



Airborne Fungal Diversity in Two Major Markets of Greater Accra, Ghana, and Associated *Aspergillus fumigatus* Contamination of Selected Fresh Fruits and Fruit Juices

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Abstract

Airborne fungi are important components of bioaerosols that influence environmental quality, food safety, and public health. This study assessed the aeromycoflora of two major markets in the Greater Accra Region of Ghana (Mallam Atta and Madina Markets) and fungal contamination of oranges (*Citrus sinensis*), mangoes (*Mangifera indica*), tomatoes (*Solanum lycopersicum*), and their freshly expressed juices. Aeromycoflora were determined using the open plate exposure method, while fungal loads on fruit peels and juices were quantified on Potato Dextrose Agar using the pour and direct plating methods. Airborne fungal populations were low, with counts of 1.51 and 1.43 log₁₀ colonies/plate/5mins at Mallam Atta and Madina Markets, respectively, showing no significant difference ($p \geq 0.05$). Fungal populations on fruit peels were similarly low, ranging from 1.26 to 1.52 log₁₀ Colonies/g. In contrast, freshly expressed fruit juices exhibited substantially higher fungal loads (3.0–3.34 log₁₀ CFU mL⁻¹), indicating that nutrient-rich fruit tissues favour fungal growth. *Aspergillus fumigatus* predominated among isolates from fruit peels and juices. Although ambient fungal loads were low, fresh fruits and especially fruit juices remained susceptible to fungal contamination during handling and storage. Improved hygiene, postharvest handling, molecular identification, and mycotoxin analyses are recommended to enhance food safety.

Keywords: Aeromycoflora; airborne fungi; *Aspergillus fumigatus*; fresh fruits; fungal contamination

Abbreviations: ANOVA, analysis of variance; CFU, colony-forming units; HSD, honestly significant difference; MM, Mallam Atta Market; PDA, Potato Dextrose Agar.

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1. Introduction

Aerobiology is the interdisciplinary study of biological particles in the atmosphere, including their sources, release, transport, deposition and effects on living organisms and the environment. These biological aerosols include fungal spores and hyphal fragments, pollen, bacteria, viruses and other biological materials. Among them, fungal propagules constitute an important component of primary biological aerosols and occur widely in both indoor and outdoor environments (Després et al., 2012; Lancia et al., 2021; Martínez-Bracero et al., 2022; Parida, Banerjee & Biswas 2023). Aeromycoflora, therefore, refers specifically to the fungal component of the atmospheric microbiota, principally spores, hyphal fragments and other fungal propagules. In addition to their ecological and public-health significance, airborne fungi may represent sources of strains with potentially useful biotechnological properties, including

the production of industrial enzymes and other metabolites (Joseph, 2024).

The composition and abundance of airborne fungi vary spatially and temporally and are influenced by local vegetation, land use, human activities and meteorological conditions, particularly temperature, relative humidity, rainfall and wind (Shah & Altaf, 2025; Martínez-Bracero et al., 2022; Odebo et al., 2020; 2018; O'Connor et al., 2014). Wind facilitates the liberation and dispersal of many dry fungal spores, whereas rainfall may remove spores from the atmosphere through wet deposition or stimulate the release of particular spore types. Consequently, the abundance and diversity of aeromycoflora can differ considerably among geographical locations and seasons. For example, Odebo et al. (2020) reported substantial spatial and seasonal variation in airborne fungal populations across five locations in Lagos, Nigeria, with *Aspergillus* and *Penicillium* being the predominant genera and fungal abundance being signifi-

cantly greater during the wet season. This interpretation is supported by the published Lagos study.

Airborne fungi are important because of their implications for human health, plant health and food quality. Genera such as *Cladosporium*, *Alternaria*, *Aspergillus* and *Penicillium* are frequently encountered in aerobiological studies and include species associated with respiratory allergies, opportunistic infections, plant diseases and deterioration of agricultural commodities (Xing et al., 2022; Nadal, Teotia & Kumar, 2022; Klarić & Pepelnjak, 2006). *Cladosporium* and *Alternaria* are particularly important outdoor airborne fungi, whereas *Aspergillus* and *Penicillium* are also frequently encountered in indoor environments and stored agricultural materials. The association of these genera with fungal allergy is well documented, although health effects depend on fungal species, concentration and duration of exposure, as well as individual susceptibility.

The occurrence of airborne fungi is particularly important in fruit and vegetable markets, where large quantities of fresh produce are handled, displayed and stored under conditions that may favour fungal contamination. Fungal propagules originating from soil, vegetation, decomposing organic matter, infected produce, market waste and surrounding environments can become airborne and subsequently settle on fresh commodities. Fruits may also become contaminated during harvesting, transportation, handling, marketing and storage, particularly when cuts, bruises and other mechanical injuries provide entry points for fungal infection. Thus, market environments may function simultaneously as reservoirs and dissemination points for fungal propagules.

Postharvest fungal deterioration represents an important constraint to the quality, shelf life and marketability of fresh fruits. Several fungal genera frequently detected in the atmosphere are also associated with postharvest diseases. Green and blue moulds of citrus fruits, for example, are principally caused by *Penicillium digitatum* and *P. italicum*, respectively (Rodrigues & Kakde, 2019; Odamtten, 2018; Eckert & Ogawa, 1988; 1989), while mango anthracnose is commonly associated with *Colletotrichum gloeosporioides* species complexes (Honger et al., 2018; Arauz, 2000). *Alternaria*, *Rhizopus*, *Mucor* and *Aspergillus* species are also associated with the deterioration of fruits and vegetables under favourable environmental and storage conditions. However, the presence of fungal spores in the surrounding air does not necessarily result in infection or spoilage; successful colonisation depends on factors such as the physiological condition of the produce, wounds, moisture availability, temperature, relative humidity and duration of storage. Studies have investigated aeromycoflora in different environments, including outdoor environment in Romania (Ianovici and Tudorica, 2009) and the library and reading room of Midnapore College (Basak et al., 2026) with its implications for human health.

Of particular food-safety concern is the genus *Aspergillus*, which contains species capable of producing potent myco-

toxins. *Aspergillus flavus* and *A. parasiticus* are important aflatoxin-producing species, while some members of *Aspergillus* section *Circumdati* are associated with ochratoxin A production. These metabolites may contaminate susceptible agricultural commodities and consequently have implications for food safety, public health and economic losses. The original manuscript also reports previous observations of *Aspergillus* species, particularly presumptive *A. fumigatus*, from decomposing fruits, vegetable wastes and soils associated with markets and other locations in the Greater Accra Region (Danso, 2021). Such environmental reservoirs could potentially contribute fungal propagules to the aeromycoflora of market environments.

Despite the potential importance of market-associated aeromycoflora to postharvest fruit quality and food safety, information on the diversity and abundance of airborne fungi in Ghanaian market environments and their possible relationship with fungal contamination of fresh fruits remains limited. Establishing this relationship is particularly relevant where fruits are displayed in open markets and subsequently processed into fresh juices with minimal processing. Therefore, this study investigated the diversity and abundance of aeromycoflora in the aerial environments of the Mallam Atta and Madina markets in Greater Accra, Ghana, with particular emphasis on the occurrence of *Aspergillus fumigatus*. The study further examined the occurrence and penetration of presumptive *A. fumigatus* on mango, orange and tomato fruits and assessed its presence in juice extracts prepared from selected fruits collected from the markets.

2. Materials and Methods

2.1 Sample collection locations

Sample area	Coordinates
Mallam Atta Market	5°34'44"N Latitude -0°12'27"W Longitude
Madina Market	5°40'48"N Latitude -0°10'13" W Longitude
*Central Region (Breman Asikuma)	5°34'52"N Latitude -0°59'40"W Longitude

* This location was used solely for comparison purposes, as it is distant from Accra and situated along the Atlantic coast near Cape Coast.

2.2 Sample collection procedure

Sample collection was conducted between March and August 2024 during the early morning hours, from 7:00 AM to 9:00 AM GMT, in order to obtain samples before extensive handling by the vendors and other consumers and to minimize cross-contamination. The two markets were selected because of their high volumes of fruit and vegetable

trade and their importance as major centres through which agricultural produce from farms and other parts of the country is conveyed into Accra. Samples of the oranges (Late Valencia cultivar), mangoes (variety locally known as 'Saloon' mangoes) and tomatoes (*Solanum lycopersicum*) were handled with sterile surgical gloves to avoid contamination and were placed individually in sterile, previously labelled Ziploc bags. The bags were labelled appropriately with the market and vendor locations from which they were purchased. At each market, five vendor locations were randomly selected, giving a total of five vendor sampling points per market. Individual fruits were collected independently and were not pooled. For each fruit type, 25 individual fruits were collected from each market, giving 25 independent biological replicates per fruit type per market. Thus, an individual fruit constituted the biological experimental unit for fruit-peel fungal enumeration.

2.3 Estimation of aeromycoflora populations in the markets

Sterile Petri dishes containing nutrient medium (200 g peeled and cut potato tubers, boiled in 1 litre of sterile distilled water and filtered through cheesecloth), 15 g glucose and 12 g agar were prepared. Chloramphenicol (25 µg) was added to the medium as antibiotic Odebo et al., (2020). The prepared mixture was poured into medicinal flasks and then sterilised in an autoclave at 121°C under a pressure of 1.1 kg/cm² for 20 minutes.

When needed, the Potato Dextrose Agar medium was melted and poured into new 9.0 cm plastic Petri dishes and covered to allow the medium to solidify. The Petri plates containing the Potato Dextrose Agar PDA were opened, and the lid placed eccentrically on the bottom for 5 minutes and then closed again. There were three replicates for each of the purchasing points in the market. The exposed plates were returned to the laboratory in canisters to be incubated at 30 ± 2°C for 7 days after which the fungal colonies that appeared were counted and recorded. The culturable count was recorded in log₁₀ colonies/plate/5mins of sample.

2.4 Enumeration of total fungal counts on fruit peels by direct plating

This was done by the Direct Plating Method. The peel of oranges, tomatoes and mangoes purchased from vendors was surface-sterilized with 1% sodium hypochlorite to remove surface-associated microorganisms. Following surface sterilization, the fruit pieces were rinsed with sterile distilled water to remove residual sodium hypochlorite and prevent its inhibitory effect on the recovery of internal microorganisms. The samples were then dried with sterile autoclaved paper towels. Approximately 1 g of each fruit sample was severed and then placed aseptically by a sterile forceps directly onto sterilized (20 ml) Potato Dextrose Agar PDA in Petri dishes. There were 25 replicates for each fruit. The Petri dishes carrying the peels of the fruits were incubated

at 30 ± 2°C for 7 days after which the colonies developing on the plates were counted and recorded as log₁₀ colonies/g.

2.5 Identification of *Aspergillus fumigatus* colonies

A. fumigatus was identified using the morphological and taxonomic criteria outlined by Samson and van Reenen-Hoekstra (1988); Samson et al. (2007) and online databases such as Mycobank; Index Fungorum and Species Fungorum. A dense felt of dark greyish green colonies with conidiophores intermixed with aerial hyphae bearing conidiophores, typically columnar, short-walled, green, with phialides directly borne on the vesicle, with globose to sub-globose conidia.

2.6 Determination of total fungal counts in expressed juices

Mycoflora in the fruit juice and peels of samples of oranges, mangoes, and tomatoes were evaluated using the Conventional Decimal Serial Dilution Technique. A 1 ml aliquot of freshly squeezed juice from each of the three fruits was combined with 9 ml of peptone in a McCartney tube and then thoroughly mixed in a vortex mixer and then on an orbital shaker (Gallen Kamp, England) operating at 140 rpm for 10 minutes. Decimal serial dilutions up to 10⁻³ was prepared from the mixtures.

The same procedure was followed using the peels (10 g) in a conical flask. The resultant solution containing the spores was serially diluted up to 10⁻³. A one-millilitre aliquot of each dilution was transferred into calibrated sterile measuring device and then inoculated onto 20 ml Potato Dextrose Agar, PDA in duplicate. The plates were incubated at 30°C for 7 days to allow the cultures to grow and sporulate. The resulting colonies were counted and the fungal population was expressed as log₁₀ CFU mL⁻¹ of sample. The number of colonies in each treatment were counted, and the percentage (%) contribution of *A. fumigatus* to the total mycoflora was estimated.

2.7 Statistical analysis

Statistical analyses were performed using Statgraphics Plus version 5.1. Fungal population data were log-transformed and expressed as mean fungal counts (log₁₀ Colonies/g for fruit samples and log₁₀ CFU mL⁻¹ for fruit juice samples). Descriptive statistics were used to summarize the data. Differences in fungal populations among markets and sample types were evaluated using analysis of variance (ANOVA). Where significant differences were detected, mean separation was performed using Tukey's honestly significant difference (HSD) test. Statistical significance was determined at p < 0.05.

3. Results

3.1 Airborne fungal populations in the study markets

The airborne fungal populations recorded in the two markets were generally low (Figure 1). Mallam Atta Market recorded a mean fungal population of $1.51 \log_{10}$ colonies/plate/5mins, while Madina Market recorded $1.43 \log_{10}$ colonies/plate/5mins. The difference between the two markets was small ($0.08 \log_{10}$ colonies/plate/5mins) and was not statistically significant ($p \geq 0.05$), indicating comparable airborne fungal loads at both sampling locations.

3.2 Fungal populations associated with fruit peels

Fungal populations isolated from the fruit peels were consistently low across all fruit types (Figure 2). The highest fungal count ($1.52 \log_{10}$ colonies/g) was recorded on mango peels obtained from Madina Market, whereas the lowest count ($1.26 \log_{10}$ colonies/g) occurred on mango peels from Mallam Atta Market. Orange peels contained fungal populations of 1.42 and $1.38 \log_{10}$ colonies/g for Mallam Atta and Madina Markets, respectively. Tomato peels showed similarly low fungal populations, ranging from 1.36 to $1.43 \log_{10}$ colonies/g.

For comparison, cocoa bean testa collected from Breman Asikuma recorded a fungal population of $1.00 \log_{10}$ colonies/g, representing the lowest fungal count among all samples analysed.

3.3 Fungal populations in freshly expressed fruit juices

Fungal populations in freshly expressed fruit juices were considerably higher than those recorded on the corresponding fruit peels (Figure 3).

Mango juice from Madina Market exhibited the highest fungal population ($3.34 \log_{10}$ CFU mL⁻¹), whereas orange juice from the same market recorded the lowest ($3.01 \log_{10}$ CFU mL⁻¹). Tomato juice contained intermediate fungal populations, with counts of $3.20 \log_{10}$ CFU mL⁻¹ at Mallam Atta Market and $3.06 \log_{10}$ CFU mL⁻¹ at Madina Market. Overall, fungal populations in fruit juices were higher than those recorded on the corresponding fruit peels and in the surrounding airborne environment.

3.4 Relative abundance of *Aspergillus fumigatus*

The occurrence of *Aspergillus fumigatus* varied among fruit types, sample types, and market locations (Table 1; Figure 4).

Among orange samples, presumptive *A. fumigatus* constituted 22.5% of the total fungal population in juice from Mallam Atta Market compared with 6.5% in juice from Mad-

ina Market. The fungus accounted for 3.8% isolates recovered from orange peels at Mallam Atta Market and 10.7% of isolates recovered from orange peels at Madina market.

For mango samples, presumptive *A. fumigatus* represented 5.4% of fungal isolates recovered from juice and 8.2% from peels at Mallam Atta Market. In contrast, the species was not detected in mango juice from Madina Market, although it accounted for 4.9% of fungal isolates recovered from mango peels.

In tomato samples, presumptive *A. fumigatus* represented 2.0% and 2.8% of fungal isolates recovered from juice and peels, respectively, at Mallam Atta Market. The species was not detected in either tomato juice or tomato peel samples obtained from Madina Market.

The cocoa bean testa collected from Breman Asikuma also yielded presumptive *A. fumigatus*, although at a comparatively low frequency (Figure 4).

4. Discussion

Airborne microorganisms, particularly bacteria and fungi, have been identified as a possible source of significant hazards to human health, potentially leading to a spectrum of pathologic conditions ranging from infectious diseases to allergic and toxic reactions (Al-Shaarani & Pecoraro, 2026). Fungi are an essential part of airborne microbial communities, given their abundance and wide distribution in a number of environmental sources, such as soil, water and decaying vegetation (Al-Shaarani & Pecoraro, 2026). The attention on airborne fungal contaminants has dramatically increased together with the evidence of the health hazards directly caused by the fungal spores themselves or by the metabolites released by the fungal particles present in the air that people inhale (Shams-Ghahfarokhi et al., 2014; Ianovici & Tudorica, 2009). Fungal spores have the capacity to act as reservoirs for significant quantities of toxic secondary metabolites, specifically mycotoxins, thereby presenting a potential health hazard when inhaled via airborne bioaerosols and dust (Araujo & Cabral, 2010; Shams-Ghahfarokhi et al., 2014).

Fungi produce millions of spores from reproduction, employing active explosive mechanism or mechanical and passive (wind / water) mechanisms to discharge the spores from fruiting bodies. Active discharge involves specialised structures like 'Buller's' drop in mushrooms, landing spores into turbulent air to overcome the stagnant boundary layer. Passive dispersal includes wind, rain splash or by animals picking spores directly from source (Money, 2016). Spores are designed for dispersal enabling the spores to survive, reproduce and colonize new habitats speedily.

The present study provides insight into the occurrence and distribution of culturable airborne fungi in two major market environments in the Greater Accra Region of Ghana and their occurrence on the surfaces and in juice extracts of orange, mango and tomato fruits. The Plate Exposure method of (Odebode et al., 2020) at human height showed

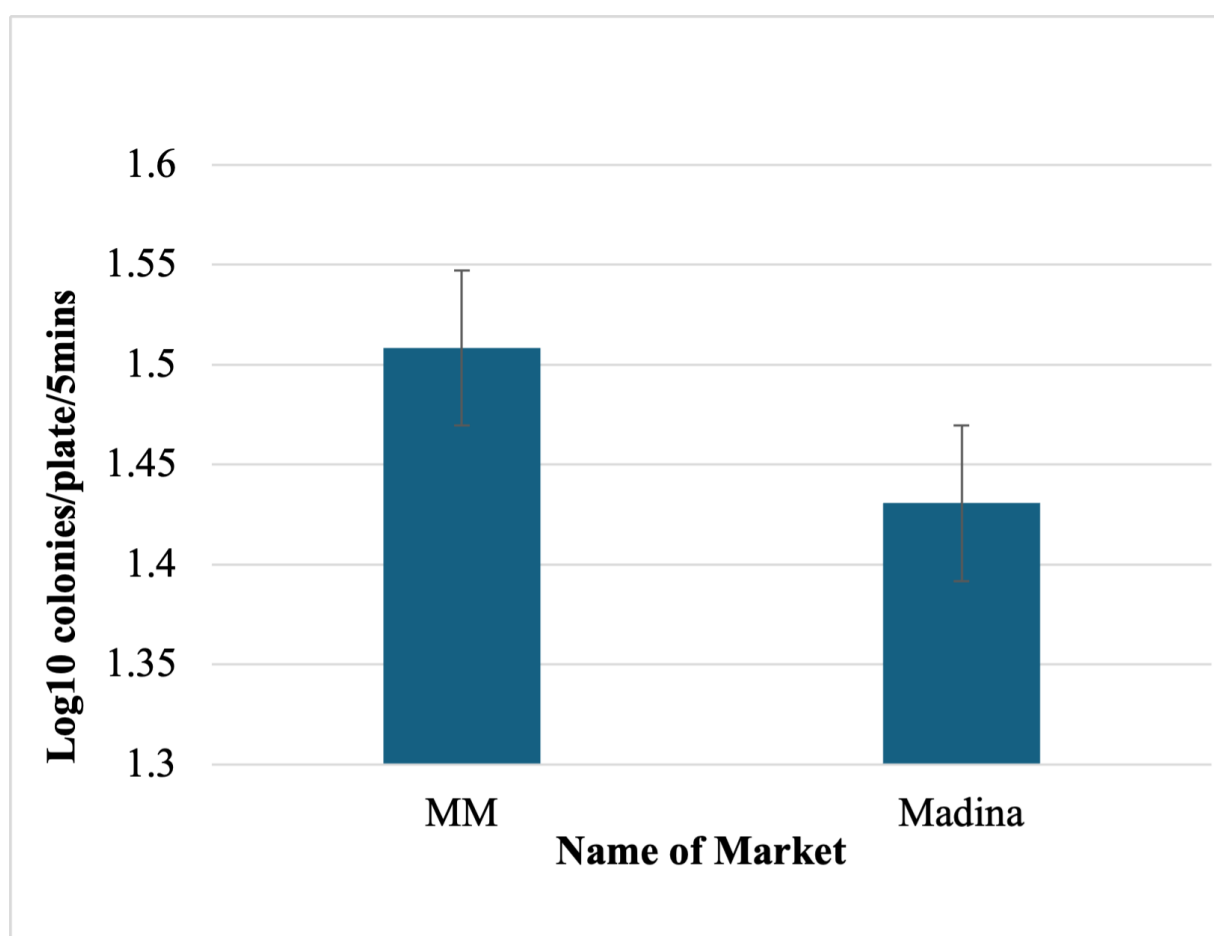


Figure 1: Comparative population of aeromycoflora isolated from Mallam Atta (MM) and Madina Markets.

Table 1: Summary of the percentage occurrence of presumptive *A. fumigatus* in fruit juices and exocarps of orange, mango, and tomato purchased from markets in Accra

Location and coordinates	Orange (%)		Mango (%)		Tomato (%)	
	Juice	Exocarp	Juice	Exocarp	Juice	Exocarp
Madina Market 5°40'48" N Latitude 0°10'13" W Longitude	6.5	10.7	0.0 (ND)	4.9	0.0 (ND)	0.0 (ND)
Mallam Atta Market 5°34'44" N Latitude 0°12'27" W Longitude	22.5	3.8	5.4	8.2	2.0	2.8

that the population of aeromycoflora in the two markets (Madina and Mallam Atta market) varied from log10 1.43 colonies/plate/5mins to log10 1.51 colonies/plate/5mins. The differences observed were marginal or insignificant ($p \geq 0.05$) Fig. 1.

The relatively similar aeromycoflora populations recorded at Madina and Mallam Atta markets suggest that the two market environments supported comparable levels of culturable airborne fungi under the conditions prevailing at the time of sampling. However, because air sampling was undertaken within a restricted morning period during the dry season, the observed fungal populations should be considered a snapshot of the aeromycoflora rather than representative estimates of the overall daily or

seasonal fungal burden.

Airborne fungal populations are influenced by several interacting environmental factors, including temperature, relative humidity, rainfall, wind, vegetation, land use and human activities. Agricultural activities and the handling of plant materials may also facilitate the release and re-distribution of fungal propagules into the atmosphere (Mitakakis et al., 2001; Bowers et al., 2013; Odebode et al., 2020). The presence of viable fungal propagules in these market environments is therefore not unexpected because markets contain multiple potential fungal reservoirs, including fresh and deteriorating produce, plant debris, soil particles, storage materials and organic waste. Nevertheless, the present study did not directly determine the sources

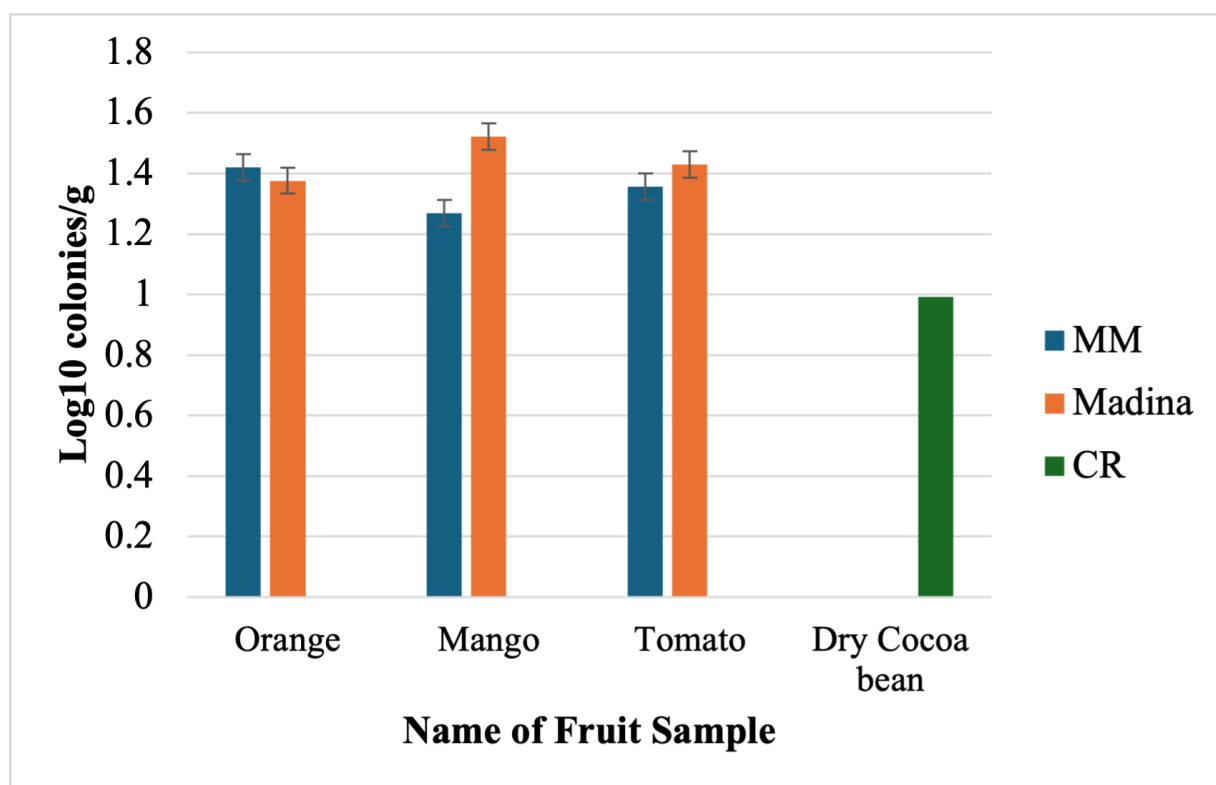


Figure 2: Enumeration of mycoflora associated with fruit peels/exocarp using the direct plating method. MM: Mallam Atta Market.

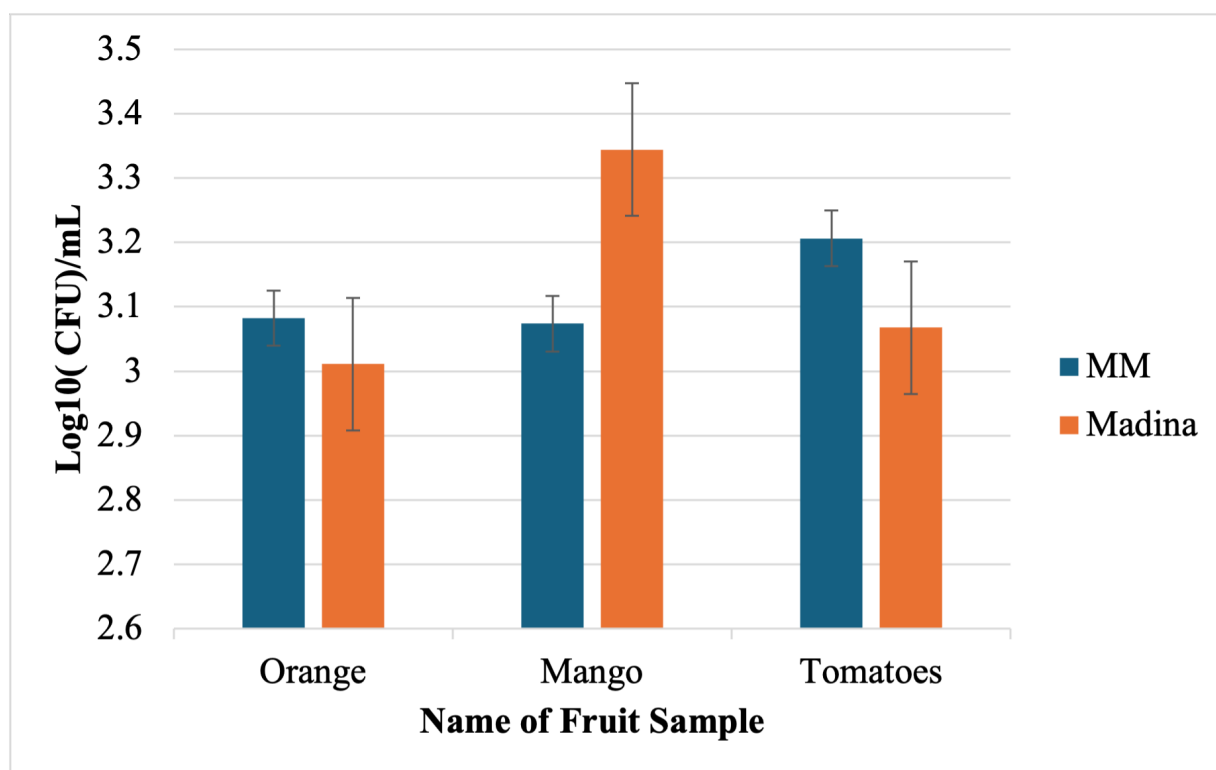


Figure 3: Profile of fungal populations isolated from juices of fruits from Mallam Atta and Madina Markets. MM: Mallam Atta Market.

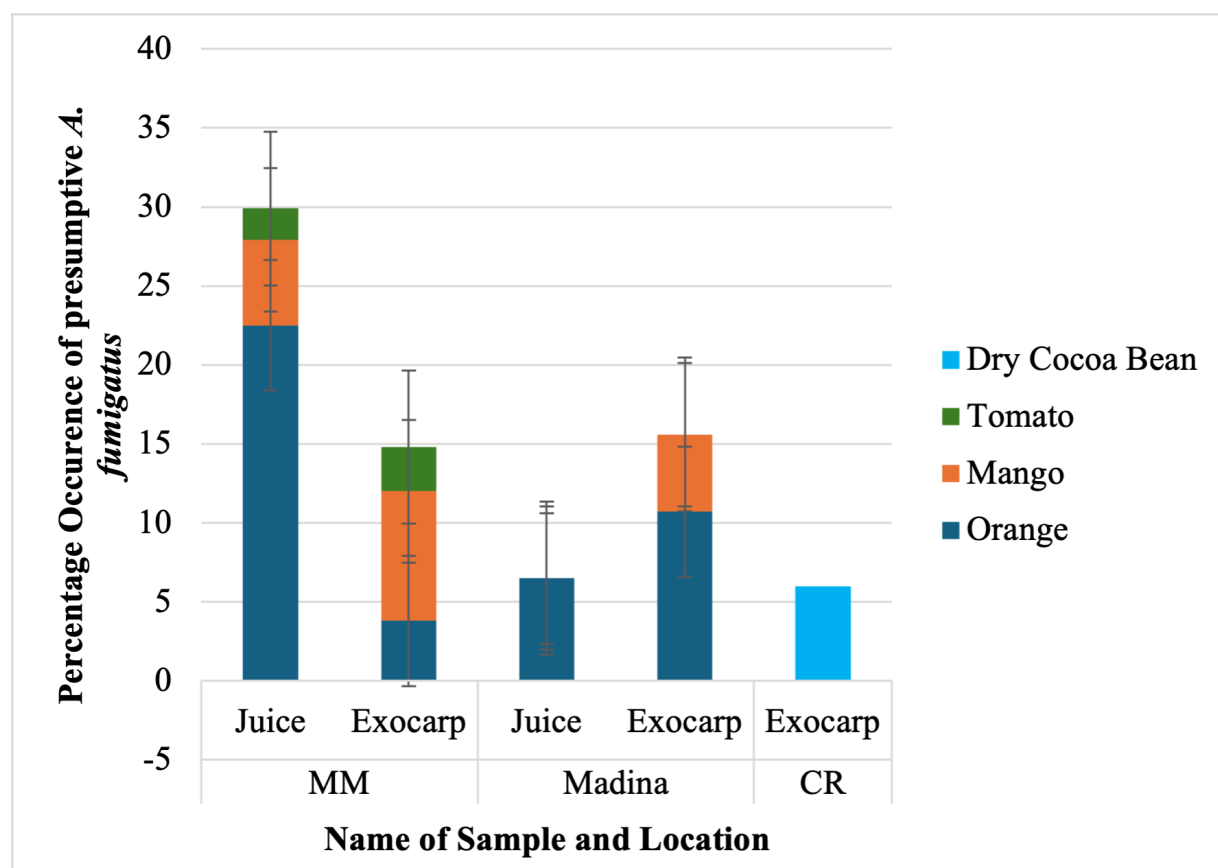


Figure 4: Percentage contribution of presumptive *A. fumigatus* to the total mycoflora isolated from fruit juice and fruit-peel samples purchased from Madina and Mallam Atta Markets in the Greater Accra Region, and dry cocoa-bean testa from Breman Asikuma.

of the airborne fungi, and the contribution of individual environmental reservoirs to the observed aeromycoflora cannot be established from these data.

Fungal populations were also recovered from the exocarps of orange, mango and tomato fruits, with relatively small differences among the fruits and between sampling locations. The occurrence of fungi on fruit surfaces is consistent with the continuous exposure of fresh produce to fungal propagules during cultivation, harvesting, transportation, handling, storage and marketing. The broadly comparable low fungal populations observed in the market air and on the fruit exocarps may indicate exposure of produce to the surrounding fungal environment. However, this association does not establish the market air as the source of the fruit-associated fungi. Fruits may acquire fungal propagules before harvest or subsequently from soil, transportation containers, storage facilities, handlers, market surfaces and other produce. Establishing transmission between market air and fruit surfaces would require molecular or strain-level comparison of isolates recovered from these different sources.

In contrast to the comparatively low fungal populations detected in the market air and on fruit surfaces, higher fungal populations were recovered from the juice extracts. Counts ranged from approximately $3.01 \log_{10}$ CFU mL⁻¹ in

orange juice from Madina Market to $3.34 \log_{10}$ CFU mL⁻¹ in mango juice from the same market, while tomato juices showed intermediate values. These observations suggest that once fungal propagules gain access to fruit tissues, the high-water activity (*aw*) and readily available nutrients within the fruit can provide favourable conditions for germination and fungal proliferation. Disruption of the fruit during juice extraction may additionally transfer surface-associated propagules into the juice. The higher counts in juice should not, however, be interpreted as direct multiplication of the market aeromycoflora because the study did not establish the origin of individual isolates or follow their movement from air through the fruit surface into the internal tissues.

The predominant fungal genera recovered from the juice extracts were *Aspergillus*, *Penicillium*, *Cladosporium*, *Mucor*, *Rhizopus* and *Fusarium*, with *Aspergillus fumigatus* occurring prominently. The occurrence of these genera is consistent with their widespread distribution in soil, plant materials, decaying organic matter, stored agricultural products and atmospheric environments. The findings also broadly agree with those of Wiafe-Kwagyan, Dzifa and Mensah (2019), who recovered *Aspergillus*, *Fusarium*, *Penicillium*, *Rhizopus*, *Rhodotorula* and other yeasts from agricultural produce sampled from markets in the Greater

Accra Region. The repeated isolation of similar fungal groups from market environments and agricultural commodities highlights the importance of appropriate handling and storage practices in limiting fungal proliferation on fresh produce. Wiafe-Kwagyan et al. (2023) similarly sampled 19 airborne fungal species from seven mushroom cropping rooms in the Greater Accra region. Their findings revealed twelve (12) genera belonging to *Aspergillus*, *Cladosporium*, *Epicoccum*, *Fusarium*, *Gliocladium*, *Mycelia sterilia*, *Penicillium*, *Rhizopus*, *Rhodotorula*, *Trichoderma*, *Verticillium* and *Saccharomyces*. The aeromycoflora was predominated by *Aspergillus* species (*A. candidus*, *A. flavus*, *A. niger*, *A. oryzae*, *A. parasiticus*).

The predominance of presumptive *A. fumigatus* in the present study is particularly noteworthy because the fungus was recovered from the aeromycoflora, fruit surfaces and juice extracts. Its occurrence across these sample types demonstrates its widespread presence within the environments and commodities examined. Presumptive *A. fumigatus* produces abundant airborne conidia and is well adapted to colonising decaying organic materials, characteristics that favour its dispersal and persistence in environments containing decomposing plant residues. Nevertheless, recovery of presumptive *A. fumigatus* from market air, fruit surfaces and juice does not demonstrate direct transmission among these compartments. Molecular characterization and comparison of isolates from the respective sources would be required to determine whether they are genetically related and to establish possible transmission pathways.

The present observations are especially relevant when compared with the earlier aeromycological survey of the Accra Metropolitan Area by Quaicoe (1991). That study, conducted between 1989 and 1991, recovered approximately 61 fungal species representing 37 genera, with *Cladosporium herbarum* and *Aspergillus* species among the predominant airborne fungi. Notably, presumptive *A. fumigatus* and *A. flavus* occurred more frequently during the dry season, whereas other fungal taxa exhibited wet-season, year-round, or bimodal occurrence patterns. The prominence of presumptive *A. fumigatus* in the dry-season samples examined in the present study is therefore broadly consistent with these historical observations. This apparent persistence of *Aspergillus* species in the aeromycoflora of Accra is noteworthy, although direct quantitative comparisons between the studies should be made cautiously because of differences in sampling locations, duration, environmental conditions and study design.

The results indicated differences in the occurrence of presumptive *A. fumigatus* among orange, mango, and tomato fruits collected from the markets. (Asante, Wiafe-Kwagyan & Odamtten, 2026).

Disease development was greatest in mango, followed by tomato, whereas orange showed the lowest disease progression. These differences were reflected in both the disease progress curves and area under the disease progress

curve measurements (Asante, Wiafe-Kwagyan & Odamtten, 2026; Simko & Piepho, 2012). The variation in susceptibility is likely related to differences in fruit anatomy, ripening physiology, tissue integrity, moisture availability, chemical composition and natural defence mechanisms rather than to any single nutritional component.

The greater susceptibility of mango may partly reflect the physiological and structural changes associated with ripening. Mango is a climacteric fruit in which ripening is accompanied by increased ethylene production, cell-wall modification and progressive tissue softening, all of which may increase susceptibility to fungal invasion. Immature mango fruits also possess defence mechanisms associated with their latex, including antifungal resorcinols and chitinase activity, which decline as ripening progresses (Karunanayake et al., 2015). Loss of these protective mechanisms, together with increasing tissue softness and availability of soluble nutrients, may therefore contribute to the relatively rapid development of presumptive *A. fumigatus* observed in mango.

Tomato likewise undergoes substantial tissue softening during ripening as pectin and other cell-wall polysaccharides are modified. Its high moisture content and relatively delicate epidermal tissues can favour fungal colonisation, particularly when mechanical injuries occur during harvesting, transportation and handling. Such injuries compromise the physical barrier provided by the fruit surface and may facilitate fungal penetration. These characteristics provide a plausible explanation for the intermediate susceptibility of tomato observed in the present study.

In contrast, the slower disease development observed in orange may be associated with the comparatively robust structural and chemical barriers of citrus fruits. The citrus rind provides a substantial physical barrier to fungal penetration and contains essential oils and secondary metabolites with reported antimicrobial activity (Salvatore et al., 2022). Citrus tissues are also acidic, and the combined effects of rind structure, low pH and antifungal phytochemicals may restrict or delay fungal establishment. These defence mechanisms are not absolute, however, and physical damage or deterioration of the rind during transportation and storage may substantially increase susceptibility to fungal infection.

The recovery of viable fungi from the juice extracts has potential implications for postharvest quality and food safety. Several genera identified in the present study such as *Aspergillus*, *Penicillium* and *Fusarium* contain species capable of producing mycotoxins under favourable environmental and substrate conditions. However, the isolation of potentially toxigenic fungi does not demonstrate that mycotoxins were produced in the fruits or juices. Mycotoxin biosynthesis is dependent on the fungal species and strain, substrate composition, water activity, temperature, duration of colonisation and other environmental conditions. Importantly, mycotoxins were not determined in the present study. Therefore, the results demonstrate fungal contamination but cannot be used to infer the presence, identity or

concentration of specific mycotoxins or to establish a risk of mycotoxicosis. Direct chemical analysis of the relevant toxins would be required to substantiate such conclusions.

The occurrence of presumptive *A. fumigatus* also has potential public-health relevance because the species is an important opportunistic pathogen, particularly among susceptible or immunocompromised individuals. It is also capable of producing several biologically active secondary metabolites such as helvolic acid, pseurotins, pyripyropenes, fumagillin, gliotoxin, fumiquinazoline C, D, F (Kamei & Watanabe, 2005; Guruceaga et al., 2020). Nevertheless, its detection in market air should not be interpreted as evidence of respiratory disease among traders or consumers. Health outcomes associated with airborne fungi depend on exposure concentration and duration, particle characteristics and individual susceptibility. The present study did not assess personal exposure, respiratory symptoms or clinical outcomes among market workers. The findings therefore provide a basis for future occupational exposure studies rather than evidence of a direct association between market aeromycoflora and respiratory disease.

The findings should be interpreted in the context of several limitations. First, the investigation was restricted to two markets in the Greater Accra Region and therefore cannot be considered representative of market aeromycoflora throughout Ghana. Second, air sampling was conducted during a limited morning period in the dry season, preventing assessment of diurnal, seasonal and longer-term temporal variations. This limitation is particularly important because previous work in Accra demonstrated marked temporal and seasonal variation in airborne fungal populations (Quaicoe, 1991). Third, the passive plate-exposure method detects only culturable fungal propagules that settle onto and grow on the selected medium and consequently does not provide a complete quantitative measure of total airborne fungal particles. Fourth, the isolates obtained from air, fruit surfaces and juices were not compared at the molecular or strain level; therefore, direct transmission among these compartments cannot be established. Finally, mycotoxin concentrations were not determined, and no clinical or occupational-health assessments were conducted.

Despite these limitations, the study provides useful baseline evidence of culturable aeromycoflora in two major markets in Greater Accra and demonstrates the co-occurrence of presumptive *A. fumigatus* and other fungal genera in market air, on fruit surfaces and in fruit juices. The inoculation experiments further demonstrate the ability of presumptive *A. fumigatus* to colonise orange, mango and tomato, with marked differences in susceptibility among the fruits. These observations reinforce the importance of hygienic handling, minimisation of mechanical damage, removal of visibly deteriorated produce and appropriate storage conditions during marketing.

5. Conclusion and Recommendations

This study demonstrated the occurrence of culturable airborne fungi in Madina and Mallam Atta markets in the Greater Accra Region of Ghana and their presence on the exocarps and in juice extracts of orange, mango, and tomato fruits. *Aspergillus fumigatus* was predominant among the fungi recovered and occurred in the market air, on fruit surfaces, and in fruit juices. Experimental inoculation further demonstrated that presumptive *A. fumigatus* could colonise all three fruits, although susceptibility differed, with mango showing the greatest disease development, followed by tomato and orange.

These findings highlight the potential importance of market aeromycoflora and postharvest handling in maintaining the microbial quality of fresh fruits. Improved hygienic handling, appropriate storage conditions, adequate ventilation, minimisation of mechanical damage, and timely removal of visibly deteriorated fruits are therefore recommended to reduce fungal contamination and postharvest deterioration.

Further studies should include more markets and geographical regions, repeated sampling across different seasons and times of day, and active volumetric air-sampling methods. Molecular characterization and strain-level comparison of fungi from air, fruit surfaces, and internal tissues are also recommended to establish possible transmission pathways. Importantly, future studies should directly quantify relevant mycotoxins in naturally contaminated fruits and juices before conclusions are drawn regarding mycotoxin exposure or associated food-safety risks.

Declarations

Authors' contributions

DAAA- data acquisition, analysis, interpretation, drafting

WKM- conception/design, data acquisition, analysis, interpretation, drafting, critical revision and final approval.

OGT- conception/design, data acquisition, analysis, interpretation, drafting, critical revision and final approval.

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Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable

Consent for publication

All authors have agreed to the publication of this manuscript in Global Science Today

Data availability

Data will be available upon request.

Use of artificial intelligence tools

No AI was used for the content except when it was used to check grammatical errors.

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