Influence of Socio-economic Factors on Prevalence of Ochratoxin A in Dry Coffee Cherry in Tharaka Nithi County, Kenya

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Abstract

Coffee is a vital cash crop worldwide, contributing significantly to foreign exchange earnings and offering potential health benefits. However, concerns over contamination with mycotoxins, particularly Ochratoxin A (OTA), have grown due to its serious health risks. This study investigated the influence of socioeconomic factors on the prevalence of OTA in dry Coffee Cherry from Tharaka Nithi County, Kenya. A cluster random sampling method was used to collect the dry coffee cherry samples and survey data from 143 farmers across three agroecological zones, employing a semi-structured questionnaire. Pathogens were isolated on Potato Dextrose Agar (PDA) media and OTA production assessed according to the International Commission on Microbiological Safety for Foods. Data was analysed using the SPSS version 28 and SAS version 9.4. The study found out that socio-economic factors significantly ($p < 0.05$) influenced coffee farming practices and prevalence of OTA. Ochratoxin A prevalence was strongly associated with agro-ecological zones, farm size, and altitude. Larger farms and lower altitudes were linked to higher OTA risks. Gender, farm size and coffee variety also influenced OTA contamination levels. The study revealed that 88.3% of coffee farmers recognized mold in dry coffee cherries, yet 22.8% consuming moldy cherries, with 64.1% unaware of the health risks. Additionally, 87.6% of farmers identified poor drying and storage practices as key contributors to OTA contamination. Key indicators of contamination included discoloration, moldy smell, and moldiness with wetness. Roasting practices varied, with 35.1% roasting dried cherries after fermentation. The study highlights significant socioeconomic factors influencing OTA contamination in coffee. To mitigate risks, it is recommended to improve farmers' awareness of mold-related health risks and implement targeted interventions in high-risk areas to reduce OTA prevalence.

Keywords: Socio- economic Factors, Dry Coffee Cherry, Ochratoxin A (OTA) Prevalence, Tharaka Nithi County

Introduction

In many developing countries, farmers lack awareness of Ochratoxin A (OTA) risks and preventive measures. Limited education and agricultural extension services hinder their ability to adopt effective strategies. In rural, economically disadvantaged areas, traditional storage practices like open drying and simple structures increase fungal contamination risk due to lack of moisture control (Imade *et al*., 2021). This lack of knowledge stems from socio-economic and infrastructural challenges, which elevate OTA risk. Awareness and resources are critical for farmers to improve practices, reduce fungal exposure, and address OTA contamination (Imade *et al*., 2021).

Environmental conditions like temperature, humidity, and moisture significantly impact OTA risk. OTA-producing fungi, such as *Aspergillus* and *Penicillium*, thrive in warm, humid environments. Tropical and subtropical regions, with high temperatures and moisture levels, create ideal conditions for OTA-producing fungi in crops like coffee, cereals, and grapes (Stefanello *et al*., 2022). High humidity during the rainy season and temperatures between 20°C and 30°C provide optimal fungal growth conditions. However, improper post-harvest handling, even in drier zones, can still lead to OTA contamination (Garbaba *et al*., 2018). Agricultural practices that enhance soil health and reduce plant stress are essential for limiting fungal contamination (Wang *et al*., 2023).

The effects of soil type and pH on fungal growth are profound. Soils rich in organic matter with a pH around 6.0 to 7.0 are ideal for fungal proliferation. Soil moisture content and texture, which impact water retention and drainage, are crucial factors for fungal growth (Wang *et al*., 2023). For instance, clay soils, with high water-holding capacity, create moist conditions conducive to fungal growth, while sandy soils may limit fungal proliferation due to faster drainage, though fungal contamination can still occur under high moisture conditions (Wan *et al*., 2020).

Irrigation practices, including the amount, frequency, and method, also significantly influence fungal proliferation and OTA contamination. Excessive irrigation can create waterlogged soils, fostering fungal growth. Regions with intense irrigation, such as continuous flooding or overhead sprinkling, may enhance fungal proliferation and OTA risk, especially for *Aspergillus ochraceus* (Naorem *et al*., 2023). Careful management of irrigation levels and methods can help mitigate OTA contamination.

Coffee cultivation is influenced by agro-ecological zones, with warm, humid climates promoting fungal growth. For instance, Arabica coffee, known for its flavour and aroma, is often grown at higher altitudes (600–2,000 meters), where cooler conditions may impact fungal susceptibility (Freitas *et al*., 2023). While Arabica's growth environment enhances its flavour, the beans are more vulnerable to fungal infection, which is linked to higher OTA contamination risk. Robusta coffee, typically grown at lower altitudes in warmer climates, exhibits greater resistance to fungal infections due to its robust characteristics, such as thicker leaves and stronger stems (Lemma & Megersa, 2021). However, Robusta varieties are not entirely immune, as fungal spores can invade through crop damage, creating pathways for contamination (de Lima *et al*., 2023).

Agricultural practices also affect OTA contamination risks. Pest control methods, for example, are essential in managing fungal spread. Pests like insects and rodents damage crops, creating entry points for fungal spores. The coffee borer beetle (*Hypothenemus hampei*), for instance, damages coffee plants, increasing vulnerability to OTA-producing fungi. Improved pest control practices can significantly reduce the risk of OTA contamination.

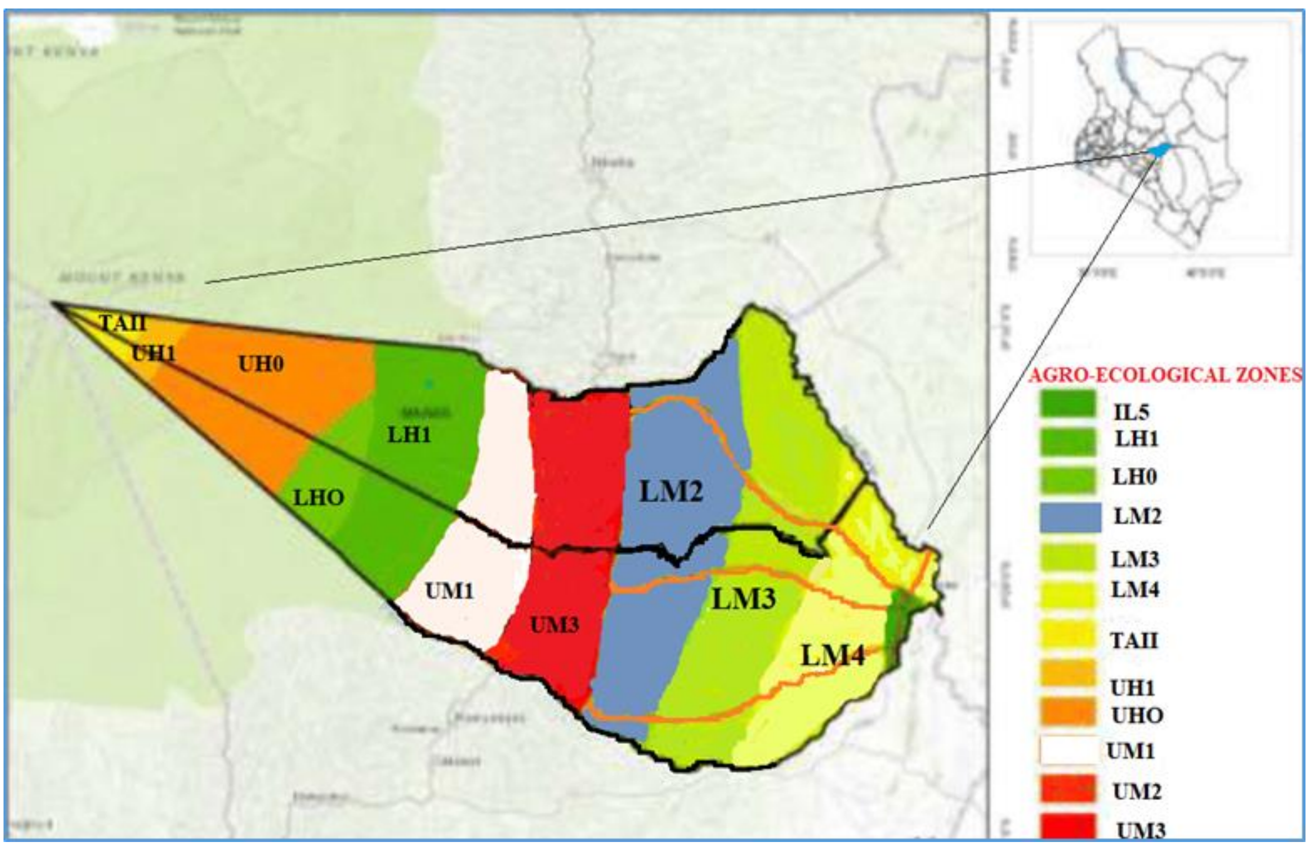
Breeding programs have developed coffee varieties resistant to fungal infections, enhancing crop resilience. Through techniques like genetic engineering and marker-assisted selection, these programs produce varieties with traits such as drought resistance and altered leaf structures to deter fungal growth (Ariyoshi *et al*., 2022). Efforts to cross-breed Arabica and Robusta coffee have yielded hybrids with robust disease resistance, thereby indirectly reducing OTA contamination. For instance, Arabica-Robusta hybrids inherit Robusta's natural resilience, providing improved resistance against pathogens while maintaining Arabica's desirable flavour profile.

Economic losses from OTA contamination are multifaceted, with direct financial losses from downgraded coffee quality, increased quality control costs, trade restrictions, and legal liabilities (Mazzafera *et al*., 2022). The financial burden on coffee producers can be substantial, impacting both profitability and sustainability. Comprehensive strategies are essential for managing OTA risks and minimizing economic impacts. These include improved quality control measures, enhanced market access strategies, and legal protections. Ochratoxin A (OTA) contamination in coffee threatens public health, crop quality, and farmer livelihoods, driven by limited awareness, inadequate storage practices, and environmental conditions favouring fungal growth. Poor pest management and inaccessible resistant varieties exacerbate risks, highlighting the urgent need for integrated strategies to ensure safer, OTA-free coffee production and economic stability.

Materials and Methods

Study Site

This study was conducted in Tharaka Nithi County, a key coffee-growing region in Kenya. The county is located between latitudes 000 07' and 000 26' South and longitudes 370 19' and 370 46' East, covering a total area of 2,662.1 km², including 360 km² of Mt. Kenya forest. The region experiences a bi-modal rainfall pattern, with the main rainy season from March to June and shorter rains from October to December (Jaetzold *et al*., 2007). Annual rainfall varies between 600 mm and 2200 mm. In the highlands, average annual temperatures range between 14°C and 17°C, while in the lowlands, they range from 22°C to 27°C, with a long-term average of 20°C. The predominant soil type is Humic Nitisols (Jaetzold *et al*., 2007). Tharaka Nithi is a significant coffee producer in Kenya, with coffee mainly grown in agro-ecological zones (AEZs) UM1, UM2, and UM3.



Study Design

A cross-sectional survey design was used to correct data on a Socioeconomic Factors on Prevalence of Ochratoxin A in Dry Coffee Cherry in Tharaka Nithi County, Kenya. The design facilitated the efficient collection of data from coffee farmers, enabling the examination of diverse variables, including education levels, storage practices, and agroecological conditions, which are critical in understanding OTA risks (Levin, 2006).

Data Collection

The sampling procedure employed a cluster random sampling approach targeting villages and farmers within Tharaka Nithi County to gather data from 143 coffee farmers. The County was divided into six wards, each serving as a cluster. Within each ward, 44 representative villages cultivating coffee were randomly selected. From these villages, coffee farmers were randomly chosen, ensuring a representative sample across the County. A semi-structured questionnaire was to collect data on farmer's socio-economic factors, which included age, gender, education, colour of post-fermentation dry coffee cherry bean, Coffee farmers' perception and knowledge about mycotoxins, factors leading to contamination of dry coffee cherry, characteristics used by coffee farmers to identify dry coffee cherry contaminated and type of dry coffee cherry roasted. One kilogram of dry coffee cherry was collected from each interviewed farmer. Samples were then placed in clean, sealed containers to prevent any contamination during transport to Chuka University Biological laboratory for further analysis.

Data Analysis

Data was analysed using Statistical Packages for Social Sciences (SPSS) version 28. Correlation analysis was used to establish the correlation between various socio-economic factors OTA prevalence.

Results

The study found that 67.6% of coffee farmers stored dry coffee cherry for 1–2 months, 31.7% for 2–3 months, and 0.7% for less than one month. Table 1 shows the color of dry coffee cherry after fermentation, with moldy/white being the most frequent (30.3%) and black/white the least (2.1%).

To assess coffee farmers' knowledge of fungal diseases, data was collected on perceptions of mycotoxins, causes of ochratoxin A, signs of contamination, and roasting practices. The study found 88.3% of farmers recognized mold in dry coffee cherry (Table 2). However, 22.8% consumed moldy cherries, and 64.1% were unaware of mold-related health risks. Additionally, 24.8% reported a cancer case in their family, irrespective of the cause.

To assess knowledge on ochratoxin A (OTA) causes, farmers identified factors like poor drying or storage of dry coffee cherry (87.6%), storage contamination (12.4%), and drying on the ground (1.4%) as causes of mold (Table 3). Most farmers (84.1%) indicated mold contamination occurs postharvest, while 15.9% linked it to preharvest conditions.

Coffee farmers identified various criteria for detecting mold contamination in dry coffee cherry (Table 4). The majority (29.7%) cited discoloration/moldy smell, while 27.6% noted moldiness and wetness. Additionally, 26.2% identified moldiness and wetness/moldy smell, and 11.7% noted moldy smell alone as signs of contamination. Only 4.8% mentioned discoloration.

Table 1: The colour of post-fermentation dry coffee cherry bean

Color of dry coffee cherry after fermenting	Frequency	Percent
Black	27	18.6
Moldy	39	26.9
White	10	6.9
Moldy/white	44	30.3
Black/moldy	22	15.2
Black/white	3	2.1
Total	145	100.0

Table 2: Coffee farmers' perception and knowledge about mycotoxins

Variable		Frequency	Percent
Dry coffee cherry getting mouldy	Yes	128	88.3
	No	17	11.7
Consume dry coffee cherry when mouldy	Yes	33	22.8
	No	112	77.2
Moulds are harmful to human health	Yes	52	35.9
	No	93	64.1
Cancer cases in family line	Yes	36	24.8
	No	109	75.2

Table 3: Factors leading to contamination of dry coffee cherry with mold (ochratoxin A)

Causes of mold (Ochratoxin A) in dry coffee cherry	Frequency	Percent
Drying dry coffee cherry on the ground	2	1.40
Poorly dried or wet dry coffee cherry /poor storage of dry coffee cherry	127	87.60
Contamination during storage	18	12.40
Total	145	100.00

Table 4: Characteristics used by coffee farmers to identify dry coffee cherry contaminated by mold (ochratoxin)

Characteristics of contamination dry coffee cherry	Frequency	Percent
Discoloration	7	4.80
Moldiness and wetness	40	27.60
Moldy smell	17	11.70
Discoloration /moldy smell	43	29.70
Moldiness and wetness/moldy smell	38	26.20
Total	145	100.0

The study found that 35.1% of coffee farmers' roasted dry coffee cherry dried after fermenting (Table 5), 22.1% roasted cherry dried on the tray outside, and 0.7% roasted cherry from the fermenting bag. Additionally, 58.6% of farmers roasted coffee for drinking purposes, while

41.4% did not. 42.1% of respondents did not provide a response.

The study found that agroecological zone, altitude, coffee variety, and farm size significantly ($p < 0.05$) impacted the prevalence of ochratoxin A (OTA) in coffee (Table 6). Among these factors, agroecological zone was the most influential, with a coefficient of -8.100, indicating that a change from zone UM1 to UM3 led to an 8.1-unit decrease in OTA prevalence. The standardized coefficient for agroecological zones (Beta = -0.650) highlighted its strong effect on OTA levels, suggesting the influence of this factor is unlikely to be random. Farm size had a significant positive impact, with a coefficient of 1.866, meaning that larger farms were associated with higher OTA prevalence. The standardized coefficient (Beta = 0.299) indicated that farm size played a more substantial role in OTA prevalence compared to coffee variety (Beta = 0.163). Altitude had a negative effect on OTA prevalence, with a coefficient of -0.135, suggesting that higher altitudes are associated with lower OTA contamination. Overall, the results underscore the importance of agroecological zones and farm size in influencing OTA levels, while altitude and coffee variety also contributed to the observed variation in OTA contamination.

Table 5: Type of dry coffee cherry roasted by the coffee farmers in Tharaka Nithi County

Type of coffee roasted	Frequency	Percent
Dry coffee cherry from the fermenting bag	1	0.7
Dried after fermenting	51	35.1
Dried on the tray outside	32	22.1
No response	61	42.1
Total	145	100

Table 6: Categorical regression model on impact of coffee varieties grown by farmers and farm size on prevalence of ochratoxin A

	Unstandardized Coefficients		Standardized Coefficients	t	p-value
	β	Std. Error	Beta		
(Constant)	44.075	6.195		7.155	<0.0001
Agroecological zones	-8.100	0.752	-0.650	-10.774	<0.0001
Coffee variety grown	0.191	0.094	0.163	2.028	0.044
Coffee farm size	1.866	0.503	0.299	3.713	<0.0001
Alitude	-0.008	0.004	-0.135	-2.242	0.027

Dependent variable: Prevalence of ochratoxin A

The correlation analysis (Table 7) revealed several significant relationships. A moderately positive correlation (0.297**) between age and farm size indicated that older respondents tend to have larger farms. Age also had a positive correlation with altitude (0.221**), suggesting older farmers tend to operate at higher altitudes. A moderate negative correlation (-0.205*) between gender and agroecological zones suggested dynamic gender representation across zones (Table 8). The prevalence of ochratoxin A was positively correlated with gender (0.217**). A moderate negative correlation (-0.184*) was found between farm size and agroecological zones. A strong negative correlation (-0.572**) was observed between ochratoxin A and agroecological zones. A moderate negative correlation (-0.270**) between coffee variety and agroecological zone indicated differential cultivation across zones. A positive correlation (0.261**) between coffee variety and farm size suggested larger farms grow specific varieties. A negative correlation (-0.243**) between farm size and altitude showed larger farms tend to be at lower altitudes. Additionally, a positive correlation (0.220**) between ochratoxin A prevalence and farm size suggested larger farms have higher ochratoxin prevalence.

Table 7. Correlation analysis socio-economics factors and ochratoxin A

	Age	Education level	Gender	Agro Ecological Zones	Farm size	Coffee variety	Altitude
Education level	-0.014						
Gender	-0.083	-0.012					
AEZ	-0.128	-0.077	-0.205*				
Farm size	0.297**	0.096	0.055	-0.184*			
Coffee variety	0.106	-0.048	0.023	-0.270**	0.261**		
Altitude	0.221**	-0.016	-0.180*	0.006	-0.243**	-0.062	
OTA	0.075	0.006	0.217**	-.0572**	0.220**	0.144	0.06

Discussion

The study revealed that the duration of dry coffee cherry storage did not significantly affect OTA prevalence. This may be due to factors that mitigate or override the potential impact of storage duration on fungal contamination and OTA production. If OTA contamination occurs immediately after harvest and storage conditions do not significantly alter contamination levels, storage duration may not have a pronounced effect (Smith *et al*., 2021). Additionally, early contamination could occur, establishing OTA levels before storage becomes relevant. If environmental conditions are well-controlled, they could diminish the impact of storage duration on OTA. Sirma *et al*. (2015) also found that while storage duration can influence mycotoxin levels, storage conditions are more critical.

The majority of farmers in the study could identify fungal contamination based on the colour of dry coffee cherries after fermentation. However, 64.1% were unaware that some molds are harmful to human health. Farmers should be encouraged to inspect beans showing moldy characteristics, as these are likely to have higher OTA contamination. Regular visual inspections and prompt removal of contaminated beans could mitigate the risk. For more accurate assessments, farmers might need to use diagnostic methods, such as laboratory tests, since colour-based identification alone might not reliably detect OTA contamination. Ye *et al*. (2016) similarly found that visual indicators like colour do not always correlate with contamination levels.

The study showed a significant positive correlation between farmers' perception of mold and their likelihood to consume moldy cherries, highlighting the need for better education on the health risks of mold consumption. This underscores the necessity of raising awareness among farmers about mold-related health risks, as emphasized by Silva *et al*. (2000). The weak correlation between perception and OTA prevalence suggests that knowledge about mold does not always align with contamination levels. The study also found that farmers with lower levels of knowledge and poor storage practices, such as sun-drying on trays, were more likely to consume moldy cherries. Education and better storage techniques are crucial for reducing OTA risks.

There was a significant correlation between OTA prevalence and coffee types. This suggests that the type of coffee roasted can influence OTA contamination levels. Saverini *et al*. (2018) noted that while roasting practices are generally standardized, the type of coffee used could still impact mycotoxin levels. The positive correlation with OTA prevalence suggests that roasting methods might play a role in contamination.

A significant positive relationship between gender and OTA prevalence was observed, with females showing higher levels of contamination. This could reflect gender differences in behavior or exposure risks. A small but positive effect of age on OTA prevalence suggests older individuals may have a slightly higher risk due to longer exposure durations or changes in health status over time. However, age alone was not a major predictor compared to other factors. The negative relationship between education level and OTA prevalence indicates that higher education is associated with lower OTA levels, likely due to better knowledge and practices regarding food safety. Duarte *et al*. (2012) similarly noted that gender and age differences influence OTA contamination in consumed food.

The agro-ecological zone had the most substantial impact on OTA prevalence, indicating that shifting between zones could significantly alter OTA levels. This aligns with García-Cela *et al*. (2015), who found that geographical location influences OTA contamination due to varying climatic conditions. High-altitude regions, typically cooler and more humid, are conducive to fungal growth, contributing to higher OTA levels. This study found the highest OTA prevalence in UM1, a high-altitude zone. Environmental factors such as temperature, humidity, and precipitation across zones play a significant role in Aspergillus fungal growth and subsequent OTA production. Battilani and Camardo Leggieri (2015) supported this by showing how regional differences in climate and management practices impact OTA levels.

Farm size had a considerable positive effect on OTA prevalence. Larger farms may experience higher OTA levels due to increased scale, management challenges, and greater exposure to contamination. Larger farms often face difficulties in maintaining uniform post-harvest handling and storage practices, which can lead to higher contamination risks. Kamala *et al*. (2017) found that larger operations often struggle with maintaining quality standards, which can result in higher mycotoxin contamination. In large farms, larger volumes of beans stored over extended periods or under suboptimal conditions can create favourable environments for OTA-producing molds. Saha and Mondal (2022) similarly noted that larger agricultural operations face greater challenges in maintaining effective quality control measures, increasing the risk of contamination.

The coffee variety grown also influenced OTA prevalence, though to a lesser extent. Certain varieties may be more resistant to fungal infections, leading to lower OTA levels. Taniwaki *et al*. (2003) suggested that some coffee varieties are more susceptible to fungal infections due to their biochemical properties. However, the environmental factors and farming practices, such as post-harvest handling, appear to have a more immediate and significant impact on OTA contamination than coffee variety itself (Wang *et al*., 2023). These practices, particularly in harvesting and post-harvest handling, may overshadow the influence of coffee variety on OTA contamination.

Altitude had a smaller impact on OTA prevalence, suggesting that higher altitudes might also have mitigating factors. Cooler temperatures and lower humidity at certain altitudes could reduce the conditions favourable to OTA-producing fungi. Paterson and Lima (2010) highlighted that altitude influences fungal growth, but its impact is complex and modulated by other climatic factors.

The findings also revealed that the age of respondents correlated positively with farm size and altitude, indicating that older farmers tend to own larger farms at higher elevations. This aligns with Mossmann *et al*. (2017), who found that experienced farmers typically have more extensive and better-located farms.

Gender showed significant correlations with OTA prevalence, suggesting differences in farming practices and exposure risks between male and female farmers. Female-managed farms had higher OTA contamination levels, possibly due to factors such as less access to resources, decision-making power, and agricultural tools. Quisumbing and Doss (2021) noted that gender disparities in agricultural roles and resources can influence farming practices and the management of OTA contamination. Women's limited access to financial resources and agricultural inputs could make their farms more susceptible to contamination, reflecting the observed positive correlation between gender and OTA prevalence.

Conclusion

In conclusion, this study underscores the complex interplay of socio-economic factors, farming practices, and environmental conditions in influencing ochratoxin A (OTA) contamination in coffee. To mitigate OTA risks, it is essential to raise awareness about the health dangers of mold, promote proper drying and storage techniques, and implement region-specific interventions, particularly in larger farms or areas with higher altitudes. The study found no significant effect of storage duration on OTA prevalence, suggesting that factors such as storage conditions and timing of contamination play a more critical role in mold levels.

Although most farmers could identify moldy cherries through visual signs, a large proportion were unaware of the health risks associated with mold contamination. This calls for increased education on the dangers of mold, especially regarding toxins like OTA. Furthermore, despite recognizing moldy cherries, some farmers still consumed them, highlighting the need to address both awareness and behaviour. Additionally, gender and age were correlated with higher OTA prevalence, with female farmers and older individuals showing greater contamination levels, suggesting differences in exposure risks and handling practices.

The agroecological zone was identified as the most significant factor influencing OTA contamination, with regions at higher altitudes showing greater contamination levels. Cooler, more humid climates appear to promote fungal growth, increasing OTA production. The study also found that larger farms tend to have higher OTA contamination levels, likely due to challenges in maintaining consistent post-harvest handling practices. This highlights the need for improved management, particularly for larger operations.

Recommendations

This study recommends expanding farmer training on mycotoxin awareness, improving storage facilities, and promoting mold-resistant coffee varieties. Special attention should be given to larger farms, which face challenges in uniform post-harvest handling. Education on proper drying and storage practices, including avoiding ground drying and poorly ventilated spaces, is crucial to reducing mold and OTA contamination. Climate-sensitive interventions tailored to specific agroecological zones, particularly high-altitude areas, are essential for controlling fungal growth. Additionally, providing resources and support to female farmers and implementing regular OTA monitoring will help mitigate risks, improve agricultural practices, and enhance both health and productivity.

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