TO WHAT EXTENT DOES INCENTIVIZED TECHNOLOGY ADOPTION IMPROVE FARMERS' OUTCOMES? EVIDENCE FROM THE AGRESULTS AFLASAFE PROJECT IN NIGERIA

by

ADEDAYO A. ADEDIRAN

(Under the Direction of GENTI KOSTANDINI)

ABSTRACT

This study examines the effectiveness of the Aflasafe project in promoting structural support for agricultural development and poverty alleviation through an agricultural market-driven approach. Using data from the Aflasafe Final project and the Living Standards Measurement Survey, the study investigates changes in farmers' productivity and market participation due to their participation in the program. The results indicate that the AgResults model helps solve critical structural challenges and improves farmers' productivity and market participation. However, factors such as farm size, educational status, gender, seasonal rainfall, and fertilizer cost have varying impacts on productivity and market participation, highlighting the importance of considering social and economic contexts. The study concludes that the AgResults model represents a viable solution to address structural issues in agriculture and can potentially transform the agricultural sector globally.

INDEX WORDS: Agricultural Technology Adoption Project, Propensity Score Matching, Aflatoxin, Nigeria

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BTech, Ladoke Akintola University of Technology, 2018

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2023

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May 2023

DEDICATION

I dedicate my work to Almighty Allah, who have persistently and consistently showed up for me before and during this program. I appreciate my one-in-a-million parents Mr. & Mrs. Adediran who set the path to this, every success I have achieved and will achieve, through their dedication, prayers, moral and financial support. I am also grateful for the ever-relenting support and love of my incredible sibblings - Halimat Adediran, Zainab Adediran and Faruq Adediran who have been through thin and thick with me from the very beginning. My heartfelt gratitude to my beautiful partner and best friend, Ekram Mohammed for her emotional support and love through this program and choosing to walk with me even in the most turbulent days. This would not have been possible without any of you.

ACKNOWLEDGEMENTS

I would like to acknowledge my advisor, Professor Genti Kostandini for his continuous support, and guidance throughout this project. His kindness and understanding spirit is one-of-a-kind. I would also like to thank Dr. Ellen McCollough for the valuable pep talks that made this thesis a success. Her passion for her students and research is inspirational. Thank you to Dr. Mateusz Filipski for his valuable comments and feedback which helped improve this thesis. I also acknowledge my committee of friends and family for their support which made my time at UGA eventful.

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CHAPTER 1

INTRODUCTION

Recently, there has been a surging interest in understanding the impact of technology adoption on farmers' productivity. With the rapid pace of technological progress, there is a need to understand how these advancements can be leveraged to improve farmers' livelihoods, especially in developing countries. The Aflasafe project in Nigeria is a prime example of incentivized technology adoption aimed at improving farmers' productivity and increasing their income. The Aflasafe project, backed by the AgResults initiative, has been implemented in Nigeria to address the problem of aflatoxin contamination in crops. Aflatoxins are toxic compounds produced by certain strains of the fungi *Aspergillus flavus, A. parasiticus*, and *A. nomius (Kumar et al., 2017; Payne & Brown, 1998)* that infects crops such as maize and groundnuts (Jelinek et al., 1989; Severns et al., 2003) significantly reducing crop yield and quality. The Aflasafe project gave farmers access to the Aflasafe technology that effectively controls aflatoxin contamination, improving crop yield and quality. Aflasafe, which is developed by the International Institute of Tropical Agriculture (IITA) in Nigeria in partnership with the Agriculture Research Service of the United States Department of Agriculture and the University of Ibadan, is a product created from four native strains of non-toxic Aspergillus fungi: Aspergillus flavus L, Aspergillus flavus S, Aspergillus parasiticus AP01, and Aspergillus parasiticus SM01. These strains outcompete and displace the aflatoxin-producing strains in the soil ("Tackling Toxins with Aflasafe™," 2013).

This thesis examines the impact of incentivized technology adoption on farmer productivity, using data collected in the Aflasafe project's final year as well as data from the World Bank Living

Measurement Survey for states that were not part of the Aflasafe project. This analysis provides provide valuable insights into the extent to which incentivized technology adoption improves farmer productivity and the impact it has on their livelihoods. The study focuses on the average yield per hectare, which is a critical metric for assessing farmers' productivity. By examining the data from both sources, we provide a comprehensive evaluation of the impact of incentivized technology adoption on farmer productivity and shed light on its role in improving farmers' livelihoods. The findings of this study are of significant interest to policymakers, development organizations, and the agricultural sector, and provide valuable insights into the effectiveness of incentivized technology adoption to improve farmer productivity.

In conclusion, this thesis contributes to the existing body of knowledge on the impact of technology adoption on farmer productivity and provides evidence-based recommendations for improving farmers' livelihoods in developing countries.

The structure of the rest of the thesis is as follows: Chapter 2 presents a literature review. Chapter 3 details the data, methodology and empirical methods used for our analysis. Chapter 4 presents the results and discusses the relationship between participation in the project and maize yield and profitability. Finally, Chapter 5 summarizes the findings and offers concluding remarks.

CHAPTER 2

LITERATURE REVIEW

2.1 Maize Production in Nigeria and Sub-Saharan Africa

Maize (Zea mays) is Africa's most important staple crop, grown on nearly 30 million hectares of land and supporting over 300 million people on the continent (Fisher et al., 2015). The crop occupies approximately 24% of the total farmland in Africa and it is grown on over 40 million hectares of sub-Saharan Africa (JECFA, 2018; Blankson et al., 2019; Sirma et al., 2018). It is also commonly referred to as corn (Kosemani & Bamgboye, 2021). Maize is the primary cereal cultivated in over half of the countries in Sub-Saharan Africa and one of the top cereals in more than three-quarters of these countries (FAO, 2021). People consume more than 100g of maize per day in over half of the countries in the region. According to the International Institute of Tropical Agriculture, Nigeria produces the highest quantity of maize in Africa, with over 33 metric tons/year, with 78% of the production aimed for human consumption (USDA, 2012). With the region's population projected to double over the next 30 years (Krishna et al., 2021), the demand for cereals is expected to increase threefold (Van Ittersum et al., 2016). Another major factor expected to drive this high demand, especially in Nigeria, is increased income and demand for animal protein. Given the importance of maize as a primary livestock feed, increasing human demand for animal protein will inadvertently lead to more demand for maize. Between 2003 and 2015, Nigeria's feed volume increased by 600% from three hundred thousand to 1.8 million tons (Liverpool-Tasie et al., 2017). The expected increase in direct and indirect demand for maize poses new food safety threats across Sub-Saharan Africa. However, unlike other major crops such as rice, wheat, and soybean, where there are similarities in yield growth rates in high and low-income countries, there remains a large gap between the maize yield growth rates of high- and low-income countries (Iizumi et al., 2018).

In contrast to global maize trends, maize production has been associated mainly with an increase in the area rather than yield in most of Sub-Saharan Africa(Carletto, Jolliffe, et al., 2015). Between 1961 to 2019, the area under maize production in West African countries increased by 456.2% from 2,332,309 ha to 12,972,300 ha relative to an increase in yield from 96,090 ha/hg to 231,815 ha/hg, equivalent to about 141.25% growth (Achli et al., 2022). This pattern of expansion-based production growth is only sustainable in the short run.

Based on production potentials, Nigeria is divided into four groups: low, medium, medium to high, and high maize production potential. According to a PWC 2021 report, maize yield in Nigeria stands at less than two tonnes per hectare (t/ha) relative to 4.9 t/ha and 4.2 t/ha in South Africa and Ethiopia, respectively**.** Given this comparatively low average yield of maize despite being the largest producer of maize in Africa, the country is shifting significant attention to finding innovative ways to produce maize varieties that are high-yielding and highly tolerant to diseases, droughts, and pests.

Intercropping with maize is common, particularly among farmers who operate on a subsistence level and engage in semi-intensive agriculture. Eneh and Onwubuja (1997) advocated mixed cropping of maize as a method for greater land utilization and an increase in yearly crop production compared to maize mono-planting. Their study found that maize mono-planting led to lower crop yields. The fact that vast tracts of land have been set aside for the cultivation of maize is evidence that the crop can satisfy the demands of the global food market. In 2018, Nigeria was the country in Africa that produced the most maize, with 4.8 million hectares of land producing 10.2 million tons (Abdulkareem & Fatima, 2021). Several advancements have been accomplished thanks to the aid of breeders and agronomists. One of these is the establishment of proliferating cultivars with resistance to disease, Striga infestation, and low nitrogen (Kamara et al., 2014).

2.2 Climate, temperature, and rainfall requirements

Due to the fact that there are so many different breeds of maize, it can be cultivated in a diverse array of climatic circumstances. However, typically maize requires consistent heat throughout its active life. Ideally, the crop does well in areas characterized by isotherms between 21 °C and 27 °C during the warmest month. In contrast, maize does not grow well in areas with growing seasons characterized by temperatures below 14 °C (Adeagbo et.al. 2021; Isonguyo, 2020). Despite being able to withstand temperatures as high as 35 °C, maize yields can be negatively affected by high temperatures, especially when it coincides with pollen release. At various phases of growth, maize reacts differently to temperature fluctuations. A temperature of around 18 degrees Celsius seems to be ideal for germination. Poor germination rates come from temperatures under 14 degrees Celsius, typical of the dry harmattan season (Kamara et al., 2020). Cold and moist conditions are ideal for several microorganisms that cause illnesses in maize seedlings and kernel rots (Ezeaku et.al. 2020).

Beyond the heat requirement, maize requires a sufficient water supply, which means farmers in sub-Saharan Africa interested in an all-year-round planting may need to adopt irrigation during the dry seasons. Ideally, the crop requires between 480 to 880 mm of evenly dispersed precipitation, depending on the variety (Blessing et al., 2021). In the early growth phases, the crop's moisture requirements are minimal, but they rapidly increase until the blooming stage and subsequently decline as the crop matures. A brief period of stress during blossoming, when maize is most susceptible to moisture stress, can reduce crop yield by 30–35% (Kamara et al., 2020). Based on rainfall and plant cover, Nigeria's ecological zones have been established and represent differences in agricultural practices and productivity limitations (Climate Change Knowledge Portal, 2021). Based on growth potential, the Sudan savanna and the southern and northern savannas of Guinea have been identified as the best regions for optimal returns for maize production (Durodola & Mourad, 2020). The southern Guinea savanna has an average annual rainfall of roughly 1000 mm, which spans 170 wet days between late May and early October. The northern Guinea savanna receives roughly 800-900 mm of rain during 150–160 wet days (Odekunle, 2004). In the Sudanese savanna, yearly rainfall is rarely more than 700 mm and typically spans 120 wet days (Offiah et.al. 2020). The cultivars that are suited to various zones, as well as the production potential, vary greatly. The potential steadily rises from Sudan to the savanna zones of southern Guinea. Nonetheless, farmers from other zones of the country can still obtain good numbers from planting maize thanks to cultivars that can withstand various climatic conditions.

2.3 Challenges to maize production in Nigeria

2.3.1 Inadequate soil fertility

One of the reasons why the country's agricultural projects have not been successful has been attributed to poor soil fertility. A common feature of Nigerian soils is their high degree of weathering, resulting in the presence of low-activity clays like kaolinite. This characteristic renders them susceptible to fertility depletion when utilized for continuous arable farming with insufficient nutrient replacement (Federal Fertilizer Department, 2012). Inadequacies in primary macronutrients such as nitrogen, phosphorus, and potassium are prevalent and have been documented in various regions throughout the country (Ekeleme et al., 2014; Hengl et al., 2017).

On the part of farmers, limited knowledge and ineffective land management have been responsible for a significant number of instances of soil abuse and harm (Tambo & Abdoulaye, 2013). Although management is a problem, the results suggest that the challenges affecting soil fertility are also heavily determined by the circumstances of the climate and the environment (Akinfenwa, 2020).

Along with soil erosion, the other main causes of low yields include a decline in organic material and soil bioactivity, a decline in soil structure and other soil physical qualities, a reduction in the presence of essential minerals (N, P, and K), and an increase in toxicity brought on by acidification or pollution (Lal & Okigbo, 2020). Nigeria is one of the countries with considerably diminishing soil fertility, according to FAO (2000). Nigeria lost 48 kg of nutrients per hectare (ha) in 2000 compared to 100 kg of nutrients per year, or 24 kg of nutrients per hectare (ha) in 1990, 4 kilograms of P_2O_5, and 10 kilograms of K_2O. The amount has purportedly decreased significantly due to interventions made by succeeding administrations and other international organizations through investments in fertilizer (Food and Agriculture Organization, 2022).

According to Kehinde and Umar (2021), most of the country's soil is naturally low fertile and needs more nutrients replenished. Nigeria is one of the sub-Saharan African nations with the lowest per-ha use of mineral fertilizers, with 10 kg of nutrients (N, P_2O_5, K_2O) annually, compared to the global average of 90 kg, 60 kg in the Near East, and 130 kg/ha annually in Asia.

2.3.2 Aflatoxin

Aflatoxins are highly toxic compounds that can cause severe health effects, including death, to humans and animals (Bryden, 2012). Prolonged exposure to aflatoxins is a significant cause of stunting and liver cancer (Gong et al., 2004). Aflatoxins are not safe at any level of exposure and may even cause death (Williams et al., 2004) and have also been linked to the rapid progression of HIV/AIDS (Gong et al., 2002; Turner et al., 2003). Beyond the health impacts of directly consuming aflatoxin-contaminated food on human beings, there are also adverse impacts on livestock consuming aflatoxin-contaminated feed, with reports of reduced growth and productivity rates of the animals (Bryden, 2012). Four Aflatoxin types have been found in agricultural produce Aflatoxin (AFB1), AflatoxinB2 (AFB2), Aflatoxin G1, and Aflatoxin G2. However, AFB1 and AFB2 are the two most significant, with AFB1 said to be the most virulent (V & Vasanthi, 2003). Crops susceptible to aflatoxins include maize, groundnuts, chili peppers, cottonseed, and tree nuts (Cotty et al., 1994; Cotty & Bhatnagar, 1994; Singh & Cotty, 2019). Typically, these crops become contaminated before harvest, and if conditions are favorable for toxin formation, the concentration of aflatoxins continues to increase during storage (Bandyopadhyay et al., 2007; Diedhiou et al., 2011; Kachapulula et al., 2019). Groundnuts and maize are particularly susceptible to aflatoxins. Since maize is an essential crop for food security in Africa, controlling aflatoxins in maize can significantly impact the region's development (Liu & Wu, 2010; Williams et al., 2004).

Most import-dependent countries set a minimum aflatoxin tolerance threshold per crop, resulting in African farmers losing over US$450 million yearly in export potential. For instance, the European Union rejected over 10 million USD of chili peppers from Ethiopia in 2017. These types of incidences pose dire effects on Africa and its already-struggling economies. The situation is even worse in Sub-Saharan Africa (SSA), where human and animal aflatoxin exposure is relatively high compared to other regions (JECFA, 2018; Sirma et al., 2018; Blankson et al., 2019). A study by (Ogara et al., 2017), reported that 47% of their samples of Nigerian maize exceeded the European Union limit of 4 µg/kg for aflatoxins in food. Figure 1 illustrates the prevalence of Aflatoxin in Nigeria.

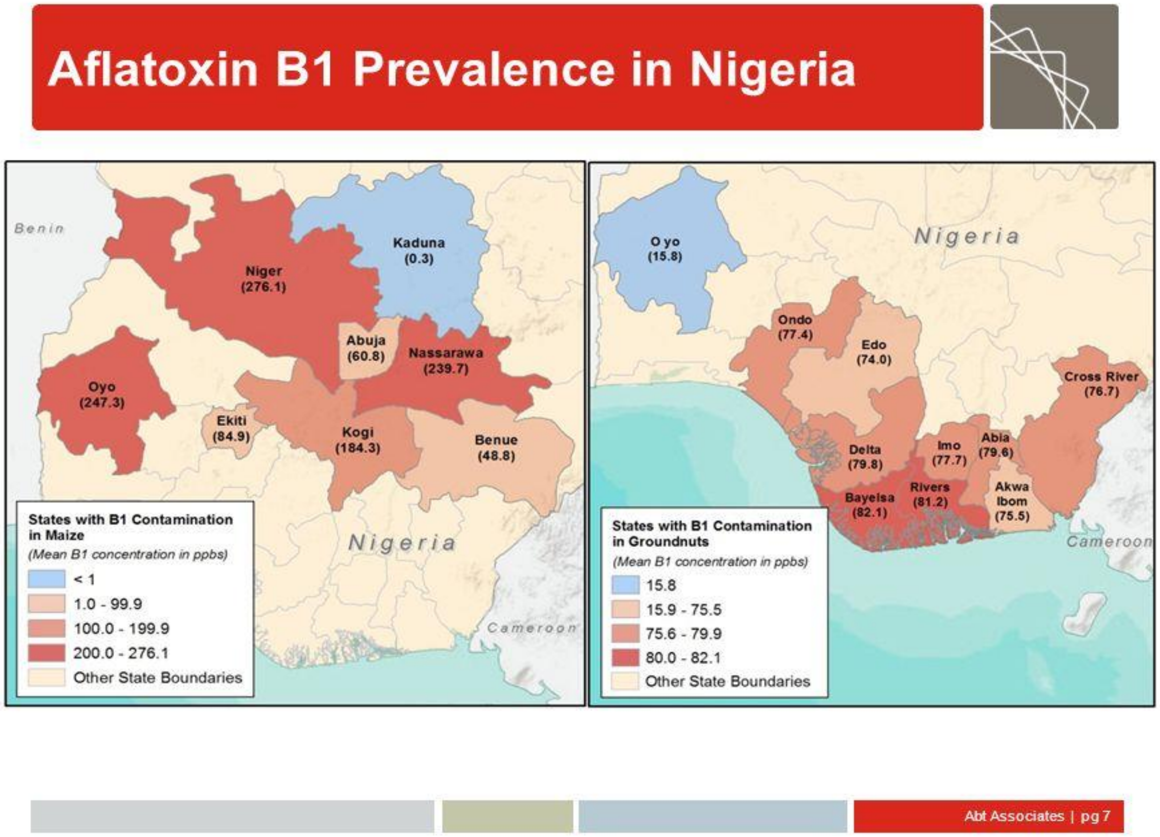

Figure 1: Aflatoxin B1 Prevalence in Nigeria *(Source: Abt Associates (2013)*

In Nigeria and many other African countries, regulations for aflatoxins are in place, but there needs to be more enforcement of these regulations. Additionally, small-scale farmers in Nigeria commonly consume the maize they grow, which means that a large portion of the maize consumed is not subject to regulation as it never enters the market (AgResult, 2020). Other factors contributing to the ineffectiveness of rules include unregulated markets, a lack of adequate infrastructure, skilled labor, and financial incentives to measure aflatoxins (Williams et al., 2004). In cases involving observable food quality attributes, sellers typically are forced to go for lower prices. For instance, Kadjo et al. (2016) found that buyers in the Republic of Benin bargain for lower prices for grains visibly affected by insect infestation. Contrarily, sellers' typical approach to having more information than buyers about potential food safety risks is to offer more for sale. Although other key players along the food value chain (e.g., food processing companies) exercise caution in offering food items that comply with safety regulations for fear of displeasing their customer base (Hoffmann & Moser, 2017), they tend to gain little to nothing for taking such risk. Hoffmann et al. (2020) found that the premium price sellers gained for selling aflatoxin-safe maize during a marketing campaign organized by a major supplier of maize flour in Kenya didn’t sustain beyond the campaign. When critical characteristics of food products are only sometimes verifiable, disregarding food safety regulations can even be more costly, given that it becomes even more challenging for consumers to ascertain the level of toxicity of the product they buy (Sanou et al., 2021).

Research on aflatoxin contamination in Africa is more than 50 years old (Logrieco et al., 2018), and there persists a growing need to translate research findings into applications to fight the menace as more than 500 million Africans are still exposed at multiples of acceptable limits.

2.4 Aflasafe as an effective tool for combating Aflatoxin.

There have been many strategies to combat aflatoxin contamination at different stages of production (Aoun et al., 2022; Mahuku et al., 2019; Seetha et al., 2017). In Nigeria, for instance, initial efforts included testing fungal communities linked to maize and field soils and assessing the aflatoxin-producing potentials of the fungi (Atehnkeng et al., 2008; Donner et al., 2009). However, when used in isolation, most of these practices have proven to be limited in effectively reducing contamination above safe, import-permissible thresholds, especially in tropical and subtropical countries (Ayalew et al., 2017). A proven effective, and practical strategy is using atoxigenic isolates of Aspergillus flavus as biocontrol agents (Ortega-Beltran et al., 2022). Atoxigenic isolates used on the field at the right stage of crop production create a founding population that fights off toxin-producing strains of *A. flavus* from the field through the deliberate introduction of indigenous but non-toxic, harmless strains – a process known as 'competitive exclusion,' and thus reduce aflatoxin accumulation in treated crops. In light of this, the United States Department of Agriculture developed the Aflasafe™ - Agricultural Research Service (USDA-ARS) for cottonseed production in the United States. Aflasafe™ is a biocontrol product that uses specific strains of the Aspergillus fungus that do not produce toxins, which competes with and reduces the presence of the toxic strains. The technology was extended for use in other aflatoxin-prone crops produced in the United States, including maize, groundnut, almond, and figs. Heat-killed grains are coated with Aflasafe™ and scattered by hand in the field before crop flowering.

In 2003, the International Institute of Tropical Agriculture (IITA) collaborated with USDA-ARS and several other national institutions to adapt and improve the biocontrol technology for use in Nigeria and other Sub-Saharan nations (Bandyopadhyay et al., 2016). In 2014, Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) approved the complete registration of Aflasafe™ for unrestricted use in both maize and groundnut across Nigeria. Field tests in Nigeria between 2009 and 2012 showed that the use of Aflasafe™ consistently reduced aflatoxin contamination in maize and groundnut crops by 80-90% (Bandyopadhyay et al., 2016; Ezekiel et al., 2019). The benefits of Aflasafe continue during crop storage because the non-toxic *A. flavus* remains on maize, competing with the toxic *A. flavus* strains that would otherwise increase aflatoxin levels during storage. In 2012, these findings led to the production of several atoxigenic biocontrol products under the trade name Aflasafe and the wide adoption of the biocontrol product for commercial use in several African countries, including Nigeria, Ghana, Senegal, Burkina Faso, Tanzania, Kenya, Zambia, Malawi, and Mozambique (Moral et al., 2020). Each product contains four atoxigenic isolates of A. flavus native to each country as an active ingredient. These isolates belong to atoxigenic African A. flavus VCGs (AAVs), and a few products contain AAVs unique to one or more countries (Agbetiameh et al., 2019; Moral et al., 2020).

Aflasafe can be applied at any time during the growing cycle and does not affect crop yields or the natural level of fungal colonization. Aflatoxin biocontrol products have been used and adopted by farmers in the United States for more than 15 years. Nigeria is the first African country to approve the use of treatment officially. The cost to produce one kg of Aflasafe varies across locations and can range from US $0.7 to $1.2 (Bandyopadhyay et al., 2016). In Nigeria, poultry feed processors constitute the significant buyers of Aflasafe due to the adverse impacts of aflatoxins on poultry (Hoffmann et al., 2018). These companies typically provide Aflasafe and other inputs to farmers in a contract-farming setup.

However, despite the proven effectiveness of Aflasafe in controlling Aflatoxin, widespread contamination persists primarily because many actors in the maize value chain still need to learn about the dangers of aflatoxins or possible solutions such as Aflasafe. Although aflatoxin levels in food can only be accurately quantified with laboratory testing, Hoffmann et al. (2013) reported that retail prices of maize in Eastern Kenya were negatively correlated with the number of discolored kernels in the grain sample and suggested that the discoloration of kernels (which is observable) may serve as a pointer to buyers about the level of contamination (which is unobservable) in maize. However, the level of awareness about Aflatoxin and its consequences along maize and groundnut value chains still needs to be higher (Johnson et al., 2018). According to a study by Ezekiel et al. (2013), only 15% of consumers in five Nigerian states (Lagos, Ogun, Oyo, Niger, and Kaduna) were aware that groundnut (peanut) cakes could be Aflatoxin contaminated. Similarly, (De Groote et al., 2016) found from their study in Kenya that 64% of consumers interviewed knew about Aflatoxin, but only 16% were aware of its health risks. (Ragona, 2016), in a review article, argued that consumers need more evidence of the level of understanding of Aflatoxin.

In a study by Johnson et al. (2018) to assess the extent of awareness and understanding of Aflasafe and Aflatoxin among smallholder farmers in Nigeria, it was found that 100% of the surveyed farmers were aware of Aflatoxin in states where the farmers had experienced with Aflasafe. In Kwara and Benue, selected for general awareness of Aflasafe, 1% and 8% of surveyed farmers still needed to hear about Aflatoxin in each state. In the states of Bauchi and Nasarawa selected for not being aware of Aflasafe, 27% and 13% of the survey farmers were aware of Aflatoxin, respectively, in each state. These results show a correlation between the level of awareness of the aflatoxin problem/benefits of Aflasafe usage and interventions—high in the states with interventions and low in the states without intervention. Awareness of Aflatoxin and continued usage of Aflasafe was also correlated with the level of education and use of other inputs.

2.5 The AgResults Aflasafe Project in Nigeria

The AgResults Aflasafe Pilot Project started in Nigeria in 2013 under the supervision of the World Bank. The project aimed to promote the uptake of Aflasafe technology among smallholder farmers in Nigeria and, in turn, influence a long-term positive change in income and health outcomes of farmers and the public. The AgResult project raised awareness of aflatoxins and built market linkages that created a premium market by tying a monetary prize to a higher-quality product. The project offered a per unit payment premium $18.75 for each metric ton of high-Aflasafe™ maize to aggregators and grain traders for each metric ton of acceptable levels of Aflasafe strains (Bandyopadhyay et al., 2016; Johnson et al., 2018). This amounted to approximately 4.7% of the average price of maize, which was around $400 in Spring 2017. The premium covered more than the cost of Aflasafe per hectare, which was $7.50 per metric ton of maize, considering Aflasafe cost $1.5 per kilogram (Narayan & Geyer, 2022).

To qualify for the incentive payment, the maize needed to have over 70% Aflasafe concentration based on tests by an independent verifier. Additionally, the project required that the competitors aggregate the maize from smallholders. However, project did not verify the aggregation. The competitors were expected to sell the AT maize to downstream buyers who were willing to pay a premium for maize with lower aflatoxin levels.

After successfully working with 46 implementers who partnered with over 60,000 farmers from different parts of the country, the project closed out in 2019. Before the project's launch, there were a handful of instances of a partnership between the private sector and farmers in Nigeria (ABT Associates, 2014). The project sought to break that ground by creating an avenue for collaboration between farmers and private enterprises. The Project Management Unit works directly with private businesses, primarily agribusinesses called implementers, who, on the other hand, work directly with smallholder farmers. 'Implementers,' as they were called, were primarily established private enterprises with vested interests in agribusiness, specifically maize farming. On the other hand, smallholder farmers are maize farmers who farm on at most five hectares of land. Before the intervention, these farmers were not engaged in market-driven agriculture and could not produce a surplus. The partnership works such that the smallholders provide land and sometimes labor while the implementers supply technical, managerial, and market support. The implementers also assist the farmers with access to essential farm inputs and modern technology that could contribute to their agribusiness shareholdings. The Project Implementation Unit did not interfere in the partnership between the implementers and the smallholder farmers. This setup allows the implementers to engage in different business models without the influence of the Project Management Unit.

2.6.1 The Project Design

The AgResults project was based on the Theory of Change and rested on the notion that adequately incentivizing the private sector can aid the creation and scaling of new technologies which benefit smallholder farmers. Conceptually, the AgResults Aflasafe Project sought to tackle the risks of investing in the supply of high-quality maize with reduced aflatoxin levels by temporarily offsetting the underlying conditions – primarily uncertain demand – with guaranteed financial compensation for successfully taking on the supply-side risks of aggregating and selling more high-quality products (AgResults, 2018). The prize competition was set and worked by awarding participating private sector agents (aggregators and off-takers) US$18.75 for each metric tonne of Aflasafe™ - treated maize they procured from smallholder farmers. To qualify for the incentive payment, the maize was required to pass a verification process that tests for Aflasafe™ content in a laboratory before they are procured from smallholder farmers. The verification was designed such that aggregators that aggregated maize with ≥ 70% Aflasafe™ prevalence would be eligible for 100% of the prize. Maize with less than 70% Aflasafe™ prevalence would not qualify for any prize. Due to the time required to conduct the laboratory test, participating competitors were paid annually after the laboratory tests were completed, compiled, and reviewed. The first payment was rolled out in the 2014 cropping season. Over a period of four years, the Implementers received a total of $972,387 in incentives through the AgResults Pull mechanism for achieving efficient business results that match the defined development problem and outcome (AgResults, 2017). In addition, within five years, they received a total of $1,482,124.5 in premiums from selling quality maize to niche markets. Figure 2 illustrates an overview of the project's operational models.

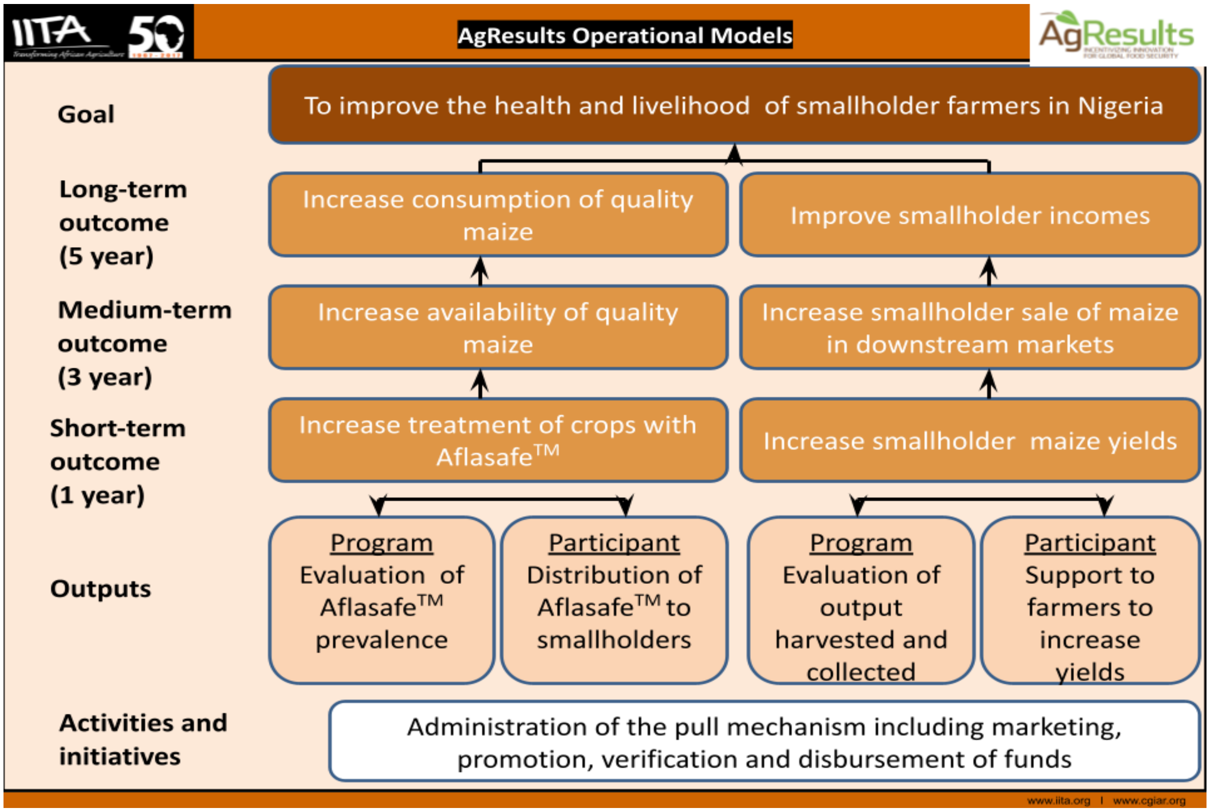

Figure 2: AgResults Operational Models (*Source: AgResults Nigeria Aflasafe Challenge Project - Final Report (2013 - 2019)*.

Competitors were selected throughout the country. Competitors were primarily private organizations who managed contract maize farming throughout the country. To qualify, a competitor had to work with and train a minimum of 300 farmers (from anywhere in the country) on the use of Aflasafe^{TM}, with no more than 5% of the farmers having a farm size above 5ha with a maximum acceptable size of 10 ha.

The term "aggregators," as used in the project, refers to competitors who had the following commitments:

- Work with a minimum of 300 smallholder farmers with ≥ 10 ha of land per smallholder farmer
- Provide Aflasafe™ to participating smallholder farmers
- Provide technical assistance to participating smallholder farmers
- Provide some or all required inputs as production finance for smallholder farmers to repay after harvest
- Aggregate (store, handle, market) Aflasafe™-treated maize and deliver it to end consumers such as feed mills, fish producers, poultry operations, and human consumption food processors.

Due to a lack of public confidence in the project in the first year, occasioned by little awareness of Aflatoxin and Aflasafe™ and the absence of a market for premium maize, there was low participation in the first year with only 1,015 farmers participating. Even when the first set of competitors was commissioned, there needed to be more farmers' involvement as most competitors needed more confidence in the technology and wanted to test it out themself before involving the farmers. The few farmers who were involved only tested the technology on a small portion of their farmlands. Once competitors and farmers confirmed the benefits of Aflasafe™ at the end of the first year, adoption rates grew astronomically to 3,271 farmers in the second year (AgResults Lesson Learn Series, 2016). Due to low participation, the first year was reframed as a baseline year and called “Year 0.” The key statistics through the six years are highlighted in Figure 3.

Parameters	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Number of implementers	4	9	16	24	20	24
Total Aflasafe purchased (tons)	24	58.2	64	168.6	276.4	404.7
Number of farmers	1,015	3,271	6,279	13,372	25,591	26,260
Treated area (ha)	1,457	4,998	6,601	20,128	29,918	36,401
Number of farmers (Male)	859	2,764	5,434	12,102	23,913	21,201
Number of farmers (Female)	156	467	844	1,270	1,678	5,059
Average productivity (tons/ha)	3.9	2.6	2.6	2.8	3.2	3.5
Total Maize produced (tons)	5,682	12,995	17,163	56,350	95,739	127,404
Total Maize Aggregated (tons)	2,031	7,290	9,363	39,212	73,259	82,355
Total maize aggregated (%)	35.7	55.6	54.6	69.6	76.5	65%

Figure 3: AgResults Project Key Statistics for Six Years (*Source: AgResults Nigeria Aflasafe^{TM} Challenge Project - Final Report (2013 - 2019)*).

The project was implemented across 15 states of the country, highlighted in the map below.

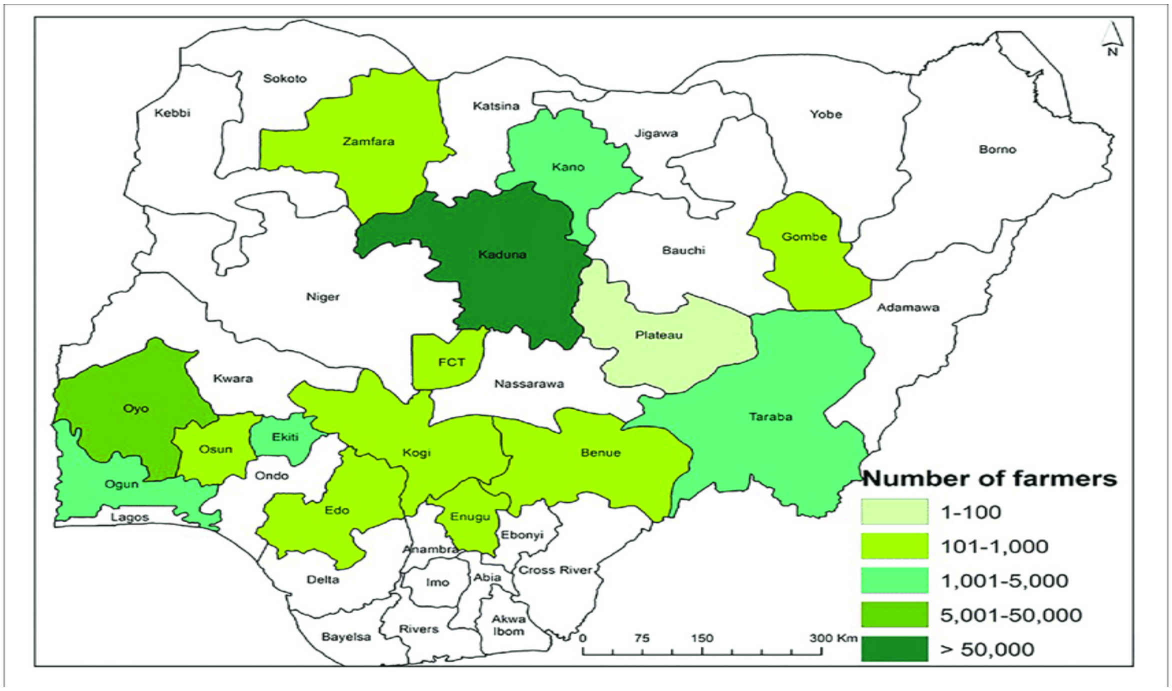

Figure 4: AgResults Project Map (Source: https://www.researchgate.net/publication/326997213)

According to Narayan & Geyer (2022), the project had a significant impact on the adoption of Aflasafe. In the villages targeted by AgResults, 57% of smallholders applied Aflasafe on at least one plot, a 56% point increase compared to the comparison group where only 1% of smallholders applied it. However, many of the participating smallholders did not apply Aflasafe on all their maize plots. Only 44% of the maize area in the treatment group was treated with Aflasafe, which is still a significant increase of 43% points compared to the comparison group. Interestingly, the study found that farmers either did not learn how to apply Aflasafe correctly or did not follow the instructions. Only 7% of the maize area in the treatment group was treated correctly, which is only 6% points lower than the comparison group. Despite the project's verification data showing that 93% of the maize passed the verification test, the evaluation found that participating farmers had a lower application rate than prescribed.

2.6.2 How the Implementers operated.

The Field Implementation level is the second layer of the project within the country, where the Implementers interact with smallholder farmers to establish a business relationship. The AgResults framework consists of nine pillars that provide support for the business and developmental partnership between the Implementers and the smallholder farmers.

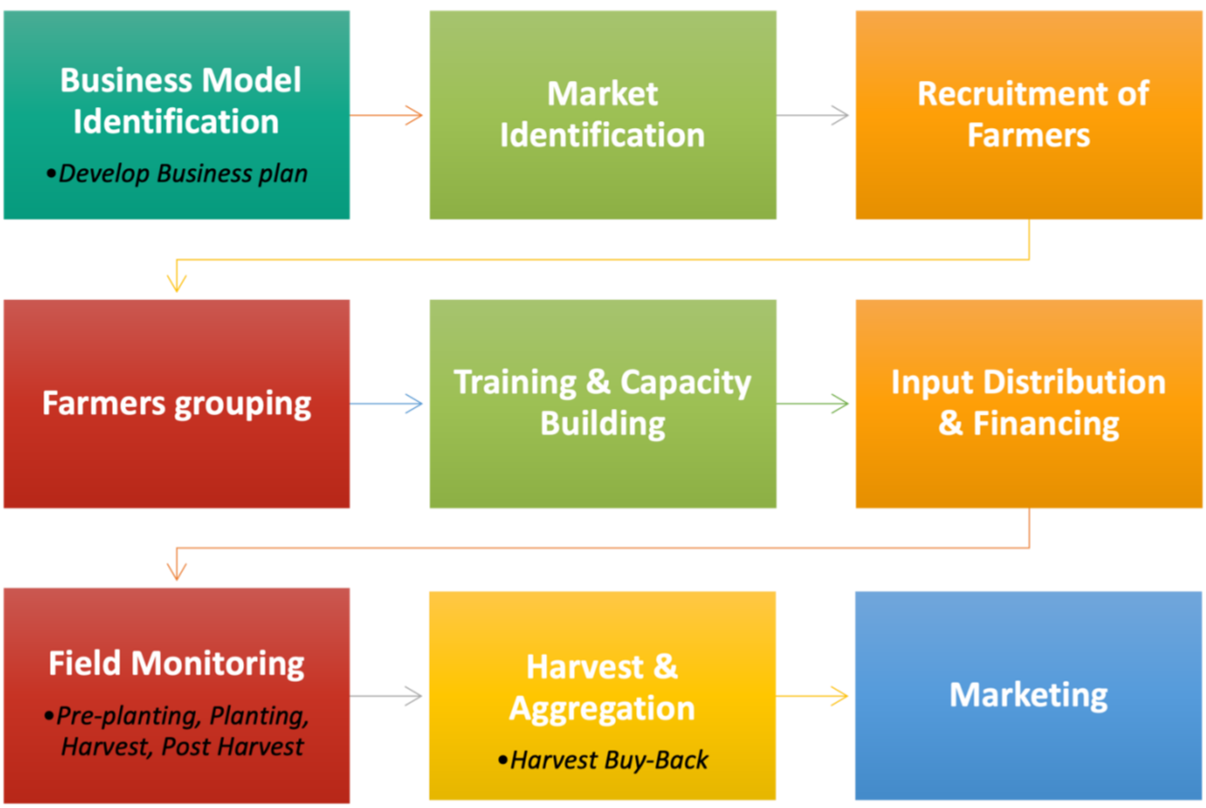

Figure 5. AgResults Implementers Agribusiness Framework

Identification of Business model: The Implementers of the AgResults project start by identifying a suitable agribusiness management approach and developing a strategic plan and business plan. They also secure sustainable financing and identify their human resource needs. Implementers use different approaches to engage staff, such as recruiting full-time or part-time employees or using ad-hoc staff as needed. All staff members receive training on agronomic practices and basic agribusiness management, including data management, bookkeeping, and information management. These trained staff members act as the intermediary between Implementers and smallholder farmers and provide agribusiness support to farmers, substituting the ineffective public sector-driven extension services.

Market Identification: The Implementers receive agribusiness training from the Project Management Unit and are encouraged to adopt a demand-driven approach to their business, producing based on specific requirements from processors rather than producing without knowledge of market needs. Before the AgResults Initiative, the norm among smallholder farmers was a supply-driven approach to agriculture. Implementers engage in early market identification to understand the specific requirements of different buyers and have a general idea about the maize market need. This understanding guides the type of maize they plant. They use the network built through the annual Innovation Platform and engage in independent market sourcing for their product beyond the Innovation Platform to achieve this.

Farmers Recruitment: The Implementers independently select smallholder farmers to work with each year based on different criteria they set. Selection criteria may include the farmers' history in agricultural practices, knowledge in maize farming, and interest in production for the market. All Implementers must meet the project implementation criteria for smallholder farmers outlined earlier, but they have some flexibility in their own selection criteria. Implementers screen and select farmers who closely match their criteria for the business venture.

Farmers Grouping: After the farmers are recruited, the Implementers may cluster them depending on the business model adopted, either before or after training. Trust groups are formed with 10-20 smallholder farmers, with a farmers leader for each group. Some Trust groups are further clustered into larger groups of 100-150 smallholder farmers, led by a Cluster leader. The leaders act as a bridge between the Implementers and the farmers, especially where large numbers of farmers are involved. Each farmer, Trust and Cluster group is given an identification code for documentation and data collection. Outstanding Trust and Cluster groups and their leaders are rewarded periodically for their business performance, which includes an increase in production and quality of crops. The awards are presented during the annual general Implementers and farmers meeting in the community where the project is being implemented. This is a way to sustain the interest of the smallholder farmers in group work and motivate them for quality performance.

Input and Input Financing: The Implementers provided smallholder farmers with necessary inputs to improve the quality and quantity of their maize crops, including access to Aflasafe and fertilizer. Harvest advances are also provided as a means of financing credit, which reduced side selling and increased aggregation of sales in formal markets. According to the Project Final Report, aggregation for sales in the formal market increased from 54% to 66% between 2013 and 2017 while sales in the informal market decreased from 38% to 13% within the same period. The ability of the farmers to honor their business agreement, including input loans and credit, determined their continuity with the Implementers in subsequent years.

Field Monitoring: The cluster and trust group leaders monitor the group's farming activities, from planting to harvest, and provide regular reports to the Implementer's staff. Inputs are distributed directly to farmers by Implementers to avoid possible rent-seeking. Cluster leaders support staff in supervising input utilization and help in disseminating information to farmers periodically.

Harvest and Aggregation: The implementers provide training on harvest and post-harvest management to smallholder farmers, which includes processes such as threshing, winnowing, cleaning, bagging, storage, and aggregation. Farmers label each bag of maize with an identification code provided by the implementers, which helps in verification and traceability. The percentage of maize collected by the implementers from smallholder farmers is based on the cost of inputs and financial credit given to farmers, with an interest rate of 3-10%. All the maize is aggregated by trust groups at community aggregation centers and then collected by the cluster group and implementer staff, who transfer it to a dedicated warehouse for quality analysis, verification, labelling, and marketing.

Marketing: The project organized market linkage workshops to connect Implementers with buyers, and some off-takers and Implementers form contractual agreements after the workshop. Implementers are responsible for sourcing their markets, and they conduct market surveys before planting to produce demand-driven crops. Implementers use various marketing strategies, such as high volume aggregation, value addition, and quality analysis to obtain premium prices from niche buyers. Smallholder farmers are given credit due to harvest advances, allowing them to delay sales until maize prices become favourable. The Innovation platform (IP) approach was used throughout the project to encourage business relationships between various actors in the Maize value-chain, such as food and feed processors, poultry industries, and implementers. The event was typically held once a year with the view to help the project actors in developing a better understanding of market challenges by discussing market requirements, supply and demand, and common business challenges while promoting relationships between Implementers and end-users of maize.

2.7 Study Area

Nigeria is located in West Africa, bordered by the Gulf of Guinea to the south, Chad and Niger to the northeast, and Benin to the west. With over 200 million people, the country is the most populous and the eighth-most populous country in the world (World Bank, 2021). Geographically, Nigeria is located in a tropical zone characterized by its equatorial and tropical rainforest climates. It spans several ecological zones, including the coastal mangrove swamps, the Guinean forest-savanna mosaic, and the Sahelian Acacia savanna. The country is home to several rivers, including the Niger and Benue rivers, which have provided fertile grounds for agriculture for centuries. Nigeria is divided into 36 states and the Federal Capital Territory. Each state is further divided into several Local Government Areas (LGAs), which are third-tier administrative divisions. In total, there are 774 LGAs in the country.

Nigeria's agricultural sector plays a significant role in its economy, contributing about 40% of its Gross Domestic Product (GDP) and providing employment for over 70% of the population. The Nigerian agricultural sector is characterized by small-scale farmers relying on traditional crop production techniques. The country is one of the largest producers of food crops in Africa. Nigeria's most widely grown crops include cassava, maize, yam, plantain, rice, sorghum, millet, beans, and cowpeas. The country is the largest producer of cassava in the world and is also a major producer of yam, plantain, maize, and sorghum. Additionally, Nigeria is a leading producer of palm oil and rubber. Despite its agricultural potential, the sector has faced several challenges, including low productivity, inadequate infrastructure, limited access to financing, and low levels of technology adoption, which limit the productivity and profitability of farmers. However, the diversity of Nigeria's climate and geography provides opportunities for farmers to grow a wide range of crops and for the country to tap into the potential of its agricultural sector. The sector has undergone some modernization in recent years, with new technologies, such as improved seeds, fertilizers, and other inputs, which have helped improve yields and increase productivity marginally.

CHAPTER 3

DATA AND METHODS

3.1 Nigerian General Household Survey (GHS)

The Nigerian General Household Survey (GHS) is a nationally representative survey of 5,000 households, implemented in collaboration with the World Bank Living Standards Measurement Study (LSMS) team as part of the Integrated Surveys on Agriculture (ISA) program. The survey includes a panel component (GHS-Panel) introduced in 2010 to develop an innovative model for collecting agricultural data, inter-institutional collaboration, and comprehensive analysis of welfare indicators and socioeconomic characteristics.

After close to a decade of visiting the same households, a partial refresh of the GHS-Panel sample was implemented in Wave 4 for the 2018/2019 sample to maintain the integrity and representativeness of the sample. The refresh sample consisted of 3,600 new households selected from a new set of 360 Enumeration Areas (EAs) and approximately 1,500 households from the original 5,000 GHS-Panel households from 2010. The combined sample of refresh and long panel EAs consisted of 519 EAs.

To collect detailed and accurate information on agricultural activities, GHS-Panel households are visited twice, first after the planting season (post-planting) between July and August and second after the harvest season (post-harvest) between January and February. All households are visited twice, regardless of whether they participated in agricultural activities. The sample generally maintains both national and zonal representativeness of the original GHS-Panel sample.

Overall, the GHS panel is a valuable source of information for policymakers, researchers, and development practitioners interested in monitoring and analyzing socioeconomic and agricultural trends in Nigeria.

Table 1 provides information on the sample of households successfully interviewed in both visits of the GHS-Panel, broken down by zone and sector, and the long panel and refresh sample. The final sample consisted of 4,976 households, of which 1,425 were from the long panel sample, and 3,551 were from the refresh sample. Table 2 presents data on the movement and attrition of long panel households in EAs retained for the Wave 4 sample. The overall attrition rate since 2010 across the EAs was 10.4%, with the highest attrition in rural EAs in South West (22.5%) and the lowest in rural EAs in North Central (4.7%). The table also shows the number of households interviewed in their original location and those that had moved and were interviewed in their new location. The number of households that had moved was in the urban South West at 46 households (25.7% of the sample). The combined sample is also roughly equally distributed across the six geopolitical zones. Two rural EAs in the North West were not visited due to conflict.

Table 1: LSMS Final Sample Distribution

Zone	Long Panel Sample	Refresh Sample	Combined Sample
NORTH CENTRAL	Urban 7 EAs, 61 HH	Rural 19 EAs, 181 HH	26 EAs, 242 HH
NORTH EAST	Urban 3 EAs, 28 HH	Rural 21 EAs, 200 HH	24 EAs, 228 HH
NORTH WEST	Urban 5 EAs, 46 HH	Rural 22 EAs, 211 HH	27 EAs, 257 HH

Zone	Long Panel Sample	Refresh Sample	Combined Sample
SOUTH EAST	Urban 7 EAs, 61 HH	Rural 19 EAs, 175 HH	26 EAs, 236 HH
SOUTH SOUTH	Urban 8 EAs, 63 HH	Rural 18 EAs, 158 HH	26 EAs, 221 HH
SOUTH WEST	Urban 21 EAs, 179 HH	Rural 8 EAs, 62 HH	29 EAs, 241 HH
TOTAL	Urban 51 EAs, 438 HH	Rural 107 EAs, 987 HH	158 EAs, 1,425 HH for Long Panel Sample; Urban 116 EAs, 1,135 HH

Table 2: Attrition and Movement of Long Panel Sample 2010–2019 (# of HH)

Zone	Original sample* (2010)	Successfully Interviewed in W4 (2019)	Original location Moved (tracked)	Total attrition (%)
NORTH CENTRAL				
Urban	70	50	11	61
Rural	190	176	5	181
Total	260	226	16	242
NORTH EAST				
Urban	30	24	4	28
Rural	210	195	5	200

Zone	Original sample* (2010)	Successfully Interviewed in W4 (2019)	Original location Moved (tracked)	Total attrition (%)
Total	240	219	9	228
NORTH WEST				
Urban	50	42	4	46
Rural	230	204	7	211
Total	280	246	11	257
SOUTH EAST				
Urban	70	56	5	61
Rural	190	167	8	175
Total	260	223	13	236
SOUTH SOUTH				
Urban	80	46	17	63
Rural	180	131	27	158
Total	260	177	44	221
SOUTH WEST				
Urban	210	133	46	179
Rural	80	49	13	62
Total	290	182	59	241

Zone	Original sample* (2010)	Successfully Interviewed in W4 (2019)	Original location Moved (tracked)	Total attrition (%)
TOTAL				
Urban	510	351	87	438
Rural	1,080	922	65	987
TOTAL	1,590	1,273	152	1,425

*Among the 159 EAs selected for the long panel.

3.2 Climate Variables

The National Aeronautics and Space Administration (NASA) Power Project Data is a comprehensive dataset that provides daily estimates of meteorological and solar energy parameters for any location on Earth. The dataset contains information on solar radiation, temperature, humidity, wind speed and direction, and pressure available are currently available at 0.5 x 0.625 degree resolution for meteorology and 1 x 1 for solar parameters. The data is collected by the NASA Langley Research Center Atmospheric Science Data Center and is freely available to the public.

As explained in more detail below, we use the total rainfall data and average daily temperature for the planting seasons for each household at the local government area level for the years 2017 and 2018 for our analysis. Details on these variables are discussed below in the summary statistics table.

3.4 Planting Season Data

The United States Department of Agriculture (USDA) Foreign Agricultural Service (FAS) develop the crop calendars for most countries. They are based on interviews with regional agricultural experts and government officials. The crop calendar for Nigeria as presented in Table 3 gives an overview of the optimal planting and harvesting period based on the crop calendar obtained from the USDA FAS.

Table 3: Maize Calendar in Nigeria

Region	Optimal Planting Period	Mid-Season	Harvesting Period
NORTH	May - June	July	August
SOUTH	March - April	May - June	July - September

The information is used to obtain each farmer's average rainfall and temperature for the year(s) under review.

3.5 Outcome and Descriptive Statistics

Our descriptive statistics present outcomes of farmers who adopted Aflasafe through the AgResults project and those who were not part of the project and thus did not adopt Aflasafe. For our treatment group, i.e., those who partook in the intervention, we specifically looked at the project's final year (2018/2019) to capture as many farmers as possible who had successfully received the intervention. The data we utilized was obtained from a 2018 survey conducted by the project’s Project Management Unit, which included information on educational status, gender, the land area planted, Aflasafe usage, fertilizer cost, yield, the quantity of maize sold, and household size. These surveys are carried out annually before and after the planting season and data is collected from 10% of smallholder farmers working under Implementers, who are randomly selected each year. This data contributes to indicators such as input types and quantities, yield, and maize sales at formal and informal markets. The PMU also collects general information on all participating farmers, including names, locations, contact details, and planting dates. GPS coordinates are taken to verify farmer authenticity and farmland size. The PMU works with Implementers to capture details on farmer fields, including names, sizes, and locations. Sales data are also collected from all Implementers, to record the quantity and price of treated maize sold.

Furthermore, we included information on total rainfall and average temperature for the planting season based on the region where the farmer was located. Figure 6 presents the map of the treatment and control groups to illustrate the geographic distribution of farmers in our analysis. This figure highlights the differences in the locations of the farmers in our study and provides a useful visual representation of our study setting.

Table 4 displays the descriptive statistics of farmers who were not part of the project and did not adopt Aflasafe and are part of our control group. To prevent any spillover effects, we carefully selected farmers in areas that were not part of the project intervention for our control group. This is a realistic assumption, as Aflasafe is still unknown to many farmers in Nigeria, particularly those outside the intervention areas. We gathered data for these farmers from the Nigerian General Household Survey (GHS), with 736 farmers included in our analysis. We focused exclusively on maize farming-related information. Our analysis revealed that 86% of the sampled farmers were male, with 65% of them have received some formal education. On average, these farmers had a household size of 6.64 people and cultivated 1.29 hectares. None of these farmers used Aflasafe or incurred any expenses related to the product.

Regarding weather variables, the average temperature during the maize planting season in areas where these farmers were located in 2018 was 25.89 degrees Celsius, with a standard deviation of 1.45 degrees Celsius. During the planting seasons of 2017 and 2018, the total rainfall in these areas was 1058.72 mm and 969.95 mm, respectively. On average, these farmers spent 94353.32 Naira (258.50 USD) per hectare on fertilizer and obtained a yield of 1139.49 kg per hectare. The average quantity sold per hectare was 272.31 kg, while the average quantity kept for other uses (such as home consumption, gifts, etc.) was 867.17 kg per hectare.

Table 4: Summary statistics of farmers in the Control Group

	Obs.	**Mean**	**Std. Dev**	**Min**	**Max**
Gender (male = 1, female = 0)	736	0.86	0.34	-	-
Education (Formally Educated = 1, Non-Formal Educated = 0)	736	0.65	0.48	-	-
Household Size	736	6.64	3.75	1.00	29.00
Area (ha)	736	1.29	1.58	0.00	13.61
Aflasafe quantity used(kg)	736	0.00	0.00	0.00	0.00

	Obs.	Mean	Std. Dev	Min	Max
Cost of Aflasafe (usd/ha)	736	0.00	0.00	0.00	0.00
Fertilizer Cost (usd/ha)	736	258.50	643.30	0.00	8442.67
Yield (kg/ha)	736	1139.49	1215.19	3.95	5922.05
Quantity sold (ha)	736	272.31	708.42	1200.00	0.00
Quantity Kept (kg/ha)	736	867.17	1019.48	1228.28	0.00
2018 Temperature (celsius)	736	25.89	1.45	21.26	30.07
2017 Rainfall (mm)	736	1058.72	523.71	426.08	2611.63
2018 Rainfall (mm)	736	969.95	460.74	302.76	2184.59

* *We used #1 USD = 365 Naira as our exchange rate throughout our analysis based on the prevailing official rate used for the project in 2018.*

Table 5 summarizes the descriptive statistics for the farmers in the treatment group who adopted Aflasafe through the AgResults project. The sample size for the treatment group is 2,761. The data reveal that most of the sampled farmers in the treatment group were male and had some formal education (77%). On average, the farmers had a household size of 7.63 people and cultivated an area of 1.52 hectares, with a wide range of land sizes from 0.20 to 53.00 hectares. The farmers who received Aflasafe used an average of 9.36 kg per hectare of the product, with a standard deviation of 2.33kg per hectare. The average cost of Aflasafe usage was 7472.39 Naira (20.47 USD) , with a maximum cost of 135000.00 Naira (369.86 USD).

Regarding fertilizer usage, farmers spent an average of 40372.09 Naira per hectare (110.61 USD), with a standard deviation of 14648.08 Naira (40.13 USD). The average yield was 3330.57 kg per hectare, ranging from 167.92 to 5850.00 kg per hectare. The average quantity of maize sold per hectare was 2195.73 kg, while the average quantity kept for other uses was 1134.84 kg. The average temperature during the planting season in 2018 was 25.65 degrees Celsius, with a standard deviation of 0.68 degrees Celsius. The total rainfall during the planting season in 2017 and 2018 were 1063.18 mm and 931.04 mm, respectively.

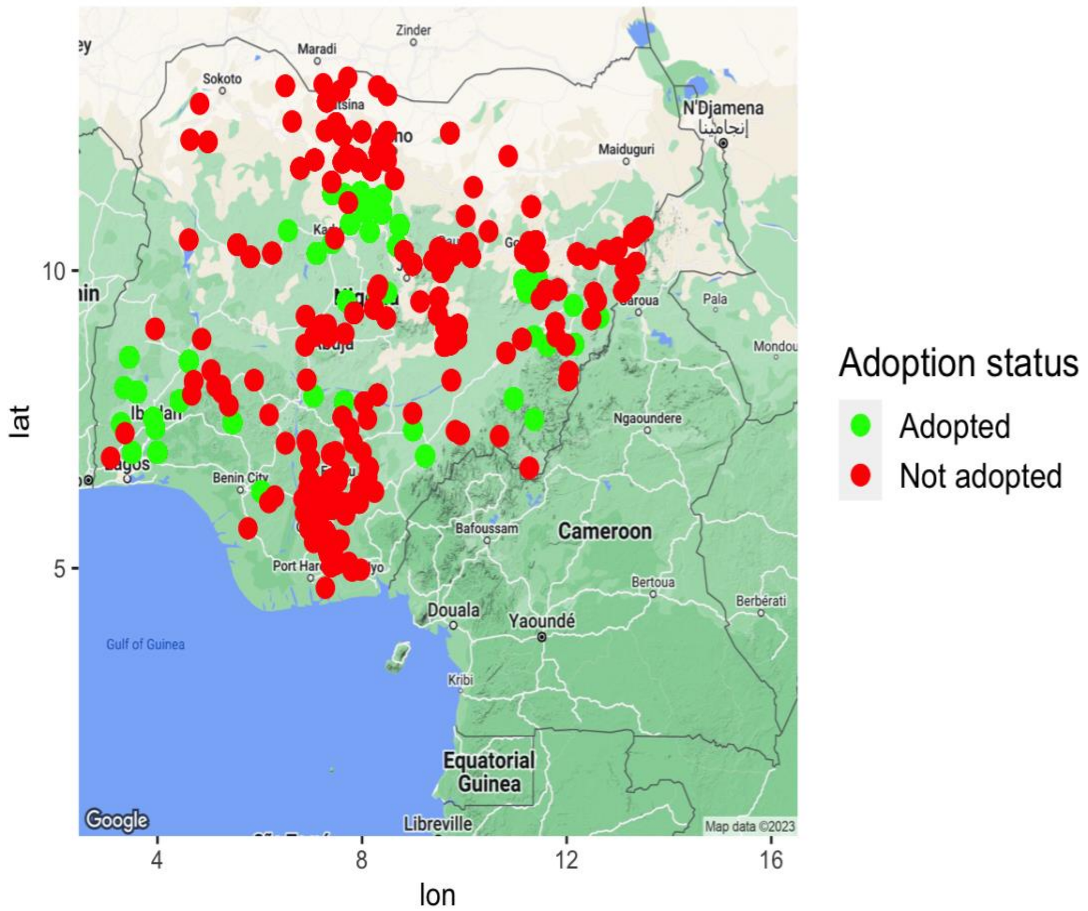

Figure 5: Map of distribution of farmers in the control and treatment groups

Table 5: Summary statistics of farmers in the Treatment Group

	Obs.	Mean	Std. Dev	Min	Max
Gender (male = 1, female = 0)	2761	0.77	0.42	-	-

	Obs.	Mean	Std. Dev	Min	Max
Education (Formally Educated = 1, Non-Formal Educated = 0)	2761	0.77	0.42	-	-
Household Size	2761	7.63	4.86	0.00	36.00
Area (ha)	2761	1.52	1.85	0.20	53.00
Aflasafe quantity used(kg)	2761	13.84	14.42	0.00	250.00
Cost of Aflasafe (usd/ha)	2761	13.85	3.45	0.00	44.38
Fertilizer Cost (usd/ha)	2761	110.61	40.13	0.00	575.34
Yield (kg/ha)	2761	3330.57	1112.64	167.92	5850.00
Quantity sold (ha)	2761	2195.73	1424.44	0.00	5000.00
Quantity Kept (kg/ha)	2761	1134.84	1201.75	0.00	5580.00

	Obs.	Mean	Std. Dev	Min	Max
Total 2018 Planting Season Temperature (°C)	2761	25.65	0.68	22.43	27.55
Total 2017 Planting Season Rainfall (mm)	2761	1063.18	256.86	568.24	1876.37
Total 2018 Planting Season Rainfall (mm)	2761	931.04	418.72	398.75	1694.67

3.5.1 Summary of Balance for Treatment versus Control Groups

Table 6 provides summary statistics on the balance between the treatment and control groups, showing the means for each variable in the treatment and control groups, as well as the standard mean difference (SMD), variance ratio, and the empirical cumulative distribution function (eCDF), mean and maximum. The SMD is a measure of the standardized difference between the means of the two groups, with values greater than 0.2 generally indicating meaningful differences. The variance ratio indicates whether the variances of the two groups are similar or different, with values close to 1 indicating similar variances. The covariates included in our analysis are area, education, gender, household size, fertilizer cost per hectare, quantity sold per hectare, rainfall in 2017 and 2018, and temperature in 2018.

For the variables area, education, gender, and household size, the means in the treatment group are very close to those in the control group, with the standardized mean differences ranging from 0.09 to 0.29. This indicates that the data selection process successfully created similar groups of farmers regarding these characteristics.

However, for fertilizer cost per hectare, the mean in the treatment group is much lower than in the control group, with a standardized mean difference of -3.69. This indicates that the provision of necessary inputs to farmers in the form of credit advance by the Implementers has likely led to a reduction in the cost of fertilizer for the farmers. It is possible that the Implementers were able to obtain inputs at a lower cost than farmers in the control group due to project-specific innovations such as the Innovation Platform, which provides them access to bulk purchasing and distribution channels. By providing inputs to the farmers, the Implementers may have eliminated the need for farmers to purchase inputs at a higher cost from intermediaries. This would have translated to significant savings for the farmers and contributed to the improved outcomes observed in the treatment group. Furthermore, the project's external evaluator reported that the top three reasons why smallholder farmers engaged with the Implementers were the ability to produce healthier crops (51%), output purchase guarantee (36%), and receiving input on credit (33%) (Abt Associates, 2017).

For rainfall in 2017 and 2018 and temperature in 2018, the means in the two groups are fairly similar, with standardized mean differences ranging from -0.36 to 0.17. This suggests our data include similar groups of farmers in terms of these weather-related variables.

Table 6 shows that the treatment and control groups are mostly balanced on key observable characteristics, with fertilizer cost per hectare being the major exception. These differences are taken into account when estimating the impact of the treatment.

Table 6: Summary of Balance between Treatment and Control Groups

	Means Treated	**Means Control**	**Std. Mean Diff.**	**Var. Ratio**
Area (ha)	1.5212	1.2892	0.1253	1.3681
Formal Education	0.7736	0.6508	0.2935	.
Male	0.7744	0.8628	-0.2115	.
Household Size	7.6273	6.6314	0.2032	1.6825
Fertilizer Cost (usd/ha)	110.61	258.50	-3.6852	0.0039
Total Planting Season Rainfall (mm)	931.0447	969.9527	-0.0929	0.8259
Total 2018 Planting Season Temperature (°C)	25.6474	25.8923	-0.3580	0.2239
Obs.	2761	736		

3.6 Methodology

Ordinary Least Squares (OLS) regression was employed in our analysis, a well-established method in econometrics for estimating the relationship between a dependent variable and one or more independent variables. The treatment status was included as the main explanatory variable, while other relevant control variables, such as gender, education, area, and household size, were also included in the model.

If a design for a project depends on identifying the treatment and comparison group after the fact, selection bias becomes a challenge. The chosen villages for AgResults may have underlying factors that could account for the observed differences between the two groups, even if AgResults were not present. For this reason, we also utilized propensity score matching to improve the balance between the treated and control groups and reduce the potential for selection bias. This technique involves creating a matching model that predicts the probability of being assigned to the treatment group based on observed covariates. The matched sample was then used to estimate the average treatment effect on the outcome variables, accounting for differences in observable characteristics between the treatment and control groups. We utilized propensity score matching to identify only those farmers who were most alike in terms of demographic and farm characteristics across both groups.

To assess the impact of the treatment, we estimated the treatment effect on two key outcome variables: profit margin and yield per hectare. We employed robust standard errors to account for potential heteroscedasticity.

The model specification for our analysis is as follows:

$$Y = \beta 0 + \beta 1T + \beta 2X + \varepsilon. \qquad (1)$$

where Y is the dependent variable (either profit margin or yield per hectare), T is a binary variable indicating whether the farmer is in the treatment group (T=1) or control group (T=0), X is a vector of all control variables used, $\beta 0$ is the intercept, $\beta 1$ is the treatment effect, $\beta 2$ is the vector of coefficients for the control variables, and ε is the error term.

Also, we used robust standard errors in our analysis to address potential issues with heteroscedasticity and model misspecification. Heteroscedasticity occurs when the variance of the dependent variable is not constant across all values of the independent variables. This violates the assumptions of classical regression analysis, which assumes that the variance of the errors is constant. Robust standard errors allow for more accurate inference in cases where the errors may be heteroskedastic or correlated. By using robust standard errors, the regression analysis is less sensitive to violations of the assumption of homoscedasticity, thereby providing more reliable estimates of the coefficients. This approach is preferred over the conventional approach of assuming homoscedasticity and using ordinary least squares (OLS) regression, which can produce biased and inconsistent estimates in heteroscedasticity.

As mentioned earlier, in addition to OLS, we employed Propensity Score Matching (PSM) to improve the balance between the treated and control groups. The PSM method attempts to estimate the treatment effect by matching the treated and control groups on a set of observed covariates, thereby creating two groups that are as similar as possible. This helps to mitigate the impact of selection bias and confounding variables.

The first step in PSM is to estimate the propensity score, which is the probability of being in the treatment group given a set of observed covariates. This can be estimated using a binary logit or probit model, with the treatment variable as the dependent variable and the observed covariates as the independent variables. The estimated propensity scores are then used to match treated and control observations using matching algorithms such as nearest neighbor, kernel, or radius matching.

After matching, the balance between the treated and control groups is assessed using standardized differences or statistical tests. If the balance is achieved, the treatment effect is estimated using the matched sample by regressing the outcome variable on the treatment variable, controlling for any remaining covariates that may affect the outcome.

As the project data are clustered in villages, it isn't easy to achieve a perfect balance of farmer characteristics that may explain why their villages were chosen as AgResults villages or not and are not simultaneously influenced by AgResults. We found that propensity score-based weighting did not achieve balance on a few characteristics. We tested for non-equivalence for certain background characteristics involving treatment-comparison differences. To achieve better balance, we used the nearest method in propensity score matching to select only observations that share similar characteristics across the two groups as covariates in all impact regressions.

The propensity score method used in this study is based on the following econometric equation:

$$Y = \alpha + \beta T + \gamma PS + \delta X + \varepsilon \qquad (2)$$

Where Y represents the outcome variable (e.g., maize yield), T is a binary variable indicating treatment status (T=1 for treated and T=0 for control), PS is the estimated propensity score, X is a vector of covariates used to control for differences between the two groups, and ε is the error term. The propensity score, PS, is the conditional probability of being in the treatment group given the covariates X, given as:

$$P = Pr(T = 1|X) = F(\alpha + \gamma X). \quad (3)$$

Where P is the propensity score, T is the treatment variable, X is a vector of observed covariates, α is the intercept, γ is a vector of coefficients on the covariates, and F is the cumulative distribution function of the logistic distribution for logit.

The propensity score matching nearest method was then utilized to balance the treated and control groups. After conducting the propensity score matching, we examined the balance of the matched data and found that all variables that were previously causing imbalance now had a standard mean difference of less than 0.5. This indicates that the treated and control groups are now more comparable in observable characteristics, reducing the risk of bias in our estimates. Table 7 summarizes the balance achieved through the matching process, including means and standard mean differences for each variable, while Figure 7 shows the distribution of the Propensity Scores. In the next chapter, we compare regression results from the pre-matched and post-matched data to further assess the effectiveness of our method. This will allow us to confidently evaluate the effectiveness of our approach and ensure that our conclusions are based on sound statistical analysis.

Table 7: Summary of Balance for Matched Data

	Means Treated	**Means Control**	**Std. Mean Diff.**	**Var. Ratio**
Area (ha)	1.9107	1.5330	0.2040	4.1328
Formal Education	0.7125	0.6916	0.0500	.
Male	0.7352	0.8641	-0.3084	.
Fertilizer Cost (usd/ha)	99.59	85.30	0.3561	0.2860

	Means Treated	Means Control	Std. Mean Diff.	Var. Ratio
Total 2018 Planting Season Rainfall (mm)	810.0342	916.0692	-0.2532	0.8490
Total 2018 Planting Season Temperature (°C)	25.8056	25.6162	0.0073	0.3907
Obs.	574	574		

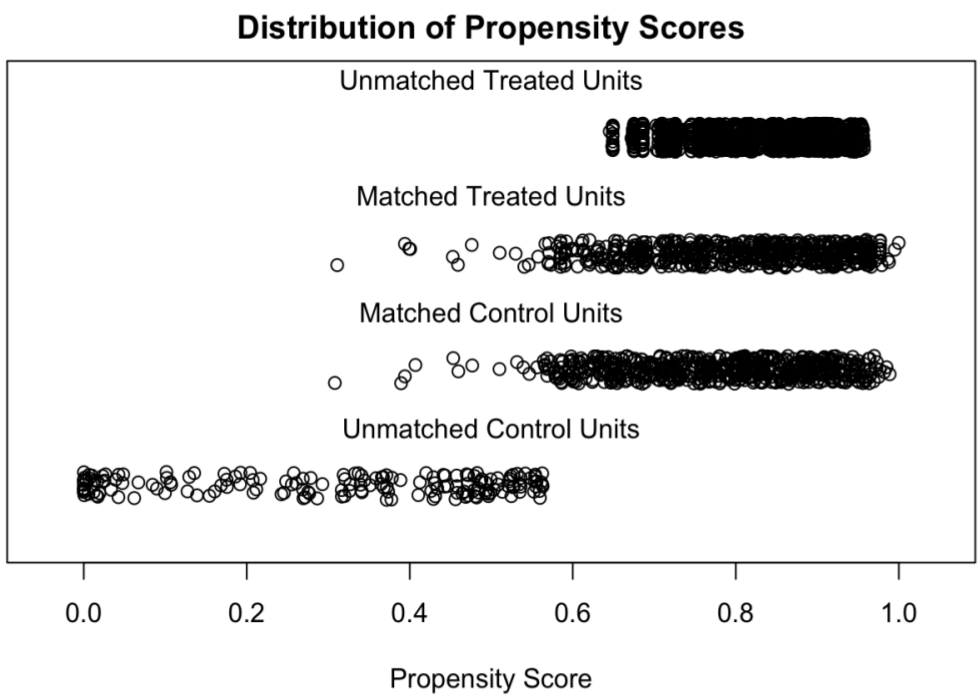

Figure 6: Distribution of Propensity Scores

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Impact on Productivity

The effects of aflasafe use on maize yield is presented in Table 8.

Table 8: Heteroscedasticity-robust standard errors Regression Results: Yield Per Hectare

variable		
	Pre-matching	Post-Matching
aflasafe_or_not	2311.706463 *** (76.346560)	2374.64187 *** (109.96368)
Area (ha)	-18.298168 * (9.555564)	-25.44885 ** (11.01150)
Formal Education	-44.951434 (42.301760)	-189.79611 *** (67.27638)
Male	510.977570 *** (41.910038)	402.72585 *** (78.01721)
Total 2018 Planting Season Temperature (°C)	135.422315 *** (33.876301)	-15.32153 (45.76172)
Total 2018 Planting Season Rainfall (mm)	-0.277582 (0.228759)	-0.52932 (0.42426)
Total 2017 Planting Season Rainfall (mm)	1.016273 (0.262613)	0.24794 (0.42057)

Fertilizer Cost (usd/ha)	0.805853 *** (0.065503)	4.53757 *** (0.38568)
Household Size	16.945095 *** (3.953271)	11.53676 * (6.89450)
Intercept		
State fixed effects	YES	YES
Observations	3497	1148
R-squared	0.26166	0.35761

NB: ***In all tables, *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively*****.**

The coefficient of participation in the AgResults Aflasafe project is positive and highly significant and highly significant at the 1% level, indicating that the use of aflasafe has a positive effect on yield per hectare in both column 2 and column 3. The pre-matching result indicates that farmers who participated in the project and used aflasafe had a higher yield per hectare than those who did not. However, the pre-matching results may have suffered from selection bias due to the non-random assignment of farmers to the treatment and control groups. The post-matching results show that the positive and statistically significant coefficient remains even after propensity score matching was used to control for observable differences between the treatment and control groups. This suggests that the effect of participating in the project and using aflasafe on the yield per hectare is robust, not due to selection bias, and is not driven by state-level factors. Based on the result, it could be inferred that farmers who participated in the AgResults-Aflasafe project, on average, made about 2.374 tons of maize per hectare more than those who did not participate after controlling for other variables. This result is consistent with economic theory, which suggests that access to improved agricultural technologies and practices can lead to higher agricultural productivity and yields. The findings suggest that aflasafe usage is associated with lower exposure to aflatoxin, which can negatively affect crop yields. Using aflasafe reduces the risk of crop contamination and thus improves crop quality and yield. Furthermore, farmers who participated in the project and used aflasafe may have had access to other agricultural technologies and knowledge that could enhance crop productivity, partly explaining the observed positive effect.

Other variables also have a significant impact on yield per hectare. Formal Education has a negative coefficient, indicating that farmers who have at least 5-years of formal education had lower yields. This finding may be explained by the fact that more educated farmers may have higher opportunity costs. As a result, they may be more likely to engage in alternative income-generating activities rather than investing in agriculture. This explanation is consistent with previous research that has established a positive correlation between education and non-agricultural income in developing countries (Seetha et al., 2017). Also, it is plausible that the training and resources provided by implementers to the farmers mitigated the positive effect of formal education on yield. Such trainings may have leveled the playing field between educated and non-educated farmers, leading to a smaller or negative effect of education on yield.

Our results also show that male farmers recorded higher yields before and after matching at 10% and 5%, respectively. Gender inequality in access to resources, such as land, fertilizers, seeds, and credit, is common in many rural areas of developing countries, including Nigeria. These disparities often lead to lower productivity and profitability for female farmers, limiting their ability to contribute to food security and economic growth (Bello et al., 2021; de Brauw, 2015; Oseni et al., 2015). Moreover, gender norms and stereotypes may limit female farmers' ability to make decisions about their farm operations or restrict their mobility and access to markets (*Urban Institute*, 2019; Murugani et al., 2014; Pierotti et al., 2022; Sharaunga & Mudhara, 2016).

Farm size had a negative association with yield per hectare, which was significant at the 1% level after applying propensity score matching. Empirical evidence from agricultural and development economics literature supports the existence of an inverse relationship (IR) between farm size and farm productivity (Omotilewa et al., 2021). This relationship has been established for many years, with Chayanov (1926) in Russia and Sen (1966) in India being among the earliest researchers to document it. The phenomenon has also been widely observed among sub-Saharan African (SSA) farmers cultivating farms of 5 hectares (ha) and below. Various studies (e.g., (Barrett, 1996; Carletto et al., 2013; Carletto, Gourlay, et al., 2015; Julien et al., 2019)), have established this relationship. If we assume that smallholders are indeed more productive, it follows that reserving as much of sub-Saharan Africa's potentially available cropland as possible for smallholder-led farms could promote farm productivity objectives, as suggested by Hazell et al. (2010).

Our preliminary model results suggest that seasonal temperature and rainfall have no significant positive influence on maize yield. When we ran the post-matching model, the effects of these variables remained insignificant, but now they were negative with only previous season's rainfall being positive. Our results are consistent with previous studies (e.g., Adejuwon, 2005; Tingem et al., 2008) which found that variations in both rainfall and temperature do not directly relate to the variations in maize yield in West Africa. While rain is helpful for stable maize production, it also leads to nitrogen leaching from nutrient poor soils, bringing about a negative feedback to yield (Ray et al., 2015). Furthermore, farmers adopt various management strategies to overcome the high rainfall variability (Bayala et al., 2012) consistent with the climate-information support given by the implementers to farmers who participated in the project.

We found a consistently positive and 1% significance for fertilizer cost in both models. This suggests that fertilizer use positively affected maize yields, which is consistent with the well-established relationship between fertilizer use and agricultural productivity.

Finally, the farmer's household size returned a positive and highly significant coefficient before matching, but this became non-significant after matching. This suggests that the effect of household size on yields may be confounded by other variables, such as farm size, farmers' experience, participation of the household members, and management practices.

The post-matching model suggests a better fit with a higher R-squared value of 0.35761 compared to 0.26166 in the pre-matching model.

4.2 Impact of Aflasafe intervention on market participation outcomes

Table 9 shows the impact of Aflasafe Intervention on the quantity of maize yield kept at home for consumption and other uses.

Table 9: Heteroscedasticity-robust standard errors Regression Results: Share of Yield Kept at Home

Variable	Coefficient (standard error)	
	Pre-matching	Post-Matching
Used Aflasafe (dummy)	63.6372011 *** (1.8554568)	-6.3012e+01 *** (3.1794e+00)

Area (ha)	-0.3122163 (0.2065538)	2.1679e-01 (2.6752e-01)
Formal Education (dummy)	-1.9483585 ** (0.9148110)	1.6731e-01 (1.6366e+00)
Male	-1.2510905 (0.9255658)	8.0877e-01 (1.9162e+00)
Total 2018 Planting Season Temperature (°C)	10.5460724 *** (2.5527618)	5.3211e+00 (4.8321e+00)
Total 2018 Planting Season Rainfall (mm)	-0.0231327 *** (0.0054590)	3.7894e-02 *** (1.1697e-02)
Total 2017 Planting Season Rainfall (mm)	0.0293103 *** (0.0057192)	-3.4708e-02 *** (1.0705e-02)
Total 2017 Planting Season Temperature (°C)	-8.5840393 *** (2.5547290)	-7.8829e+00 (4.9410e+00)
Yield (kg/ha)	-0.0040269 *** (0.0003754)	1.9660e-03 *** (7.3935e-04)
Fertilizer Cost (usd/ha)	0.0054330 *** (0.0014460)	-4.0314e-02 *** (9.9290e-03)
Household Size (persons)	0.0988311 (0.0857144)	-2.3280e-01 (1.6763e-01)
Intercept		
State fixed effects	YES	YES
Observations	3497	1148
R-squared	0.29253	0.33968

NB: ***In all tables, *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.***

The used aflasafe (dummy) coefficients indicate the effect of the adoption of aflasafe on the share of maize yield kept at home for household consumption. In the post-matching model, the coefficient for used aflasafe is estimated to be -63.012 with a standard error of 3.179, which is statistically significant at the 1% level. This negative coefficient implies that adopting aflasafe had a significant negative effect on the quantity of maize yield kept at home by farmers for household consumption. Specifically, on average, farmers who adopted aflasafe kept 63.012 kg less maize for household consumption compared to those who did not adopt aflasafe. This result is consistent with the hypothesis that aflasafe adoption could improve the quality of maize and reduce the incidence of aflatoxin contamination, making more of the maize available for sale or other uses beyond household consumption. It has been established in many studies that improved technology adoption can have a significant positive impact on commercialization among rural households. For instance, Asfaw et al., (2010) found that the adoption of improved agricultural technologies significantly enhance commercialization among the rural households in Ethiopia, as higher productivity brings about higher output market integration. which aligns with the result of our regression.

In the post-matching model, the coefficient for Area is estimated to be positive and statistically significant at the 10% level, indicating that an increase in the cultivated land area by one hectare is associated with an increase of 0.217 percentage points in the share of maize yield kept at home. This result suggests that larger farms may have a higher capacity to produce more maize, leading to a greater amount of maize available for household consumption which is consistent with our a-priori expectation.

The coefficient for Formal Education is positive but not statistically significant in the post-matching regression, implying that there is no significant relationship between the level of formal education and the share of maize yield kept at home for household consumption after controlling for other factors. This means that formal education does not play a significant role in determining the quantity of maize yield kept for household consumption. However, in the pre-matching regression, the coefficient for Formal Education is negative and statistically significant at the 5% level, suggesting that farmers with formal education keep a lower share of maize yield at home for household consumption than those without formal education. This implies that farmers with formal education may be more likely to sell their maize produce, indicating that they are more market-oriented consistent with Jones (2017).

In the post-matching model, the Male (household head dummy) coefficient has a positive value of 0.809, which is not statistically significant at the 10% level. This suggests that being a male household head does not have a significant effect on the share of maize yield kept at home for household consumption. This result may indicate that in the context of maize production in Nigeria, gender may not be a significant factor in determining the allocation of maize yield for household consumption. However, from the positive coefficient we got, our result doesn't completely rule out the issue of gender-based differences, as male farmers typically produce more maize as shown in Table 8 and thus have more to keep for consumption and other uses. Previous studies have estimates gender differences in agricultural productivity across sub-Saharan African countries at an average of 25% (Gebre et al., 2021; Kilic et al., 2015).

In the case of the 2018 seasonal rainfall, while the relationship with yield was negative, the positive coefficient for the share kept at home suggests that farmers may have prioritized their own household food security over maximizing their yield. The farmers may also have been concerned about the potential impact of lower rainfalls on their crops in the future and thus decide to err on the side of caution to ensure they are food secure in the face of potential drought or other weather-related issues. Additionally, the lower average seasonal rainfall in 2018 may have also played a role in the farmers' decision to retain more of their harvest for possible gains in subsequent months during the off-season given the lower yield recorded in the season.

On the other hand, the positive relationship between 2017 rainfall and yield suggests that the farmers had a successful crop harvest that year, which may have given them more confidence to sell a larger share of their harvest and generate income rather than retaining it for home consumption. Additionally, the higher average seasonal rainfall in 2017 may have reduced concerns about scarcity and led to a greater willingness to sell off more of the harvest. This result is consistent with Guido et al., (2020) who opined that a considerable percentage of farmers base their decision making on their expectations of upcoming seasonal climate which are mostly formed based on the prior season.

Also, we found yield to be significant at the 1% level and has a positive sign which implies that, holding all other variables constant, an increase in maize yield leads to an increase in the share of yield kept at home. This finding is consistent with the basic economic intuition that as the yield of a crop increases, the amount available for consumption or sale also increases. Therefore, a higher yield can provide households with more food to consume or sell, leading to a greater share of the crop being kept at home.

The coefficient for fertilizer cost is negative and statistically significant for both pre-matching and post-matching regression models. This suggests that there is an inverse relationship between fertilizer cost and the quantity of maize yield kept at home for household consumption. Specifically, a dollar increase in fertilizer cost per hectare is associated with a decrease in the share of quantity of maize yield kept at home for household consumption by 4.03% in the post-matching model. This result may imply that farmers who spend more on fertilizer to increase their crop yields may be more likely to sell their surplus harvest in the market rather than keep it for household consumption. It may also suggest that farmers who spent less on fertilizer during planting season may be more likely to keep their maize for household consumption rather than selling it.

CHAPTER 5

CONCLUSION

The study examined the effectiveness of the AgResults Aflasafe project in enhancing structural support for rural development and poverty alleviation through an agricultural market-driven approach. By utilizing secondary data from the AgResults final project and the Living Standards Measurement Survey, the study addressed two main research questions. Firstly, it investigated the changes in farmers' productivity due to their participation in the Aflasafe program. Secondly, it explored the extent to which participation in the Aflasafe program improved farmers' participation in the market which was one in line with the objective of the program to reduce subsistence farming.

The data were analyzed using descriptive statistics, OLS regression, and propensity score matching. The study found that farmers who participated in the AgResults initiative experienced a substantial increase in productivity and market participation due to focusing on production tailored to market needs. The study also found that the AgResults model helped in solving critical structural challenges such as extension services, access to finance and inputs, land access and utilization for optimal output, and market access through a private sector-driven agriculture-managed system.

The study results highlighted that beyond participation in the program, factors such as farm size, educational status, male, and fertilizer cost were important determinants of farmers' productivity measured in yield per hectare.

Our results also suggest that the impact of the project on farmer's market participation is subject to certain factors, such as using aflasafe, being male, higher lower fertilizer cost, higher rainfall in the previous season, lower rainfall in the current season and higher yield. These highlight the importance of considering the social and economic context in which the project operates. For instance, the gender factor could be explained by the fact that men traditionally have greater access to resources, such as land and credit, which enable them to invest more in their farms. This suggests that efforts need to be made to address gender inequalities and promote greater participation of women in agricultural programs.

The AgResults model represents a new approach to agricultural development that encourages private sector engagement at both the upstream and downstream. Unlike traditional approaches, the AgResults model views farmers as partners, rather than beneficiaries, and seeks to address critical structural constraints, such as extension services, access to finance, inputs, land utilization, and market access. This study has demonstrated the effectiveness of the AgResults model in enhancing structural support for rural development and poverty alleviation, highlighting its potential to be adopted globally.

The findings of this study reveal that timely support, such as training, advisory extension services, inputs, aggregation, and warehousing, can significantly increase smallholder farmers' income and output. By facilitating access to necessary inputs and enabling farmers to develop new skills, access quality-sensitive premium markets, and transition from subsistence to market-driven enterprises, the AgResults model has shown its ability to alleviate rural poverty in Nigeria.

Moreover, the study shows that the AgResults model is a business-managed environment that offers substantial market participation growth for smallholder farmers compared to fragmented ones. The model facilitates the production of better-quality crops that are aggregated for formal and informal markets. The adoption of innovative techniques to control aflatoxin contamination in the AgResults Aflasafe project has also helped farmers increase their productivity and profitability.

However, the impact of the AgResults model is subject to social and economic factors, such as gender and fertilizer cost, which need to be considered to ensure equitable outcomes. Further research into the sustainability, scalability, and replicability of the AgResults model and the impact of agribusiness initiatives on other related sectors is recommended.

In conclusion, the AgResults model represents a viable solution to address structural issues in agriculture and contribute to sustainable rural development and poverty reduction. Its market-driven approach, private sector engagement, and support to smallholder farmers have the potential to transform the agricultural sector globally.

The research conducted faced several challenges that are worth noting to ensure transparency and accuracy. Despite these limitations, the study offers important insights into the impact of the AgResults Aflasafe project on smallholder farmers.

One of the primary limitations encountered was the difficulty in accessing data. This included the absence of essential information such as prices sold, input costs aside from fertilizer, and demographic characteristics of farmers.

Overall, while the study faced certain limitations, the findings still offer valuable insights into the potential benefits of the AgResults model for smallholder farmers. These findings should be interpreted within the context of the study's limitations, and further research into sustainability, scalability and replicability is recommended.

By acknowledging and addressing these limitations, we can continue to improve the quality and reliability of research in this field.

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