Sentam Research & Publishing

Vol. 2, Iss. 1 (2026)
Pages: 29-44

Open Journal of Food, Agriculture and Biotechnology

Volume 2, Issue 1, 2026

Journal homepage: https://sentam.org/journals/ojfab



Atoxigenic Biocontrol and the Aflatoxin Interception Problem in East African Maize Systems

Daniel K. Wekesa[1*] *& Amina N. Nanyonga*[2]

[1*]Coastal Food Safety and Storage Research Unit
[2]Kilimanjaro Institute for Postharvest Systems and Food Security

ABSTRACT

Aflatoxin contamination of maize remains among the most persistent food safety failures in East Africa, implicated in recurrent acute poisoning episodes and in chronic exposure across large populations. Biocontrol products containing atoxigenic strains of Aspergillus flavus have been developed, registered, and deployed in several countries of the region, and field evaluations consistently report substantial reductions in contamination on treated crops. National contamination burdens have nevertheless remained high, which indicates a persistent gap between demonstrated biological efficacy and observed system level outcome. This narrative review synthesises evidence on aflatoxin burden, biocontrol mechanism and performance, postharvest handling, and regulatory infrastructure across Kenya, Tanzania, Uganda, and the wider East African Community. The review draws on peer reviewed literature, regional standards, and institutional documentation published up to the middle of 2026. Findings indicate that the gap between efficacy and outcome is not explained by weakness in any single intervention, but by the very small share of regional grain that passes through any formal control point at all. The review introduces the Aflatoxin Risk Interception Framework, which models contamination control as a sequence of six interception points and treats biological efficacy and interception coverage as independent parameters at each point. The framework predicts that system level outcome is bounded by the weakest coverage term rather than by the strongest efficacy term, which reframes the policy problem from technology performance towards technology reach. Practical implications include prioritising interventions that operate before grain leaves the farm, integrating biocontrol with drying and storage rather than promoting it in isolation, and reconsidering the reliance on market entry testing in a system where most grain never enters a formal market.

Keywords:
aflatoxin, atoxigenic biocontrol, maize, food safety, East Africa, postharvest handling

INTRODUCTION

Maize occupies a position of exceptional importance in East African food systems, supplying over one third of dietary calories across the region and dominating both smallholder cropping patterns and national food security policy. That centrality makes contamination of the crop a matter of population level consequence rather than an isolated quality concern. Aflatoxins, produced principally by Aspergillus flavus and Aspergillus parasiticus, contaminate maize in the field and continue to accumulate wherever storage conditions permit fungal growth (Gachara et al., 2024).

[*]Corresponding Author: Coastal Food Safety and Storage Research Unit; Email: dkwekesa@gmail.com

Published: August 1, 2026

This is an open access article licensed under CC BY license (http://creativecommons.org/licenses/by/4.0/)

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

The consequences in this region have been unusually severe and unusually well documented. An outbreak in eastern Kenya during 2004 produced 317 recorded cases and 125 deaths, making it among the most severe episodes of acute human aflatoxin poisoning recorded anywhere (Azziz-Baumgartner et al., 2005). Contamination in that episode reached concentrations more than two hundred times the applicable national limit, and subsequent surveillance established that elevated contamination persisted across the affected region in non-outbreak years as well (Daniel et al., 2011). Laboratory analysis of implicated food samples confirmed extreme aflatoxin B1 concentrations in maize collected from affected households (Muture & Ogana, 2005).

A biological control technology addressing preharvest contamination has been available in the region for more than a decade. Products containing atoxigenic strains of Aspergillus flavus, marketed under the Aflasafe trademark, displace toxin producing strains through competitive exclusion and have been formulated with strains native to individual countries. Field evaluations conducted across multiple seasons and agroecologies report consistent and statistically significant reductions in contamination on treated crops (Mahuku et al., 2022).

The analytical puzzle addressed by this review arises from the coexistence of these two observations. A technology of demonstrated biological efficacy has been registered and promoted for more than a decade, yet contamination surveys continue to report substantial proportions of regional maize exceeding regulatory limits. Explanations advanced in the literature have tended to focus on adoption constraints, cost, or awareness, each treated as an obstacle to be removed. This review advances a different account, in which the gap arises structurally from the architecture of the grain system rather than from deficiency in any individual intervention or in farmer behaviour.

REVIEW APPROACH AND EVIDENCE BASE

This study is a narrative review employing structured synthesis across four evidence categories, a design appropriate where the analytical object is a system spanning biological, technological, and institutional components. Systematic meta-analysis was not attempted because the underlying studies differ substantially in design, sampling frame, analytical method, and reporting convention, which precludes meaningful quantitative pooling.

The first evidence category comprised peer reviewed journal articles addressing aflatoxin occurrence, biocontrol mechanism and performance, postharvest handling, and exposure assessment in East African and comparable settings. Searches combined terms covering aflatoxin, Aspergillus, biocontrol, maize, and the names of individual countries. Articles were retained where they reported primary data or substantive synthesis, and where complete bibliographic details including digital object identifiers or stable repository links could be confirmed.

The second category comprised regional and international standards, including East African Standards for maize grain and the associated regulatory limits. The third category comprised institutional and technical documentation from research organisations and regional trade bodies. The fourth category comprised production and consumption statistics used for contextual quantification of the grain mass subject to contamination risk.

Synthesis proceeded by first characterising the burden, then examining each intervention point in turn across two dimensions, namely the reduction achieved on material subject to the intervention and the proportion of regional grain actually subject to it. The framework presented subsequently emerged from the recognition that these two dimensions vary independently and that most published evaluation reports only the first. Quantitative statements reproduced from individual studies retain the units and framing of

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

their sources, and no attempt is made to derive pooled effect estimates. Because much of the underlying evidence is observational and cross sectional, associative rather than causal language is used throughout.

AFLATOXIN BURDEN IN EAST AFRICA

Acute Episodes and Chronic Exposure

Acute aflatoxicosis has been documented repeatedly in the eastern districts of Kenya over a period exceeding four decades. An episode in 1981 produced twenty cases and twelve deaths, associated with maize containing aflatoxin concentrations reaching several thousand micrograms per kilogram. The 2004 episode was substantially larger, and case control investigation established that affected households stored maize under conditions permitting continued fungal growth, with serum biomarker concentrations distinguishing cases from controls (Azziz-Baumgartner et al., 2005).

Characterisation of the causal organism established that a small sclerotial morphotype of Aspergillus flavus, distinct in aflatoxin producing capacity from more commonly encountered types, was associated with the lethal contamination levels observed (Probst et al., 2007). This finding carries direct implications for biocontrol design, since the competitive dynamics between introduced atoxigenic strains and resident toxigenic populations depend on the identity and fitness of the resident population.

Assessment of commercially traded maize during the same episode established that contamination was not confined to affected households but was present within the regional market system, indicating circulation of contaminated grain beyond the immediate outbreak area (Lewis et al., 2005). Documented episodes of acute poisoning have not been confined to Kenya alone. Outbreaks were recorded in the Chemba and Kiteto districts of Tanzania during 2016 and 2019, with fatalities reported following consumption of maize based foods, and comparable incidents have been documented in Uganda (Gachara et al., 2024). The geographic distribution of acute episodes therefore extends across the semiarid zones of at least three partner states rather than clustering in a single national hotspot.

Chronic exposure is considerably more widespread than acute poisoning and considerably less visible. Cross sectional biomarker assessment in Kenya during 2007 documented detectable aflatoxin albumin adducts across a large proportion of the sampled population, indicating routine dietary exposure well beyond the districts associated with acute episodes (Yard et al., 2013). Exposure also occurs through animal products, since aflatoxin B1 consumed in feed is partially metabolised and excreted in milk, creating a secondary exposure pathway of particular relevance for young children (Sirma et al., 2019).

Contamination Prevalence in Maize

Surveillance conducted in eastern Kenya across three consecutive years found that 41 percent and 51 percent of household maize samples exceeded the applicable national limit during the outbreak years of 2005 and 2006 respectively (Daniel et al., 2011). Elevated contamination persisted during the non-outbreak year, which establishes that acute episodes represent the extreme tail of a continuously elevated distribution rather than discrete and separable events.

Regional synthesis indicates that maize contamination is neither uniform nor confined to recognised hotspots. Reported contamination levels in East African Community maize span several orders of magnitude, with extreme values in Kenyan samples reaching tens of thousands of micrograms per kilogram, and with substantial contamination also documented in Tanzanian and Ugandan grain (Gachara et al., 2024). Fungal community characterisation in northern Ugandan storage grain has identified diverse assemblages of storage fungi, indicating that contamination risk is present across production zones not historically associated with acute episodes (Wokorach et al., 2021).

Prevalence estimates vary considerably with sampling frame, and this variation is itself analytically informative. Studies sampling household stores in recognised hotspot districts

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

report the highest exceedance proportions, studies sampling formal market channels report intermediate values, and studies sampling processed products from larger millers report the lowest. This ordering is consistent with progressive removal of visibly damaged grain as material moves towards formal processing, and it means that any single prevalence figure describes the sampling frame as much as it describes the underlying contamination.

Contamination varies substantially with season, altitude, rainfall pattern, and the interval between physiological maturity and harvest. Drought stress during grain filling predisposes maize to preharvest infection, while rainfall during the drying period predisposes grain to postharvest accumulation. This dual sensitivity means that both unusually dry and unusually wet seasons can generate elevated contamination through different mechanisms, which complicates seasonal forecasting and early warning.

Health and Economic Consequences

Chronic aflatoxin exposure is associated with hepatocellular carcinoma, with the association substantially amplified among individuals also carrying chronic hepatitis B infection, a combination of considerable relevance across much of the region (Hamid et al., 2013). Aflatoxin B1 is classified as a human carcinogen, and the attributable share of liver cancer incidence in high exposure settings is substantial although difficult to quantify precisely.

Association between aflatoxin exposure and impaired child growth has been documented across multiple African settings, and burden estimation using biomarker and anthropometric data from four countries has attributed a measurable share of childhood stunting to aflatoxin exposure (Rasheed et al., 2021). The evidence base for this association is less settled than that for hepatocellular carcinoma, and causal interpretation remains contested, but the potential population burden is large given the prevalence of both exposure and stunting.

Economic consequences of contamination operate through several distinct channels simultaneously. Contaminated grain that is detected is removed from human food markets, reducing effective supply and household income. Contaminated grain that is not detected imposes health costs that fall largely outside the agricultural sector and are therefore invisible in agricultural accounting. Trade consequences arise where regional or international buyers apply testing requirements, and regional standards have been identified as functioning simultaneously as consumer protection and as a technical constraint on cross border grain trade.

The distribution of these costs across actors is deeply uneven and shapes the incentive structure decisively. Producing households bear health costs directly but perceive them only indirectly, since chronic effects manifest over decades and are attributed to other causes. Traders and processors bear rejection costs immediately and visibly, which explains why formal sector actors have generally been more responsive to contamination management than producing households. Public health systems bear the treatment costs of liver disease and of impaired child development without any budgetary mechanism connecting those costs to agricultural investment decisions.

BIOLOGICAL BASIS OF ATOXIGENIC COMPETITION

Mechanism of Competitive Displacement

Aspergillus flavus populations in any given environment comprise genotypes that differ in their capacity to produce aflatoxins, with some genotypes unable to produce them at all owing to deletions or mutations within the aflatoxin biosynthesis gene cluster. Biocontrol exploits this natural variation by introducing large quantities of atoxigenic genotypes into the crop environment shortly before the period of greatest infection susceptibility. The introduced genotypes occupy the ecological niche that toxigenic genotypes would otherwise occupy, and the resulting shift in population composition reduces the aflatoxin content of the harvested crop (Khan et al., 2021).

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

The technology is delivered on a sterilised sorghum grain carrier coated with the selected atoxigenic strains, broadcast by hand into the field approximately two to three weeks before flowering. Sporulation on the carrier releases inoculum that colonises developing grain, and the displacement effect subsequently carries through into the harvested crop. The mechanism is competitive rather than antagonistic in the conventional sense, since the introduced strains do not suppress total Aspergillus populations but instead alter their composition.

An important property of this mechanism is that the displacement effect persists into storage. Grain harvested from treated fields carries a fungal community dominated by atoxigenic genotypes, so that where storage conditions subsequently permit fungal growth, that growth occurs disproportionately among genotypes incapable of producing toxin. This carryover property means that preharvest treatment provides partial protection against postharvest accumulation, though it does not eliminate the need for adequate drying and storage.

Product Development in the Region

Product development for East Africa began with characterisation of resident Aspergillus populations and identification of native atoxigenic genotypes suitable for use as active ingredients. Work in Kenya identified candidate atoxigenic isolates from local populations and evaluated their potential to reduce contamination in Kenyan maize (Probst et al., 2011). Selection criteria emphasised native origin, competitive fitness across target environments, and genetic stability of the atoxigenic phenotype.

The resulting Kenyan product, designated Aflasafe KE01, entered evaluation and subsequently registration, and has been assessed in the aflatoxin prone counties of the lower eastern and coastal zones. Tanzanian product development followed a parallel path, producing two formulations each containing four atoxigenic genotypes native to and widely distributed within Tanzania, evaluated across four regions over two seasons (Mahuku et al., 2022). Tanzania approved the first of these products for use in 2018.

The requirement for country specific formulation is a consequence of the mechanism rather than a regulatory artefact. Competitive displacement depends on the introduced genotypes being adapted to the target environment and competitive against the resident population, and genotypes performing well in one country may perform poorly in another. This requirement raises development cost and lengthens the interval between technology conception and national availability, which has practical implications for the pace at which coverage can expand across the region.

Manufacturing and distribution present a further constraint that is distinct from product development. Biocontrol products require sterile manufacturing conditions, quality assured carrier material, and cold chain independent distribution to reach farmers before the application window. Manufacturing capacity in the region has historically been concentrated in a small number of facilities, and production volume has therefore constrained the area that could be treated in any given season irrespective of demand. This supply side constraint is frequently omitted from adoption analyses that attribute limited uptake exclusively to farmer decisions.

Registration pathways add a further interval between product development and availability. Biocontrol products are typically regulated as biopesticides, requiring efficacy and safety dossiers, and the review capacity available for such applications in regional regulatory authorities is limited. The cumulative interval from population characterisation through product formulation, field validation, registration, and manufacturing scale up has commonly extended across the better part of a decade in the countries where the process has been completed.

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

FIELD EFFICACY EVIDENCE AND LIMITATIONS

Documented Efficacy

Field evaluations across the region consistently report statistically significant reductions in aflatoxin contamination on treated crops. Tanzanian evaluation across two years and four regions reported significant reductions in both maize and groundnut, with no observed alteration in total Aspergillus section Flavi population, confirming that the effect operates through compositional change rather than population suppression (Mahuku et al., 2022). Continental evidence accumulated over a decade of commercial usage in West Africa reports comparable performance sustained across widely varying seasons and locations.

Evidence on treatment frequency indicates that the active ingredient genotypes carry over between seasons, so that fields treated in one year retain an altered fungal community composition in subsequent years. Evaluation of different application regimens over three years found measurable carryover of biocontrol genotypes, with implications for the frequency of application required to sustain protection (Atehnkeng et al., 2022). This finding is economically consequential, since annual reapplication represents a recurring cost that carryover may partially offset.

Reported reduction magnitudes across African evaluations have commonly fallen within a broad band extending from roughly half to nearly complete elimination of contamination relative to untreated comparison fields, with variation attributable to season, location, baseline contamination pressure, and application conditions. This variability is itself important for policy purposes, since planning based on the upper end of the reported range will systematically overstate expected benefit. Reporting conventions also differ, with some studies reporting proportional reduction and others reporting the proportion of samples brought below a regulatory threshold, and these two quantities can diverge substantially where baseline contamination is extreme.

Efficacy has also been documented against contamination arising during storage following treatment. Where treated grain was subjected to conditions simulating poor storage, contamination remained lower than in comparably stored untreated grain, confirming the carryover protection described above. This property is particularly relevant in the regional context, where storage conditions are frequently the dominant contributor to final contamination levels.

Boundary Conditions

Three boundary conditions qualify the efficacy evidence and merit explicit statement. The first boundary condition concerns the specificity of biological action. Atoxigenic Aspergillus biocontrol addresses aflatoxin and does not act upon toxins produced by other fungal genera, and Fusarium derived toxins including fumonisins occur widely in regional maize alongside aflatoxins. Products are therefore partial solutions to a multiple mycotoxin problem, and evaluation confined to aflatoxin may overstate the food safety benefit delivered. Investigation of whether displacement of toxigenic Aspergillus creates ecological opportunity for other toxin producing genera has produced mixed findings, with most studies reporting no systematic increase in Fusarium toxins but at least one reporting elevated fumonisin concentrations in treated fields at a single location. The weight of evidence does not support a general concern of this kind, but it does support routine multiple mycotoxin monitoring wherever biocontrol is deployed at scale.

The second concerns the relationship between preharvest treatment and postharvest conditions. Carryover protection reduces but does not eliminate postharvest accumulation, and grain stored at moisture contents permitting vigorous fungal growth will accumulate toxin even where the resident community has been shifted towards atoxigenic genotypes. Treatment is therefore

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

complementary to adequate drying and storage rather than substitutable for them.

The third concerns the conditions under which efficacy has been measured. Evaluations are typically conducted on fields where application timing, rate, and method conform to protocol, frequently with technical supervision. Performance under unsupervised farmer application, with variable timing relative to flowering and variable broadcast uniformity, is less well documented. The distinction between efficacy under controlled conditions and effectiveness under ordinary conditions is standard in intervention evaluation and applies here with full force.

POSTHARVEST INTERCEPTION POINTS

Drying and Moisture

Moisture content is the single most important determinant of postharvest aflatoxin accumulation, since fungal growth requires water activity above a threshold that corresponds approximately to fourteen percent grain moisture. Grain dried to twelve percent and maintained at that level will not support meaningful fungal growth regardless of storage duration, whereas grain stored at sixteen percent will accumulate toxin rapidly. Controlled comparison has confirmed a positive relationship between stored grain moisture content and subsequent contamination, with the highest concentrations recorded in the wettest grain held in permeable bags.

Drying practice across the region frequently falls short of this requirement. Drying maize on bare ground exposes grain to soil borne inoculum and to rewetting from ground moisture, and on farm evaluation in Uganda found the highest mould infection and contamination levels where bare ground drying was combined with permeable bag storage (Akumu et al., 2020). Raised drying racks and tarpaulins are inexpensive relative to most agricultural inputs and address the problem directly.

The binding constraint on drying is frequently meteorological rather than technological. Where harvest coincides with rainfall, adequate field drying may be impossible irrespective of practice, and mechanical drying capacity is largely absent from smallholder systems in the region. This constraint is expected to intensify where rainfall becomes more variable, which places drying capacity among the more consequential adaptation investments for regional food safety.

Storage Technologies

Hermetic storage operates by restricting gas exchange, so that respiration by grain, insects, and fungi depletes oxygen and suppresses further biological activity. On farm evaluation in Uganda found that storage in permeable polypropylene bags produced contamination levels several times higher than storage in hermetic bags and metallic silos, with metallic silos performing best across drying treatments (Akumu et al., 2020). Improved drying and storage practices together reduced losses, mould infection, and contamination by more than half relative to prevailing practice.

An important technical qualification applies to all hermetic storage technologies. Hermetic storage preserves the condition of grain entering it but does not improve grain that enters wet, and grain sealed at high moisture may accumulate toxin within the sealed environment. Evaluation of hermetic bag performance across storage environments has established that efficacy depends materially on the moisture content at sealing (Lane & Woloshuk, 2017). Sequencing therefore matters, and promotion of hermetic storage without corresponding attention to drying may produce disappointing outcomes.

Integrated evaluation combining preharvest biocontrol with controlled storage conditions supports this sequencing logic. Combining biocontrol application before tasselling with hermetic storage of adequately dried grain preserved grain quality and minimised contamination over an extended storage period, whereas either intervention alone produced smaller benefit. Interventions at successive points in the chain are therefore complementary in a

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

specific technical sense rather than merely additive.

Sorting And Aggregation

Physical sorting to remove visibly damaged, discoloured, and mouldy kernels reduces contamination substantially, because aflatoxin distribution within a grain lot is extremely heterogeneous and concentrated in a small proportion of kernels. Hand sorting is labour intensive but requires no purchased input, which makes it accessible to households with limited cash. Its effectiveness depends on the correlation between visible damage and contamination, which is strong but incomplete, since contaminated kernels are not always visibly abnormal.

Aggregation points represent the first stage at which grain from many producers is combined, and they therefore constitute the natural location for systematic quality management. Aggregation also creates a specific risk, since combining a small quantity of heavily contaminated grain with a large quantity of clean grain produces a lot that is uniformly contaminated at an intermediate level and can no longer be separated. Aggregation without prior screening therefore converts a localised problem into a distributed one.

Farmer knowledge regarding these handling practices is uneven across the region. Survey work in the Rift Valley region of Kenya documented substantial disparities in postharvest knowledge among maize farmers, with knowledge gaps corresponding to identifiable contamination risks (Gachara et al., 2022). Knowledge disparity of this kind is amenable to extension intervention, though extension coverage is itself a constraint across much of the region.

STANDARDS AND TESTING INFRASTRUCTURE

The East African Community has harmonised maximum limits for aflatoxins in maize through the East African Standard for maize grain, which sets total aflatoxins at ten micrograms per kilogram and aflatoxin B1 at five micrograms per kilogram for grain intended for human consumption (East African Community, 2011). These limits are more demanding than the guidance level applied in the United States and considerably less demanding than the limits applied within the European Union, placing the region at an intermediate position internationally (Gong et al., 2015).

Harmonisation of limits across partner states was pursued explicitly as a trade facilitation measure, following identification of divergent national tolerances as a technical barrier to regional grain trade. Analysis of the harmonisation process has noted that the resulting regional standards are in several respects more demanding than the corresponding international reference standards, so that harmonisation delivered convergence among partner states without delivering alignment with international norms (Keyser, 2012).

Enforcement capacity has not matched the ambition of the standards. Food control systems across the region contend with multiple and uncoordinated agencies, limited inspection capacity, and unclear allocation of responsibility among regulatory bodies (Marangu et al., 2024). The more fundamental constraint on enforcement is structural rather than administrative. In subsistence communities constituting a large majority of the regional population, the proportion of production consumed within the producing household ranges from sixty to ninety percent, which means that most aflatoxin prone staple food is consumed without passing any quality control whatsoever (Gong et al., 2015). Much of the grain that is sold moves through informal markets rather than through the formal food industry, which further reduces the fraction subject to any systematic checking (Gong et al., 2015).

The consequence is a regulatory system whose formal stringency and practical reach are sharply divergent. Grain entering formal commercial channels is subject to limits comparable to those applied in far wealthier jurisdictions, while the majority of grain by mass is subject to no effective control at all. Surveillance of formal channels accordingly measures the contamination status of an unrepresentative minority of the national grain

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

mass, and inference from such surveillance to population exposure is correspondingly unreliable.

Comparison across jurisdictions illustrates the position that regional standards occupy and the trade implications that follow. The gap between the regional limit and the limit applied by the most demanding destination markets is substantial, and grain fully compliant with regional requirements may nonetheless be inadmissible to those markets. This divergence means that contamination management sufficient for regional trade is insufficient for extraregional trade, so that producers oriented towards different markets face materially different compliance requirements from the same crop.

Table 1: Comparative maximum limits for aflatoxins in maize across selected jurisdictions.

Jurisdiction or standard	Total aflatoxins	Aflatoxin B1	Principal orientation
East African Community	10 micrograms per kilogram	5 micrograms per kilogram	Regional harmonisation and consumer protection
European Union	4 micrograms per kilogram	2 micrograms per kilogram	Precautionary consumer protection
United States guidance	20 micrograms per kilogram	Not separately specified	Commodity trade practicality
Common developing country range	10 to 20 micrograms per kilogram	Variable	Balance of protection and supply availability

THE AFLATOXIN RISK INTERCEPTION FRAMEWORK

Framework Structure

The evidence reviewed above indicates that contamination is neither generated nor controlled at a single point, but accumulates across a sequence of stages at which interruption is possible. The Aflatoxin Risk Interception Framework proposed here models control as a sequence of six interception points extending from field inoculum management through market entry testing. Each point is characterised by a distinct mechanism, a distinct set of enabling requirements, and a distinct position in the temporal progression of contamination.

The first interception point concerns field inoculum, addressed principally through atoxigenic biocontrol and secondarily through varietal resistance and agronomic management of drought stress. The second concerns harvest timing, since delayed harvest of mature grain in the field extends the period of exposure to infection and rewetting. The third concerns drying, addressed through raised racks, tarpaulins, and where available mechanical drying capacity. The fourth concerns storage, addressed through hermetic bags, metallic silos, and moisture monitoring.

The fifth interception point concerns aggregation, at which sorting and cleaning can remove the small proportion of kernels carrying the large majority of the toxin load. The sixth concerns market entry, at which sampling and analytical testing determine whether a lot may proceed into the human food chain. These six points exhaust the practical opportunities for interruption within current technology, and interventions promoted in the region map onto one or more of them without exception.

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

Figure 1: Structure of the Aflatoxin Risk Interception Framework

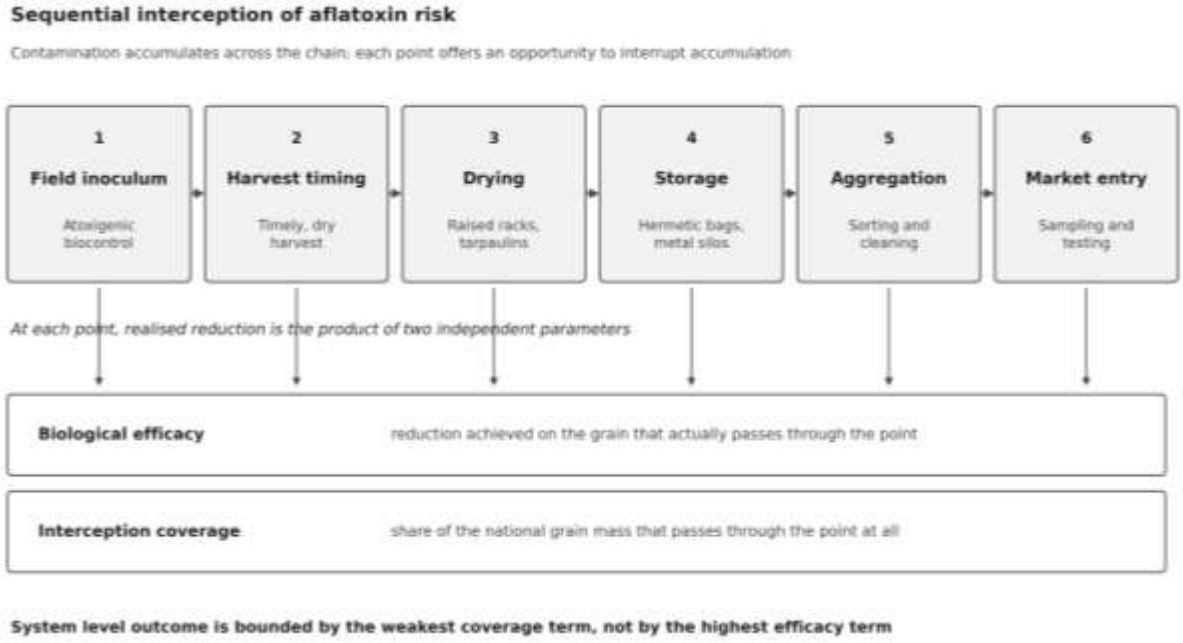


Figure 1 shows the structure of the aflatoxin risk interception framework showing six sequential interception points and the two independent parameters governing realised reduction at each point.

Efficacy and Coverage as Parameters

The distinctive analytical proposition of the framework is that performance at each interception point is governed by two parameters that vary independently and are frequently conflated in both research reporting and policy discussion. Biological efficacy denotes the proportional reduction in contamination achieved on material that actually passes through the interception point under the conditions of application. Interception coverage denotes the share of the total regional grain mass that passes through that point at all.

Published evaluation overwhelmingly reports the first parameter and rarely reports the second. A field trial reporting substantial reduction in treated fields establishes efficacy under the conditions tested, and says nothing whatever about the proportion of regional maize area that is treated. A survey reporting the proportion of formally marketed grain exceeding regulatory limits establishes something about the material tested, and says nothing about the far larger mass of grain that is never presented for testing.

The framework holds that the system level reduction attributable to any interception point is the product of these two parameters, and that the aggregate system outcome is bounded by the point with the weakest coverage rather than improved by the point with the strongest efficacy. This proposition carries an implication that is uncomfortable for conventional practice. An intervention delivering seventy percent efficacy across five percent of the grain mass reduces system level contamination by approximately three and a half percent, and improving its efficacy to ninety percent raises that figure to four and a half percent. Improving its coverage to fifty percent would raise it to thirty five percent.

The framework therefore predicts that marginal returns to further efficacy research at any interception point are small relative to marginal returns to coverage expansion at the same point. It also predicts that interception points located late in the chain will exhibit systematically lower coverage in this region, because grain progressively exits the formal

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

system as it moves from field towards market. Points located before the household storage stage retain access to the full grain mass, whereas points located at market entry access only the marketed surplus.

Table 2: . Interception points, mechanisms, and the two governing parameters within the proposed framework.

Point	Mechanism	Principal efficacy determinant	Principal coverage determinant
1. Field inoculum	Competitive displacement by atoxigenic strains	Application timing relative to flowering	Product availability, price, and extension reach
2. Harvest timing	Reduced field exposure after maturity	Labour availability at harvest	Household labour and weather conditions
3. Drying	Moisture reduction below fungal growth threshold	Drying surface and ambient conditions	Ownership of racks, tarpaulins, or dryers
4. Storage	Restricted gas exchange and moisture stability	Moisture content at sealing	Ownership of hermetic bags or silos
5. Aggregation	Removal of visibly damaged kernels	Correlation of damage with contamination	Share of grain passing through aggregation
6. Market entry	Analytical detection and lot rejection	Sampling protocol and laboratory capacity	Share of grain entering formal markets

Applying the Framework Regionally

Application of the framework to the East African evidence produces a coherent explanation for the observed gap between efficacy and outcome. At the first interception point, biological efficacy is well documented and substantial across multiple countries and seasons. Coverage, however, is constrained by product availability, by price relative to smallholder cash liquidity, and by extension reach. Contingent valuation work in aflatoxin prone Kenyan counties found mean willingness to pay in a range that brackets the reference price of the comparable Nigerian product, with information from extension services and access to credit both positively associated with willingness to pay (Migwi et al., 2020). Willingness to pay at approximately the prevailing price implies that coverage is highly sensitive to price, credit access, and information, none of which is presently assured at scale.

At the third and fourth interception points, efficacy is again well established, with improved drying and storage together reducing contamination by more than half under on farm conditions (Akumu et al., 2020). Coverage depends on ownership of inexpensive but nonetheless purchased equipment, and hermetic bags in particular require periodic replacement, which converts a capital purchase into a recurring cost. Knowledge disparities documented among Kenyan maize farmers indicate that coverage is further constrained by variation in awareness of the practices concerned (Gachara et al., 2022).

At the sixth interception point, efficacy is high in the narrow sense that competent laboratory analysis reliably detects contamination in the sample tested. Coverage is nevertheless the lowest in the entire sequence, because between sixty and ninety percent of production in subsistence communities never enters a market at all. Investment concentrated at this point therefore purchases the smallest achievable system level benefit per unit of expenditure, notwithstanding that it is the point at which regulatory authority is most clearly established and institutional attention most readily directed.

A useful practical diagnostic follows directly from this line of reasoning. For any proposed intervention, the relevant question is not whether it reduces contamination on the material it touches, which is generally established, but what proportion of the national grain mass it can plausibly touch at full deployment. Interventions with a plausible ceiling below ten percent of the grain mass cannot deliver population level exposure reduction irrespective of their biological performance, and should be justified on other

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

grounds such as trade protection or commercial quality assurance.

The framework consequently reorders intervention priority relative to conventional practice. Interception points one through four retain access to substantially the whole grain mass and should carry the greatest share of investment. The fifth interception point occupies an intermediate position between these two groups. Point six should be understood as protecting the marketed fraction and the trade relationships that depend upon it, rather than as a population level exposure control instrument.

Regional Trade Implications

The framework carries implications for regional grain trade that differ from those usually drawn. Kenya is a structural maize deficit market that imports substantial volumes from Tanzania and Uganda, and contamination status in exporting partner states therefore bears directly on consumer exposure in the importing state. Harmonised regional limits were designed precisely to manage this interdependence, and they establish a common threshold against which cross border consignments may be assessed.

The logic of interception coverage complicates this arrangement considerably in practice. Cross border grain moves through both formal and informal channels, and the informal share is substantial along several regional corridors. Consignments moving formally are subject to inspection and testing, while consignments moving informally are not, with the consequence that harmonised limits discipline the fraction of cross border trade that is already most visible and least likely to be problematic. Contamination entering the importing market through informal channels is unaffected by the harmonised standard.

A second complication concerns the incentive that testing at the point of import creates. Where a consignment is rejected on testing, the grain is not destroyed but redirected, commonly into animal feed channels or into informal human food markets where testing does not occur. Rejection therefore relocates contaminated grain rather than removing it from the food system, and in the absence of a disposal mechanism the population level exposure benefit of border testing may be considerably smaller than the rejection statistics suggest.

These observations do not argue against harmonised standards, which serve legitimate trade facilitation and formal sector protection functions. They argue instead for analytical clarity about what harmonised standards can accomplish. Harmonised limits create a shared basis for formal trade and protect consumers of formally traded grain, and they should be evaluated against those objectives. Population exposure reduction requires interventions positioned earlier in the chain, where coverage of the total grain mass remains achievable.

Barriers to System Level Effectiveness

Four barriers to coverage expansion emerge from the synthesis, ordered by the difficulty of their resolution. The first is the misalignment between who bears the cost of intervention and who receives the benefit. A household purchasing biocontrol or hermetic storage bears the full cost immediately, while a substantial share of the benefit accrues as avoided chronic health damage distributed across household members over decades and invisible at the point of decision. Private willingness to pay will therefore fall systematically below social value, which is a standard argument for public cofinancing.

The second barrier is the absence of price signals rewarding safer grain. Where grain is sold into markets that do not test, and where testing where it occurs is not reflected in price, producers face no commercial return on investment in contamination control. Experimental work has examined whether simulated market premiums and bundled insurance alter adoption behaviour, which reflects recognition that adoption decisions respond to market structure rather than to information alone.

The third barrier is the multiple mycotoxin character of the problem. Interventions targeting aflatoxin specifically may leave Fusarium derived toxins unaddressed, and co-occurrence of multiple

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

mycotoxins in regional maize is well documented. A household investing in aflatoxin control obtains a smaller reduction in total mycotoxin exposure than the aflatoxin figures alone would suggest, which weakens the private case for investment.

The fourth barrier to coverage expansion is climatic in origin. Drought stress during grain filling and rainfall during drying both promote contamination through distinct mechanisms, and increasing variability in rainfall distribution raises the frequency of both conditions. Climatic susceptibility has been identified as an integral component of the regional contamination problem rather than an external modifier of it (Gachara et al., 2024). Coverage expansion must therefore proceed against a background risk that is itself increasing.

A fifth consideration cuts across the four barriers and deserves separate statement. Coverage expansion at any interception point requires a delivery channel capable of reaching households that are, by definition, weakly connected to formal markets and to formal extension. The households consuming the largest share of their own production are precisely those least reached by input distribution networks, credit institutions, and advisory services. Coverage is therefore not merely a matter of price and awareness but of institutional reach, and interventions that rely on market channels to achieve distribution will systematically under serve the population segment carrying the greatest exposure burden.

This observation suggests that delivery models matter as much as technologies. Producer organizations, faith-based networks, school feeding programmes, and community health structures reach populations that agricultural input markets do not, and each represents a potential channel for either information or subsidised physical inputs. Evaluation of alternative delivery channels against coverage outcomes, rather than against adoption among those already reached, would address a question that the existing literature has largely left unexamined.

Policy Implications and Research Priorities

Five policy implications follow from the framework, ordered by the ratio of expected system level benefit to implementation cost. The first is the reallocation of investment towards interception points that retain access to the full grain mass, principally field treatment, drying, and household storage. This reallocation does not require new technology and can be effected through existing extension and input distribution channels.

The second is the promotion of interventions in technically coherent sequences rather than as independent options. Hermetic storage of inadequately dried grain delivers limited benefit, and biocontrol treatment followed by poor storage forfeits much of the preharvest gain. Extension messaging organised around a sequence of drying followed by storage, with field treatment where available, corresponds to the technical logic of the system in a way that single technology promotion does not.

The third is the treatment of biocontrol pricing and credit as coverage instruments rather than as commercial details. Given evidence that willingness to pay sits close to the prevailing price and responds to credit access, modest changes in either could produce disproportionate changes in coverage. The fourth is the repositioning of market entry testing as a trade protection instrument, evaluated against trade objectives, rather than as a population health instrument evaluated against exposure objectives that it cannot achieve at current coverage.

The fifth is investment in drying capacity as a climate adaptation measure. Where harvest period rainfall becomes more frequent, field drying will fail more often, and mechanical or solar assisted drying capacity accessible to smallholders addresses a constraint that no amount of behavioural change can overcome.

Four corresponding research priorities follow from the implications set out above. Measurement and reporting of interception coverage alongside efficacy would allow evaluation of system level

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

rather than plot level performance. Estimation of the grain mass fraction passing each interception point in each partner state would supply the parameter values the framework requires. Evaluation of intervention bundles rather than individual technologies would test the sequencing proposition directly. Assessment of total mycotoxin exposure rather than aflatoxin alone would establish the true magnitude of the benefit available from aflatoxin specific interventions.

Limitations of this Review

Three principal limitations qualify the conclusions that this review presents. The first concerns the coverage parameter central to the proposed framework, for which direct measurement is largely absent from the published literature. Coverage statements in this review rest on production and consumption structure rather than on direct enumeration of treated area or equipped households, and should therefore be read as structural inference rather than measurement.

The second limitation concerns geographic and evidential asymmetry across the region. Kenya and Tanzania are represented far more extensively in the aflatoxin literature than Uganda, Rwanda, Burundi, and the newer partner states, which reflects the concentration of documented acute episodes and of research investment rather than the underlying distribution of risk. Characterisation of the less studied jurisdictions is correspondingly provisional and should be treated cautiously.

The third limitation concerns the properties of the proposed framework itself. The proposition that system level outcome is the product of efficacy and coverage at each point is presented as an organising structure rather than as a validated quantitative model, and no attempt has been made to estimate the parameters empirically or to test the multiplicative specification against alternatives. The framework generates testable predictions concerning the relative returns to efficacy and coverage investment, and those predictions remain open to empirical examination.

CONCLUSION

Aflatoxin contamination of maize in East Africa presents an unusual configuration in which an effective technology has been available for over a decade without producing a commensurate reduction in population level contamination burden. Atoxigenic biocontrol products have been developed with strains native to individual countries, evaluated across multiple seasons and agroecologies, and shown to reduce contamination substantially on treated crops. Improved drying and storage practices have been shown to reduce contamination by more than half under ordinary farm conditions.

This review has argued that the persistence of the burden despite these demonstrated effects is not adequately explained by deficiency in any individual intervention. It arises instead from the architecture of the regional grain system, in which the great majority of maize by mass is consumed within producing households and never passes through any point at which control could be exercised. Regulatory limits that are internationally respectable in their stringency reach only the marketed minority of the crop.

The Aflatoxin Risk Interception Framework proposed here separates biological efficacy from interception coverage and treats them as independent parameters at each of six sequential control points. Its central proposition is that system level outcome is bounded by the weakest coverage term rather than raised by the strongest efficacy term. Its central practical implication is that investment should shift towards interception points that retain access to the full grain mass, and that market entry testing should be understood as protecting trade rather than as controlling population exposure.

Reframing the problem in this way changes the research agenda as much as the policy agenda. Efficacy has been measured extensively and coverage has been measured scarcely, with the consequence that the parameter governing system outcome is the parameter about which least is known. Establishing how much of the regional grain mass passes each interception point, in each

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

partner state and in each season, would do more to inform aflatoxin policy in East Africa than further demonstration of effects that have already been demonstrated repeatedly.

REFERENCES

Akumu, G., Atukwase, A., Tibagonzeka, J. E., Apil, J., Wambete, J. M., Atekyereza, P. R., Kiyimba, F., & Muyonga, J. H. (2020). On-farm evaluation of effectiveness of improved postharvest handling of maize in reducing grain losses, mold infection and aflatoxin contamination in rural Uganda. *African Journal of Food, Agriculture, Nutrition and Development*, *20*(05), 16522–16539. https://doi.org/10.18697/ajfand.93.19790

Atehnkeng, J., Ojiambo, P. S., Ortega-Beltran, A., Augusto, J., Cotty, P. J., & Bandyopadhyay, R. (2022). Impact of frequency of application on the long-term efficacy of the biocontrol product Aflasafe in reducing aflatoxin contamination in maize. *Frontiers in Microbiology*, *13*, 1049013. https://doi.org/10.3389/fmicb.2022.1049013

Azziz-Baumgartner, E., Lindblade, K., Gieseker, K., Rogers, H. S., Kieszak, S., Njapau, H., Schleicher, R., McCoy, L. F., Misore, A., DeCock, K., Rubin, C., Slutsker, L., & the Aflatoxin Investigative Group. (2005). Case–Control Study of an Acute Aflatoxicosis Outbreak, Kenya, 2004. *Environmental Health Perspectives*, *113*(12), 1779–1783. https://doi.org/10.1289/ehp.8384

Daniel, J. H., Lewis, L. W., Redwood, Y. A., Kieszak, S., Breiman, R. F., Flanders, W. D., Bell, C., Mwihia, J., Ogana, G., Likimani, S., Straetemans, M., & McGeehin, M. A. (2011). Comprehensive Assessment of Maize Aflatoxin Levels in Eastern Kenya, 2005–2007. *Environmental Health Perspectives*, *119*(12), 1794–1799. https://doi.org/10.1289/ehp.1003044

East African Community. (2011). *EAST AFRICAN STANDARD: Maize grains—Specification* (HS 1005.90.00). East African Community. https://law.resource.org/pub/eac/ibr/eas.2.2011.html

Gachara, G., Suleiman, R., El Kadili, S., Ait Barka, E., Kilima, B., & Lahlali, R. (2022). Drivers of Post-Harvest Aflatoxin Contamination: Evidence Gathered from Knowledge Disparities and Field Surveys of Maize Farmers in the Rift Valley Region of Kenya. *Toxins*, *14*(9), 618. https://doi.org/10.3390/toxins14090618

Gachara, G., Suleiman, R., Kilima, B., Taoussi, M., El Kadili, S., Fauconnier, M. L., Barka, E. A., Vujanovic, V., & Lahlali, R. (2024). Pre- and post-harvest aflatoxin contamination and management strategies of Aspergillus spoilage in East African Community maize: Review of etiology and climatic susceptibility. *Mycotoxin Research*, *40*(4), 495–517. https://doi.org/10.1007/s12550-024-00555-0

Gong, Y. Y., Routledge, M., Kimanya, M. E., Musoke, G., Nelson, F., Sonoiya, S., & Manyon, V. (2015). *Aflatoxin Standards for Food: Knowledge Platform 2015 Situational Analysis East Africa Region* (Technical Policy Paper No. 8). International Institute of Tropical Agriculture. https://aflasafe.com/wp-content/uploads/pdf/TPP-8-Aflatoxin-Standards-for-Food.pdf

Hamid, A. S., Tesfamariam, I. G., Zhang, Y., & Zhang, Z. G. (2013). Aflatoxin B1-induced hepatocellular carcinoma in developing countries: Geographical distribution, mechanism of action and prevention. *Oncology Letters*, *5*(4), 1087–1092. https://doi.org/10.3892/ol.2013.1169

Keyser, J. (2012). *Regional Quality Standards for Food Staples in Africa: Harmonization not Always Appropriate* (Africa Trade Policy Note No. 33). World Bamk. https://documents1.worldbank.org/curated/en/357541468192844868/pdf/728540BRI0Box30onal0Standards0FINAL.pdf

Khan, R., Ghazali, F. M., Mahyudin, N. A., & Samsudin, N. I. P. (2021). Biocontrol of Aflatoxins Using Non-Aflatoxigenic Aspergillus flavus: A Literature Review. *Journal of Fungi*, *7*(5), 381. https://doi.org/10.3390/jof7050381

Lane, B., & Woloshuk, C. (2017). Impact of storage environment on the efficacy of hermetic storage bags. *Journal of Stored Products Research*, *72*, 83–89. https://doi.org/10.1016/j.jspr.2017.03.008

Lewis, L., Onsongo, M., Njapau, H., Schurz-Rogers, H., Luber, G., Kieszak, S., Nyamongo, J., Backer, L., Dahiye, A. M., Misore, A., DeCock, K., Rubin, C., & the Kenya Aflatoxicosis Investigation Group. (2005). Aflatoxin Contamination of Commercial Maize Products during an Outbreak of Acute Aflatoxicosis in Eastern and Central Kenya. *Environmental Health Perspectives*, *113*(12), 1763–1767. https://doi.org/10.1289/ehp.7998

Mahuku, G., Mauro, A., Pallangyo, B., Nsami, E., Boni, S. B., Koyano, E., Mponda, O., Ortega-Beltran, A., Atehnkeng, J., Aquiline, F., Samuel, R., Njela, J., Cotty, P. J., & Bandyopadhyay, R. (2022). Atoxigenic-based technology for biocontrol of aflatoxin in maize and groundnuts for Tanzania. *World Mycotoxin Journal*, *16*(1), 59–74. https://doi.org/10.3920/WMJ2021.2758

Marangu, N., Mhando, K., & Mwau, J. (2024). Enhancing Food Safety and Facilitating Orderly Grain Markets in East Africa through Self-Regulation – EAGC. *Eastern Africa Grain Council*. https://eagc.org/2024/02/05/enhancing-food-safety-and-facilitating-orderly-grain-markets-in-east-africa-through-self-regulation/

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

Migwi, B., Mutegi, C., Mburu, J., Wagacha, J., Cotty, P., Bandyopadhyay, R., & Manyong, V. M. (2020). Assessment of willingness-to-pay for Aflasafe KE01, a native biological control product for aflatoxin management in Kenya. *Food Additives & Contaminants: Part A*, *37*(11), 1951–1962. https://doi.org/10.1080/19440049.2020.1817571

Muture, B., & Ogana, G. (2005). Aflatoxin levels in maize and maize products during the 2004 food poisoning outbreak in eastern province of Kenya. *East African Medical Journal*, *82*(6). https://doi.org/10.4314/eamj.v82i6.9296

Probst, C., Bandyopadhyay, R., Price, L. E., & Cotty, P. J. (2011). Identification of Atoxigenic *Aspergillus flavus* Isolates to Reduce Aflatoxin Contamination of Maize in Kenya. *Plant Disease*, *95*(2), 212–218. https://doi.org/10.1094/PDIS-06-10-0438

Probst, C., Njapau, H., & Cotty, P. J. (2007). Outbreak of an Acute Aflatoxicosis in Kenya in 2004: Identification of the Causal Agent. *Applied and Environmental Microbiology*, *73*(8), 2762–2764. https://doi.org/10.1128/AEM.02370-06

Rasheed, H., Xu, Y., Kimanya, M. E., Pan, X., Li, Z., Zou, X., Shirima, C. P., Holmes, M., Routledge, M. N., & Gong, Y. Y. (2021). Estimating the health burden of aflatoxin attributable stunting among children in low income countries of Africa. *Scientific Reports*, *11*(1), 1619. https://doi.org/10.1038/s41598-020-80356-4

Sirma, A., Makita, K., Grace Randolph, D., Senerwa, D., & Lindahl, J. (2019). Aflatoxin Exposure from Milk in Rural Kenya and the Contribution to the Risk of Liver Cancer. *Toxins*, *11*(8), 469. https://doi.org/10.3390/toxins11080469

Wokorach, G., Landschoot, S., Audenaert, K., Echodu, R., & Haesaert, G. (2021). Genetic Characterization of Fungal Biodiversity in Storage Grains: Towards Enhancing Food Safety in Northern Uganda. *Microorganisms*, *9*(2), 383. https://doi.org/10.3390/microorganisms9020383

Yard, E. E., Daniel, J. H., Lewis, L. S., Rybak, M. E., Paliakov, E. M., Kim, A. A., Montgomery, J. M., Bunnell, R., Abudo, M. U., Akhwale, W., Breiman, R. F., & Sharif, S. K. (2013). Human aflatoxin exposure in Kenya, 2007: A cross-sectional study. *Food Additives & Contaminants: Part A*, *30*(7), 1322–1331. https://doi.org/10.1080/19440049.2013.789558

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org