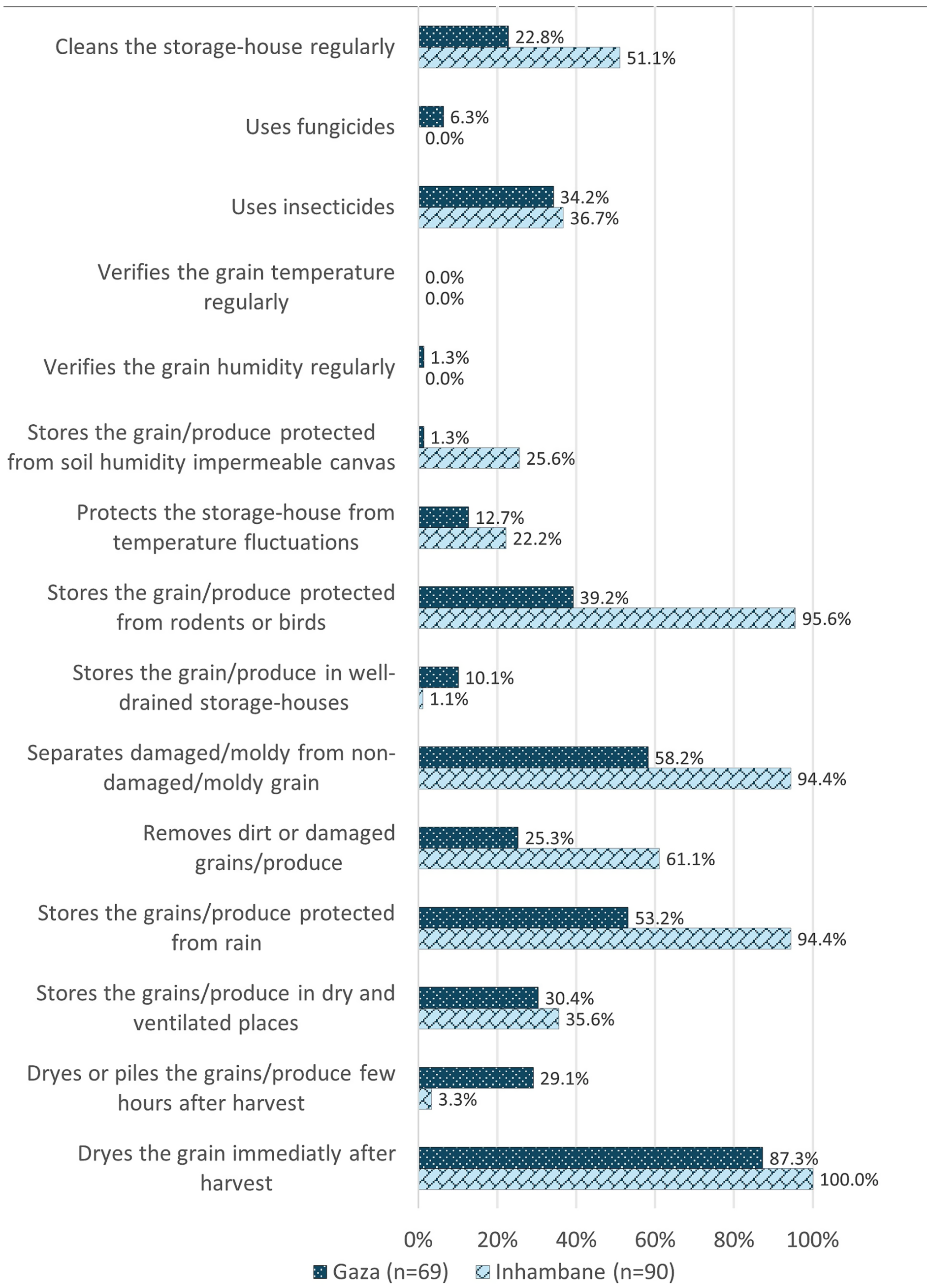

FIGURE 14
Measures adopted by farmers to reduce fungal contamination of crops after harvest and during storage.

less experience in identifying fungi and mycotoxins. Therefore, there is greater involvement in agriculture by those who live exclusively from this activity. Also, avoiding losses in income and production due to food contamination with fungi or mycotoxins becomes a priority for farmers without another source of income. The results showed that individuals who have been involved in agriculture for more than 10 years have higher level of knowledge. Apparently, experience allows, on the one hand, to identify fungi and mycotoxins more easily and to be aware of the conditions that easily promote their appearance and, on the other, to better understand the agricultural practices that should be implemented to prevent their appearance and development.

Independently of the demographic characteristics, the farmers interviewed in the present study showed an extraordinarily lower level of knowledge on fungi and mycotoxins than farmers from other countries, as reported for Ethiopia (Kibret et al., 2019), Ghana (Kortei et al., 2023), Kenya (Lesuuda et al., 2021; Gachara et al., 2022) and Tanzania (Magembe et al., 2016). Only one third of the farmers in the two provinces of Mozambique knew that eating moldy foods can cause human disease, and only 2% were aware of animal disease effects. The scenario of lack of knowledge on mycotoxins is even more worrying given that the majority of farmers from Gaza and Inhambane (86.7 and 98.9%, respectively) had never heard of mycotoxins, and only 2 farmers knew that they were toxic

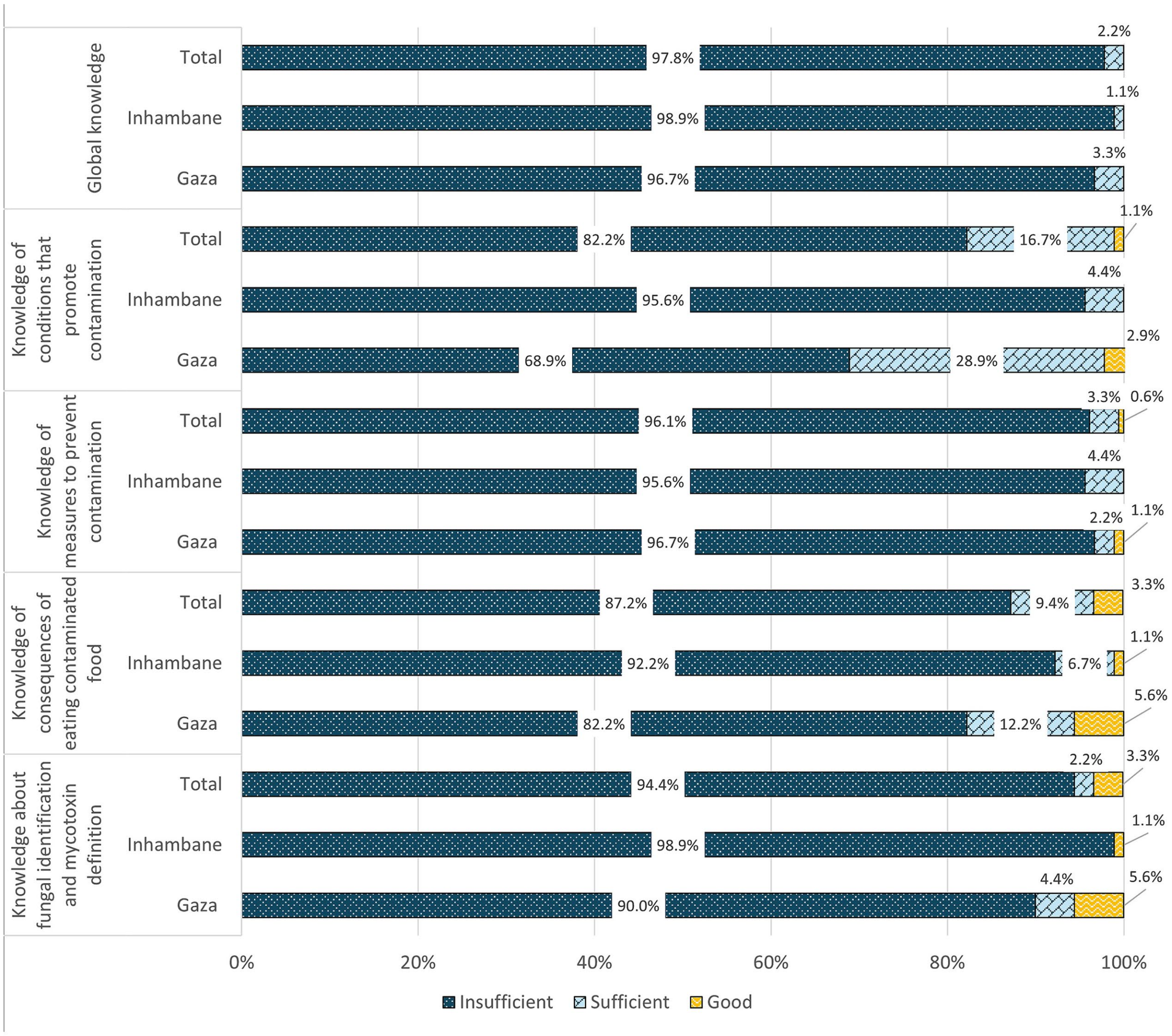

FIGURE 15
Level of farmers' knowledge about fungi and mycotoxins.

TABLE 5 Estimate model of the level of knowledge about fungi and mycotoxins, considering socioeconomic and geographic variables.

Variables	Coefficients (β)	SD	*t*	*p*	Tolerance	VIF
Intercept	19.789	1.313	15.068	<0.001		
Province (D1) Reference: Inhambane (0)	6.025	0.813	7.410	<0.001	0.937	1.067
Gender (D2) Reference: female (0)	3.339	0.895	3.732	<0.001	0.814	1.229
Age: > 45 years old (D5) Reference:15–25 years old (0)	3.230	0.881	3.666	<0.001	0.839	1.192
Primary education (D6) Reference: none (0)	2.182	0.866	2.519	0.013	0.823	1.214
Secondary (1st cycle; D7) Reference: none (0)	7.269	1.472	4.939	<0.001	0.738	1.354
Other sources of income (D11) Reference: no (0)	-2.911	0.968	−3.007	0.003	0.862	1.160
Experience as farmer (D13) Reference: ≤10 years (0)	2.916	1.072	2.721	0.007	0.852	1.174

Model statistics: n = 148; R^2 = 0.418; $R^2_{Ajusted}$ = 0.389; ε = 4.777; Z = 14.346; p < 0.001.

metabolites produced by food contaminating fungi. Gachara et al. (2022) reported that 61% of the Kenyan farmers were aware of aflatoxins and used cultural and storage practices specifically directed to control fungal and mycotoxin contamination. Kibret et al. (2019) found that in Ethiopia, most participants in a group discussion on mycotoxins had already heard about aflatoxins and their impacts through awareness training provided by a non-profit organization and government agricultural workers. In addition to the lack of knowledge, Jolly et al. (2009) report that, although farmers in some African countries are aware of the harmful consequences of ingesting contaminated food, its origin and traditional corrective practices, these are not strictly respected in practical terms.

The high percentage of producers who use foods with mold for human or animal consumption represents an increased risk of exposure to mycotoxins. The consumption of foods with mold is probably due to a lack of knowledge about the consequences, since the number of producers who use foods with mold/fungi is higher in Inhambane, where there is a reduced number of producers who know how to identify mold/fungi contamination in food, compared to Gaza. The consumption of moldy foods in the two provinces can be related to the sharp increase in esophageal cancer in Mozambique. According to Lorenzoni et al. (2015), this type of cancer, uncommon in the 1950s, showed a sharp increase over the study period (1991–2008). The reasons for this are not well understood, but factors such as dietary deficiencies and mycotoxins have been investigated as causes of the relatively high rates of esophageal cancer. Also, more than half of the Inhambane farmers stated that they use moldy grains as animal feed. Phokane et al. (2019) also reported that most farmers in KwaZulu-Natal, South Africa, used the moldy maize to feed domestic livestock, in particular chickens. Sineque et al. (2017) studied the level of aflatoxin B1 in tissues from chicken produced in Mozambique, and reported that the toxin was found in 39% of liver samples and 13.8% of gizzards, with mean levels of 1.73 μg/kg and 1.07 μg/kg, respectively. Although the AFB1 levels were lower than the allowed limits, the results confirm the potential of aflatoxin carry-over from contaminated feed to livestock, and the secondary intake from humans.

Many agricultural practices have been implicated in reduced mycotoxin accumulation in crops. Crop rotation, removal of crop debris and the use of fungicides tend to reduce the fungal inoculum available for subsequent infection (Marocco et al., 2008; Munkvold, 2003; Marete et al., 2020; Phokane et al., 2019). The use of improved or good-quality seeds and the adjustment of the sowing and harvest dates also help mitigating mycotoxin accumulation of grains in the field (Kimanya et al., 2009; Marete et al., 2020; Biemond et al., 2021), mostly mycotoxins like fumonisins, zearalenone and trichothecenes produced by the so-called field fungi, *Fusarium* spp. (Marocco et al., 2008; Munkvold, 2003). On the other hand, other types of fungi and mycotoxin contamination predominate in the post-harvest stage. *Aspergillus flavus* and similar species (section *Flavi*), responsible for aflatoxin production, are considered storage fungi due to their ecophysiological characteristics (Rodrigues et al., 2012). In our study, farmers from both provinces used at least one of multiple pre-harvest measures, with Gaza farmers using more technological techniques, like the use of chemicals and improved seeds, or crop rotation, while farmers from Inhambane mostly reported to just plow the soil and remove debris. On the other side, at the post-harvest stage, farmers from Inhambane showed to be more careful in preserving the grain in good condition by removing dirt and drying the crops immediately after harvest, and protecting the grain from rain, birds and rodents, removing damaged and moldy grain and cleaning the storehouse regularly. Drying is a key step in grain preservation, as grain moisture is the main factor that makes the environment favorable for the development of insects and microorganisms (Magan and Aldred, 2007; Ng'ang'a et al., 2016; Ziegler et al., 2021). Sorting damaged or moldy grains was reported to be an effective practice for mycotoxin removal from grains (Kimanya et al., 2009; Mogensen et al., 2011; Matumba et al., 2015; Phokane et al., 2019). Matusse et al. (2024) reported significantly higher levels of aflatoxin contamination of corn and peanuts produced in Gaza than those from Inhambane, which could be a reflection not only of the climate conditions, but also of the differential type of post-harvest care taken in the two provinces. Interestingly, although most farmers responded that they do not know the consequences of fungal and mycotoxin contamination of their crops in terms of income loss or health effects, they apply one or several pre- and post-harvest measures to control loss. This is evidence that they are traditionally prepared or instructed by farm technicians to apply such conditions, but are not properly informed or do not fully understand the reasons to do that.

Hermetic storage, in particular metal silos and hermetic bags, has been increasingly tested and promoted as an alternative grain storage option in SSA (e.g., Tefera et al., 2011; Chigoverah and Mvumi, 2016; Chris et al., 2016; Phokane et al., 2019; Worku et al., 2022). These practices have been successfully implemented in many regions of SSA, but elevated costs are still a deterrent for poorer subsistence farmers (Chris et al., 2016). Gachara et al. (2022) stated that 30% of Kenyan farmers acknowledged the benefits of using appropriate hermetic storage conditions and considered the cost acceptable in relation with gain. Studies from Mozambique (Njoroge et al., 2014; Williams et al., 2014) also reported hermetic bags to provide adequate and affordable solution for post-harvest management of grain storage. These bags are locally available, but farmers tend to not use them due to elevated cost when compared with other common materials. In the surveyed provinces of Mozambique, 200 L metallic drums and 50 kg non-hermetic bags are the storage conditions mainly used by farmers for grain storage. In Gaza, 35% of the farmers also use traditional barns for corncob storage, and buckets for beans. These methods do not provide sufficient pest and mold control, and losses are high. According to CEAGRE (2021b), storage has received special attention in Mozambique, regarding the stages of the post-harvest management chain, possibly because it is the stage where the country's greatest post-harvest losses of agricultural products are recorded. This statement is in line with the results of the present study, in which a large part of the contamination in cereals, legumes and peanuts was perceived by farmers during the post-harvest stage (storage). Nonetheless, in general, the results obtained in the survey indicate a substantial lack of knowledge on the part of producers regarding issues related to contamination by fungi and mycotoxins. Clear demonstration of the effectiveness and of the highly favorable cost/benefit ratio of improves storage technologies, as demonstrated by Chris et al. (2016), as well as adequate training, need to be performed locally to farmers.

The best way to prevent fungal development and mycotoxin accumulation in food crops is to follow Good Agricultural and

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Management Practices, from field to storage. Education, training and continued technical support are fundamental for these practices to be properly implemented and continued by low-income subsistence farmers. In Gaza and Mozambique, only 30 and 10% of the farmers, respectively, claimed to have received training in good agricultural and management practices, but around 90% of those consider it necessary to reinforce and update their knowledge. Also, most of the farmers with no training (88.9% in Gaza and 97.5% in Inhambane), declared to be interested in training in that area. Most farmers also claim that they are not associated with a farmers' cooperative or association (68% in Gaza, 83% in Inhambane) and half say they do not have any type of technical support. Low training and association of farmers seems to be a strong hindrance to the improvement of agricultural and storage practices. In this respect, since 2007, several different programs and strategies have been implemented in the Mozambican agricultural sector that refer to greater productivity and production, the introduction of equipment and inputs (seeds and fertilizers), marketing, rural extension, and food security (Capaina et al., 2024). Examples are the Agrarian Extension National Program (PRONEA 2007–2014), the Integrated Agriculture Technology Transfer Program (PITTA), the Strategic Plan for the Development for the Agrarian Sector (PEDSA 2011–2020) and the Operational Plan for Agriculture Development (PODA 2015–2019). Externally funded projects like the Continental Program on Post-Harvest Losses Reduction, funded by FAO (FAO, 2011) and the SUSTENTA Program, funded by the World Bank (2020–2023),[1] were also implemented. The objectives of these programs were generally to: (a) improve the capacity to implement extension programs within a pluralist and participatory framework; (b) increase the technical and management capacity of producers in the planning, monitoring, and evaluation process and in the provision of services; and (c) provide extension services at provincial and district level to promote agricultural productivity and the sustainable use of resources. But, according to Capaina et al. (2024) many of these projects deemed unproductive, unsustainable and inadequate for the smallhold Mozambican farmers reality and needs, which constitute 98% of all farmers, and the agricultural practices have essentially remained the same as those traditionally practiced.

5 Conclusion and recommendations to farmers and other entities

This study showed that there is little knowledge by small-size and medium-size farmers about the contamination of food crops with fungi and mycotoxins, and about the pre- and post-harvest measures to mitigate their occurrence. Unknowing of the severe health effects, there is a high percentage of farmers who consume moldy food or use it as animal feed. The overwhelming majority of farmers in the provinces of Gaza and Inhambane have an insufficient overall level of knowledge regarding issues related to the presence and consequences of fungi and mycotoxins in agricultural products.

The predominant grain crops produced and consumed in these provinces are corn, rice, beans and peanuts. It has been previously reported that, except for beans, these crops have high or extremely high levels of aflatoxin contamination, with emphasis on corn, which represents a high risk of exposure of the rural population to mycotoxins. Although farmers acknowledge that corn frequently suffers fungal attack, the post-harvest measures applied to the crops are empirical and not optimized to fungal control. Farmers tend to follow traditional storage methods, like barns, bags and metallic drums, and their knowledge on adequate storage methods is low.

This study underlines the importance of training, education and technical support to farmers, to implement or improve the application of pre- and post-harvest measures directed to fungal control. Considering the differences between provinces in farmers' characteristics, level of knowledge and traditional practices, training and education plans should be adjusted to local specificities. Special emphasis should be given to training young women from the province of Inhambane.

Based on the results of this study, the following recommendations are given:

a) **To farmers:**

- Pursue basic knowledge of the main aspects of a good storage environment, including an appropriate storage facility and the execution of pre-storage activities, such as drying, threshing or cleaning of agricultural products;
- Avoid the use of moldy foods for animal and human consumption;
- Join farmers' associations and cooperatives, and push the implementation of Good Agricultural Practices adjusted to local conditions;
- Persuade agricultural entities to create farmers' schools and training sessions.

b) **To researchers and academia:**

- Repeat this study in the central and northern regions of the country, considering the provinces that are the largest producers of grains (cereals and legumes);
- Intensify the training of students, researchers and agricultural technicians in the country, to increase knowledge on the subject as well as knowledge dissemination.

c) **To the farmers' associations, public entities and other organizations linked to agriculture:**

- Support academic knowledge and technical training of researchers, students and technicians, so that they can serve as highly trained dissemination actors and create pyramidal dissemination chain networks.
- Create effective and comprehensive post-harvest management training programs for farmers, through rural extension actions, to create and disseminate knowledge regarding the occurrence of fungi and mycotoxins in agricultural products and, thus, reduce the current level of post-harvest losses and food insecurity in the country;
- When creating and applying training programs, consider the significant contribution of young women to food security, their

1 https://projects.worldbank.org/en/projects-operations/project-detail/P168940

growing role in subsistence agriculture and their major involvement in household food production.

- Implement phytosanitary inspection actions of farmers' fields and warehouses with a view to reducing the level of contamination and consumption of products contaminated by mycotoxins.
- Create mycotoxin control plans targeted at the main agricultural products produced in the different provinces.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. All farmers were given an explanatory presentation of the survey objective, and written informed consent was obtained prior to administering the questionnaires.

Author contributions

JB: Conceptualization, Supervision, Writing – review & editing, Methodology, Investigation, Formal analysis, Writing – original draft, Visualization, Resources. CM: Supervision, Methodology, Writing – review & editing, Conceptualization, Investigation, Visualization, Resources, Funding acquisition, Project administration, Validation. AB: Investigation, Writing – original draft, Formal analysis. MR: Writing – original draft, Visualization, Formal analysis, Methodology. AV: Funding acquisition, Writing – review & editing, Methodology, Conceptualization. SA: Conceptualization, Methodology, Writing – review & editing, Funding acquisition. PR: Supervision, Project administration, Conceptualization, Methodology, Writing – review & editing, Funding acquisition, Writing – original draft, Visualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1622532/full#supplementary-material

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