TWO ESSAYS ON PEANUT AFLATOXIN RISK IN GHANA

by

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(Under the Direction of Nicholas Magnan)

ABSTRACT

This dissertation consists of two essays on aflatoxin risk mitigation in peanuts in Ghana. The first essay uses a unique dataset that combines aflatoxin test results with detailed survey data to examine how the constraints Ghanaian households face affect their peanuts production, drying, and storage practices, and how these practices affect aflatoxin levels. Results show a significant association of high aflatoxin levels with delayed harvest and drying on bare dirt, while sorting by quality results in a reduction in aflatoxin levels.

The second essay assesses the effect of post-harvest measures (here improved methods of groundnuts drying and storage) on aflatoxin contamination levels in peanuts crops for subsistence farmers in the Northern and Upper East Region of Ghana. The result shows that sun drying on a tarpaulin reduces aflatoxin levels in groundnuts by approximately 40 percent compared to status quo methods of drying.

INDEX WORDS: Aflatoxin, peanuts, post-harvest constraints, post-harvest practices, Ghana

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DEDICATION

I dedicate this dissertation to my lord and personal savior, Jesus Christ, who made all possible; to the loving memory of my father, Michael William Abudu; to my loving wife, Rhoda Kanyam, for her prayers and selfless support and encouragement; my daughter Daniella and sister, Linda.

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CHAPTER 1

CONSTRAINTS TO ADOPTING BETTER POST-HARVEST PRACTICES AMONG GROUNDNUT FARMERS AND THEIR IMPLICATIONS ON AFLATOXIN

1.1 INTRODUCTION

Aflatoxins (AFs) are carcinogenic metabolites produced by species of Aspergillus fungi, namely Aspergillus flavus and Aspergillus parasiticus (N'Dede et al., 2013) and found in diverse foods and feeds. They are invisible, odorless and tasteless, yet they have been found to pose a profound threat to food safety and human health. Consumption of moderate to high levels of aflatoxins has been linked with increased risk of liver cancer, kidney inflammation, spleen enlargement, reduced sperm count, infertility, birth defects, low birth weight, and growth inhibition in young children (Turmer et al., 2007; Agnes & Akbarsha, 2003; Uriah, Ibeh, & Oluwafemi, 2001; Jackson & Groopman, 1999).

Of the 550,000–600,000 new cases of liver cancer worldwide, aflatoxin exposure may account for between 25,200 and 155,000 of these cases every year, especially in Asia and sub-Saharan Africa (SSA) (Liu & Wu, 2010). In 2004, Kenya experienced the most severe episodes of acute human aflatoxin poisoning in history. 317 cases were reported, and 125 people died, presumably from eating large amounts of highly contaminated maize (Lewis et al., 2005). It is estimated that the annual loss to African food exporters of cereals, dried fruit and nuts from attempting to meet European Union aflatoxin standards is roughly $US 670 million (Otsuki et al., 2001).

Aflatoxin contamination of crops can occur during pre-harvest, harvest, and post-harvest. However, in most instances, aflatoxins are formed after harvest. Because much food contamination occurs during post-harvest, harvesting the crop at the right time, rapid drying on platforms to avoid contact with soil, restricting humidity during storage, sorting at various stages (including removing damaged, shriveled, and immature pods) and using new or clean storage bags before storage could potentially reduce fungal growth and toxin production. For example, Kaaya et al. (2005) found that aflatoxin levels in maize increased 4-fold and more than 7-fold when harvest was delayed by 3 and 4 weeks, respectively, after maturity. Awuah and Ellis (2002) reported that when groundnuts were dried to 6.6 percent moisture level, they were free of fungi regardless of the local storage protectants used for six months. Park (2002) also found that sorting out physically damaged and infected grains can result in a 40 to 80 percent reduction in aflatoxin levels.

Despite the seemingly basic nature of good practices, unfortunately, their adoption is low in Africa and thus aflatoxin levels are high. For instance, in Ghana, about 20 to 33 percent of wholesalers seldom or almost never sort their groundnuts (Florkowski & Kolavalli, 2013). Typically, all harvested peanuts are laid out on the ground in large piles to dry and are often left exposed to dust, dirt, and insects. Under these conditions, the groundnuts are persistently exposed to soil contamination that is the source of fungi (Kaaya, Kyamuhangire, & Kyamanywa, 2006; Okello et al., 2010). Also, farmers often store nuts in bags that previously stored other grains and rarely are steps taken to clean these bags before storage. As a result of these poor practices, the groundnuts that are produced, consumed and sold in Ghana are frequently contaminated by toxigenic fungi and contain aflatoxin in amounts exceeding allowable and safe limits.

This essay examines how the constraints that Ghanaian household face affect their groundnut production, drying, and storage practices, and how these practices affect aflatoxin levels in their peanuts production. Based on the findings, the study attempts to suggest solutions that, hopefully, will minimize aflatoxin contamination in groundnuts in Ghana and SSA in general. We use a unique dataset that combines aflatoxin test results with detailed survey data to carry out this study.

The essay is organized as follows. Section 2 presents some background to the study. Section 3 describes the study area. Section 4 examines some of the post-harvest constraints in Northern Ghana. Section 5 presents the sampling methodology (participants and groundnuts), and aflatoxin testing procedure. The empirical methodology is provided in Section 6. In Section 7 we present the empirical results. Section 8 summarizes and concludes, highlighting possible policy implications.

1.2 BACKGROUND OF STUDY

Ghana is one of the leading producers of groundnuts, also known as peanuts, in the world. The country is ranked 11th in the world for production volume (in-shell peanuts) and 4th in Africa, behind Nigeria, Senegal and Cameroon (FAO Statistical Databases, 2012). Groundnuts are grown throughout the country but primarily cultivated in the northern half (Northern, Upper East, and Upper West regions) under Savannah and transitional-savannah conditions. Groundnut is a major food in Ghana, and also an important cash crop for rural households (Tsigbey, 2003; Masters et al., 2013). Groundnut exports, however, remain limited: in 2013, the country earned just US$6.4 million from export of groundnuts (Myjoyonline, 2015). According to Awuah (2000), national per capita groundnut consumption is 0.61 kilogram per week. Also, Jolly et al. (2008) estimate that about 80 percent of Ghanaians consume groundnuts or groundnut products at least once a week and 32 percent consume groundnuts at least three times a week.

Both the importance of groundnuts to food security and their potential as an export crop makes aflatoxin a big problem for the country. Various surveys and research conducted in Ghana (Beardwood, 1964; Mintah & Hunter 1978; Awuah & Kpodo, 1996; Awuah 2000) have revealed that groundnuts and their products are high-risk commodities for aflatoxins contamination. For example, a study on aflatoxin levels of 100 groundnut paste samples purchased from selected major markets in all ten regions of Ghana showed that eighty-six contained aflatoxins at varying degrees, with 65 samples containing total aflatoxin levels greater than 30 ppb.[1] The highest total aflatoxin level recorded in this study was 3,300 ppb (Kpodo, 1995). In a study by Awuah and Kpodo (1996), it was found that groundnuts samples from 21 selected markets in the ten regions of Ghana had aflatoxin levels ranging from 5.7 ppb to 22 ppb, 168 ppb were identified with damaged kernel samples.

In spite of the significant potential for groundnuts to improve diet quality and enhance farmer incomes, public investment in groundnuts production has been relatively limited. Agricultural policies and programs in Ghana focus primarily on starchy staples and export commodities such as maize, rice, cassava, cocoa and palm oil. For instance, a recent classification of the country's agricultural research programs found that cassava, cocoa, maize and rice were the most heavily researched. Groundnuts did not make the top eight crops in terms of research efforts, attracting less than 4.5 percent of the country's agricultural research efforts (Flaherty, Essegbey, & Asare, 2010).

This study aims at contributing to the limited research efforts on groundnut production in Ghana. The findings generated from this study will contribute to the development of strategies to minimize aflatoxin contamination in Ghana and elsewhere in the region.

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[1] Aflatoxins are regulated in part per billion (ppb), with the maximum allowable level varying with country and intended use of the commodity. The European Union limits for total aflatoxins ranges from 4-15 ppb. The United States food safety regulations include a limit of 20 ppb for total aflatoxins. Both Australia and Canada set limits of 15 ppb for total aflatoxins in nuts

1.3 STUDY AREA

The study was conducted in the Northern and Upper East regions of Ghana. The Northern Region is the largest region in Ghana regarding land area. Specifically, the region has a total land area of about 70,384 sq. km, which is approximately 30% of the total land space of Ghana. The Upper East region occupies a total land area of about 8,842 sq. km, which translates into 2.7 percent of the total land area of the country (Government of Ghana, 2016).

Agriculture, hunting, and forestry are the primary economic activities in both regions, and the main crops are millet, guinea corn, maize, groundnut, beans, sorghum, tomatoes, and onions. Together with the Upper West region, the Northern and Upper East regions account for 94 percent of the groundnuts production in Ghana (Angelucci & Bazzucchi, 2013). In a typical farming community, in these areas, more than 90% of farm families will cultivate groundnuts, and of their crops, this is the one most likely to be marketed commercially (Tsigbey, 2003; Masters et al., 2013). However, the constraints imposed on groundnut production in the two regions are enormous. Productivity has been declining over the years due to poor crop management practices and lack of institutional support (Bucheyeki et al., 2008).

1.4 POST-HARVEST CONSTRAINTS IN NORTHERN GHANA

One of the main interest is in this study is to examine the constraints that households face and how these constraints affect their post-harvest management. This is addressed by answering the question: What are the characteristics of households who adopt good post-harvest management practices and why would they do so? We begin by reviewing some diagnoses of household constraints in groundnut farming:

Gender: In Ghana, women play a major role in the agricultural sector in general and the groundnut sector in particular. In groundnut cultivation, women are involved at all stages, from tillage onward to harvesting, drying, sorting, storage, and selling. In addition to these farming roles, women are often responsible for managing complex households. In a typical household, women are responsible for processing and preparing food, collecting fuel and water, caring for children and the elderly, engaging in trade and marketing, and maintaining their homes.

This additional work burden and time scarcity limit their attempts to engage in efficient and productive farming activities at optimal times, such as harvesting their groundnuts on time, threshing immediately after harvest, sorting, and drying; just to mention a few, which are often major causes of low productivity. Also, even though women represent a crucial resource for agriculture, because of their gender, they face constraints regarding their access to agricultural resources that reduce their productivity and their efficiency in post-harvest management. For example, Doss and Morris (1999) found evidence from Ghana that suggests that gender-linked differences in the adoption of modern maize varieties and chemical fertilizer are not attributed to the inherent characteristics of the technologies themselves but instead result from gender-linked differences in access to complementary inputs. Thus, the expectation is that female farmers, in general, are less likely to adopt superior post-harvest management practices, *ceteris paribus* and have limited access to post-harvest facilities which in turn affect their post-harvest management.

Labor supply: Groundnuts production is labor intensive and time-consuming. It consists of land preparation, seed extraction, cultivation, harvesting, stripping, drying, shelling, and sorting. Result from a gross margin experiment reported that stripping and shelling were the major labor intensive activities in groundnut production and contributed to about 40 percent of the total production cost (Ngulube et al., 2001; Minde et al., 2008). In Northern Ghana, like many other African countries, it is observed that labor shortages often occur at peak harvest periods, even in areas that normally have surplus labor supply. In the survey, about 25 percent of the respondent reported that the timing of harvest and stripping was affected by labor availability. This means that handling of larger volumes of groundnuts depends on the availability of labor in the family and the amount of labor that can be hired in the local labor market.

Thus we expect labor supply, measured as the household size (only labor input of adult household members (above 14 years old) is considered in this study) to have a positive effect on post-harvest management practices. The intuition is that larger households have readily available and cheap labor to manage post-harvest practices effectively compared to smaller-sized households. On the other hand, larger households could increase the social responsibility of the household, in general, and exert pressure on the available post-harvest resources or facilities. In this regard, we expect the effect of labor supply on post-harvest management to be favorable or adverse.

Household headship: The relationship between household heads and groundnut production activities cannot be overemphasized. Traditionally, household heads are primarily responsible for the economic well-being of the household. They affect both the manner in which household resources are utilized and disbursed within the household, and the way in which households are networked for the exchange of resources with other households (Lloyd & Gage-Brandon, 1993).

They are also socially obligated in managing agriculture production and exercise complete control, with few, if any, external limits, over the farming decisions of the household. These factors all have implications for agriculture practices. Farmers who are household heads are more autonomous and have more control over resources, by virtue of their position, and are more able to influence production decisions than farmers who are not household heads. For instance, household heads can leverage their position to mobilize other household members for harvest thus preventing delays in harvest. On the other hand, the increase in the socio-economic responsibility that comes with being a household head could affect the effectiveness of the household head in engaging in good farming practices. The apriority expectation is a positive or negative effect of household head on post-harvest management.

Years of Education: The role of education in post-harvest management cannot be over emphasized. It is natural to think of education when we think of post-harvest management. For instance, Jolly et al. (2006) in a survey in Ghana found that people with secondary or higher level of education were more likely to sort their food before preparation.

However, one of the major problems facing agricultural productivity in Ghana, particularly in the Northern Ghana, is illiteracy. Educational levels in the Northern Ghana lags behind the rest of the country and is characterized by extremely low participation rates (Casely-Hayford & Ghartey, 2007). Although, farmers usually have valuable experience and rich knowledge of local conditions of how best to exploit their environment successfully, the level of formal education in the region is low because there is a general view in the region that education has no economic value to the household, and the benefits of schooling are primarily non-economic in nature given that farming methods in the region are largely traditional in nature (Weir, 1999). With the low level of literacy of farmers, extension and research efforts are more tedious, and this has affected agricultural practices and posed a greater challenge to agricultural productivity and development over the years. Thus, we expect farmers with some formal education to manage post-harvest challenges better than those without any formal education.

Primary and Secondary occupation: In northern Ghana, farming is the prime occupation of the population. Most farmers regard food crop cultivation as their major occupation for subsistence. However, in some instances, one will find people whose primary occupation is not farming but are actively involved in groundnut farming mainly because groundnut is a major cash crop in the region. We expect groundnut farmers whose primary occupation is farming to deal better with post-harvest practices than those groundnut farmers whose main occupation is not farming. The reasoning is premised on the fact that farmers whose primary occupation is farming hold more local knowledge of low-cost post-harvest methods and coping strategies in dealing with post-harvest challenges.

In some other limited instances, there are some farmers engaged in more ephemeral activities such as casual labor on farms, livestock keeping, and petty trading to supplement their limited income. We argue that this practice of having a minor secondary occupation could affect the effectiveness of farmers in handling post-harvest management issues.

Income constraints: Any discussion of post-harvest management and the adoption of good agricultural practices has at its heart reflection on the critical role played by income. Income constraints affect the ability of farmers and households to adopt good farming practices. For instance, Agricultural Cooperative Development International (ACDI) has observed that poor producers, in Kenya, are the least likely to adopt aflatoxin risk reduction technologies since they lack the necessary resources, and, thus, they are the most susceptible to aflatoxin exposure (Narrod, 2011)[2].

In Ghana**,** the Northern and Upper East region are impoverished and considerably poorer than the other regions. The Upper East region has the second highest poverty headcount in Ghana followed by the Northern region (Ghana Statistical Service, 2015). Given that majority of the farmers, in the region, operate barely subsistence farms with very low incomes from their holdings, we expect income constraints to affect the ability of farmers to adopt good post-harvest practices.

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[2] ACDI is a private, nonprofit organization that promotes economic opportunities for cooperatives, enterprises, and communities through the innovative application of sound business practice.

Farm size and production volume: The size of groundnut land cultivated and the level of output also tend to pose a challenge to groundnut farming activities. Groundnut production involves a lot of handling: harvesting, stripping, drying, sorting, shelling, etc. As production increases, proper post-harvest handling measures become a problem thus exposing the pods of the groundnuts to injury due to mishandling, which tends to harm the quality of output. Based on the preceding argument, we expect an inverse relationship between production volumes and good post-harvest practices. On the other hand, farmers with large production volumes can generate larger incomes and make higher investments and as a result, adopt effective post-harvest management techniques.

Similarly, the size of land cultivated can cause harvest and threshing delays, among other factors, given the limited post-harvest facilities. Also, a larger farm could result in more investment in farm maintenance and less available resources for the acquisition of post-harvest facilities. Based on the preceding argument, we expect the volume of production and farm size to either have a positive or adverse effect on post-harvest practices.

Other farm lands: The size of land cultivated, besides groundnuts, also tend to pose a challenge to groundnut farming activities. In Northern Ghana, farmers keep other farm lands to cultivate other crops, besides groundnuts. The major drivers of other farm lands include increasing income, balancing food demand, and increasing community food security. Other food crops are in the following order of importance: yam, cassava, sorghum and millet (Tsigbey, 2003). Given the limited post-harvest facilities, the management of other farm lands, besides groundnuts, could have an inverse relationship with post-harvest practices. We measure other farm lands as the proportion of land used for cultivating other crops besides groundnuts.

1.5 SAMPLING METHODOLOGY AND AFLATOXIN TESTING

1.5.1 SAMPLING OF COMMUNITIES AND PARTICIPANTS

The data used in the study were obtained from a survey conducted from November 2014 to January 2015. A three-stage sampling technique was employed: in the first stage, purposive sampling was used to select eight dominant groundnut producing districts from the regions.[3] In the second stage, simple random sampling was used to select five communities from each of the eight selected districts. In total, 40 communities were selected. In the third stage, households in which at least one member grew groundnuts in the most recent agricultural season at the time of the survey were randomly selected from the communities. Within these households, the primary respondent was the individual who harvested the most groundnuts in the most recent agricultural season, and still had some groundnuts in store. Altogether, 25 households were targeted for the survey from each of the 40 selected communities. In total, 1005 households were selected.

After the selection of the households, questionnaires were administered to groundnut producers by enumerators in local dialects. The survey contained questions on household composition, health status, post-harvest preparation and storage practices, recent sales, and basic wealth indicators. Samples were also collected on the day of the survey for aflatoxin testing. The samples were transferred on the same day to the Department of Biotechnology, at the University for Development Studies, Nyankpala, Ghana and stored at -20 degrees Celsius to prevent further post-harvest accumulation of molds and aflatoxin until analysis (Anderson et al., 1995).

[3] Some changes have already been made in terms of districts since the survey. In the year 2004, Karaga district was separated from Gushiegu-Karaga district. Similarly, the Kassena-Nankana district was divided into two – the Kassena-Nankana East and Kassena-Nankana West districts in 2008 and Tolon-Kumbungu was split into two separate districts. In 2012, Savelugu-Nanton was also made municipality. For the purpose of this study, we will retain the old classifications.

1.5.2 GROUNDNUT SAMPLING

Sampling is one of the most vital steps for accurate analysis of aflatoxin in food commodities. The sampling procedure is complicated by the extremely skewed distribution of aflatoxin (Okello et al., 2010). Due to the high skewness nature of fungal distribution, the study adopted a sampling protocol consistent with Schuller, Horwitz, and Stoloff (1976) and Whitaker and Dickens (1983).

For farmers with less than five bags of groundnut production, samples were taken from each bag and combined into one large lot sample.[4] For farmers with 6 to 20 bags, half the total number of bags were randomly selected from which samples were taken (e.g. for six bags, three bags were randomly selected, for eight bags, four, etc.). For farmers who stocked large groundnut lots (greater than 20 bags but less than 40), the whole groundnut stack was divided into four quadrants, and samples were randomly taken from a bag from each quadrant and a final one from the middle of the pile. For farmers with 40 bags or more, samples were randomly selected from two bags from each quadrant as above, and a final two from the middle of the stack. All samples were delivered to the laboratory for analysis in sterile sampling bags and were thawed for three weeks at -4 ^{0}C in their original form before analysis to maintain the optimum condition that does not allow the buildup of aflatoxin and other mycotoxins.

1.5.3 DETERMINATION OF AFLATOXIN CONTENT

The Romer FluoroQuant Afla Test Kit System for groundnuts was used to test for aflatoxin.[5] The entire samples from each farmer were mixed thoroughly and milled in the laboratory using a Waring commercial blender to obtain finely grounded sample that can pass through a 20 mesh

[4] Each bag of groundnuts weighed about 100 kilograms.
[5] The FluoroQuant Afla test is a rapid, quantitative fluorometric test for detection of total aflatoxin. It is validated with the United States Department of Agriculture Grain Inspection, Packers and Stockyards Administration and approval for use in raw unblanched peanuts, and raw blanched peanuts.

sieve. Analytical samples of 50 grams of the ground sample were triturated in a blender in 86% methanol (86 milliliters (ml) absolute methanol in 14 ml distilled water), until thoroughly mixed. The extract was transferred to a conical flask and shaken for 30 minutes. The extract was then filtered into a glass container and analyzed for aflatoxin contamination using the Romer FlouroQuant (FQ) Reader and test kits.

1.6 EMPIRICAL METHODOLOGY

In this paper, we attempt to explain how constraints Ghanaian household face affect their groundnut production, drying, and storage practices, and how these practices affect aflatoxin levels in their groundnuts production using a two-stage least squares (2SLS).

1.6.1 TWO-STAGE LEAST SQUARES REGRESSION

As discussed in section 1.4, the effect of post-harvest practices on aflatoxin levels could be driven by household constraints, which suggest an endogeneity problem pertaining to the relationship between Aflatoxin levels and post-harvest practices, i.e., post-harvest practices are endogenous, potentially to factors that affect aflatoxin levels directly. For instance, a survey in Ghana found that people with secondary or higher education were more likely to sort their food before preparation (Jolly et al., 2006). Similarly, ACDI has observed that poor producers, in Kenya, are the least likely to adopt aflatoxin risk reduction technologies since they lack the necessary resources, and, thus, they are the most susceptible to aflatoxin exposure (Narrod, 2011). These examples show how constraints such as education and income affect the adoption of best practices.

One approach in dealing with this problem is to adopt a two-stage least squares (2SLS) instrumental variable approach. The first step in this approach is to show a direct impact of household constraints on post-harvest practices. The second step is to show that those post-harvest practices have an impact on aflatoxin levels. By tracing the effect of household constraints on the post-harvest practices, this approach reduces the risk of selection bias and captures only the components of post-harvest practices that are driven by household constraints. In addition to mitigating bias, this is a useful approach because the first stage estimates themselves are important. They shed light on what constraints limit adoption of best practices.

In the first stage, we estimate the following equation:

$$\mathrm{X} = \alpha + Z'B + \mu \qquad (1)$$

The first stage is to treat production, drying, and storage practices as our dependent variables and use household constraints as the independent variables. Thus, X contains harvest delay—delaying harvest by a day or more, threshing/stripping delay—delaying threshing by two or more days, drying days, drying on dirt, sorting, use of new storage containers, and the use of wooden pallet and storage duration. Z contains the household constraints which include gender, labor supply, measured as household size, household head status, the level of education—having some formal education, occupation (primary and secondary occupation), income constraints, farm size, production volume and other farm lands, besides groundnuts. The β are the corresponding coefficients to be estimated, and the μ is the stochastic error term. Each of the variables in X is regressed against all the constraints identified.

In the second stage of the 2SLS, we estimate equation (2), the fitted values from the first stage, which by construction are independent of the respective error terms, are used as instrumental variables in the second stage, where aflatoxin level serves as the dependent variable.

$$Y = \infty + \hat{Z}'\gamma + \varepsilon \qquad (2)$$

where Y is the logarithm (log) of aflatoxin concentration level in parts per billion (ppb). We took the log of aflatoxin concentration level to reduce the extrema in the aflatoxin data and curtail the effects of outliers (Wooldridge, 2003). $\hat{Z}$ contains the fitted values of Y from equation (1). γ are the corresponding coefficients to be estimated and ε is the stochastic error term. Because regressions relying on inter-village variation are problematic due to potential omitted variable bias, we included village fixed effects to control for all observed and unobserved village level determinants on aflatoxin levels. We also cluster at the regional level since villages and households of the same region share environmental risk factors.

Based on previous studies, we expect harvest delay, threshing delay, drying on dirt, and longer storage duration to increase aflatoxin level all things being equal. On the other hand, we expect drying days, sorting, the use of new storage containers, and the use of wooden pallets to reduce aflatoxin levels (see, for example, Hamiton, 2000; Hell et al., 2003; Park, 2002; Okello et al., 2010; Hell et al., 2011; Waliyar et al., 2013).

Table 1.1 displays the summary of descriptive statistics, including variable mean, standard deviation, minimum and maximum values. The average aflatoxin level recorded was 63 ppb, which is above the 15 ppb set for peanuts in the Codex Alimentarius.[6]

Table 1.1: Descriptive Statistics

Variable	Obs.	Mean	Std. D.	Min	Max
Dependent Variable					
Aflatoxin concentration level	920	63.12	333.44	0.66	6061
Constraints					
Female	1005	0.32	0.47	0	1
Labor supply	1005	5.19	2.96	1	25
Household head	1005	0.7	0.46	0	1
Education	1005	0.21	0.41	0	1
Primary occupation	1005	0.94	0.24	0	1
Secondary occupation	1005	0.40	0.49	0	1
Income constraints	1005	0.42	0.49	0	1
Farm size in acres	1005	1.88	1.72	0.2	30
Production volume in bags of 100 kg	1005	5.76	6.59	0.08	64

[6] The Codex Alimentarius is a collection of internationally recognized standards, codes of practice, guidelines, and other recommendations relating to foods, food production, and food safety (http://www.fao.org/fao-who-codexalimentarius/about-codex/en/)

Other farm lands	1005	4.68	6.47	1	68
Post-harvest Practices					
Harvest delay in days	1005	0.24	0.43	0	1
Threshing delay in days	1005	0.6	0.49	0	1
Drying days	1005	6.4	2.12	1	14
Dirt drying	1005	0.59	0.49	0	1
Sorting	1005	0.54	0.5	0	1
New storage container	1005	0.44	0.5	0	1
Wooden pallet	1005	0.78	0.41	0	1
Storage duration in months	1005	6.1	1.56	1	10

In the sample, 32 percent of the respondents interviewed were females and 70 percent were household heads. The average labor supply, measured as household size (only labor input of adult household members (above 14 years old) is considered in this study), is about five persons. Twenty-one percent had some formal education. This is an indication of the low level of educated farmers involved in agriculture in general and groundnuts production in particular. Over 94 percent of those interviewed work on the farm and 40 percent have a secondary occupation in addition to farming. This should not be surprising given that majority of the farmers in the region operate barely subsistence farms with very low incomes from their holdings.

On production and harvest related issues, the average farmer cultivated 1.88 acres of land for groundnut production and 4.68 acres for other crops, besides groundnuts. This is understandable because maize, soya, rice and millet are currently the dominant crops grown in the region. The average groundnut production was approximately six bags (each bag weighed about 100 kilograms). Twenty-four percent of households delayed harvest for a day or more, while 60 percent delayed threshing by two or more days. This is staggering, considering the importance of timely harvest and threshing to aflatoxin control. Fifty-nine percent dry their groundnuts on some form of dirt. This practice of drying on bare dirt exposes the groundnuts to fungal spores and moisture in the dirt, making them susceptible to fungi contamination and invasion by Aspergillus flavus and Aspergillus parasiticus. About 46 percent reported non-sorting of their groundnut which is unfortunate because sorting out physically damaged and infected grains can result in a 40 to 80 percent reduction in aflatoxin levels (Park, 2002). Average drying days were approximately six.

Considering storage, 44 percent indicated they use new containers for storage while 49 percent reported that they use some old containers with and without cleaning them. This is unfortunate because there is a high probability that these reused containers will be contamination by Aspergillus spores (Awuah & Kpodo, 1996; Hell et al., 2008). The average households expect to keep their groundnuts for six months. Additional details about the variables are provided in Table 2.8 in Appendix A.

1.7 RESULTS

Table 1.2 reports the first and second stage results of the 2SLS. In columns (2) – (9), we report the first stage of the 2SLS where the post-harvest variables–harvest delay, threshing delay, drying days, drying on dirt, sorting, use of new storage containers, use of wooden pallet and storage duration, are regressed on household constraints. Column (1) shows the estimates from the second stage of the 2SLS where the log of aflatoxin is regressed on the instrumental variables obtained from the fitted values in columns (2) – (9).

In the first stage, the results show that female farmers use fewer days in threshing but are more likely to dry their groundnuts on dirt and store their groundnut for a longer period than their male counterparts. The reasons could be that threshing groundnuts is predominantly a female activity. Men, generally, allocate less time than women to activities relating to threshing, sorting and shelling. The tendency for women to keep their groundnuts in storage for a longer period than men could be because of the other income generating activities women tend to engage in. In northern Ghana, like other parts of Africa, women are more likely than men to engage in ephemeral activities such as petty trading and casual labor on farms to supplement their income. The additional income reduces the need to sell their groundnuts, which explains why they can keep groundnuts in storage for much longer time compared to men.

Also, the higher likelihood of women to dry on bare dirt could be that women farmers have limited access to post-harvest facilities or materials, such as tarpaulins or improved drying surface, than men. This result was expected and confirms the findings of Doss (1999) that gender affect farmers' access to land, labor, and other agricultural inputs. This finding or observation is critical from a policy standpoint. It illustrates the gender-specific constraints in post-harvest management. Given the major role played by women in the groundnut sector, closing the gender gap in access and use of post-harvest facilities and resources could unlock the productivity potential of women and lead to better post-harvest practices.

Labor supply affect harvest delays, drying techniques and sorting decision. The results show that households with more labor are more likely to use fewer days in harvesting. A possible explanation may be that larger households have adequate labor to assist in harvesting compared to smaller sized farm households. Also, households with more labor are more likely to dry on dirt and less likely to sort their groundnuts. The reason could be more labor could exert tremendous pressure on the limited post-harvest facilities, like available improved drying surface, thus forcing members with no options but to dry on dirt. Similarly, more labor could increase household responsibilities thus reducing the necessity of some post-harvest practices like sorting. In this context, labor supply is indirectly linked to aflatoxin production through its effects on harvesting, drying and sorting. For effective post-harvest management, there is, therefore, the need for government and interested stakeholders to provide simple post-harvest equipment, such as groundnuts shellers and strippers, to the farming communities to reduce the labor demand in post-harvest management.

Household heads tend to dry on dirt and store their groundnuts for a longer period compared to non-household heads. The likelihood of household heads to dry their groundnuts on bare dirt is counterintuitive since one would expect that household heads to have more control over post-harvest resources by virtue of their position and should be more able to dry their groundnuts on improved surface compared to non-household heads. Household heads ability to keep their groundnuts in storage for a longer period compared to non-household heads could be because of their ability to affect how household resources are utilized and disbursed within the household. They could use this ability to their favor thus enabling them to keep their groundnuts in storage for a much longer period.

Also, farmers with some form of formal education and those whose primary occupation is farming tend to keep their groundnuts in storage for a much more extended period. This should not be surprising because farmers in Northern Ghana, generally, store their groundnuts for a longer period. Because groundnut is a cash crop, and the most likely crop to be marketed commercially, coupled with the limited income generating options in the region, most farmers tend to keep their groundnuts as a store of income, after harvest, until the next farming season where they sell to raise capital for farming activities.

The results also show that farmers with secondary occupations are more likely to sort their groundnuts. This contradicts apriority expectation of a negative relationship but is not unreasonable. A possible explanation may be that farmers with secondary occupations may have smaller production volumes, compared to farmers whose sole occupation is farming, thus, their ability to sort their groundnuts because of the relatively smaller production volume. On the other hand, farmers with secondary occupation are more likely to delay in harvest, i.e., use more days in harvesting than farmers with no secondary occupation. This was expected because keeping a second job compromises the farmers effectiveness and efficiency in managing post-harvest issues. This observation is very relevant for policy makers, particularly those concerned with rural farm household food security. Subsistence farmers keep secondary jobs because of the very low incomes from their farm holding which is primarily driven by the inefficient agricultural market system in Ghana. If the agricultural market system is structured, it will boost the income of farms thus reducing their dependency on secondary occupation, which will go a long way to affect their effectiveness and efficiency in post-harvest management, an essential strategy for aflatoxin reduction.

Farm size contributes to threshing delay and reduces the likelihood of using new storage containers. In Northern Ghana, farmers thresh their groundnuts in the field, and this process is preceded by heaping stalks of groundnuts at selected points in the field. The larger the farm, the longer the process of gathering and heaping the stalks of groundnuts for threshing, hence threshing delay. Also, a farmer with a larger farm may have to spend more resources in maintaining the farm which intend reduces his ability to afford post-harvest materials such as new storage containers.

The volume of production is found to have a positive and significant effect on drying days and storage duration. The increase in production volume is met with increases in drying days and storage duration. This could be because as production increases most farmers tend to harvest and dry their groundnuts in batches given the limited drying space in most farming communities. This process of harvesting and drying in batches increases drying days. Also, farmers with larger volumes of production can afford to sell some of the output and keep the rest for the lean season where they get a better price, thus explaining why storage duration tends to increase with production volumes.

Other farm lands cultivated increases the likelihood of drying groundnuts on bare dirt, storing groundnuts on wooden pallets and increases storage duration. Given the competing demand for the limited post-harvest facilities, it should not be surprising that groundnuts are dried on bare dirt when more other farm lands are kept. Other farm lands, also, increases the storage duration of groundnuts because it leads to the production of other crops which intend reduces the farmer's dependency on groundnuts. Interestingly, however, other farm lands increases the likelihood of storing groundnuts on wooden pallets. One would expect that the competing demand for the limited post-harvest facilities would undermine the storage of groundnuts on wooden pallet. This finding shows the importance of groundnuts to the farmer.

Table 1.2: Determinants of Aflatoxin levels with post-harvest constraints

	SECOND STAGE	FIRST STAGE							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variables	Log(Aflatoxin)	Harvest delay	Threshing delay	Drying days	Dirt drying	Sorting	New container	W. Pallet	Stora. duration
Intercept	0.429	0.196*	0.493***	8.095***	0.416***	0.851***	0.304**	0.716***	5.356***
	(2.3560)	(0.1070)	(0.1320)	(0.6530)	(0.1160)	(0.1130)	(0.1220)	(0.1110)	(0.3800)
Female		0.0354	-0.132***	-0.0609	0.145***	0.00107	0.00806	-0.0152	0.232**
		(0.0367)	(0.0371)	(0.2040)	(0.0395)	(0.0355)	(0.0464)	(0.0391)	(0.0994)
Labor supply		-0.0160***	0.0000946	-0.0117	0.0268***	-0.0218***	0.00808	0.00175	0.0102
		(0.0051)	(0.0047)	(0.0264)	(0.0051)	(0.0064)	(0.0062)	(0.0042)	(0.0174)
Household head		0.0337	-0.00525	-0.0406	0.131***	-0.0558	-0.0157	0.00978	0.319***
		(0.0324)	(0.0319)	(0.1720)	(0.0410)	(0.0367)	(0.0403)	(0.0368)	(0.1200)
Education		-0.0308	-0.0593	0.0216	0.00427	-0.0515	0.0309	0.00532	0.209*
		(0.0391)	(0.0400)	(0.1840)	(0.0447)	(0.0386)	(0.0427)	(0.0359)	(0.1120)
Primary occupation		-0.0181	-0.0931	-0.269	0.00988	-0.0000438	-0.1	-0.0248	0.435**
		(0.0678)	(0.0572)	(0.2900)	(0.0768)	(0.0671)	(0.0766)	(0.0628)	(0.2150)
Secondary occupation		0.0959***	0.0227	-0.159	-0.00654	0.114***	0.0193	0.00598	-0.0999
		(0.0331)	(0.0298)	(0.1460)	(0.0358)	(0.0379)	(0.0333)	(0.0341)	(0.1300)
Income constraints		-0.00846	0.0319	0.0872	-0.0566	0.0427	0.00794	-0.0153	-0.135
		(0.0275)	(0.0339)	(0.1410)	(0.0364)	(0.0355)	(0.0352)	(0.0271)	(0.1020)
Farm size		0.00872	0.0156**	-0.0472	-0.00619	-0.000255	-0.0298***	0.0116	-0.0411
		(0.0119)	(0.0077)	(0.0434)	(0.0138)	(0.0130)	(0.0099)	(0.0079)	(0.0396)
Production volume		0.00352	-0.000719	0.0280**	0.00113	0.0036	0.00495	0.000924	0.0333***
		(0.0036)	(0.0034)	(0.0111)	(0.0033)	(0.0036)	(0.0031)	(0.0020)	(0.0106)
Other farm lands		0.000468	0.00253	-0.00498	0.00549*	0.000438	-0.00306	0.00470***	0.0219**
		(0.0025)	(0.0017)	(0.0080)	(0.0032)	(0.0023)	(0.0022)	(0.0016)	(0.0094)
Harvest delay	1.818***								
	(0.6670)								
Threshing delay	-1.28								
	(1.2310)								
Drying days	0.186								
	(0.2690)								

Dirt drying	0.294***								
	(0.0817)								
Sorting	-1.750***								
	(0.6660)								
New container	0.288								
	(0.2240)								
W. Pallet	3.77								
	(3.4420)								
Storage duration	-0.324								
	(0.3150)								
Wu-Hausman test of end *(p-v)*	0.0164								
Sargan test of overid (*p-v*)	0.4840								
Number of instruments	10								
Observations	920	920	920	920	920	920	920	920	920
R-squared		0.106	0.357	0.238	0.161	0.241	0.143	0.179	0.111

Notes: Standard errors are in parentheses. *Denotes statistical significance at the 10% level. **Denotes statistical significance at the 5% level. ***Denotes statistical significance at the 1% level. See notes to Table 2.8 in Appendix for the definition of variables. Wu-Hausman test of end (p-v) reports the p-value for endogeneity test. The null hypothesis is that the variables under consideration can be treated as exogenous. The test favors the endogeneity of the variables.
Sargan test of overid (*p-v*) reports the p-value for overidentifying restrictions. The null hypothesis is that there are no overidentifying restrictions.

In the second stage of the 2SLS, the results show that harvest delay and drying on bare dirt increases aflatoxin levels, while sorting groundnuts by quality has the opposite effect. Aflatoxin levels increased 5-fold when groundnuts harvest was delayed by a day or more. This should not be surprising because harvest delay increases mold incidence, insect damage, and infestation by bad fungi, which are linked to aflatoxin contamination. This shows that for improved harvest quality of groundnuts, farmers should harvest immediately the crops that are matured. Similarly, drying nuts on dirt increase aflatoxin levels by 34 percent. This is because drying on bare dirt exposes the groundnuts to fungal spores and moisture in the dirt, making them susceptible to fungi contamination and invasion by Aspergillus flavus and Aspergillus parasiticus.

Sorting out physically damaged and infested groundnuts (based on mold content, empty pods and reduced size), on the other hand, reduces aflatoxin levels by 83 percent. This is consistent with the findings of Park (2002) that sorting out physically damaged, and infected grains can result in a 40 to 80 percent reduction in aflatoxin levels. These findings confirm and reinforce other findings of the importance of timely harvest, drying groundnuts on improved surfaces and sorting groundnuts by quality to aflatoxin reduction.

Some discussion is needed on the validity of the instruments. For household constraints to be valid instruments, it must transmit its influence on aflatoxin levels solely through post-harvest practices (the instrumental variable exclusion restriction). This means that (1) constraints must correlated with farmers' practices but must not directly affect aflatoxin levels, and (2) constraints must be exogenous to all other important and unobserved factors that also affect aflatoxin levels. While household constraints and characteristics that we use as instruments could influence one's ability to adopt proper post-harvest handling measures it is virtually impossible for aflatoxin to be produced in crops on the basis of these constraints and therefore are not concerned by (1) above. With respect to (2) above, it is possible that unobserved factors at the individual and village level affect both aflatoxin levels and practices even though we control for village fixed effects that may influence some constraints to post-harvest practices. Also, it possible that the constraints we use as instruments affect farmers' practices we do not observe or that there is unobserved heterogeneity in the farmers' practices we do observe. The exclusion restriction would be violated if the unobserved practices or unobserved heterogeneity in observed practices are correlated with aflatoxin levels and constraints. Given the wide range of production and post-harvest practices we observe in our data, we are unaware of any other practice that would affect aflatoxin levels and also the constraints and characteristics we observe. Unobserved heterogeneity in practices is a greater concern, but for the most part this data should be accurate as the variables are generally binary and easy for farmers to recall.

Also, Hausman test of endogeneity and sargen test on overidentifying restrictions is passed as indicated by the results reported in Table 1.2. We therefore conclude that our main finding concerning the effect of post-harvest practices on aflatoxin levels can be interpreted as causal and not as a result of endogeneity.

1.8 CONCLUSION

The economic literature on aflatoxin contamination is still growing as researchers continue to search for feasible control strategies to minimize its effect and impact on food production. As a result, numerous post-harvest practices have been considered to assess the causes and determinant of aflatoxin levels. However, previous studies estimating the effect of post-harvest practices on aflatoxin levels have focused only on the effects of these practices without assessing the constraints on these practices, and this study addresses this issue. This study uses a unique dataset that combines aflatoxin test results with detailed survey data to examine how the constraints Ghanaian household face affect their groundnut production, drying, and storage practices, and how these practices affect aflatoxin levels in their peanuts production.

The results reveal the gender-specific constraints in post-harvest management and provide some evidence that gender affect farmers' access to post-harvest facilities and resources. Also, the impact of agricultural labor supply on post-harvest management is revealed, particularly those relating to the timing of harvest, drying technique and sorting decision. The results show that households with more labor are likely to use fewer days in harvesting, more likely to dry on dirt and less likely to sort their groundnuts. This variability in post-harvest management is due to the amount of labor available and the additional social responsible each unit of labor add.

Another notable result is the effect of household headship on post-harvest management. The result shows that the ability of household heads to influence post-harvest decisions, by virtue of their position, is mixed. We also note that farmers whose sole occupation is farming tend to keep their groundnuts in storage for a much longer period. Farmers with secondary jobs tend to experience harvest delays. Also, farm size contributes to threshing delay and reduces the likelihood of using new storage containers, while the volume of production extends the number of drying days and storage duration. Other farm lands cultivated, besides groundnuts, increases the likelihood of drying groundnuts on bare dirt, storing groundnuts on wooden pallet and increase in storage duration.

The overarching findings are that aflatoxin levels increase 5-fold when groundnuts harvest is delayed by a day or more. Similarly, drying nuts on dirt increase aflatoxin levels by 34 percent. Sorting out physically damaged and infested groundnuts (based on mold content, empty pods and reduced size), on the other hand, reduces aflatoxin levels by 83 percent. These findings confirm and reinforce other findings of the importance of timely harvest, drying groundnuts on improved surfaces and sorting groundnuts by quality to aflatoxin reduction.

From a policy standpoint, this study has provided useful information and strategies for reducing aflatoxin. Efforts and interventions to mitigate the impact or control the level of aflatoxin should not only consider the important role played by post-harvest practices but the household constraints that affect these practices thus rendering them ineffective in reducing aflatoxin levels.

CHAPTER 2

POST HARVEST INTERVENTION MEASURES IN REDUCING AFLATOXIN IN GHANA

2.1 INTRODUCTION

Various simple practices can be used to manage aflatoxins in crops such as harvesting the crop at optimum maturity, rapid drying on improved surfaces or raised platforms to avoid contact with soil, controlling for moisture content and humidity during drying and storage, and using new or clean storage bags before storage. Aflatoxin reduction under these practices can vary from 63 to 88 percent depending on location (Waliyar et al., 2013).

Regrettably, in many SSA countries, many farmers are not even aware of the effect of these simple practices for aflatoxin control. In Ghana, for example, most farmers sun-dry groundnuts on the bare ground, a laborious and time-consuming method that makes them susceptible to humidity and fungal contamination (Turner et al., 2005; Okello et al., 2010). Also, farmers often store groundnuts in containers that previously stored other crops and rarely are steps taken to clean these bags before storage. As a result of these poor post-harvest practices, the groundnuts that are produced, consumed and sold in Ghana are frequently contaminated by toxigenic fungi and contain aflatoxin in amounts exceeding the allowable limits.

This study seeks to assess the impact of specific post-harvest practices on aflatoxin contamination in groundnuts grown and stored by farmers in the Northern and Upper East Region of Ghana. We worked with 40 farmers across 20 villages to implement an on-farm experiment in which each farmer varied the post-harvest measures applied across nine bags of groundnuts according to a 3 by 3 design. The experimental design tested all nine combinations of two different drying techniques plus status quo drying, and two different storage techniques plus status quo storage. We then compared aflatoxin contamination levels across nuts assigned to each post-harvest treatment three months later. As part of the study, we provided farmers with locally procured plastic tarpaulins and racks for drying, wooden palettes and clean storage bags for storage of nuts.

The essay proceeds as follows. Section 2 presents the study design. In Section 3 we describe the sampling methodology. Moisture analysis and aflatoxin testing procedures are presented in Section 4. In Section 5 we present the main empirical results. Section 6 summarizes and concludes.

2.2 SAMPLING OF COMMUNITIES AND PARTICIPANTS

The study was conducted in 20 selected villages, 10 in the Northern region and 10 in the Upper East region of Ghana, the primary commercial groundnut production regions in the country. The communities were purposively selected based on their involvement in groundnut production. In every community, we recruited, by a purposive sampling procedure, two subsistence farming households actively involved in peanut farming and its associated post-harvest handling who expected to harvest at least ten bags of 50 kg.

During the recruitment, the survey staff visited the homes of potential study households, obtained consent and administered structured questionnaires. The respondents were asked, among other things, questions about the expected date of harvest, the variety of groundnuts cultivated, and their drying methods (where and how they dry groundnuts after harvest). They were also asked about the type of storage containers they used—whether they use new bags or old bags, how they store groundnuts—whether they place the bags of groundnuts directly on the ground during storage, or put them on a pallet or other platforms to keep them off the floor, and their storage period. Three drying systems were identified in the two regions. Concrete and dirt floor drying were found in the Northern region while roof drying was predominantly used in the

Upper East region. Groundnuts storage in bags was the most common among all farmers in the two regions. A total of 14 representing 39% and 21 representing 60% of the respondents store their groundnuts in Jute sacks and plastic sacks respectively.

In the end, farmers who expected to harvest at least ten bags (each bag weighed about 50 kg) of one variety were eligible to participate. Before accepting to participate, the farmers were encouraged to confer with members of the family since groundnut production is a household affair. In total, 40 farmers consented to participate with 360 bags of groundnuts included in the experiment.[7]

2.3 STUDY DESIGN

Three visits were made to study farmers: the first was to identify and recruit eligible participants for the study as described in section 4. The second was at harvest time in September or October 2014 for the Northern region and November or December 2014 for the Upper East region . The third visit was three months after nuts were placed into storage.

At the second visit, conducted during the gorundnut harvest, groundnuts were first mixed to achieve homogeneity and then a 200 gram sample was taken.[8] The samples were transferred on the same day to the Department of Biotechnology, University for Development Studies in Ghana (UDS) and stored at -20 degrees Celsius to prevent further accumulation of molds and aflatoxin until analysis (Anderson et al., 1995).

At this stage, we introduced the package of intervention measures to improve the drying and storage of groundnuts. Trained students from UDS were employed to explain the intervention strategy and demonstrates the different intervention techniques to the farmers.

[7] The study was conducted with the approval of the International Food Policy Research Institute Review Board.
[8] Compensation was given to the farmers for the samples taken.

At the third visit, conducted three months after nuts had been placed in storage, groundnuts samples were taken from each of the nine experimental bags and transferred on the same day to the Department of Biotechnology, UDS and stored at the appropriate temperature to prevent further postharvest accumulation of molds and aflatoxin until analysis.[9] Additional visits—three visits per farmer— were made to farmers between the primary visits to verify compliance with the intervention measures.

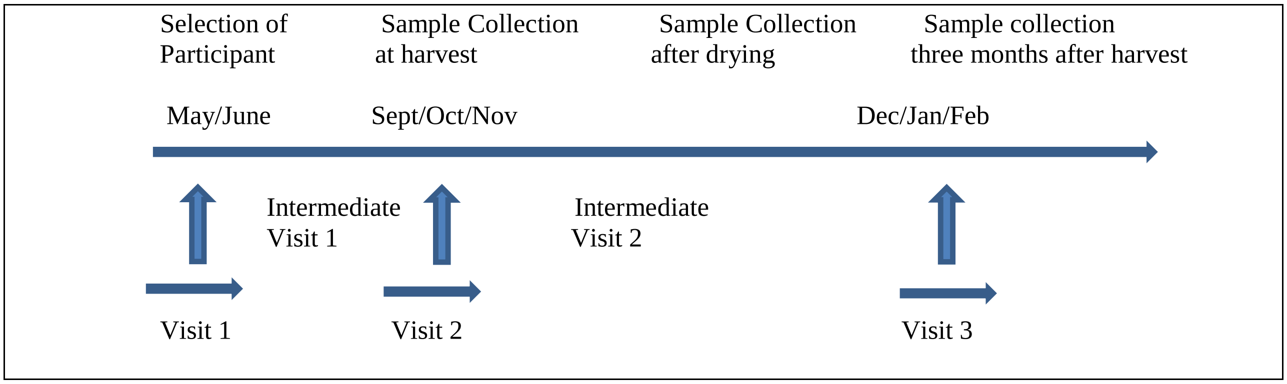

Figure 2.1: Outline of study design. 40 people from 20 villages participated.

2.3.1 INTERVENTION STRATEGIES

The post-harvest drying and storage intervention was based on a 3 x 3 research design (nine treatments) as shown in Table 2.1. To assess the effectiveness of the various intervention technologies, farmers were introduced to plastic tarpaulins and locally made racks for drying their peanuts, wooden pallets and clean storage bags for storing their nuts. The combination of the intervention technologies used was varied across the nine treatments.

[9] Three months was chosen because, a period of three months is long enough for aflatoxin development in A. flavus-infected foods (Sauer & Tuite, 1987). Also, the majority of farmers in Ghana store groundnuts for two to six months while a few others may go up to one year.

Table 1: The combination of technologies used.[a]

	Status quo drying	Rack drying	Tarpaulin drying
Status quo storage	1 bag	1 bag	1 bag
Palette + clean plastic bag	1 bag	1 bag	1 bag
Palette + clean jute bag	1 bag	1 bag	1 bag

[a]The average expected groundnut production was 16 bags (of 50 kg each). Nine bags (each bag weighed about 50 kg) were used in these nine treatments.

Status quo drying: Groundnuts were dried on the dirt floor, concrete floor or roof top, according to farmers' usual practices.

Rack drying: Groundnuts that were dried on racks provided through the study.

Tarpaulin drying: Groundnuts were dried on plastic tarpaulins provided through the study.

Status quo storage: Groundnuts were stored according to farmers' usual practices, generally in previously used storage bags made of woven plastic, placed directly on the floor or on stones.

Palette + clean plastic bag: Groundnuts were stored in new woven plastic bags and placed on a wooden palette.

Palette + clean jute bag: These are groundnuts stored in new jute bags and placed on a wooden palette.

Trained field staff asked study participants to dry and store one bag of their groundnuts according their usual practices (status quo drying and status quo storage). One of the 50 kg bags nuts dried according to status quo practices was stored in a new plastic bag and another was stored in a clean jute bag. Both of these bags were placed on wooden palette. One 50 kg bag that had been rack-dried was stored the usual way (status quo storage), one was stored in a new plastic bag on a palette, and one was stored in a new jute bag on a palette. Similarly, of the nuts dried on the plastic tarps, one 50 kg bag was subjected to status quo storage one was placed in a new plastic bag on a pallete, and one in a new jute bag on a palette. Just before storage, 200 gram sample was taken from each drying treatment to check for moisture content.

2.3.2 DRYING ON RAISED RACKS

Traditionally, small holder farmers in the study regions traditionally stack their harvested crop in heaps in the fields where they were cultivated for several days to dry before removing nuts from the plants. Large heaps may concentrate and accumulate moisture, leading to a slow drying process under humid conditions which can allow fungal growth and increase the risk of aflatoxin contamination (Okello et al., 2010). As an alternative to this practice, drying racks made from locally purchased tree posts were provided. The racks consisted of several horizontal poles bookended by two crossed pieces of wood on either side, which served to create four pointes of contact with the ground. Immediately after harvest, the groundnuts stalks were propped on the rack for drying. Drying on the rack increases air flow, thus avoiding moisture buildup and expediting drying. Drying of groundnuts on raised racks has been examined and used by many researchers and non-governmental organizations in some developing countries with some relative success.[10]

2.3.3 DRYING ON PLASTIC TARPAULIN

Traditionally, once groundnuts have been plucked from the plant, the nuts are laid out on the ground (often directly on bare earth) to dry in the sun. Contact with soil during this process exposes nuts to humidity and fungal contamination. At night or in the event of unexpected rains, most farmers cover their groundnuts with thatch instead of bringing them inside. Due to rains that frequently persist at harvesting and drying times, it is hard to achieve the recommended moisture level for safe storage with this practice. Therefore, locally produced plastic tarpaulins for sun-drying were provided.

[10] See for example Fintrac: http://www.fintrac.com/ag-innovation/frame-drying-huts; Hayma, J. (2003). AD31E the storage of tropical agricultural products. Agromisa Foundation.

Drying on tarpaulins limits direct exposure of the groundnuts to dust, dirt and disease-causing organisms found in the soil. Farmers were each given one impermeable plastic tarps, each measuring 12 by 12 feet, purchased at a cost of US$6 each including shipping. They were advised to dry their groundnuts in a layer not exceeding four centimeters deep. In the event of rains, and at night, farmers were encouraged to bring their groundnuts inside to prevent them from moisture.

2.3.4 STORAGE BAGS

The storing stage is very important to reduce attack and damage from insects and fungi. If groundnuts are improperly stored (i.e., if storage containers are not cleaned and are infected with mold spores or under high humidity with inadequate protection or in an improperly dried state), fungal growth is likely.

In Northern Ghana, however, farmers frequently do not take proper steps to clean their storage containers or make sure storage containers are not infected with mold spores. Farmers were each given six new jute and woven plastic bags for use in the two non-status quo storage treatments purchased at a cost of US$1 each including shipping. These storage bags are made of materials that allow air to circulate and flow.

2.3.5 WOODEN PALETTE

The storage surface of groundnuts is an essential factor when considering aflatoxin formation. To prevent the growth of fungi in storage, containers should be stored off the ground. They should be laid on a platform of wooden planks to ensure free air circulation. Unfortunately, in these regions, bags of groundnuts are often stored on the floor or stones leading to the risk of humidity from the earthen floors. We provided locally made wooden pallets on which to store the bags for use in both improved storage treatments (Turner et al., 2005).

2.3.6 GROUNDNUT SAMPLING

Sampling is an important step in measuring and testing aflatoxin contamination in grains due to the extremely heterogeneous and highly skewed distribution of aflatoxin contamination within a single lot of nuts (Okello et al., 2010). A sampling protocol consistent with (Schuller, Horwitz, & Stoloff, 1976; Whitaker & Dickens, 1983) was used to obtain representative samples of nuts.

Groundnut samples were obtained at three different times during the experiment: first at harvest time (phase 1); second after drying but before storage (phase 2); and third, three months after storage. At the first phase, samples of freshly harvested groundnuts were randomly taken from each of the four quadrants of the field while harvesting was ongoing. This sampling protocol was adopted to ensure that a representative sample of groundnuts was obtained from the field of each farmer. After drying had been completed (phase 2), several small samples were taken at random from lots of groundnuts subjected to each of the three drying protocols (Tarpaulin, Rack, and Status Quo drying methods) for moisture analysis.

At the third phase, samples were randomly obtained from the top, middle, bottom and sides of bags assigned to each of the nine different treatments as shown in Table 1. Samples were thoroughly mixed at the bag level to form one representative sample per treatment per farmer and were analyzed for aflatoxin contamination. All samples were delivered to the laboratory for analysis in paper bags and were stored for a week at -4 ^{0}C in their original form before analysis to stall the activities of the Aspergillus species.

2.4 DETERMINATION OF MOISTURE CONTENT AND AFLATOXIN LEVEL

2.4.1 DETERMINATION OF MOISTURE CONTENT

The amount of moisture in groundnuts is one of the most important considerations in determining whether aflatoxin will develop in groundnuts after harvest. The maximum moisture content for storage of groundnuts (unshelled) is 9% while that for shelled groundnuts is 7% (Odogola, 1994; Waliyar et al., 2007; 2008). At these moisture contents, if the relative humidity is maintained at 70% and temperature 25 – 270 ºC, nuts may be stored safely for approximately one year (Okello et al., 2010).

The moisture content of the groundnut samples was determined using the standard oven-dry test method. The samples were dried at 100 °C to constant weight, and the mean moisture content was calculated on a wet percentage basis (Kaaya et al., 2006).

2.4.2 DETERMINATION OF AFLATOXIN CONTENT

The Romer FluoroQuant Afla Test Kit System for groundnuts was used to test for aflatoxin. The samples obtained from the nine treatments, as described above, were mixed thoroughly and ground in the laboratory using a Waring Blender with a stainless steel container. From each blended sample, an analytical sample of fifty grams (50 g) was then obtained and triturated in a blender in 86% acetonitrile (86 ml absolute acetonitrile in 14 ml distilled water) until thoroughly mixed, for one minute. The blended mixture was filtered using fluted filter paper into a conical flask, and 1000 microliter (μL) of the filtrate was pipetted into a cuvette, containing 1000 μL diluent (25ml of deionized water per a developer concentrate). The cuvette was capped and placed in a vortex for 5 seconds. The cuvette was them wiped with lint-free paper, then, inserted into a calibrated fluorometer and analyzed for aflatoxin contamination.[11]

2.4.3 COMPENSATION FOR ADVERSE IMPACT

Payment was made to farmers for nuts found to be contaminated above 10ppb in the drying treatment and in some cases the groundnuts were retrieved. The payment made spanned the current

11 Since the use of predetermined standards in most analytical laboratories helps in obtaining accurate values, pre-determined aflatoxin levels of groundnut paste imported from the United States were tested to ensure that the FQ Reader values were consistence with these standards.

market price, which at the time of the study was reported by the participants to be 120 Ghana cedis per 100 kilogram bag on average (approximately 32 USD).

2.5 RESULTS

We present the result of the moisture content analysis and assess the relative effectiveness and impact of the various intervention groups on aflatoxin levels.

2.5.1 MOISTURE CONTENT ANALYSIS

The results of the number of drying days and moisture content after drying in the two regions are presented in Table 2.2 and 2.3 respectively. As shown in Table 2.2, there was a significant difference (Hotelling F (2, 35); p = 0.0000) among the mean drying days of the tarpaulin, rack and status quo drying methods.[12] The average drying days for the tarpaulin was eight days while the rack and status quo drying days were 12 days and eight days respectively. Because it is onerous to transport nuts prior to plucking, rack drying was conducted in the field, often far from the homestead. According to farmer reports, this made it difficult for the farmers to cover the rack-dried nuts quickly in the event of unexpected rains, leading to longer drying times under this treatment.

Table 2.2: Analysis groundnuts drying days

		Drying Days (Days)	
Intervention Measures	No of samples	Range	Mean
Tarpaulin	111	4-13	7.92
Rack	111	5-23	12.32
Status Quo	111	3-14	8.49
Hotelling F(2,35)			(*p*=0.0000)

Note: The null hypothesis of the Hotelling's T-squared statistic is that the mean drying days for the Tarpaulin, Rack and status Quo treatments are the same. As shown, there is a significant difference (Hotelling F (2, 35) =28.07, p=0.0000) among the mean drying days of the various treatment groups.

[12] Hotelling's T-squared statistic is a multivariate generalization of the univariate t statistic used in undertaking tests of the differences between the (multivariate) means of different population samples.

The mean moisture content, for each drying treatment, is presented in Table 2.3. Hotelling's T-squared statistic was used to determine whether there were significant differences in moisture content among the different treatment groups. The moisture content level was significantly (p=0.0070) lower for the rack intervention, followed by the status quo, while groundnuts from the tarpaulin had the highest mean moisture content levels. This variation could be explained by the variability in the drying days of the various methods as shown in Table 2.2. However, as shown in Table 2.3, the mean moisture content levels for each of the three methods were below the recommended moisture content for groundnuts[13], i.e.; they were all below 9 percent at the 1 percent significant level.

Table 2.3: The moisture content of groundnuts after drying but before storage

		Moisture Content (%)	
Intervention Measures	No of samples	Range	Mean
Tarpaulin	111	2.19-8.88	5.41*** (0.291)
Rack	111	2.23-7.37	4.71*** (0.257)
Status Quo	111	2.30-8.78	5.24*** (0.296)
Hotelling F(2,35)			(p< 0.0070)

Note: Values in parentheses are standard errors.
*Denotes statistical significance at the 10% level.
**Denotes statistical significance at the 5% level.
***Denotes statistical significance at the 1% level.

Ho: μ >9% (The mean moisture content for Tarpaulin, Rack, and Status Quo treatments are greater than 9%)
Ha: $\mu \leq$9% (The mean moisture content for Tarpaulin, Rack, and Status Quo treatments are less than or equal to 9%)

[13] The recommended moisture content for storage of groundnuts (unshelled) is 9% while that for shelled groundnuts is 7% (Odogola, 1994; Waliyar et al., 2007; 2008).

2.5.2 REGRESSION OF AFLATOXIN LEVELS ON TREATMENT GROUPS

To assess the relative effect of each intervention groups and isolate the impact of drying type and storage type on aflatoxin concentration levels, we run a simple regression of the log of aflatoxin levels on the drying and storage regimes. We took the log of aflatoxin concentration level to reduce the extrema in the aflatoxin data and curtail the effects of outliers (Wooldridge, 2003). Thus, we regress the log of aflatoxin levels on tarpaulin use, rack use, plastic bags and jute bags, after difference out any variation in aflatoxin levels present at the time of harvest. Hence, the log of aflatoxin is the aflatoxin level from harvest time to three months later. The status quo drying method is the reference category against which the effects of the tarpaulin use and rack use are assessed. Similarly, plastic bags and jute bags are assessed against the status storage method.

As shown, in Table 2.4, the use of using a tarpaulin on aflatoxin levels is negative and statistically significant at a conventional 5% level. This shows that the practice of drying nuts on tarpaulins plays a major role in controlling aflatoxin buildup compared to status quo drying. The use of tarpaulin reduces aflatoxin levels by about 40 percent compared to the status quo methods of drying. Drying on a tarpaulins limits the exposure of the groundnuts to dust, dirt and disease-causing organisms found in the soil.

The rack, on the other hand, increased aflatoxin contamination compared to the status drying methods. This could be due to the fact that racks were erected in the field far from farmers' homes, which made it difficult to protect these nuts from attach by pests or to cover them in case of rain or overnight humidity..

In contrast to the sharp differences seen across drying treatments, aflatoxin levels of nuts stored in new plastic, new jute, and reused plastic bags were indistinguishable.

Table 2.4: Regression of Aflatoxin levels on treatment groups

Variable	Aflatoxin
Intercept	2.529***
	(0.712)
Tarpaulin	-0.405**
	(0.178)
Rack	1.547***
	(0.485)
Plastic bag	0.194
	(0.187)
Jute bag	0.0644
	(0.157)
Observations	279
R-squared	0.171

Notes: Standard errors are in parentheses.
*Denotes statistical significance at the 10% level.
**Denotes statistical significance at the 5% level.
***Denotes statistical significance at the 1% level.

2.6 CONCLUSION

Results from this study show that the use of tarpaulins for sun-drying groundnuts can significantly reduce the accumulation of aflatoxin post-harvest. For the 40 farmers who participated in this experiment, use of tarpaulins reduces aflatoxin levels in groundnuts by about 40 percent compared to status quo methods of drying. Drying nuts on a rack in the field prior to plucking, on the other hand, had a positive effect on aflatoxin levels. The results also show that aflatoxin contamination is not significantly affected by the use of new plastic, new jute, or reused plastic storage bags.

Availability and cost are key determinants of farmers' adoption of any new technology or practice. While tarpaulins of the type used in this study are not locally available,[14] plastic sheeting can be found in nearby markets, at a price of US$6 for the same area as the tarps provided through this study. Efficacy of plastic sheeting for aflatoxin control is expected to be the same as that of

[14] Heavy-duty tarps are available at a cost of 200 Ghana cedis ($ 50 USD) for 12 by 12 feet.

the tarpaulins used in this study, though it is likely not as durable so could be used for only one or two seasons. As evidenced by farmers' status quo practices, use of either plastic sheeting or tarpaulin is very low in the study region. This is likely due to lack of knowledge about the problems caused by aflatoxin, or the effect of drying on a barrier for controlling the toxin. Other barriers also exist, in particular the poverty and lack of liquid assets among farmers in Northern Ghana, many of whom grow groundnuts primarily or solely for subsistence.

Two limitations of this study are the relatively small sample size and the fact that exposure was monitored only three months post-harvest. However, the results provide significant new information on levels of aflatoxin in groundnuts in the study are (Northern and Upper East regions) and is the first we know of that evaluates the relative impacts on aflatoxin of six simple, low-cost technologies for on-farm drying and storage in a semi-subsistence setting.

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APPENDIX A

Table 2.8: Data definition, type and measurement

Variable Name	Variable Type	Description of Variable	Measurement
Aflatoxin concentration level	Continuous	The aflatoxin concentration levels	Parts per billion (ppb)
Female	Categorical	The respondent is a female	Female=1 Male=0
Labor supply	Continuous	The size of the household	Number of persons
Household Head	Categorical	The respondent in the head of the household	Respondent is the head of household =1 Otherwise=0
Education	Categorical	The education level of the respondent	Some formal education=1 No formal education=0
Primary occupation	Categorical	The primary occupation of the respondent	Work on the farm =1 Non-farm work=0
Secondary occupation	Categorical	Does the respondent has a secondary occupation	Has a secondary occupation =1 None=0
Income constraints	Categorical	What prompted the respondent to take groundnuts out of storage for sale	Income constraints=1 Others=0
Farm size	Continuous	The size of land used for groundnuts cultivation	Acres
Production volume	Continuous	The level of output produced	Measured in jute bag. A jute sack weighs approximately 100kilograms when filled with peanuts
Other farm lands	Categorical	The size of land used for cultivation other crops besides groundnuts	Acres
Harvest delay	Categorical	The number of days labor constraints change the time at which you uprooted.	One or more days=1 None=0
Threshing delay	Categorical	The number of days you waited, after uprooting the first nuts, before plucking the pods from those stems	Two or more days=1 At most a day=0

Drying days	Continuous	The number of days it took to dry the groundnuts after plucking	Days
Dirt drying	Categorical	The surface on which groundnuts is dried	Dry on dirt=1 All others drying surfaces=0
Sorting	Categorical	Whether you sort groundnuts by quality after drying	Sort=1 No sorting=0
New Storage Container	Categorical	Whether you use old containers or new containers	New Containers=1 Some Old Containers=2
Wooden Pallet	Categorical	The surface on which groundnuts is stored	Wooden pallets/ Other platform=1 Directly on the floor =0
Storage Duration	Continuous	Storage duration since harvest	Months