Azzy Xiang
Dublin Jerome High School
Dublin, OH, USA
Nigeria, Spoilage, Food Loss and Waste

"LET IT DRY": A SOLAR-ASSISTED INDIRECT FORCED-AIR DRYING PROGRAM TO REDUCE AFLATOXIN RISK IN NORTH-CENTRAL NIGERIA'S SMALLHOLDER MAIZE SUPPLY

It is October in Benue State, Nigeria. Chukwuemeka is a 42-year-old maize farmer who just brought in two and a half hectares of corn cobs. His harvest was carefully shelled over three days by his wife Ngozi and their four children. The grain is piled on tarpaulins in the open yard, set out to dry. But the rainy season has not ended, and afternoon downpours are still common. After four days of intermittent drying and re-wetting, the maize looks "dry enough" to Ngozi, who bags it and stacks the sacks in the earthen storage room, a smile on her face.

What neither of them can see, or even smell or taste, is that within 48 hours of being above safe moisture levels, *Aspergillus flavus* has already begun to colonize the grain. Silently, it produces one of the most potent, naturally occurring carcinogens on Earth. By the time the Chukwuemeka and his neighbors consume the aflatoxin B1-contaminated maize over the next six months, over shared family gatherings and warm dinnertime stories, they will ingest a substance that causes liver cancer and stunts growth of innocent children. This is the story about a failed drying step and the catastrophic, invisible consequences that follow smallholder maize farmers across Benue and neighboring Kaduna State during the October-November harvest.

BACKGROUND

The Federal Republic of Nigeria is Africa's most populous nation, home to about 220 million people, of whom roughly 53% live in rural areas. 21% of Nigeria's annual gross domestic product is supported by agriculture, which also employs 70% of the rural workforce (IFAD, 2025). Despite this agrarian depth, Nigeria hosts a food-insecure population ranking among the highest on the planet; 30.6 million Nigerians face acute food insecurity at "Crisis" level or worse during the lean season (FAO, 2025).

The smallholder maize farmer is the backbone of Nigeria's domestic food supply. Maize and cassava are grown by 50% of Nigerian farming households, and the average farm in the north-central states of Benue and Kaduna covers 2-3 hectares of maize cultivation (Ogunniyi et al., 2021). Smallholders collectively produce 90% of the nation's food on rain-fed plots (FAO, 2018; IFAD, 2025; Statista, 2024). In the north-central region, a typical family's diet centers on maize staples, revolving around *ogi* (fermented maize porridge), *tuwo masara* (thick maize pudding), boiled or roasted cobs, beans, yams, and occasional protein from fish or bush meat. Maize provides about half of daily caloric intake, and households are heavily dependent on the crop (Wudil et al., 2023). Access to healthcare is limited, as insurance coverage remains below 2.2% nationally and the distance from the nearest paved road to travel to understaffed rural clinics averages 14 kilometers for most smallholder farms (Adekunle & Vincent, 2025; Ahmed et al., 2017). Access to grid electricity is largely absent as well, which has serious implications for grain drying

and storage technology adoption. Poverty incidence among farming households in Benue State stands at a high of 70%, a quantification of the economic fragility of these families and how vulnerable they are to crop loss (Upev et al., 2021).

THE CHALLENGE AND ITS IMPACT

Nigeria's post-harvest loss crisis is staggering in scale; nationally, losses are valued at ₦3.5 trillion annually, more than nine times the government's 2024 agricultural budget (Oladeinde et al., 2024). Improper drying of grain and maize is the primary upstream cause (Okojie & Jaiyesimi, 2024). An empirical review of Nigerian agricultural systems estimated an overall post-harvest loss rate of 24.9% of maize, while 33.1 million people are becoming acutely hungry (Ogundele, 2022; WFP, 2025).

The core of this food loss is a biological clock unaware to most rural farmers. Maize harvested during the October-November season in the north-central belt of Nigeria generally has a moisture content of about a quarter wet basis, well above the 13% threshold below which fungal growth is suppressed (Suherman et al., 2024). When grain is spread on tarpaulins or concrete pads for open-air sun drying, intermittent rainfall and high ambient humidity across these multi-day drying periods result in the grain cycling above and below safe moisture levels, almost sinusoidally. Under these conditions, *Aspergillus flavus* colonizes grain within 48 hours and begins producing aflatoxin B1 (AFB1), the most hepatotoxic mycotoxic known (NIH, 2023), particularly in conditions with temperatures above 25°C.

The health consequences of what appears to be a small and convenient maize drying habit are disproportionately severe. AFB1 is classified as a "Group 1" human carcinogen by the International Agency for Research on Cancer (IARC), meaning the evidence of its causal role in hepatocellular carcinoma (HCC) in humans is unequivocal and severe (Meki & Al-Qhtani, 2025). Globally, aflatoxin may be responsible for up to 28.2% of all new HCC cases each year, which amounts to up to 155,000 cases annually (Liu & Wu, 2010). Nigeria is identified as a very high-risk environment for primary HCC because its population faces high aflatoxin dietary exposure, which multiplies individual risk for HCC by up to 30-fold (NIH, 2023). Resulting Nigerian cases of aflatoxin-induced liver cancer each year leads to associated financial losses approaching USD $997 million annually (Falaju, 2021).

For children, the consequences are far compounded. Chronic aflatoxin ingestion is associated with developmental delays and immune suppression; the stunting of 4.4 million under-five Nigerian children can be attributed to aflatoxin exposure, an alarming figure reported from the most vulnerable (Adetunji et al., 2017). Women in maize-farming households also manage grain storage to process maize into daily meals while feeding maize porridges to infants. Families often cannot afford to discard contaminated grain, even when visual spoilage is apparent (Upev et al., 2021). But even worse, aflatoxin contamination is invisible to the naked eye, and without lateral flow test kits, which are not available in most rural areas, families have no way to know if their grain is unsafe. The environmental conditions further turn this into a recurring cycle of food contamination. Northern Nigeria's climate is characterized by post-harvest temperatures of 22-33°C and relative humidity of 40-90% during the October-November seasons, creating peak optimal conditions for *Aspergillus* proliferation during the drying window (Abdurrazaq et al., 2022; Climate Data, 2026; Travelscoop, 2026).

Quantitative surveys make the identification of the contamination source concrete. A study of maize found aflatoxin B1 concentrations of up to 140 μg/kg in maize, more than 70 times the EU's maximum limit of 2 μg/kg (Mwalwayo & Thole, 2016). Aflatoxins were present in 73.8% of regular maize food samples in Nigeria, with 41.9% of such samples exceeding the national threshold (Akullo et al., 2025). However, these dangerous implications do not deter the reliance on maize to sustain the increasing population in Nigeria; maize yielded the highest estimated dietary intake (EDI) of any Nigerian staple, 36.7 ng/kg body weight per day (Becker-Algeri et al., 2023).

EXISTING SOLUTIONS AND THE REMAINING GAP

Existing interventions address different points in the aflatoxin pathway, but none directly resolve the drying-stage bottleneck identified above. Hermetic storage bags like the Purdue Improved Crop Storage (PICS) bags protect grain from moisture ingress and oxygen during storage (Akullo et al., 2025). However, hermetic storage only addresses the post-drying phase and requires grain to enter storage already adequately dried; they cannot compensate for unsafe moisture at harvest. Biocontrol agents such as *Aflasafe* have shown 82-95% reductions in maize aflatoxin before harvest in multi-year trials, but this does not address contamination when wet grain is exposed during post-harvest drying in wet-season conditions (Bonkoungou et al., 2024). Centralized mechanical dryers, such as the AFEX commodity exchange's 100,000-metric-tonne grain drying center in Kaduna State, can provide controlled drying powered by diesel and grid electricity, but these facilities are inaccessible to the dispersed rural smallholder located far from paved roads, and fuel and electricity are costly to procure and maintain (FAO, 2018; Oladeinde et al., 2024).

Solar drying provides a better intermediate-technology fit by addressing the drying stage and avoiding dependence on grid electricity and continuous fuel purchases. Evidence from Nigeria supports its feasibility directly; a solar tunnel dryer in Abakaliki improved maize moisture removal by 44% relative to open-air drying, and a mixed-mode solar dryer tested in Makurdi achieved moisture contents as low as 11.75% after identifying an optimal airflow condition (Kuhe et al., 2019; Uwa et al., 2024). Directly coupled photovoltaic dryers designs also exist, allowing forced-air drying without grid electricity or batteries, appropriate for off-grid African smallholders (Mumba, 1995). One design dried 100 kg of maize from 24% to 14% moisture in 9 hours, compared to 4 days for open-air sun drying, a 90% reduction in drying time; forced-air drying that included washing and aeration also significantly reduced aflatoxin levels ($p < 0.05$) in Lagos market samples (Ahmad, 2002; Akinniyi, 2025).

These findings show that controlled thermal drying is a viable foundation that can suppress aflatoxin accumulation beyond merely preventative measures, but they do not address the more specific engineering question of how to optimize a dryer for the post-harvest conditions of north-central Nigeria to mitigate aflatoxin in maize, and if that is truly feasible.

The proposal aims to improve upon the existing approach involving solar technology instead of introducing an untested solution. Its contribution is to combine indirect forced convection and photovoltaic-powered airflow with a novel model of cooperative ownership and process optimization for the specific climate and grain conditions of north-central Nigeria.

RECOMMENDATION

The proposal is the establishment of the Solar Grain Drying Program (SGDP), involving the deployment of a novel design for an indirect forced convection solar dryer (IFCSD) unit. The program would begin as a village-level intervention in north-central Nigeria, with an initial pilot in the Benue and Kaduna states. Indirect forced-convection solar dryers would be deployed through existing farmer cooperatives, using process optimization to match the system to local harvest conditions. Instead of immediately attempting nationwide deployment, the pilot would establish the technological and economic feasibility and accessibility of the solution, allowing for consistent adoption by farming communities before expansion to other maize-producing regions.

Technical Design. The IFCSD unit consists of three integrated systems: (1) a flat-plate solar air collector fabricated from a galvanized iron absorber plate, coated with high-absorptivity black paint and covered with a polycarbonate glazing sheet; (2) a PV-powered DC fan for forced air convection that eliminates grid dependency; and (3) an insulated drying chamber with perforated trays for grain loading, designed for a batch capacity of 500 to 800 kg. The indirect design, in which heated air passes through the grain, prevents photodegradation of grain proteins via solar radiation. This novel engineering technique allows for more uniform temperature distribution throughout the grain bed (ScienceDirect Topics, 2022).

Computational Validation. The engineering question behind this proposal is whether the suggested decentralized dryer could reliably bring a 500 kg batch of maize below the 13% moisture threshold within a single solar day under north-central Nigeria's harvest conditions. To answer this, a simulation was constructed in Python using October-November ambient conditions of 22-33°C and 40-90% relative humidity (Climate Data, 2026; Travelscoop, 2026). The model represented a flat-plate solar collector as a heater with solar irradiance of 550-600 W/m², modeled ambient humid air using psychrometric relationships through CoolProp's humid-air property calculations, and represented the drying chamber as a simplified moisture-transfer function based on thin-layer drying behavior for maize. Collector area was varied from 4 to 8 m² and airflow across operating conditions to identify the combination that minimized drying time and maintained sufficient thermal input, with the process flow diagram displayed in **Figure 1**. The results provide a design target for prototyping, and field measurements of moisture reduction and drying time would be used to validate performance before scale-up.

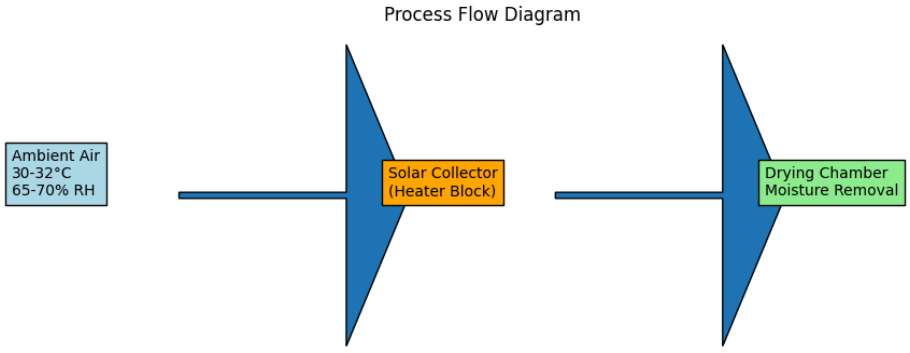


Figure 1. *Process Flow Diagram.*

A sensitivity analysis identifies the operational optimum, an air outlet temperature from the collector of 68.82 °C and an air mass flow rate of 0.0800 kg/s that is consistent with the peak drying efficiency reported in Makurdi field tests. There is a theoretical latent heat requirement of approximately 129.78 MJ to evaporate 57.5 kg of water from a 500 kg batch, corresponding to 11.5% of the batch mass. This is the water removal required under the modeled drying scenario to bring maize from its post-harvest moisture content to below the 13% safety threshold (FAO, 2024). Under the simulated solar irradiance and collector efficiency, this energy input is achievable with an 8.00 m² collector over the predicted drying period of 5.07 hours. A 10W PV-powered DC fan can provide the forced convection continuously during daylight hours.

Further, the sensitivity analysis also shows why airflow in the IFCSD matters, and the relationship is illustrated in **Figure 2**. Lower flow rates (i.e., 0.01 to 0.03 kg/s) produce higher outlet temperatures closer to 80°C due to reduced convective heat capacity, but they remove moisture more slowly; increasing airflow to approximately 0.06-0.08 kg/s improves moisture transport and reduces drying time despite lower air temperature of 45-55°C. Similarly, increasing collector area from 4 to 8 m² substantially reduces drying time, with diminishing returns beyond approximately 7 m². These results identify an operating region of roughly 65-70°C and 0.06-0.08 kg/s airflow, with an 8 m² collector providing the strongest balance between drying speed and system size, something that can be feasibly constructed in an open agricultural space.

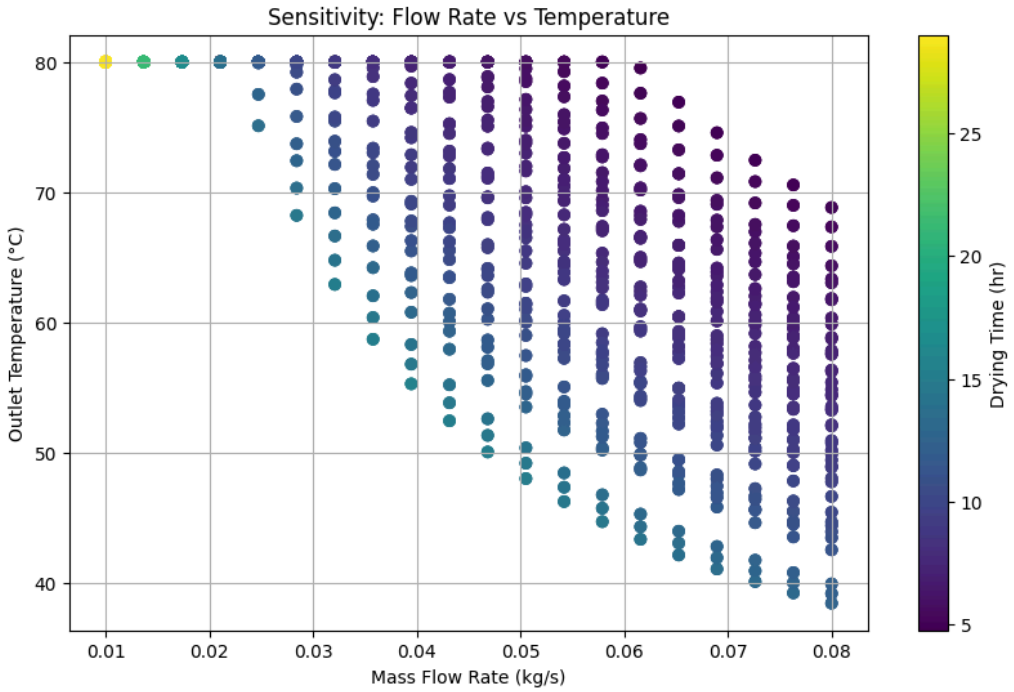


Figure 2. *Flow Rate vs. Temperature.*

When the optimum is generalized, the peak operating region is therefore identified at intermediate-to-high flow rates and moderate outlet temperatures of ~65 to 70°C, where a balance is achieved between sufficient thermal energy and moisture transport. The relationship between collector area and drying time is a clear inverse trend shown in **Figure 3**, as increasing collector area from 4 m² to 8 m² significantly

reduces drying time across all operating conditions. At lower collector areas of 4 to 5 m², drying times are highly variable and frequently exceed 10 hours, especially at lower outlet temperatures. Collector areas of 7 to 8 m² consistently achieve drying times below 8 hours, with optimal cases approaching 5 to 6 hours. Diminishing returns are observed at higher areas, indicating that beyond approximately 7 m², further increases in area yield smaller incremental reductions in drying time. System performance becomes increasingly limited by air mass flow rate and moisture transfer kinetics.

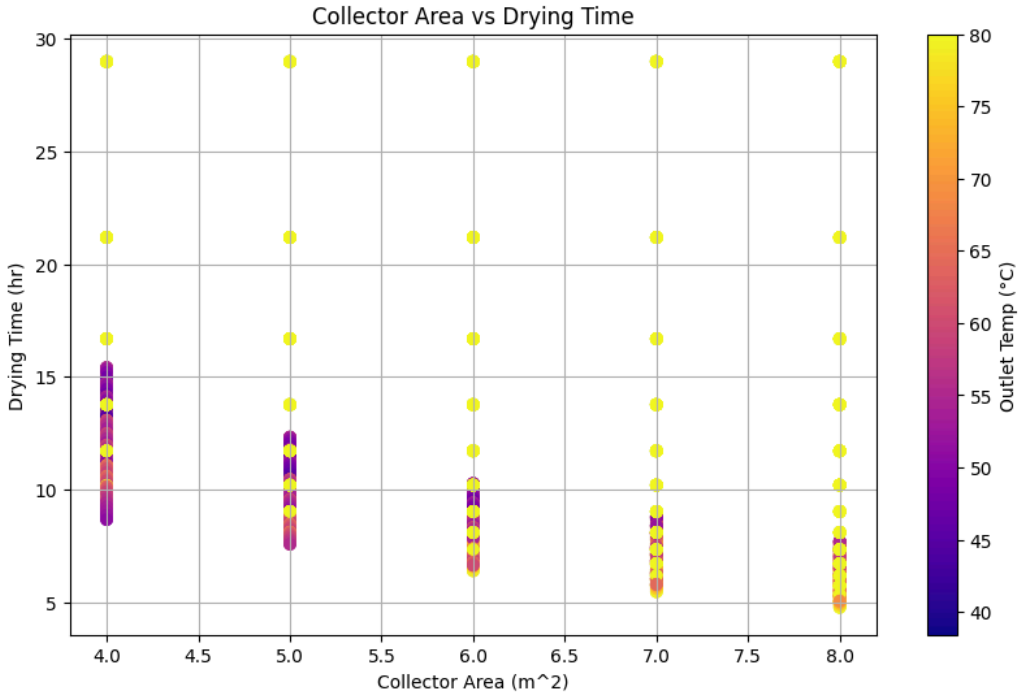


Figure 3. *Collector Area vs. Drying Time.*

The simulation establishes technical feasibility for the proposal and helps mitigate aflatoxin contamination, a major source of economic loss in the agricultural sector. An 8 m² collector and approximately 0.08 kg/s airflow could reduce a 500 kg batch to safe moisture levels within 5-6 hours under favorable solar conditions using only a 10 W photovoltaic fan. The food-security significance is the time saved between harvest and safe storage. Faster, controlled drying reduces the period in which grain remains vulnerable to moisture-driven fungal growth, and preserves a greater share of the harvest for household consumption or sale. For farmers, this means less grain loss and more marketable product; for households, safer maize; for cooperatives, a shared productive asset; and for the wider food system, more of the food reaching consumers safely and abundantly.

Implementation Model. The SGDP would be deployed in an existing cooperative structure. A cooperative of 12-15 farming families share one IFCSD unit, with a rotating drying schedule during the post-harvest period. The unit is designed for construction from locally sourced materials, including a galvanized iron sheet, polycarbonate glazing available in state capitals, wooden frame, and locally fabricated perforated drying trays. The total capital cost is estimated at ₦450,000-₦600,000, or

approximately USD $280-375. Divided among 12-15 households, this is roughly ₦37,500-₦50,000 per household, a meaningful but achievable investment relative to the average annual income of ₦350,000 for a Kano-region smallholder (Aminu et al., 2022). However, despite this, the cooperative model would also be paired with initial public and philanthropic financing, with households contributing through a smaller cost-sharing and user-fee structure for maintenance and replacement parts. This reduces any potential up-front barrier and preserves community ownership.

Funding and Policy Pathway. Nigeria's National Agricultural Policy explicitly mandates a 50% reduction in post-harvest losses by 2027, aligning directly with the SGDP's objectives (DAWN Commission, 2025). The Agricultural Transformation Agenda Support Programme phase II (ATASP-II), jointly funded by the IFAD and the Nigerian government, specifically supports post-harvest infrastructure for smallholder cooperatives and would be an appropriate primary financing vehicle. Further, the Nigeria Incentive-Based Risk Sharing for Agricultural Lending (NIRSAL) offers concessional loan products for agricultural equipment that societies can access.

Stakeholders. The SGDP program assigns different responsibilities to groups that will determine its success. Farming cooperatives own, schedule, operate, and maintain the IFCSD dryers. State agricultural development programs provide technical training and extension support. Financing institutions and agricultural programs reduce the initial capital barrier. Local fabricators construct and repair the dryers using regionally available materials, reducing dependence on imported equipment. Farmers and their households receive the primary benefits, including less post-harvest grain loss and more grain available for sale and safe consumption. This distribution of responsibility balances local implementation with government and institutional support.

Pilot and Scale-Up. The first phase would establish 50 cooperative dryers in the Benue and Kaduna States, covering about 750 farming households. These two states are a practical starting point because the target population is concentrated in north-central maize-producing communities and the proposed design is already parameterized for their harvest-season conditions. Rollout would be supported by state-level agricultural deployment programs (ADPs) and NGO partners that already operate food security programs in the region; cooperatives retain ownership and responsibility for daily operation. Community ownership through the cooperative model builds a sense of communal responsibility and allows for cultural adaptation of the technology, which is absent from previous top-down government drying initiatives.

Expansion to other regions should occur only after the pilot demonstrates reliable drying performance and sustained community use that lead to measurable reductions in post-harvest loss and aflatoxin exposure. In the long run, the IFCSD design is inherently low-maintenance, with a collector lifespan of 15-20 years with periodic re-painting of the absorber plate. It has no moving parts except for the DC fan replaceable at approximately ₦3,000 and no fuel costs, which would allow sustaining the solution for extended periods of time once adopted.

Evaluation. The pilot should be evaluated against measurable outcomes. Each cooperative should track the proportion of maize batches reaching ≤13% moisture, alongside drying time per batch and the quantity processed per drying cycle. Food-security impact should be measured as the proportion of harvested grain retained as marketable food. Where testing is available through ATASP-II funding, maize

samples before and after drying can also be analyzed for aflatoxin concentration to determine if the improved moisture control is effectively resulting in reduced contamination. Finally, adoption should be measured through cooperative participation and training completion, and continued use of the dryer throughout subsequent harvests. These measurements allow the SGDP program to determine if the simulated performance results in real food-security gains before scaling.

Risks and Mitigation. Four limitations must be addressed from the beginning in order to ensure successful adoption. Technical feasibility alone is not enough for a practical implementation of the IFCSD.

(1) Farmers accustomed to free open-air drying may initially hesitate to adopt a system requiring a shared investment and scheduled use. The cooperative model addresses this by making the dryer collectively owned and allowing families to rotate drying slots during harvest.

(2) The initial capital cost may exceed what an individual household can afford; therefore, pilot financing should subsidize or provide low-interest financing for the first cooperative units rather than requiring individual purchases.

(3) Improper operation could undermine the system's benefits. Each cooperative should receive a moisture meter, available at approximately ₦8,000 per unit, and training through state agricultural extension services, with grain dried until measurements confirm moisture below the 13% safety threshold. As a supplementary form of support, student societies and internships such as Leadership Initiatives often connect with local Nigerian states to deliver workshops on public health and agriculture, and are able to deliver appropriate education for unit use.

(4) Overcast weather can reduce solar performance during the tail end of the rainy season. A supplemental biomass heat source using locally available maize residues can provide backup drying capacity when solar input is insufficient, adding minimal cost and maximizing food quality and abundance (Okonkwo & Ertekin, 2022).

CONCLUSION

Aflatoxin contamination of maize in north-central Nigeria is a thermodynamic failure that occurs in a 48-hour window between harvest and safe storage. When maize stays above safe moisture levels during warm and humid conditions, farmers risk losing food and income as their households are exposed to contamination that cannot be detected by sight and taste. Subsistence farmers continue to feed their children a Group 1 carcinogen because there is no other choice.

The SGDP program targets this specific bottleneck. It adapts solar drying to the realities of smallholder communities instead of suggesting another expensive and impractical centralized system. Through decentralized operation, photovoltaic-powered airflow, locally sourced construction, cooperative ownership, and moisture-based quality control, an off-grid and budget-friendly solution addresses this failure without overreliance on foreign intervention. Most importantly, process simulation provides an engineering basis for the proposed design. Under modeled north-central Nigerian harvest conditions, an 8

m² collector operating at approximately 0.08 kg/s airflow could reduce a 500 kg maize batch to below 13% moisture in roughly 5-6 hours, helping reduce a major post-harvest pathway for aflatoxin contamination and contributing to the broader effort to reduce Nigeria's ₦3.5 trillion post-harvest loss burden.

The proposal would begin with a measurable pilot in Benue and Kaduna States and its success judged by farmers' ability to consistently achieve safe moisture levels while reducing drying time and contamination levels, and maintaining the equipment. If these outcomes are demonstrated, the model can be adapted and expanded to other maize-producing regions.

Solving food-security problems depends on keeping the food safe and available to communities that most need it. The SGDP offers a practical path in addressing one of Nigeria's biggest food-security gaps by targeting a major preventable point of loss between harvest and consumption.

REFERENCES

Abdurrazaq, M., Tijjani, B. M., & Atta, H. I. (2022). Assessment of aflatoxin contamination in maize and groundnuts during storage in Giwa community, Kaduna State Nigeria. ResearchGate. https://www.researchgate.net/publication/368449532

Adetunji, M. C., Atanda, O. O., Ezekiel, C. N., Dipeolu, A. O., Uzochukwu, S. V. A., Oyedepo, J., & Chilaka, C. A. (2017). Risk assessment of mycotoxins in stored maize grains consumed by infants and young children in Nigeria. Toxins, 9(7), 58. https://pmc.ncbi.nlm.nih.gov/articles/PMC5532550/

Adekunle, W., & Vincent, O. (2025). Analysing the determinants of healthcare insurance uptake in Nigeria. BMC health services research, 25(1), 1310. https://doi.org/10.1186/s12913-025-13422-0

Ahmad, A. (2002). Evaluation of a solar crop dryer for rural applications in Nigeria. ResearchGate. https://www.researchgate.net/publication/285636917

Ahmed, U.I., Ying, L., Bashir, M.K., Abid, M., Zulfiqar, F. (2017). Status and determinants of small farming households' food security and role of market access in enhancing food security in rural Pakistan. PLOS One, 2017, 12(10), e0185466. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0185466

Akinniyi, J.N. (2025). Assessment of total aflatoxin in selected crops using enzyme-linked immunosorbent assay (ELISA): A sustainable monitoring and control of aflatoxin in both rural and urban areas in Nigeria. Korean Journal of Food Preservation, 2025, 32(1), 65-76. https://www.researchgate.net/publication/389978789_Assessment_of_total_aflatoxin_in_selected_crops_using_enzyme-linked_immunosorbent_assay_ELISA_A_sustainable_monitoring_and_control_of_aflatoxin_in_both_rural_and_urban_areas_in_Nigeria

Akullo, J., Okello, D. K., Ogwang, J., Ogali, I., Okello, H., & Odong, T. L. (2025). A comprehensive review of aflatoxin in groundnut and maize products in Africa: Prevalence, detection and mitigation strategies. Journal of Food Quality, 2025, 2810946. https://doi.org/10.1155/jfq/2810946

Aminu A., Halliru M., Ubale S., Mustapha A., Mustapha A. L., Rano N.B., Idris A.A., Ladi H., & Bello M.M. (2022). Household productivity and poverty assessment in Sudano-Sahelian region, Northern Nigeria. British Journal of Multidisciplinary and Advanced Studies. https://bjmas.org/index.php/bjmas/article/download/147/version/351/412/159

Becker-Algeri, T. A., Castagnaro, D., de Bortoli, K., de Souza, C., Drunkler, D. A., & Badiale-Furlong, E. (2023). Quantitative assessment of aflatoxin exposure and hepatocellular carcinoma (HCC) risk associated with consumption of select Nigerian staple foods. Frontiers in Sustainable Food Systems, 7, 1128540. https://doi.org/10.3389/fsufs.2023.1128540

Bonkoungou, S., Dagno, K., Basso, A., Ekanao, T., Atehnkeng, J., Agbetiameh, D., Neya, A., Toure, M., Tiendrebeogo, A., Konate, M., Outani, B., Konlambigue, M., Callicott, K. A., Cotty, P. J., Dieng, I., Falade, T. D. O., Bandyopadhyay, R., & Ortega-Beltran, A. (2024). Mitigation of aflatoxin contamination of maize, groundnut, and sorghum by commercial biocontrol products in farmers' fields across Burkina Faso, Mali, Niger, and Togo. PMC. https://pmc.ncbi.nlm.nih.gov/articles/PMC11554699/

DAWN Commission. (2025). Reducing post-harvest losses in Southwest Nigeria. Development Agenda for Western Nigeria. https://dawncommission.org/wp-content/uploads/2025/09/Reducing-Post-Harvest-Losses-in-Southwest-Region.pdf

Falaju, J. (2021). Nigeria loses $997 million yearly to aflatoxin-induced liver cancer. The Guardian. https://guardian.ng/business-services/nigeria-loses-997-million-yearly-to-aflatoxin-induced-liver-cancer/

Food and Agriculture Organization of the United Nations (FAO). (2018). Nigeria small family farms country factsheet. FAO. https://openknowledge.fao.org/server/api/core/bitstreams/8ce31a78-2848-4388-87a9-a3b1abb73e40/content

Food and Agriculture Organization of the United Nations (FAO). (2024). Maize in human nutrition. FAO. https://www.fao.org/4/t0395e/T0395E04.htm

Food and Agriculture Organization of the United Nations (FAO). (2025). Latest food insecurity figures reveal persistent threats to the lives of 30.6 million people. FAO Nigeria. https://www.fao.org/nigeria/news/detail-events/en/c/1735060/

International Fund for Agricultural Development (IFAD). (2025). Nigeria country profile. IFAD. https://www.ifad.org/en/w/countries/nigeria

Kuhe, A., Ibrahim, J. S., Tuleun, L. T., & Akanji, S. A. (2022). Effect of air mass flow rate on the performance of a mixed-mode active solar crop dryer with a transpired air heater. International Journal of Ambient Energy, 43(1), 531-538. https://doi.org/10.1080/01430750.2019.1653970

Liu, Y., & Wu, F. (2010). Global burden of aflatoxin-induced hepatocellular carcinoma: A risk assessment. Environmental Health Perspectives, 118(6), 818-824. https://pmc.ncbi.nlm.nih.gov/articles/PMC2898859/

Malwad, D. S., & Sonawane, D. C. (2024). A review on recent advancements in indirect solar dryers. Journal of Renewable Energy and Environment, 11(1), 174-191. https://www.researchgate.net/publication/371280144_A_Review_on_Recent_Advancements_in_Indirect_Solar_Drying_of_Agricultural_Products

Meki, T. M., & Al-Qhtani, M. (2025). Toxicity, mitigation, and chemical analysis of aflatoxins and other toxic metabolites produced by Aspergillus: A comprehensive review. Toxins, 17(7), 331. https://doi.org/10.3390/toxins17070331

Mumba, J. (1995). Development of a photovoltaic powered forced circulation grain dryer for use in the tropics. Renewable Energy, 6(7), 855–862. https://doi.org/10.1016/0960-1481(94)00088-N

Mwalwayo, D. S., & Thole, B. (2016). Prevalence of aflatoxin and fumonisins (B1 + B2) in maize consumed in rural Malawi. Toxicology reports, 3, 173-179. https://doi.org/10.1016/j.toxrep.2016.01.010

National Institutes of Health (NIH). (2023). Aflatoxin toxicity. StatPearls. https://www.ncbi.nlm.nih.gov/books/NBK557781/

Ogundele, F. (2022). Post harvest losses and food security in Nigeria: An empirical review. African Journal of Food Science, 5(3), 77-89. https://www.researchgate.net/publication/365055741

Ogunniyi, A.I., Omotoso, S.O., Salman, K.K., Omotayo, A.O., Olagunju, K.O., & Aremu, A.O. (2021). Socio-economic drivers of food security among rural households in Nigeria: Evidence from smallholder maize farmers. Social Indicators Research, 155, 925-944. https://doi.org/10.1007/s11205-020-02590-7

Okonkwo, H. & Ertekin, C. (2022). Review on Solar Drying in Nigeria. Turkish Journal of Agricultural Engineering Research, 3(2), 397-429. https://www.researchgate.net/publication/366729472_Review_on_Solar_Drying_in_Nigeria

Oladeinde, O., Adamolekun, R., Mojeed, A., & Ekatt, N. (2024). Investigation: How Nigeria can resolve its multi-trillion naira post-harvest losses (IV). Premium Times. https://www.premiumtimesng.com/agriculture/agric-special-reports-and-investigations/724953-investigation-how-nigeria-can-resolve-its-multi-trillion-naira-post-harvest-losses-iv.html

Okojie & Jaiyesimi. (2024). Annual N3.5trn post-harvest loss swallows five-year agric budget. BusinessDay NG.

https://businessday.ng/agriculture/article/annual-n3-5trn-post-harvest-loss-swallows-five-year-agric-budget/

ScienceDirect Topics. (2022). Solar dryer overview. ScienceDirect. https://www.sciencedirect.com/topics/engineering/solar-dryer

Statista. (2024). Agriculture in Nigeria — Statistics and facts. Statista. https://www.statista.com/topics/6729/agriculture-in-nigeria/

Suherman, S., Asy-Syaqiq, M. A., Hadiyanto, H., Djaeni, M., & Prasetiyono, B. W. H. E. (2024). Advancements and 4E + Q performance analyses in solar drying for maize kernels preservation: A comprehensive review. Journal of Food Process Engineering, 47(6), e14659. https://doi.org/10.1111/jfpe.14659

Upev, S.K., Onu, J.I., Mshelia, S.I., Michael, A. (2022). Poverty and its alleviating strategies among rural farming households in Benue State, Nigeria. Academia.edu. https://www.academia.edu/61611720/Poverty_and_its_Alleviating_Strategies_among_Rural_Farming_Households_in_Benue_State_Nigeria

Uwa, R. U., Nworie, I. C., Agbo, P. E., Otah, P. B., Famuyibo, D. A., Brown, N. W., & Ugo, B. E. (2024). Design of a low-cost natural convection solar tunnel dryer to reduce postharvest losses in Abakaliki, southeastern Nigeria. World Journal of Advanced Research and Reviews, 24(2), 984-989. https://doi.org/10.30574/wjarr.2024.24.2.3328

Weather in Nigeria during October. (2026). Travelscoop. https://travelscoop.co.uk/weather-october/nigeria

Weather Nigeria in October 2026: Temperature & Climate. (2026). Climate-Data.org. https://en.climate-data.org/africa/nigeria-153/c/october-10/

World Food Programme (WFP). (2025). Economic hardship, the climate crisis and violence in the northeast projected to push 33.1 million Nigerians into food insecurity in 2025. WFP. https://www.wfp.org/news/economic-hardship-climate-crisis-and-violence-northeast-projected-push-331-million-nigerians

Wudil, A. H., Ali, A., Aderinoye-Abdulwahab, S., Raza, H. A., Mehmood, H. Z., & Sannoh, A. B. (2023). Determinants of food security in Nigeria: Empirical evidence from beneficiaries and non-beneficiaries of rice farmers of the Kano River Irrigation Project. Frontiers in Sustainable Food Systems, 7, 999932. https://doi.org/10.3389/fsufs.2023.999932