PHYSICAL AND BIOLOGICAL APPROACHES TO PREVENT AFLATOXIN CONTAMINATION IN PEANUTS AND THE AGRICULTURAL ENVIRONMENT

by

ESTHER YEBOAH AKOTO

(Under the Direction of JINRU CHEN)

ABSTRACT

The objective was to use physical (solar drying) and biological approaches (composting) to prevent aflatoxin contamination in peanuts and the agricultural environment. For solar drying, an indirect wooden solar dryer was constructed. The performance was determined by drying 18-72 kg of freshly harvested peanuts. Equal amounts of peanuts were dried simultaneously on cement concrete floor under open sun for comparison. Composting was conducted using aflatoxin-contaminated peanut meal as a model matrix at 40°C for 6 wk. Water and three different commercial starters and/or an accelerator were added to the contaminated peanut. Aflatoxin B_1, B_2, G_1 and G_2 were quantified at the end of each week. Solar dried peanuts attained moisture content below 10% in four days. Peanuts in the solar dryer experienced much lower temperatures than those dried under the open sun. Solar dried peanuts had a lower level of lipid oxidation and a higher rate of germination compared to open sundried peanuts. Composting reduced aflatoxin levels in aflatoxin-contaminated peanut meal.

INDEX WORDS: Peanuts, aflatoxins, compost, solar drying, agricultural environment

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DEDICATION

Unendingly, I reverend my thesis to my Lord and personal savior, Jesus Christ for the unmerited favor to pursue graduate studies. This is dedicated to my parents, Vivian Mensah and Joseph Kojo Yeboah (deceased) for the encouragement and support to pursue education as the only female child to them. My four brothers were the wings on which I flew to my success in pursuing my dreams. Greater are the heights to reach as I prepare towards my oncoming Ph.D. studies. Daddy Yeboah, I look forward to dedicating the Ph.D. dissertation to my kids as you wished when you were physically with us.

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CHAPTER 1

INTRODUCTION

Peanut (*Arachis hypogaea*) is a staple food commodity in many countries in Africa (Keny and Finn, 2004), and it serves as a major protein source in tropical and semi-tropical areas (FAO, 2005). According to Food and Agriculture Organization (FAO, 2005), peanuts are also rich source of carbohydrates and fats. The inhabitants in the developing regions of the world consume peanuts roasted, milled, boiled and made into milk (Asibuo et al., 2008). Commercially, countries such as Ghana export peanut for foreign exchange hence resulting in income generation and creation of jobs (Frimpong, 2015). Although a good source of nutrition and income, peanut production in Africa is traditionally low due to inadequate rain, climate change, low technology for small scale farmers, diseases and pests as well as mycotoxin-producing fungi contamination (*e.g.* aflatoxins; Wayne, 2007).

In some cases, aflatoxin contamination does not only reduce peanut yield but also cause health problems to both humans and animals when contaminated nuts are consumed (Zain, 2011). Studies in Benin, Togo and the Gambia have linked aflatoxin exposure to kwashiorkor, liver cancer and increased susceptibility to hepatitis (Magan and Aldred, 2007). A cross-sectional study of children in Gambia also found that 93% of the children had been exposed to some level of aflatoxins (Gong et al., 2002). Mycotoxins are produced during pre-harvest as well as postharvest handling of agricultural products (FAO, 2005). Magan and Aldred (2007) linked the production of mycotoxins to intrinsic factors (moisture content, water activity and

nutrient composition) of the plant, extrinsic factors (climate, temperature and oxygen level), and processing factors (handling of grains, drying, blending). Among the mycotoxins, aflatoxin is a major one produced by *Aspergillus flavus* and *Aspergillus parasiticus* (Varga et al., 2015). FAO reported that 25% of the world's food crops are affected by aflatoxin contamination. Moreover, the Centers for Disease Control and Prevention (CDC) has estimated that 4.5 billion people in the developing world are exposed to aflatoxins (CDC, 2012). Aflatoxin contamination of grains causes $750 million losses in African countries (Jolly et al., 2009) and this is a major economic concern for most countries in sub-Sahara including Ghana. Most peanuts produced in Ghana are above the United Nations limit of 30 ppm for aflatoxin (Nathan Associates Inc., 2014) resulting in technical hindrances to trade that causes food insecurity problems (Unneveher, 2003).

Insufficient drying, pests, contamination of soil with toxigenic *Aspergillus* fungi as well as poor storage conditions are the contributing factors to the production of aflatoxins (FAO, 2005). As aflatoxin contamination is a major problem in developing countries, several methods have been employed to prevent contamination and reduction of toxin levels in agricultural produce (FAO, 2005). The methods include pre-harvest techniques such as breeding mold-resistant peanut species, irrigation, fertilizer application, weeding and harvesting on time. The post-harvest techniques include drying directly under the sun or using mechanized dryers and storing the peanuts at low and controlled relative humidity and aerated conditions (FAO, 2005). Mechanized drying is advantageous over traditional open sun drying because the latter exposes peanuts to adverse conditions such as sunlight, dust, dirt insects, and rain (Weiss and Buchinger, 2011). These factors facilitate fungus growth and subsequent aflatoxin contamination (Weiss and Buchinger, 2011). Mechanical drying has taken precedence in most developed countries

while open sun drying remains to be the most common method for drying agricultural products (Chua and Chu, 2003).

Mechanized drying of peanuts in developing countries is impractical due to limited resources including lack of income to procure equipment, labor cost and machine-operating fuel (Amruta and Ramakrishnaro, 2013). There is the need to implement affordable and accessible drying technologies, including solar drying, which is a re-emerging technology for drying foods (Amruta and Ramakrishnaro, 2013).

Fertilizer application is beneficial in improving crop yield for peasant farmers and preventing pathogen invasion of farm crops (FAO, 2016). Lack of finance and resources prevent peasant farmers in developing countries from procuring inorganic fertilizer for their agriculture fields, and they in turn apply agricultural waste such as peanut shells as soil amendment (Endris and Dawid, 2015). Aside affordability, some of the inorganic fertilizers have adverse effects (Prakash et al., 2010), and there is the need to utilize compost materials to minimize inorganic fertilizer application. FAO (2005) reported that composts made from organic wastes has a potential of increasing soil organic matter as well as supply plant nutrients in a slowly available form to improve growth.

Although composting is a great means of soil-enrichment for peanuts cultivation, research links *Aspergillus* contamination of soil to composting with agricultural waste (Ashraf et al., 2007). There is the need of pre-treating peanut waste (shells and kernels) to reduce aflatoxin contamination and incorporating the solid waste as compost, to reduce cost of production and improve soil enrichment to increase yield.

Objective of the research

To use physical and biological approaches to prevent aflatoxin contamination in peanuts and agricultural environments

CHAPTER 2

LITERATURE REVIEW

1. Peanut history and cultivation

Peanuts (*Arachis hypogaea*) originated in South America, specifically Bolivia and the surrounding countries and currently, are grown throughout the tropical and warm temperate areas in the world including Africa, Asia and United States (Putnam et al., 1991) on over 42 million acres of land. Putnam et al. (1991) stated that in 1990, FAO listed peanut as the third major oilseed in the world and only inferior in importance to soybean and cotton. India, China and United States have been the leading producers of the oil seed for over 25 years ago, (Putnam et al., 1991); developing countries in Africa are increasing production of peanuts amid the various challenges such as drought, poverty, and conflicts (Prasad, 2010).

In Africa, peanuts are cultivated mainly by Nigeria, Sudan, Senegal, Chad, Ghana, Congo and Niger (Prasad, 2010). In 2007, peanuts were cultivated on 9.04 million ha of land and the total peanut yield was 8.7 million tons in Africa (Mohammed, 2014). In 2010, average productivity in the region was 964 kg/ha which is poor when compared to the United States and other developed countries where it was close to 3,500 kg/ha (Verheye, 2010). While the 2010 average productivity of peanuts in Nigeria was 1,720 kg/ha, Sudan had 500 kg/ha and Senegal was close to 700 kg/ha (Verheye, 2010), Ghana on the other hand, produced 346.9 kg/ha (MOFA, 2011). Table 2.1 provides the world production of peanuts by country.

In Ghana, peanuts are produced in four main regions; Northern, Upper-West, Upper-East and some villages in the Ashanti Region (MOFA, 2011). Northern Ghana is the largest peanut production region in the country with a yield of 1.92 million tons per hectare in 2010, followed by Upper-West Region and together, the two regions produced 80% of peanuts in Ghana (Ibrahim and Florkowski, 2015; MOFA, 2011). The nuts are usually mixed cropped with major crops such as yam, maize and millet (Tsibey et al., 2003). Peanuts are usually processed into paste, edible oil and consumed with plantain by Ghanaians (Asibuo et al., 2008) and the benefits of the crop includes but not limited to industrial use, nutritional use and cash generation (FAO, 2005; Settaluri et al., 2012).

2. Nutritional benefits of peanuts

According to some researchers, the protein content of peanut is comparable to that of animal proteins including casein, eggs and meat (Settaluri et al. 2012). Peanuts are rich in protein, carbohydrate, fat and oils, minerals and vitamins (Mckevith, 2005). When considering protein content, peanuts are known to contain all the 9 essential amino acids required for various metabolic activities in the body (Mckevith, 2005). Due to this, researchers in nutrition are substituting cow milk with peanuts in ready to eat foods to mitigate malnutrition problems globally (Mckevith, 2005). In countries like India whose main staple foods are rice and potato with high carbohydrates, addition of peanuts to the diet enhances nutrition value of the meal (Mckevith, 2005). Peanuts also contain 24.64 g of monounsaturated fatty acids (oleic acid) and 15.69 g polyunsaturated fatty acids which reduce risk of coronary heart diseases (Masters et al., 2013). In addition, peanuts contain fat soluble and essential vitamins such as vitamin E which is an antioxidant and minerals (Table 2.2).

3. Economic importance of peanuts and challenges faced by developing countries

Peanuts are an important food and oil crop although world trade in peanuts did not achieve significance prior to development of peanut oil industry. For decades now, peanuts have been a cash crop generating income for poor farmers in the developing countries especially in Sub-Saharan Africa and Asia. In Senegal for example, 70% of the rural workforce is employed in peanut production which accounts for 60% of the households' agricultural income (Diop et al. 2004). Angelucci and Bazzucchi (2013) reported that peanut is commercialized by farmers in Ghana; irrespective of their farm size and approximately 50-85% peanut producers in Ghana market their produce for income. From 2005 to 2010, Ghana exported a range of 593-6,461 MT of peanuts for income generation (FAOSTAT, 2012). Although peanuts are a cash crop, developing countries in sub-Saharan Africa example Nigeria have lost their market share due to inability to meet the quality demands of edible peanuts (Diop et al., 2004).

4. Peanut production quality and safety issues

Global production of peanuts is faced with challenges including toxigenic mold contamination. In some Asian and African countries, approximately 30.97 million tons of peanuts and pistachios were contaminated by *A. flavus* and *A. niger* (Khosravi et al., 2007). Campbell et al. (2003) reported that fungal infestations happen before harvesting, after harvesting, during drying and storage of the peanuts. Factors noted to facilitate the contamination include storage temperature, moisture content and draught conditions on farm (Campbell et al. 2003).

4.1. Mold contamination and aflatoxin production

Aspergillus flavus and *Aspergillus parasiticus* are the main species that cause aflatoxin contamination in peanuts (Diao et al., 2014). These molds produce four kinds of aflatoxins

namely B_1, B_2, G_1 and G_2. Aflatoxin B_1 is the most prevalent as well as toxic among the four toxins (Diao et al., 2014). Aflatoxin contamination of agricultural produce causes annual losses of more than $750 million in Africa (N'dede et al. 2012). The United States also reported an annual income loss of more than $100 million due to aflatoxin contamination (N'dede et al. 2012). Various studies have been conducted to determine the stages of aflatoxin contamination in peanuts.

4.2. Stages of aflatoxin contamination in peanut production

Aflatoxin contamination in peanuts can occur in the field before harvest, during harvest or after harvest (Torres et al., 2014). The post-harvest contaminations can occur during drying and storage. Diao et al. (2015) reported that the pre-harvest factors include peanut cultivars, soil type, fungi species, climate and weather conditions, agricultural practices, harvesting time and moisture content. Cotty and Jaime-Garcia (2007) stated that drying, storage and transportation conditions are the main factors resulting in post-harvest aflatoxin contamination. For drying conditions, Torres et al. (2014) reported that timely drying and maintaining moisture content less than 10% during storage can effectively control aflatoxin contamination after harvest.

4.3. Health implications of aflatoxins

Epidemiological studies have linked aflatoxin consumption to incidence of liver cancer in humans (Gong et al., 2002). Furthermore, developing countries have the highest incidences of aflatoxicosis (Gong et al., 2002). Gong et al. (2002) that in Benin and Togo, children exposed to highest aflatoxin levels had stunted growth. In Gambia, children exposed to high aflatoxin levels had low immunity and reduced secretion of Immunoglobulin-A in saliva (Guchi, 2015). Ghana is of no exception, changes in immune cell subsets were observed after exposure of the immune cells to aflatoxin B_1. Animals are likewise, are affected by aflatoxin poisoning and the effects

are species dependent (Guchi, 2015). Poultry fed feed contaminated with 3.5 mg/kg of aflatoxin showed reduced body weight and increased liver and kidney weights (Smith et al., 1992). Asquith (1991) discovered that mature horses showed symptoms of jaundice and anorexia prior to death when fed with 58. 4 µg/kg aflatoxin-contaminated feed. These findings and others have triggered WHO, European Union (EU) and U.S. Food and Drug Administration (FDA) to set different total aflatoxin limits for animal feed ranging from 5-300 ppb depending on the age and type of animals and the type of feed (FDA, 2008).

4.4. Methods to control aflatoxin contamination

The best way to control aflatoxin contamination in peanuts is to prevent it from occurring, although this is a challenging goal to meet. Various methods have been devised to control aflatoxin contamination and these include pre-harvest methods and post-harvest methods.

4.4.1. Pre-harvest methods

The pre-harvest means include controlling kernel moisture content and temperature in the soil by irrigation (Dorner, 2008) and biological controls such introduction of a non-toxigenic strain of *A. flavus* to the soil during peanut development. The non-toxigenic mold (afla-guard®) competes with toxigenic mold and results in deletion of the entire aflatoxin gene cluster (Chang et al. 2005). Additionally, peanut breeding to produce germ plasm resistant to fungal growth or aflatoxin contamination is employed (Brown et al. 2003). The other control measures include controlling nitrogen stress and crowding of plants by weeding intermittently and fertilizer application (CAST, 2003).

4.4.2. Post-harvest methods

Peanuts are more susceptible to mold contamination and aflatoxin contamination during the curing and storage stages (Diao et al., 2014). Diener and Davis (1970) reported that

aflatoxin production in peanuts can be prevented by rapidly drying peanuts to a water activity below 0.83 and moisture content less than 10%. Cole et al. (1995) also reported that segregating peanuts and storing them in a low humidity environment controlled aflatoxin production.

4.4.2.1. Drying techniques

There are a vast number of peanut curing techniques ranging from open sun drying, solar drying to mechanize drying. Peanut producers use each curing method depending on resources and size of farm cultivated. In developing countries, majority of the poor farmers use open sun drying which is stated to cause deterioration to the quality of peanuts. Mechanical drying is another alternative, but most farmers in developing countries are unable to afford equipment and fuel required for the operation.

4.4.2.1.1. Solar drying

Solar food processing is an emerging technology that provides good quality foods at low to no additional fuel costs (Amruta and Ramakrishnaro, 2013). The principle of solar drying is the accumulation of solar energy on a solar collector, the heating of air and the subsequent reduction in relative humidity of the dryer to evaporate the moisture in food (Amruta and Ramakrishnaro, 2013). Different kinds of solar dryers have been used in various steps in the food processing chain. Table 2.3 illustrates the main types of solar dryers and their mode of operation. Foods dried with solar drying technology include cassava, grapes, tomatoes, apricots, and pistachios. Direct solar drying has limited use in spices and oilseeds due to the direct exposure of the produce to solar radiation. Indirect solar drying has received attention in drying legumes *e.g.,* pistachios and other agricultural products such as cereals and tomatoes. There is limited research on the performance of indirect solar dryer in curing peanuts to ensure quality.

4.4.2.1.1.1. Passive solar drying

Indirect solar dryers are used for more heat-sensitive food products including oilseeds, fruits and vegetables. Madhlopa et al. (2007) developed an indirect type of natural convection solar dryer. The dryer consisted of a chimney, collector-storage thermal mass and drying chamber. The dryer was used to dry fresh pineapple and they reported reduction to moisture content of 11%. The drying efficiency was stated as 11-15%. Othieno et al. (1981) on the other hand, developed an indirect solar dryer for maize. The dryer was made up of a glazed passive solar heater and the chamber was made up of hardboard. The researchers reported of reduction of maize moisture content from 20% to 12% within 3 days. Mohanraj et al. (2009) also developed an indirect solar dryer for drying chili and they reported an estimated thermal efficiency of 21%.

Based on these research findings, Belessiotis and Delyannis (2011) listed the advantages of indirect solar dryer as high drying, no losses to drying material, smaller surface area required for drying due to stacking of trays, product quality, increased productivity and flexibility of dryer to accept similar seasonal crops. Belessiotis and Delyannis (2011) mentioned relatively high initial capital as the only challenge of passive solar drying.

4.5. Soil amendment with agricultural waste

Addition of organic materials of different sources is one of the most common reintegration practices to improve soil quality (Weber et al. 2007). The addition of organic matter improves soil aggregation, water-holding capacity, hydraulic conductivity, bulk density, fertility and resistance to water and wind erosion (Celik et al. 2004) and serve as nutrients for plant growth (Magdoff, and Weil, 2004). On the other hand, excessive use of chemical fertilizers is linked to depletion of organic matter (Sleutel et al., 2003). This implies that organic

wastes are potential fertilizers when used as compost in agricultural fields to fight nutrient degradation and soil erosions. Some of the raw materials used in soil amendment include sawdust, cedar chips, bagasse, rice hulls and sewage sludge (Leconte et al., 2009). Torkashvand et al. (2015) reported the utilization of peanut shells as compost for growing ornamental plants. The various ways of applying agricultural waste to crop fields include mulching or composting the material before applying to the fields. With mulching, there are uncertainties about the re-introduction of pathogens, diseases and toxins into the soil (Wan et al., 2005). Composting on the other hand, is the controlled management of biological process of microorganisms such as bacteria, fungi and actinomyces to decompose organic residue into useful nutrient for plants nutrition. Composting is also known to reduce the weed seeds, pathogens and complex toxins when done under the proper conditions (Hoitink et al., 1997; Wan et al., 2005).

4.6. Peanut waste: raw material for soil amendment

Peanut waste (shells and meal; a 40-50% protein residue after extraction of peanut oil) are generated from peanut farms and processing areas. In developing countries, *e.g.*, Ghana, Tsibey et al. (2003) reported that such wastes are used as mulch materials around homes and farms. In other places, worldwide, peanut wastes are used as composting materials. Torkashvand et al. (2015) used peanut organic waste as a growth medium for ornamental plants in Iran by composting and the researchers observed an increase in growth indices. Khomami (2015) planted marigold and *Viola tricolor* plants in composted peanut shell and an improvement was observed in growth indices such as height, stem and leaf dry weight. Badar et al. (2015) planted chickpea in composted peanut shells and observed an increase in root and shoot length. Although peanut waste shows tremendous performance as a compost material for plant growth, there are series of questions concerning the fate of aflatoxin contamination in peanut waste.

Previous research shows that plants such as peanuts and green leafy vegetables are capable to uptake aflatoxin from contaminated soil although the mechanism is not completely understood (Snigdha et al., 2013; Hariprasad et al., 2013).

4.7. Problems with peanut waste as soil amendment

Although peanut wastes are used for various soil enrichments *e.g.* mulching and composting, concern has been raised about physical, chemical and microbiological contaminations. The chemical contaminations include high levels of heavy metals while the microbiological contaminations include toxigenic mold growth accompanied by aflatoxin contamination (Sanders et al., 1984). Sanders et al. (1984) found 13-353 ppb levels of aflatoxin in peanut hulls. Similarly, Lien et al. (1998) reported of 10^3 CFU/g of *A. parasiticus* and *A. flavus* on peanut hull used as chicken litter material. In addition, they found 39 ppb of aflatoxin in the material.

4.8. Ways to control aflatoxigenic molds and aflatoxins

Chemical and microbiological approaches have been used to decontaminate aflatoxin in food and feed. Chemically, ammonia, either gaseous or in solution was used to detoxify peanut, cotton and corn meals (Cucullu et al. 1976) as has sodium bisulfite (Moerck et al., 1980; Hagler et al., 1982). Other chemical treatments include calcium hydroxide (Codifer et al., 1976), hydrogen peroxide and sodium borate but with limited research on these treatments (Piva et al., 1995). In addition, combinations of heat, pH and chemical treatments have shown tremendous detoxification of aflatoxins (Hakan and Nas, 2009). Although no physical methods are used to decontaminate aflatoxin, physical processes such as peanut screening and sorting of peanuts are used to reduce the level of aflatoxin contamination (Dorner, 2008). Detoxification of aflatoxins

by different microorganisms has gained attention within few years to identify the applicability of microorganism to produce safe food and feed.

4.8.1. Microbiological control

Biodegradation of aflatoxins in food and feed using microorganisms or enzymes is gaining recognition (Wu et al. 2009). Soil bacteria such as *Flavobacterium aurantiacum* incubated at 28°C for 12 h degraded all aflatoxin G and 50% of aflatoxin B in milk (Shapira, 2004). Other soil bacteria including *Nocardia asteroids* and *Corynebacterium rubrum* have been shown to detoxify aflatoxins on potato extract agar (Arai et al., 1967; Shapira, 2004). Teniola et al. (2005) reported that *Rhodococcus erythropolis* degraded AFB_1 by 83% in liquid cultures and cell free extracts. Fungi are among the group of microorganisms identified to detoxify aflatoxin. *Aspergillus niger, Eurotium herbariorum, Rhizopus sp* and non-aflatoxigenic *A. flavus* were able to reduce AFB_1 to aflatoxicol by reducing the cyclopentenone carbonyl on AFB_1 in sucrose-salt-asparagine liquid medium (Nakazato et al. 1990). Protozoa, *Tetrahymena pyriformis* degraded AFB_1 by 75% within 30 h in proteose-peptone broth (Teunission and Robertson et al., 1970). Equally, yeast and lactic acid bacteria reduced aflatoxin by adhesion of toxin to their cell walls in wine and milk, respectively (Peltonen et al., 2001).

4.9. Composting: a means of aflatoxin decontamination

Composting is a metabolic process that involves the natural breakdown of complex organic waste by microorganisms to simple and stable organic compounds that support plant growth. The process results in ammonia production and changes in temperature and pH and these factors were reported to aid in decontamination of aflatoxin. Based on the reviews, there is a prospect of decontamination of aflatoxin by composting agricultural waste.

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Table 2.1. Worldwide peanut production (million metric tons) by countries (Adapted from Soyatech, 2016)

		Worldwide Peanut Production (million metric tons)
#1	China	13,420,000
#2	India	7,700,000
#3	United States	1,880,000
#4	Nigeria	1,510,000
#5	Indonesia	1,130,000
#6	Burma	710,000
#8	Chad	450,000
#9	Senegal	450,000
#10	Ghana	440,000
#11	Argentina	420,000
#12	Vietnam	400,000
#13	Sudan	370,000
#14	Congo	360,000
#15	Burkina Faso	320,000
#16	Guinea	250,000
#17	Brazil	220,000
#18	Egypt	190,000
#19	Mali	160,000
#20	Mexico	90,000
	Total	30,470,000

Table 2.2. Nutrient composition of raw peanuts (Adapted from Master et al., 2013)

Nutrient	**Unit**	**Nutrient Amount (per 100 g)**
Energy	kcal	567
Protein	g	25.8
Fat	g	49.2
Fatty acids, total saturated	g	6.8
Fatty acids, total monounsaturated	g	24.4
Fatty acids, total polyunsaturated	g	15.5
Carbohydrate	g	16.1
Fiber	g	8.5
Calcium, Ca	mg	92
Iron, Fe	mg	4.6
Magnesium, Mg	mg	168
Phosphorus, P	mg	376
Potassium, K	mg	705
Sodium, Na	mg	18.0
Zinc, Zn	mg	3.27
Thiamin	mg	0.64
Riboflavin	mg	0.13
Niacin	mg	12.1
Vitamin B-6	mg	0.35
Folate, DFE	µg	240
Vitamin E (alpha-tocopherol)	mg	8.3

Table 2.3. Classification of solar food dryers (Adapted from Amruta and Ramakrishnaro, 2013).

Category	**Description**
Direct solar dryer	Food is placed in a closed container. Solar radiation is allowed to fall on food directly through a clear cover.
Indirect (passive) solar dryer	Fresh air is heated in a solar heat collector and passed through the food placed in a drying chamber. The food is not directly exposed to solar radiation.
Mixed dryer	Food is dried through a direct sun as well as by hot air heated through a separate solar collector
Hybrid dryer	Solar heat as well as conventional electricity or fuel is used for drying

CHAPTER 3

USE OF PEANUT MEAL AS A MODEL MATRIX TO STUDY THE EFFECT OF COMPOSTING ON AFLATOXIN DECONTAMINATION

[1]Akoto, E.Y., Klu, A.K., Lamptey, M., Asibuo, J., Davis, J., Phillips, R., Jordan D., Rhoads, J., Hoistington, D. and Chen J. To be submitted to Environmental Microbiology, John Wiley and Sons Ltd

Summary

In many developing countries, aflatoxin-contaminated peanut wastes are often used as mulching materials or soil amendments, and this practice can introduce aflatoxins and aflatoxin-producing mold into subsequent farming seasons. This research evaluated the effectiveness of composting as a means of aflatoxin decontamination using highly contaminated peanut meal as a model matrix at 40 ºC for 6 wk. The composting methods resulted in 72.2-154.9, 7.4-17.6, 1.2- 6.9, and 0.0-2.1 ppb reduction in the levels of aflatoxin B_1, B_2, G_1 and G_2, respectively in peanut meal. *Aspergillus flavus* and *A. parasiticus* counts and total mold counts decreased from 10^3-10^5 to <10 CFU/g. Composting time and the type of starters used significantly influenced aflatoxin content, while the presence of an accelerator did not affect aflatoxin levels. The highest level of toxin decontamination occurred in the first week when compost temperature and ammonia concentration were high. Micronutrient contents of resulting composts were within the accepted range for fertilizers, except for calcium. Heavy metal content was below the maximum allowable levels except nickel in one of the samples. Aflatoxin reduction was also observed in an up-scale experiment using contaminated agriculture waste as raw materials. Results suggest that composting could be employed to decontaminate aflatoxin-containing agricultural waste in developing countries.

Introduction

Aflatoxins have significant economic impact on several crops including peanuts, *Arachis hypogaea* L. (Richard and Payne, 2003). The Food and Agriculture Organization estimated that 25% of the world's crops are affected by aflatoxins each year (Boutrif and Canet, 1998; Schmale, 2013). Crop contamination with aflatoxins remains to be one of the primary causes of post-harvest losses in developing countries. A recent World Bank study indicated that the European Union's regulation on aflatoxins costs Africa $750 million annually in the reduced export of cereals, dried fruit and nuts (Agyei, 2013). African economies lose about $450 million annually to aflatoxin contamination out of a global estimation of $1.2 billion (Atser, 2009). Awuah *et al.* (2006) reported that at least 5 to 15% of peanuts harvested in Ghana are discarded during sorting due to aflatoxin contamination.

According to Tsigbey (2003), peanut shells produced in Northern Ghana are often used as mulching materials around rural households. They are also used with other peanut wastes such as shells for organic soil amendment in agricultural production fields (Torkashvand *et al.,* 2015; Badar *et al.,* 2015). Although the use as a soil amendment is important for recycling of waste materials, concerns have been raised about aflatoxin and aflatoxin-producing fungal contamination in subsequent planting seasons (Reddy *et al*., 2004). Thus, it is imperative that soil amendments and organic fertilizers are free of aflatoxin and aflatoxin producing fungi.

Physical and chemical approaches for aflatoxin control have been studied globally at laboratory levels, but many limitations and impracticability have been observed (Piva *et al*., 1995; Huwig *et al*., 2001; Diaz *et al.,* 2004). In comparison, biological approaches using beneficial microorganisms such as bacteria and fungi have been shown to successfully reduce the

level of aflatoxins in microbiological media (Phillips *et al.,* 1994). Mohsen *et al*. (2012) reported that, *Bacillus subtilis* UTBSP1, isolated from pistachio nuts reduced the level of aflatoxin B_1 in pistachio nuts by 95%. According to Alberts *et al.* (2006), extracellular extracts of *Rhodococcus erythropolis* degraded 67% of aflatoxin B_1 in Standard I broth (1/5% w/v peptone, 0.3% yeast extracts, 0.6 % sodium chloride and 0.1% D (+) glucose). Lactic acid bacteria including, *Lactobacillus acidophilus, L. bulgaris* and *L. plantarum*, were reported to prevent mold growth by competition with aflatoxin producing molds (Ellis *et al.,* 1991; Tchikoua *et al.,* 2015). The restriction of mold growth by the presence of organic acids and proteinaceous compounds produced by lactic acid bacteria has been reported by Batish *et al.* (1989, 1990). Furthermore, Jones *et al.* (1995) found in a field trial that aflatoxin in broiler and turkey litter mixtures was degraded after 6 or 10 weeks of storage at 28 °C.

Unfortunately, these previous studies utilized individual microorganisms or a combination of them for the control of aflatoxins in microbiological media or animal waste. The use of a similar approach for control of aflatoxins in peanut production waste, which may have a high level of aflatoxin contamination, has not been attempted. We have assessed the possibility of using composting as a means of controlling aflatoxin contamination and fungus growth by using peanut meal with a high level of aflatoxin contamination as a model matrix. The nutrient quality and heavy metal content of the resulting compost as crop fertilizers were also evaluated.

Results

Effect of composting time, stirring, and the presence of starters and/or accelerator on compost temperature, pH and ammonia concentration

Table 3.1 indicates that stirring the compost materials resulted in a significant decrease in the average compost temperature and increase in average ammonia concentration ($p<0.05$); however, it had no significant influence on compost pH ($p>0.05$).

As composting time increased, the temperature, pH and ammonia concentration of collected samples peaked at the end of the first week before decreasing during the subsequent weeks of the process (Table 3.1). On average, samples with the accelerator had a slightly, but significantly, higher pH and ammonia concentration, but had a relatively lower average temperature (Table 3.1).

The average temperatures of samples with starter E and B were similar ($p>0.05$), but were significantly higher than control sample P (without starter or accelerator) and samples with starter J ($p<0.05$, Table 3.1). Sample P had a slightly, but significantly higher average temperature than samples with starter J ($p<0.05$, Table 3.1). The average pH values in samples inoculated with starter E or J were significantly different from those of control sample P and the samples inoculated with starter B ($p<0.05$, Table 3.1). The average ammonia concentrations in samples with starter E, B or J were not significantly different from each other ($p>0.05$, Table 3.1), but were significantly higher than the average ammonia concentration in the control sample P ($p<0.05$).

Effect of composting time and the use of starters and/or accelerator on compost aflatoxin content

Composting time and type of starter and/or accelerator used in the study had significant influences on the aflatoxin levels (Tables 3.2 and 3.3). The highest aflatoxin B_1 concentration was observed at the start of composting, and decreased during the experiment ($p<0.05$, Table 3.2). On average, samples with the accelerator had significantly higher levels of aflatoxins except for aflatoxin G_2, which was the lowest concentration of any aflatoxin ($p<0.05$, Table 3.2). Statistical analysis revealed that the addition of the accelerator only resulted in higher levels of aflatoxin B_1, B_2 and G_2 in samples with starter E (Table 3.2). When the accelerator was absent, samples with starter E had the lowest aflatoxin B_1 and B_2 contents (Table 3.3).

Compost micronutrient, carbon, nitrogen and heavy metal content

The carbon content of the eight compost samples ranged from 31.7 - 39.4% and the nitrogen content was from 7.2 to 8.2% (Table 3.4). Samples with the accelerator but no starter (PA) had the highest nitrogen content of 8.7% and samples with no starter and accelerator (P) had the lowest nitrogen content of 7.2% (Table 3.4). The C/N ratio of the compost samples ranged from 4.4 to 4.6 with the control sample P having the lowest C/N ratio (Table 3.4). The highest C/N ratio was observed in samples with starter B (with or without the accelerator).

The micronutrient content of potassium, magnesium, molybdenum and phosphorus of different compost samples were within the accepted range for organic fertilizers except for calcium (Table 3.5). The heavy metals contents of boron, cadmium, chromium, copper, lead,

zinc, silicon and aluminum of the compost samples were within the accepted range for organic fertilizers except for the content of nickel in sample inoculated with starter B (Table 3.6).

Aspergillus flavus *and* A. parasiticus *counts and total mold counts*

Average *A. flavus* and *A. parasiticus* counts decreased from 3.12 log CFU/g in the 1st week to below the detection limit (<10 CFU/g) in the 2nd week and remained undetectable till the end of 6th week (data not shown). The average total mold counts fluctuated during the composting process, but reduced from the initial 5.0 log CFU/g to below the detection limit (<10 CFU/g) by the end of the 6th week (data not shown).

Up-scale composting in Ghana

Total aflatoxin level in the compost material inoculated with starter E in the field up-scale experiment decreased 786.01 ppb in the 6 wk composting period. In the material that was not inoculated with starter E, total aflatoxin level decreased 2,275.97 ppb.

Discussion

In the present study, compost temperature was significantly higher in the 1st week, which is similar to the observation made by Pagans *et al*. (2006) who recorded high temperatures in the first 3-5 days during the composting of 5 different solid wastes with microorganisms naturally present in the starting materials. In contrast to what we observed in our study, Liu and Cai

(2014) reported that when kitchen biogas was composted, a high temperature was not observed until after 12 days. Increased temperature during the initial stage of composting could be caused by the metabolic activity of thermophilic microorganisms (Pagans *et al.,* 2006). By the second to last week of composting, mesophilic microorganisms take over, resulting in a decrease in compost temperatures.

It was proposed that high ammonia concentration coincides with thermophilic stages of the composting process and ammonia emissions are an indication of biological activity of composting materials with high nitrogen material (Liao *et al.,* 2014). The present study utilized peanut meal which has high nitrogen content, and it is evident, according to the results in Table 3.1, that higher temperatures in the 1st week of composting corresponded to higher ammonia contents in compost. At initial state of composting, high temperature and pH result in the volatilization of ammonia and non-ammonium ions (Liu and Cai, 2014). Similar to what happens to compost temperature, the outgrowth of mesophilic microorganisms in the subsequent stage of process is responsible for the reduction in ammonia concentration in compost (Pagans *et al.,* 2006). Another plausible explanation as to why ammonia concentration decreased with time is that, by the latter stage of composting, remaining nitrogen is bound to complex organic molecules and may be involved in humus formation which prevents ammonia release and volatilization (Parades *et al.,* 2002; Baddi *et al.,* 2004).

Beck-Friis *et al.* (2001) stated that, at the initial stages of composting, the pH increases due to the breakdown of complex proteins to nitrogen and ammonia ions. The nitrogen in the form of ammonia ions dissolve in water to form ammonium ions which subsequently raises the pH of the compost. The reduction of compost pH in the subsequent weeks of the process might

be the result of organic acid production, primarily acetic acid and lactic acid as reported by Sundberg and Jonsson (2008).

Results of the present study show that the content of aflatoxins, especially that of aflatoxin B_1 was significantly reduced during composting. Mishra and Das (2003) suggested that microbial degradation of aflatoxin B_1 occurs when the double bond of the terminal furan ring of the toxin is cleaved or the lactone ring of the toxins is removed. Dada and Muller (1983) reported that lactic acid fermentation reduced aflatoxin B_1 by 12-16% in *ogi,* a fermented food from maize and sorghum. Fermentation by yeast that was artificially inoculated in bread resulted in 19% reduction in aflatoxin B_1 (El-Banna and Scott, 1983). Steinkraus (1983) reported that fermentation with *Neurospora sitophila* and *Rhizopus oligosporus* resulted in 50% and 70% aflatoxin reduction, respectively, in peanut cake.

In the present study, a higher aflatoxin reduction occurred in the 1st week when the ammonia concentration was high, which was similar to what was observed by Masri *et al.* (1969) and Dollear *et al.* (1968) who reported that ammoniating/moistening peanuts with 60 ml anhydrous ammonia (to 9.6%) at 97 °C reduced aflatoxin B_1 content from 709 to 98 ppb. Furthermore, Brekke *et al.* (1975) proposed that the rate of aflatoxin detoxification depends on ammonia concentration, moisture level and fermentation temperature.

In addition to ammonia, microbial enzymes are believed to play a role in aflatoxin degradation during composting/fermentation. Enzymes from *Pseudomonas* spp. degraded aflatoxin B_1 by 52-74% (Sangare *et al.,* 2014). Intracellular extracts of *R. erythropolis* used by Teniola *et al.* (2005) degraded aflatoxin B_1 content by 70% in 1 hour. A study is underway in our laboratory to determine the relationship between microbial enzyme activity and aflatoxin degradation during composting.

Compost starters are made of microorganisms that enhance the conversion of organic compounds to smaller molecules such as carbon and nitrogen and also reduce odorous gas emissions (Ohtaki *et al.,* 1998). A previous study by Chen *et al.* (2014) reported a 100% biotransformation of aflatoxin in peanut meal by using *Lactobacillus* spp. Farzareth *et al.* (2012) reported a 95% aflatoxin B_1 reduction on shelled nuts using *Bacillus subtilis*. Starter E used in our study contains *Bacillus* and *Lactobacillus* according to the information provided by its manufacturer. The starter performed very well in the laboratory scale composting experiment, however, it was out performed by the natural starter present in the raw composting material in the up-scale experiment. This result is encouraging, which suggests the addition of starter may not be absolutely necessary during a larger scale composting process.

The addition of accelerator had no influence on the aflatoxin content in majority of the compost samples except those with starter E in the present study (Table 3.3). However, overall statistical analysis revealed that samples with the accelerator had significantly higher aflatoxin content than those without the accelerator (Table 3.2). Sankare *et al.* (2014) reported that minerals including Mg^{2+}, Li^{+}, Zn^{2+}, Se^{2+} and Fe^{3+} inhibit the degradation of aflatoxins and Cu^{2+} encourages fungal growth which may cause a subsequent increase in aflatoxin contents. According to the information provided by the manufacturers, both the starter and accelerator used in the present study contain vitamins, minerals and amino acids. However, it is not clear whether these components interfered with the degradation of aflatoxin during composting.

The quality of compost as an organic fertilizer is characterized by available organic matters, as well as its micronutrient and heavy metal contents (US Compost Council, 2001). Addition of micronutrient-rich compost to deficient soils may curtail plant growth problems, enhance chlorophyll formation, activate plant enzymes, increase transportation of nutrients, and

improve the overall yield. Results of the present study showed that the nitrogen, phosphorus, potassium and magnesium contents of all composts samples were within the accepted ranges for organic fertilizers (Jacob, 1961; Martinez-Blanco *et al*., 2013). On the contrary, calcium content in the compost was lower than the accepted range. However, this problem could be easily overcome by adding other raw materials to compost such as lime or ground oyster shells. In addition to micronutrients, low heavy metal content in composts is imperative because they affect physiological and biochemical activities as well as the function of plants (Siedlecka et al., 2001).

Conclusions

Composting reduced aflatoxin levels in aflatoxin-contaminated peanut meal. Composting time and the type of starters used significantly influenced aflatoxin content, while the presence of accelerator did not affect aflatoxin levels during composting. The most toxin decontamination occurred in the first week when compost temperature and ammonia concentration were high. Significant aflatoxin reduction was also observed in an up-scale experiment using contaminated agricultural waste as raw materials. The results of the research suggest that composting can be employed by farmers in developing countries to convert agricultural wastes to safer soil amendments while controlling subsequent aflatoxin contamination of the soil and starter use during composting to control aflatoxins may not be necessary.

Experimental procedures

Sample collection

Aflatoxin-contaminated peanut meal (residue after peanut oil extraction with 48-53% protein, 32.45 carbohydrates,1.1% crude fat and 5.5% total ash alongside other constituents) was obtained from Golden Peanuts (Thomasville, GA, USA) and stored at 4 °C prior to the experiments. Three different commercial starters (B, E and J) were used either alone or in combination with a commercial accelerator (A). According to the manufacturer, ingredients in starter B were wheat and rice bran, purified and structured water (chemically or physically altered water to improve measurable and repeatable utilization by plants), sugarcane blackstrap molasses, mineral rock salt, probiotics (lactic acid bacteria) and wood shavings. Starter E was composed of alfalfa meal, seaweed extract and beneficial soil microorganisms (*Bacillus subtilis, Bacillus cereus, Bacillus megaterium, Azotobacter vinelandi, Lactobacillus acidophilus, Rhizobium japonicum and Aspergillus oryzae*). Starter J included feather meal, bone meal, processed poultry manure, sulfate of potash and non-plant food ingredients (*Arthrobacter globiformis, Azotobacter chroococcum, Azosprillum lipoferum, Pseudomonis fluorescens, Glomus intraradices, Glomus etunicatum, Pisolithus tinctorius, Scleroderma cepa, Scleroderma cintrinum, Scleroderma geastrum, Laccaria laccata, Laccaria bicolor and Nitrosopumilus martimus*). The accelerator contained water, minerals, vitamins and amino acids.

Sample preparation and composting

Eight identical samples of 450 g of peanut meal mixed with 650 g of deionized water resulting in moisture content range 49.1-65.26% were prepared. Each hydrated peanut meal sample (P) was inoculated with 5 g of one of the 3 starters to form samples PB, PE and PJ, or in combination with a 360 µl of accelerator A to form samples PBA, PEA and PJA. The control samples were peanut meal without starter or accelerator (P) or inoculated with the accelerator only (PA). The samples were stirred continuously for 3 min to ensure a uniform mixture. The initial pH and temperature readings were taken immediately after mixing, and the samples were subsequently placed in a water bath at 40 °C in a fume hood for 6 weeks. The temperature, pH and ammonia concentration of the same samples were documented twice a day, before and after stirring the composts during the composting process.

Quantitative analysis of aflatoxins in compost using HPLC

Extraction and analysis of aflatoxin in composted peanut meal samples were done through a commercial service provided by J. Leek Associates, LLC, (Albany, Georgia, USA) based on AOAC method 991.31. Aflatoxins in composted peanut meal were extracted with methanol/deionized water (60/40) and NaCl (5%) at 1:5 mass/volume ratio. The peanut meal/methanol-water mixture was blended in a high-speed blender for 1 min. After blending, the sample was filtered with a P8 filter paper (Fisher Scientific, Fair Lawn, NJ, USA). Filtered peanut meal extract was mixed with deionized water in a ratio 1:2 and then filtered again through

a G6 glass fiber filter (Fisher Scientific, Fair Lawn, NJ, USA). After filtration, 15 ml of the extract was passed through an immuno-affinity column (Waters Nova-Pak, Milford, MA, USA) at 1-2 drops /sec using a vacuum manifold. The column was washed twice with 10 ml deionized water. The column was eluted with 1 ml methanol and the eluate was then diluted two-fold with freshly prepared 1% acetic acid (Fisher Scientific, Fair Lawn, NJ, USA). Samples were analyzed on an Agilent HPLC 1100 (Aura Industries, NY, USA) equipped with a fluorescence detector and a post-column photochemical reactor for enhanced detection (PHRED). Samples (15 µl) were injected into a 4.6 x 150 mm Waters Nova-Pak C18 4 µm analytical column held at 30 °C. An isocratic method using deionized water and HPLC grade methanol mixture (55:45) at a flow rate of 1.0 ml min^{-1} was used to separate individual aflatoxins at a pressure of approximately 200 bar. PHRED-enhanced peaks were detected by fluorescence with an excitation wavelength of 360 nm and emission wavelength of 440 nm. Aflatoxin B_1, B_2, G_1 and G_2 were quantified using a 4-component aflatoxin mix (Supelco, Bellefonte, PA, USA) and three-point standard curves (2, 5 and 10 ppb) were generated daily prior to analyses. Quality assurance measures employed during the experiment included matrix spikes, blanks and daily controls.

Chemical composition of compost

Compost mineral composition analysis was performed by the University of Georgia Soil, Plant and Water Laboratory in Athens, Georgia, USA. Composted peanut meal (1 g) was mixed with 10 ml 70% nitric acid. The mixture was placed into a fluorocarbon polymer microwave vessel which was sealed and heated in a microwave oven at 220 °C for 30 min. The samples were then brought to 100 ml with deionized water and analyzed using the inductively coupled plasma-

optical emission spectroscopy (ICP-OES: Spectro Arcos FHS16 AMETEK ICP-OES, Mahwah, NJ, USA). Results were reported as parts per million (mg kg^{-1} or µg g^{-1}).

Total carbon and nitrogen content of compost

The carbon and nitrogen content of the compost was also analyzed by the University of Georgia Soil, Plant and Water Laboratory. Composted peanut meal (0.5 g) was loaded into a ceramic sample boat and combusted in an oxygen atmosphere at 1,350 °C in a LECO TruMac Total Combustion Analyzer (LECO Corporation, St. Joseph, MI, USA). Elemental carbon and nitrogen were converted into CO_2, NO_2, NO_3 and N_2. These gases were then passed through the infrared cells in the analyzer to determine the carbon content and through the thermal conductivity cell to determine the concentration of N_2. Results were reported as percentages (%) of carbon and nitrogen in the tested samples.

Aspergillus flavus *and* A. parasiticus *counts and total mold counts*

Composted peanut meal (1 g) was mixed with 9 ml sterile phosphate-buffered saline. The resulting sample was inoculated (0.25 ml per plate) onto *Aspergillus* differentiation agar supplemented with chloramphenicol selective antibiotic (0.1 mg ml^{-1}, Sigma-Aldrich, Billerica, MA, USA). Inoculated plates were incubated at 30 °C for 48-72 h. *Aspergillus* differentiation agar is a microbiological medium for the detection of *A. flavus* and *A. parasiticus* from food samples. Colonies of these two species develop intense yellow orange color, due to reaction of ferric ions from ferric citrate in the medium with aspergillic acid molecules, at the base of the

colonies. Total mold counts were determined by counting all colonies on the plates including *A. flavus* and *A. parasiticus*.

Up-scale composting in Ghana

An up-scale composting experiment was conducted at Crop Research Institute in Kumasi, Ghana. Raw material used for the experiment was a mixture aflatoxin-contaminated peanut seeds (8,200 g), peanut shells (1,900 g), peanut leaves (300g) and cowpea pods (300 g). The material was mixed thoroughly and divided into two equal portions. Each of the two portions (5,350 g) was placed into a plastic composter with tumbler for air circulation and even mixing (Envirocycle Organic Solutions, Bloomfield, CT, USA). Tap water (7600 g) was added to each of the two composters at a ratio of 90:130 (w/w), similar to the small-scale experiment conducted in the laboratory. Starter E (58.47 g) was inoculated to the material in one of the composters whereas the material in the other composter was not inoculated. The compost was stirred three times a week during a 6 wk composting period. Fifty grams of the materials in each composter was removed for total aflatoxin analysis at the beginning as well as the end of the 6 wk period.

Statistical analyses

Two replicate experiments were conducted for the laboratory portion. Version 9.1 of SAS (SAS Inst. Inc., Cary, N.C., U.S.A.) was used to determine the overall influence of composting time, starter, accelerator and stirring on compost temperature, pH, ammonia concentration, aflatoxin levels and the interactions between these variables, by performing one-way ANOVA tests.

Student's *t*-test (LSD) was conducted to determine the significance of differences at 95% confidence interval.

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Conflict of interest

No conflict of interest is declared.

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Table 3.1. Effect of stirring, composting time, type of starter and use of an accelerator on average temperature, pH and ammonia concentration of peanut meal compost.

	Stirring		**Composting Time (weeks)**							**Starter Type**				**Use of Accelerator**	
	No	Yes	0	1	2	3	4	5	6	None (P)	B	E	J	No	Yes
Temp (ºC)	32.39a	31.48b	21.62g	39.83a	36.41b	34.86c	31.31d	30.39e	29.13f	31.74b	32.23a	32.48a	31.29c	32.76a	31.11b
pH (units)	6.38a	6.37a	5.79e	7.31a	6.78b	6.24c	6.24c	6.15d	6.12d	6.32b	6.36b	6.42a	6.41a	6.35b	6.40a
Ammonia (ppm)	24.77b	50.74a	0.00d	199.77a	49.50b	6.79c	4.11cd	2.82cd	1.26cd	33.43b	38.45a	40.71a	38.41a	35.13b	40.37a

Mean values in rows followed by different letters within each treatment (stirring, composting time, starter type and use of accelerator) were significantly different ($p<0.05$).

Table 3.2. Effect of composting time, starter type and use of an accelerator on the aflatoxin content (ppb) in peanut meal compost.

	Composting Time (days)				Starter Type				Use of Accelerator	
Aflatoxin	0	2	4	6	None (P)	B	E	J	No	Yes
B_1	195.40a	150.82b	102.92c	80.91d	134.59ab	130.00bc	124.02c	141.44a	120.87b	144.44a
B_2	22.17a	17.00b	12.63c	10.05d	15.55a	15.62a	14.07b	16.63a	14.21b	16.72a
G_1	2.89a	0.00b	0.00b	0.09b	0.38b	1.07ab	0.38b	1.15a	0.40b	1.09a
G_2	1.20a	0.00b	0.14b	0.16b	0.49a	0.33a	0.27a	0.41a	0.30a	0.45a

Mean values in rows followed by different letters within each treatment (composting time, starter type and use of an accelerator) were significantly different ($p<0.05$).

Table 3.3. Aflatoxin content in peanut meal compost using different starters and an accelerator during composting.

	Aflatoxin B_1		**Aflatoxin B_2**		**Aflatoxin G_1**		**Aflatoxin G_2**	
	(ppb)							
Accelerator	-	+	-	+	-	+	-	+
Sample								
P	125.99Aa	143.19Aa	14.59Aa	14.59Aa	0.38Aa	0.38Aa	0.45Aa	0.52Aa
PB	119.81Aa	140.19Aa	14.60Aa	14.60Aa	0.41Aa	1.73Aa	0.24ABa	0.42Aa
PE	98.04Bb	150.00Aa	11.10Bb	11.10Bb	0.29Aa	0.47Aa	0.20Ba	0.34Aa
PJ	139.63Aa	143.20Aa	16.54Aa	16.54Aa	0.54Aa	1.76Aa	0.24ABa	0.58Aa

P is peanut meal only; PB, PE and PJ are peanut meal with different starters
Mean values followed by different letters for each treatment were significantly different (p<0.05). A & B indicate significant differences in samples with the same starter used, but different due to the use or absence of accelerator, a & b indicate significant differences due to the use of different starters in the presence/absence of accelerator.

Table 3.4. Total carbon (C), total nitrogen (N) and carbon/nitrogen ratio (C/N) of the peanut meal compost prepared using three different starters and an accelerator.

Sample	Total C (%)	Total N (%)	C/N ratio
P	31.67	7.19	4.41
PE	34.36	7.66	4.49
PB	35.77	7.69	4.65
PJ	38.25	8.27	4.62
PA	39.41	8.74	4.51
PBA	35.92	7.72	4.65
PEA	36.18	8.14	4.45
PJA	36.95	8.21	4.50

P is peanut meal only; PB, PE and PJ are peanut meal with different starters; PBA, PEA and PJA are peanut meal with different starters and an accelerator.

Table 3.5. Micronutrient content (mg/kg) and their accepted range (as fertilizers) in peanut meal compost prepared using three different starters and an accelerator.

Acceptable Range Sample	K	Mg	Mn	Mo	Na	P	Ca	Fe
	$3X10^3$-$1x10^4$	2×10^3-4×10^3	N.A.	≤20	N.A.	3×10^3-1×10^4	1×10^4-4×10^4	N.A.
P	14600	3499	42.06	1.31	<50.00	6912	1115	224.00
PJ	22317	4760	56.08	1.42	117.20	9897	3338	118.60
PB	17069	3228	34.00	1.17	98.80	6816	981	87.50
PE	14385	3137	34.47	1.17	58.30	6335	1111	96.30
PA	18751	4353	52.77	1.5	<50.00	8705	1320	141.20
PBA	16192	4174	53.17	1.11	98.9	8251	1247	117.40
PEA	14757	4150	48.48	1.48	55.70	8070	1384	128.60
PJA	17807	4579	61.23	1.74	89.00	8974	2844	152.10

P is peanut meal only; PB, PE and PJ are peanut meal with different starters; PBA, PEA and PJA are peanut meal with different starters and an accelerator.
N.A.: Not Applicable

Table 3.6. Heavy metal content (mg/kg) and their accepted ranges (as fertilizers) in peanut meal compost prepared using three different starters and an accelerator.

	B	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Acceptable Range	≤100	1-39	70-1200	100-1500	20-420	120-800	280-2800
Sample							
P	33.88	<1.00	<1.00	12.07	1.72	<3.05	62.01
PJ	54.65	<1.00	<1.00	15.80	2.42	<3.05	95.31
PB	35.37	<1.00	<1.00	11.62	<1.00	<3.05	58.33
PE	33.60	<1.00	<1.00	10.08	1.41	<3.05	57.24
PA	40.54	<1.00	<1.00	15.85	1.86	<3.05	80.80
PBA	39.62	<1.00	<1.00	14.16	1.16	<3.05	77.61
PEA	40.63	<1.00	<1.00	14.41	1.43	<3.05	75.24
PJA	42.74	<1.00	<1.00	18.61	1.77	<3.05	87.27

P is peanut meal only; PB, PE and PJ are peanut meal with different starters; PBA, PEA and PJA are peanut meal with different starters and an accelerator.

CHAPTER 4

SOLAR DRYING: A MEANS OF IMPROVING THE QUALITY OF PEANUTS IN GHANA

[1]Akoto, E.Y., Klu, A.K., Lamptey, M., Asibuo, J., Davis, J., Phillips, R., Jordan D., Rhoads, J., Hoistington, D. and Chen J. To be submitted to Postharvest Biology and Technology, Elsevier Publishing Company

Abstract

An indirect, passive, wooden dryer, with a galvanized steel panel (4.5 m^2) and four wire mesh shelves (2.62 m^2 each), was constructed in Kumai, Ghana. The dryer was evaluated for its capacity in drying a single layer (18 Kg), and then up-scaled to four layers (4x18 Kg) of freshly-harvested peanuts. Equal amounts of peanuts, dried simultaneously on cement concrete floor under the open sun served as comparisons. The moisture contents of solar dried peanuts decreased from 35.85-5.25% and 32.00 %-4.25% in the single-layer and four-layer drying, respectively, in 4 days. Faster drying rates were observed when peanuts had relatively higher moisture contents with R^2 values ranging from 0.72-0.95. The average daily solar radiation ranged from 360-592.99 Wm^{-2} and daily energies generated were from 42.24-69.16 MJ. The drying efficiency ranged from 1.50-6.47% in the single-layer drying and 23.07-24.93% in the four-layer drying whereas the thermal efficiency was 3.15-21.60% in the single-layer drying and 3.08-24.93% in the four-layer drying. Peanuts from the solar dryer had lower free fatty acid and peroxide values but higher germination rate compared to open sundried peanuts. The study suggests that solar drying can be used effectively for improving peanut safety and preserving peanut quality in Ghana.

Keywords: Solar drying, peanuts, temperature, moisture, lipid oxidation, germination rate

1. Introduction

Open sun drying is the most common and oldest method of extending the shelf life of agricultural products such as cereals, nuts, vegetables and spices by local farmers in developing countries (El-Sebaii and Shalaby, 2012). Open sun drying is inexpensive and easy to adopt; however, it has many drawbacks including product contamination (dirt, dust, insects, rodents and toxigenic microorganisms including *Aspergillus flavus*) and uneven moisture distribution in the end product (Pangavhane et al., 2002; Tsibey et al., 2003). Open sun drying adversely affects product quality and quantity which consequentially impact the economic value of the products (Sharma, 2009). Other forms of drying require the use of electrical energy which is not feasible in developing countries due to limited power generation and affordability (Murthy, 2009).

Solar drying is also an old, but re-emerging technology which is economical and affordable to curtail the problems associated with open sun drying (Sharma et al. 2009). Although the technology has been exploited in drying agricultural products such as maize, spices (Condori et al., 2001), and root tubers (Seidu et al., 2012), limited research has addressed its application on peanuts, a commodity of high economic and nutrition importance in most developing countries. Freshly harvested peanuts have moisture contents between 35 and 50%, which makes them conducive for microbial growth and product deterioration (Kryzanowski et al., 2006). To curtail this problem, mechanical dryings are used in developed countries to reduce the moisture content to <10% (Butts and Lamb, 2009), but these methods are not feasible in developing countries due to high equipment cost and fuel required to operate such equipment (Chua and Chou, 2003; Murphy, 2009).

The purpose of this research project was to evaluate the feasibility of employing solar drying technology to dry freshly-harvested peanuts and its impact on peanut and peanut seed quality.

2. Materials and Methods

2.1. Solar dryer design

2.1.1. Drying chamber

The drying chamber (243 cm in length X 126 cm in width X 246 cm in height) was built from well-polished, 8 mm thick plywood with two air outlets (9 cm X 236 cm) at the top of rear and front side of the chamber (Fig. 4.1). A two-way open door was located beneath the air outlet at the rear side of the chamber. The chamber had 4 equally spaced wired mesh trays (230 cm in length X 114 cm in width X 9 cm in height) with wooden blocks (Fig. 4.1). The wire mesh had openings (area; 19 cm^2) to allow air to pass through the drying peanuts. All the materials used to construct the drying chamber were obtained from Anloga wood market, Kumasi, Ghana.

2.1.2. Solar thermal collector

The solar collector of the dryer consisted of 3 pieces of corrugated UT- Gauge galvanized steel roof panel (241 cm X 214 cm per piece; Anloga wood market, Kumasi, Ghana) that were painted black. The solar collector was placed in a wooden tray which was covered with 6 mm thick standard clear greenhouse film (International Greenhouse Company, Danville, IL, USA). The collector was positioned to face south and was tilted at approximately 30° C from the

ground to receive maximum solar radiation during the drying period. The collector had an air inlet near ground level with a dimension of 225 cm length X 20 cm in width with a total area of 0.45 m^2.

2.2. Solar drying of freshly-harvested peanuts

Freshly-harvested peanuts from the Crop Research Institute (Kumasi, Ghana) were loaded onto the wire meshed trays inside the solar chamber. The drying capacity of the dryer was evaluated by drying different amounts of peanuts with varying number of trays. For single layer drying, 18 kg of freshly-harvested peanuts were loaded in tray #2, from the bottom of the dryer chamber and for four-layer drying, a total amount of 72 kg of freshly harvested peanuts were dried, with each tray having 18 kg of peanuts. For each of the 2 drying trials, equal weight of freshly-harvested peanuts was simultaneously dried on concrete floor near the solar dryer as comparisons.

The temperature and relative humidity from solar and open sun drying were collected at a 15 min interval from 8:00 am to 4:00 pm on each drying day using the SL4TH-A Button Temperature and Relative Humidity logger (Signatrol LTD., Gloucestershire, UK). The loggers were placed immediately above the drying peanuts in the solar dryer or on those undergoing open sun drying. The air flow at the inlet of the solar collector was measured with a HHEM-SD1 Environment meter (Omega Engineering Inc., Stamford, CT, USA). The incident solar radiation, ambient temperature and relative humidity data were collected from the weather station at Crop Research Institute in Kumasi, Ghana where the solar dryer was located. Peanuts from both solar drying and open sun drying were removed from drying area after 4:00 pm on

each drying day, stored at room temperature overnight, and the drying process continued until the moisture contents of all peanut samples dropped to <10%. The weight of the peanuts was subsequently taken using an Ohaus CHAMP™ bench scale (Ohaus Corporation, Parsippany, NJ, USA). Peanut weight change was determined by subtracting the weight of dried peanuts at the end of a particular drying from the peanut weight from the previous drying day. For moisture measurement, the oven method was used (AOAC, 2000). Briefly, 2 g of dried peanut samples was collected at the end of a particular drying and the samples were dried at 104° C for 18 h. The moisture content was determined by calculating the difference between the weights of the peanut sample before and after the drying step divided by the initial weight of peanut sample. A duplicate of the experiment was done Ghana at different days and triplicated at the University of Georgia, Griffin, Georgia, United States but the results presented are from one trial in Ghana.

2.3. Performance of the solar dryer

To evaluate the performance of the solar dryer, drying rate (*DR*), drying efficiency (*np*) and thermal efficiency (*nc*) were calculated from the data obtained during the drying process. The *DR* was defined as the decrease of moisture as reflected by overall peanut change during the time interval between two consecutive measurements divided by the time interval and was calculated by:

$$DR = \Delta S / \Delta t$$

The *np* was the energy used to remove water from the peanuts and was calculated by:

$$np = W * L / (Ac\ I) * 100$$

The *nc* is the ratio of energy used to heat the air entering the drying chamber to the total energy generated by the solar collector and was calculated as follows:

$$nc = M * C\ (T_o - T_i) / (Ac\ I) * 100$$

ΔS *: mass flow rate, kgs^{-1}, C: specific heat of air, J^{-1}kg^{-1}°C, Ac: collector area, m^{2,} T_0: outlet air temperature, °C, T_i: inlet air temperature, °C, I: Global solar radiation on the plane of the collector, W m^{-2}, W: mass of water removed from the wet peanuts, kg, L: latent heat of vaporization of water, and* Δt*: change in drying time.*

2.4. Chemical quality of solar dried vs. *open sundried peanuts*

2.4.1 Free fatty acids in the oil extracted from dried peanuts

About 150 g of solar-dried or open sundried peanut kernels was passed through a carver press (Carver, Inc., Wabash, IN, USA) at 2,500 psi for 15 min. The extracted oil (7.05 ± 0.05 g) was placed in a 125 ml Erlenmeyer flask. Neutral alcohol (50 ml; Fisher Scientific) and 1 ml of phenolphthalein indicator (Fisher Scientific) were then added. The sample was titrated with 0.25 M sodium hydroxide (Sigma-Aldrich, St. Louis, MO, USA), amidst vigorous shaking until a faint pink color, that persisted for at least 1 min, was obtained. The percentage of free fatty acids in the oil sample was calculated using the following method:

(V N *F / weight of sample)*

Where,

V - Volume of sodium hydroxide used

N - Normality of sodium hydroxide used

F - Equivalent factor for oleic acid

2.4.2. Peroxides in oil extracted from dried peanuts

Approximately 5.00 ± 0.05 g of oil obtained from the procedure described above was weighed into a 250 ml glass Erlenmeyer flask equipped with a stopper. Subsequently, 30 ml of acetic acid-chloroform mixture (480:320 v/v) (Sigma-Aldrich, St. Louis, MO, USA) was added and the sample was mixed until the contents in the flask were completely dissolved. Thereafter, 0.5 ml of saturated potassium iodide solution (Sigma-Aldrich, St. Louis, MO, USA) was added, and sample was mixed for 1 min. De-ionized water (30 ml) was added, and the sample was shaken vigorously to liberate iodine. The sample was then titrated against 0.1 N sodium thiosulfate (Sigma-Aldrich, St. Louis, MO, USA) using 1 ml starch solution (Sigma-Aldrich, St. Louis, MO, USA) as an indicator. Titration was continued until a blue gray color disappeared in the aqueous phase of the solution.

The peroxide value was calculated as follows:

*Peroxide value = (S *N thiosulfate * 1000)/ weight of sample*

Where:

S = titrated volume of sodium thiosulfate

N= normality of sodium thiosulfate

2.4.3. Germination rate of dried peanuts

Peanut seed germination test was performed using the Ragdoll test (AOSA, 1993). One hundred each of solar dried and open sundried peanuts were randomly selected for the germination test. For each type of dried peanuts, 6 replicates of the germination test were

performed. The seeds were placed in a brown paper (Georgia- Pacific, Atlanta, GA, USA) which was moistened, kept in a Ziploc plastic bag (Wal-Mart Stores Inc., Bentonville, AR, USA) at room temperature. The first germinated seeds count was collected after four days into the germination test and the germinated seeds were then separated from the un-germinated seeds. The final germinated seed count was collected on Day 8 of the experiment. The germination rate was calculated as the ratio of germinated seeds divided by the total number of seeds used in each replicate of the germination study and multiplied by 100.

3. Results

3.1. Single-layer solar drying

3.1.1. Temperature and relative humidity

Fig. 4.2 shows the temperature and relative humidity recorded at a 15 min interval during the 4-day single-layer solar drying and the open sun drying process. It was evident that peanuts in the solar dryer underwent drying at much lower temperatures than those dried under the open sun. According to the results of analysis shown in Table 4.1, out of the total 132 temperature readings collected during the single-layer solar drying process, 29 and 89 were in the range of 20-29.99 and 30-39.99° C, respectively, on the contrary, only 1 and 30 readings were recorded in the same ranges under the open sun drying. Table 4.1 also shows that 65 out of the 132 temperature readings were between 40-49.99^{o} C under the open sun drying and 47 of these

readings were above 43^{o} C. During the solar drying, however, 14 readings were found in the range of 40-49.99^{o} C and none of these readings were above 43^{o} C. Furthermore, no temperature readings from solar drying were in the range of 50-59.99 to 60-69.99 ^{o} C (Table 4.1), but 36 temperature readings from the open sun drying were in the range of 50-59.99 ^{o} C (Table 4.1).

Most of the relative humidity readings from the open sun drying were in the range of 20 to 30% (Table 4.2). Under the solar drying, 39 readings were in the range of 40-49.99% and contrarily, only 16 readings were in the same range under the open sun drying. However, the number of relative humidity readings in the range of 50 to 79.99% from the solar drying was relatively higher than from the open sun drying (Table 4.2).

3.1.2. Peanut drying rate

Peanut moisture content (Fig. 4.3A) and weight (Fig. 4.3B) in both solar and open sun drying processes declined with drying time, but peanuts under the open sun had much more rapid moisture loss (Fig. 4.3). The change in peanut moisture content under solar drying was gradual from 1st day to the 4th day but under the open sun drying peanuts moisture content changed from 35.85% to 10.09 % in 2 days (Fig 4.3A). After 4 days of drying, the end moisture content of peanuts dried under the open sun was 5.25% compared to a peanut moisture content of 9.19% in the solar dryer (Fig. 4.3).

The drying rates for both drying processes were higher at the beginning when peanut moisture content was higher, however, the rates decreased when moisture content and weight of peanuts decreased (Fig. 4.4). Although the trends of the two drying methods were similar, the initial drying rate in the solar dryer (Fig. 4.4A) was lower than the initial drying rate under the

open sun (Fig. 4.4B). The R-square values, that show the relationship between peanut moisture (weight) and peanut moisture (weight) change, from solar and open sun drying were both 0.95 (Fig. 4.4).

3.1.3. Performance of the solar dryer

Fig. 4.5 shows the solar radiation received by the solar collector and total energy generated during the 4-day single-layer solar drying. It was observed that as solar radiation decreased, energy generated by the solar collector also decreased. The 1st drying day had the highest solar radiation of 501.61 Wm^{-2} and simultaneously, the highest solar energy was generated by the solar collector. The solar radiations on 2nd and 4th day were essentially the same (465.36 Wm^{-2}) and comparative level of energy was generated by the solar collector on these two days (Fig. 5).

The drying efficiency of the solar dryer was from 6.47% in the 1st day of drying to 3.50% in the 2nd of drying and 1.50% in the last two days of drying (Fig. 4.6). According to the results in Fig. 6, the dryer used more energy to remove moisture from peanuts when they had relatively higher moisture contents. No difference was observed in the drying efficiency on the 3rd and 4th days of drying (Fig. 4.6). In total, 12.97 % of the energy generated by the solar collector was consumed on removing moisture from peanuts.

The average thermal efficiency of the dryer ranged from 21.60% in the first day to 6.68%, 8.46%, and 3.15% in the last three days of drying, respectively (Fig. 4.6). The highest thermal efficiency recorded on the 1st day corresponded to the highest solar radiation (Fig. 4.5).

On average, the dryer spent 9.97% of the daily energy in raising the temperature inside the solar chamber.

3.1.4. Peanut and peanut seed quality

Free fatty acid contents and peroxide values were lower in peanuts dried in the solar dryer as compared to those that were dried under the open sun (Fig. 4.7). The free fatty acid content of solar and open sundried peanuts was 0.18% and 0.39%, respectively. Similarly, solar dried peanuts had a lower peroxide value of 0.31%, whiles open sun dried peanuts had a peroxide value of 1.16% (Fig. 4.7). Furthermore, open sundried peanuts had a 40% lower germination rate on day 4 and 21% lower germination rate on day 8 of the germination study compared to peanuts from the solar dryer (Table 4.3).

3.2. Four-layer solar drying

3.2.1. Temperature and relative humidity

Fig. 4.8 shows the temperature and relative humidity that were recorded at a 15 min interval during the 4 day four-layer solar and open sun drying process. Similar to what was observed in the single-layer solar drying, a few of the temperature readings (19-33 out of the 132) from the four-layer solar drying were in the range of 20-29.99° C and most of the temperature readings (87-99 out of 132) were in the range of 30-39.99° C (Table 4.1). Eleven to

fourteen temperature readings from solar drying were in the range of 40-49.99° C but none of these values was above 43^{o} C. However, 46 readings from the open sun drying were in the range of 40-49.99° C and 36 of these readings were above 43° C (Table 4.1). Open sun drying also had many temperature readings within the range of 50-59.99° C (52 counts) and 1 was even in the range of 60-69.99° C whiles none of the temperature readings from solar drying were in the range of 50-59.99° C or 60-69.99° C (Table 4.1). The relative humidity readings followed a similar trend as what was observed in the single-layer drying (Table 4.2). The relative humidity readings from the solar dryer were within the ranges of 30 to 80% whiles those from open sun drying were in the range of 10 to 60% (Table 4.2).

3.2.2. Peanut drying rate

Similar to the single-layer drying, the moisture content of peanuts in the four-layer solar drying process decreased steadily during the 4-day drying period whiles open sun dried peanuts had a much more drastic reduction in moisture content (Fig. 4.9A). Peanut moisture content changes under solar and open sun were similar in the 1st drying day (Fig. 4.9A). By the end of day 3, however, open sundried peanuts had a moisture content of 5.87% while the moisture content of solar dried peanuts was 9.87-12.85% (Fig. 4.9A) and by day 4, moisture content of open sun dried peanuts was 4.25% whiles that of solar dried peanuts ranged from 5.91-8.03% (Fig. 4.9A). The peanut weight change curve did not illustrate any obvious difference between solar dried and open sundried peanuts (Fig. 4.9B).

3.2.2. Performance of the solar dryer

The drying rate from four-layer solar drying followed a similar trend to the single-layer solar drying. When the weights and moisture contents of peanuts were high, the drying rates were higher, however, as peanut moisture contents and weight decreased, so did peanut drying rates (Fig. 4.10). Although both open sundried and solar dried peanuts followed the same trend, the drying rates in open sundried peanuts were higher than solar dried peanuts except for the 4th day of drying (Fig. 4.10). The R-square value of solar drying was relatively higher than that of open sun drying (Fig. 4.10).

The solar radiation during the four-layer drying period was 478.81Wm^{-2} on day 1,360.90 W/m^2 on day 2,476.74 on day 3, and 592.99 Wm^{-2} on day 4. The total energy levels generated by the solar collector were 56.49, 42.23, 55.12, and 69.16 MJ on day 1 to day 4, respectively. It was evident that as solar radiation decreased, energy generated by the solar collector also decreased.

The daily drying efficiency in each of the four layers was similar to that of the single-layer drying ranging from 1.83 to 9.84% (Data not shown). It was calculated that the dryer spent 23.07 to 24.93% of the daily energy in removing moisture contents from the four layers of drying peanuts. The thermal efficiency of the four-layer solar drying process ranged from 3.08 to 24.73% depending on the drying days. Similar to single-layer drying, the 1st drying day had the highest thermal efficiency (Data not shown).

4. Discussion

Results of the present study found that open sundried peanuts experienced much higher temperatures than solar dried peanuts. Dickens and Pattee (1972) stated that the optimal temperature range for curing peanuts was 35-38^{o}C. Higher drying temperature could adversely affect the quality, especially the flavor, of peanuts (Dickens and Pattee, 1972). Peanuts dried under the open sun in the present study had higher free fatty acid content (0.31%) and peroxide value (1.16%) than those from the solar dryer (0.18% and 0.31%, respectively). A similar peroxide value of 0.60% was observed by Ayoola and Adeyeye, (2010) when peanuts were dried under the open sun. Atasie et al. (2009) however, reported a much higher peroxide value of 1.50% in open sundried peanuts. Free fatty acid content of open sundried peanuts from the study of Ayoola and Adeyeye (2010) was 0.89% while a value of 3.01% was reported by Atasie et al. (2009). The higher peroxide value and fatty acid content from open sundried peanuts indicates a higher potential of lipid oxidation and more rapid development of rancid flavor during subsequent storage. Furthermore, drying at higher temperature increases the undesirable tendency of peanuts to de-skin and split during shelling and handling (Dickens and Pattee, 1972). Drying peanuts at high temperature decreases cell aerobic respiration, a physical indication of cell damage (Forbes and Watson 1992), and increases anaerobic respiration (Roberts et al. 1984, Chung et al. 1996) and the latter causes the formation and accumulation of lactate. The lactate causes cytoplasmic acidosis which finally leads to cell death (Roberts et al., 1984).

Results of the present study indicate that open sundried peanuts had a more rapid loss in moisture content. Rapid drying is only advantageous when the quality of the peanut is warranted. Siddique and Wright (2003) observed that pea seeds dried at 60°C for 36 h reached

their desired moisture content (10%) 1-day sooner than those that were dried at 40°C for 48 h. The faster drying rate was however, at the expense of germination rate as seeds dried at 40°C had a germination rate of 90-100% while at 60 °C, the germination rate was 70-90%. Sveisson and Blornsson (1994) found that mildew grass seeds dried at 45 °C were stressed and had increased number of cracks with a germination rate of 52% but seeds dried at 25 °C had germination rate of 87%. Suresh et al. (2012) reported that peanuts dried under the open sun for 56 h had a germination rate of 89% whereas those dried under the shade for 264 h had a germination rate of 94%. The reduction in germination rate could be due to the extreme low moisture content (<5%) after drying. Hu et al. (1998) observed a reduction in germination rate from 93% to 85% when peanuts moisture content changed from 10 to <5%. A higher drying rate causes the outer layer of seed material becoming rigid but the volume of the seeds remains the same (Baker et al., 1999). As drying proceeds, the tissue of the seed splits and ruptures internally. The internal tissue consequentially shrinks and pulls away from the outside layer of the seeds (Baker et al., 1999).

The drying efficiency of the current research ranged from 1.50-6.47 in the single-layer drying (Fig. 4.6) and 23.07-24.93% in the four-layer drying (Fig. not shown). These values are in a close range as that reported by Hubackova et al. (1.50-34.62%; 2014) and Fudholi et al. (13.00-45%; 2010) when fishes and red pepper were dried respectively. Ekechukwu and Norton (1997) and Segal and Reuss (1987) reported drying efficiencies ranging from 4.10-22.80% and 15.00%, respectively when cassava was dried. The thermal efficiencies reported by these groups of researchers were however, in higher ranges (13.12-53.6% and 60%, respectively) compared to the thermal efficiencies of the dryer used in the current research. The differences in thermal efficiencies could be due to the design of the dryers and the material used in building the dryers.

The solar chamber of the present research was made of wood which has a thermal conductivity of 0.06-0.17 $Wm^{-1}K^{-1}$ (Summer, 2015) while Hubackova et al. (2014) and Fudholi et al. (2010) used a plastic (thermal conductivity 0.61-1.19 $Wm^{-1}K^{-1}$; Summer, 2015),) drying chamber equipped with a blower. However, the two dryers both had black galvanized steel plate collectors covered with greenhouse film. Dasin et al. (2015) reported a thermal efficiency of 60% when a wooden solar chamber and a black aluminum plate collector with a thermal conductivity of 205 $Wm^{-1}K^{-1}$ (Engineering Toolbox, 2011), layered beneath with gravels (thermal conductivity 0.7 $Wm^{-1}K^{-1}$, Engineering Toolbox, 2011) and covered with a clear glass was used. The thermal conductivity of clear glass is 3.15 W m^{-1} K^{-1}, which is higher than the thermal conductivity of plastic and wood.

The intensity of solar radiation at particular drying times could also affect the thermal efficiency of a dryer. The solar radiation in the current study ranged from 360-592.99 Wm^{-2} while Hubackova et al. (2004) and Dasin et al. (2015) reported a higher radiation of 800 Wm^{-2}. Dasin et al. (2015) stated that thermal performance of indirect solar dryers is dependent on the intensity of solar radiation and the difference between ambient temperature and temperature in the dryer.

Although solar drying is a useful technology relative to open sun drying and mechanical drying in developing countries, challenges of implementing the technology include dryer cost and drying capacity (Weis and Buchinger, 2012). The cost of the solar dryer used in the present study was approximately $300-400 US. Hollick (1998) reported that solar dryers could cost a few dollars to thousands of dollars depending on the capacity and sophistication. Hollick (1998) stated that a direct drying capacity of 50 kg can cost $100 while a solar tunnel-dryer capable of drying 4,500 kg of fresh fruits would cost $20,000. The maximum capacity of solar dryers for

peanuts is reported to range from 10-315 kg (Tiwari et al. 2013). The dryer used for the present study dried 72 kg of peanuts but it could accommodate approximately 250 kg based on the area in the drying chamber at the same drying time.

Whitfield (2000) stated that farming cooperatives and private enterprises, in combination with non-governmental organizations can assist in sustaining solar drying of farm produce by farmers. A strong standpoint is that peanut growers in Ghana accept the technology; Kuwornu et al. (2011) interviewed 225 farmers in Ghana and 94.5% were willing to adopt the technology and 88.2% were willing to pay for the technology.

5. Conclusions

Solar dried peanuts (single and four layers) attained moisture content below 10% in four days. In comparison, open sundried peanuts had a much more rapid moisture loss hence a faster drying rate. Peanuts in the solar dryer experienced much lower temperatures than those dried under the open sun. Faster drying rates were observed when peanuts had relatively higher moisture contents. Total energy generated by the solar collector positively correlated to the level of solar radiation. The drying and thermal efficiency observed in the present study were comparable to those of similar dryers reported in literature. Solar dried peanuts had a lower level of lipid oxidation and a higher rate of germination compared to open sundried peanuts. Thus, solar drying has the potential for improving peanut safety and preserving peanut quality in Ghana.

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Table 4.1

Ranges of temperature readings recorded by sensors placed immediately above the peanuts dried by open sun or in the solar dryer

	(20-29.99)	(30-39.99)	(40-49.99) ° C	>43	(50-59.99)	(60-69.99)
n=132						
SD (single layer)	29	89	14	0	0	0
Open sun*	1	30	65	47	36	0
SD (layer 1)	19	99	14	0	0	0
SD (layer 2)	30	91	11	0	0	0
SD (layer 3)	33	87	12	0	0	0
SD (layer 4)	27	93	12	0	0	0
Open sun	0	33	46	36	52	1

n: number of temperature readings in each layer of the solar dryer or open sun during the whole drying time
SD: solar dryer
Direct sun*: control for single layer drying of peanuts in the solar dryer
Layer 1, 2, 3, 4: each individual layer in the solar dryer
>43: number of temperature values within 40-49.99 °C and greater than 43°C

Table 4.2

Ranges of relative humidity recorded by sensors placed immediately above the peanuts dried by open sun or solar dryer.

		(10-19.99)	(20-29.99)	(30-39.99)	(40-49.99)	(50-59.99) %	(60-69.99)	(70-79.99)	(80-89.99)	(90-99.99)
(n=132)										
	SD (single layer)	0	0	23	39	26	12	25	7	0
	Open sun*	0	41	52	16	15	7	1	0	0
	SD (layer 1)	0	0	19	27	23	30	16	11	6
	SD (layer 2)	0	0	10	21	17	22	27	24	0
	SD (layer 3)	0	0	13	15	22	18	29	25	10
	SD (layer 4)	0	0	10	15	15	19	37	22	14
	Open sun	10	38	37	28	9	9	1	0	0

n: number of temperature readings in each layer of the solar dryer or open sun in the whole drying time
SD: solar dryer
Open sun*: control for single layer drying of peanuts in the solar dryer
Layer 1, 2, 3, and 4: each individual layer in the solar dryer

Table 4.3

Germination rate of peanut seeds dried directly under the sun and in a solar dryer

	Solar dried (%)	**Direct sun dried (%)**
4 days	93	53
8 days	97	76

Figures legend

Fig. 4.1. The solar dryer used in the study.

Fig. 4.2. Temperature and relative humidity recorded by sensors placed immediately above the peanuts dried under the open sun or in the solar dryer. Temperature and relative humidity abbreviations (TSD, TOD- temperature readings in the single-layer solar drying and under open sun respectively; RHSD, RHOD-relative humidity in the single-layer solar dryer and under open sun drying respectively).

Fig. 4.3. Moisture (A) and weight (B) of peanuts dried by open sun or solar dryer (single layer)

Fig. 4.4. Peanut drying rate from a single layer of solar drying (A) or open sun drying (B).

Fig. 4.5. Average solar radiation absorbed by the solar collector and daily solar energy generated by the solar dryer.

Fig. 4.6. Drying efficiency and thermal efficiency of single layer solar drying.

Fig. 4.7. Free fatty acid content and peroxide value of peanuts dried under the open sun or in the solar dryer.

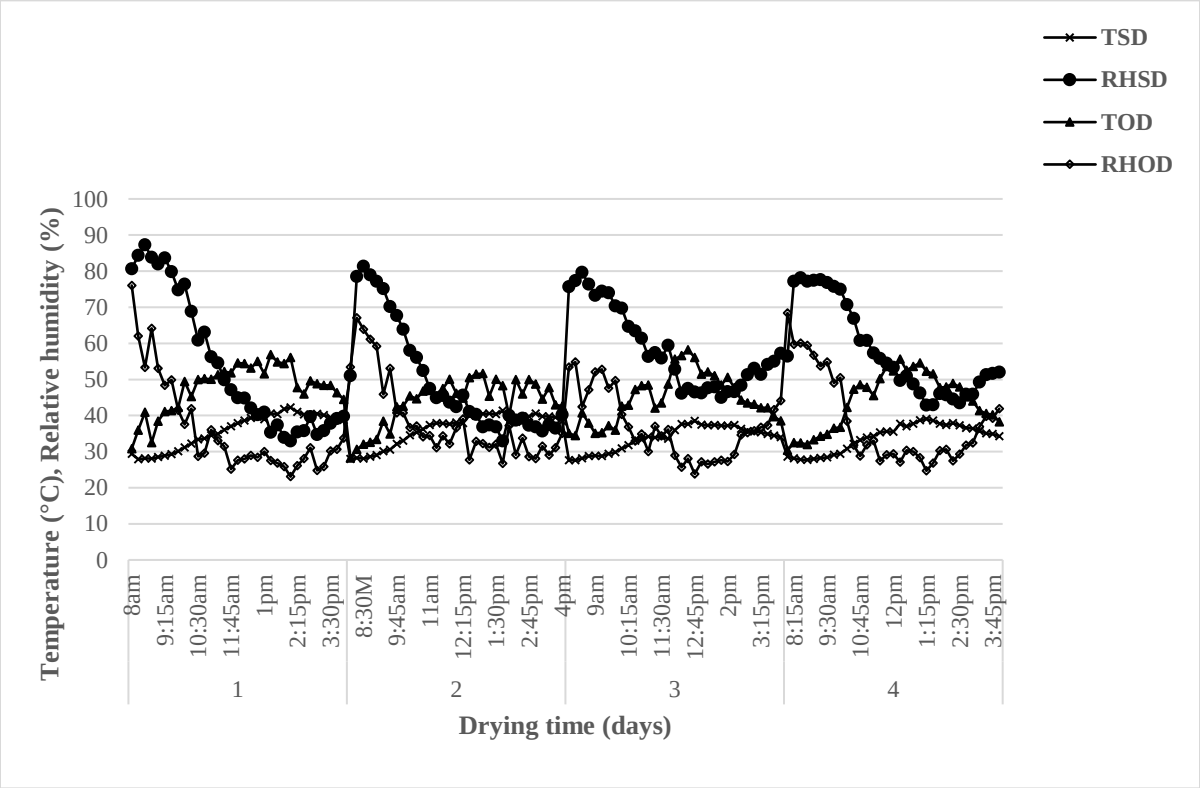
Fig. 4.8. Temperature and relative humidity recorded by sensors placed immediately above the peanuts dried under open sun or in the solar dryer (four layers). Temperature and relative humidity abbreviations (T1-T4, T_{open}- temperature readings in the four-layer solar drying process and under the open sun respectively; RH1-RH4, R_{open}- relative humidity in the four-layer solar drying process and under the open sun drying respectively).

Fig. 4.9. Moisture (A) and weight (B) of peanuts dried under the open sun or in the solar dryer (4 layers).

Fig. 4.10. Peanut drying rate in the solar dryer (4 layers; A) or under the open sun (B).

Fig. 4.1. Akoto et al.

Fig. 4.2. Akoto et al.



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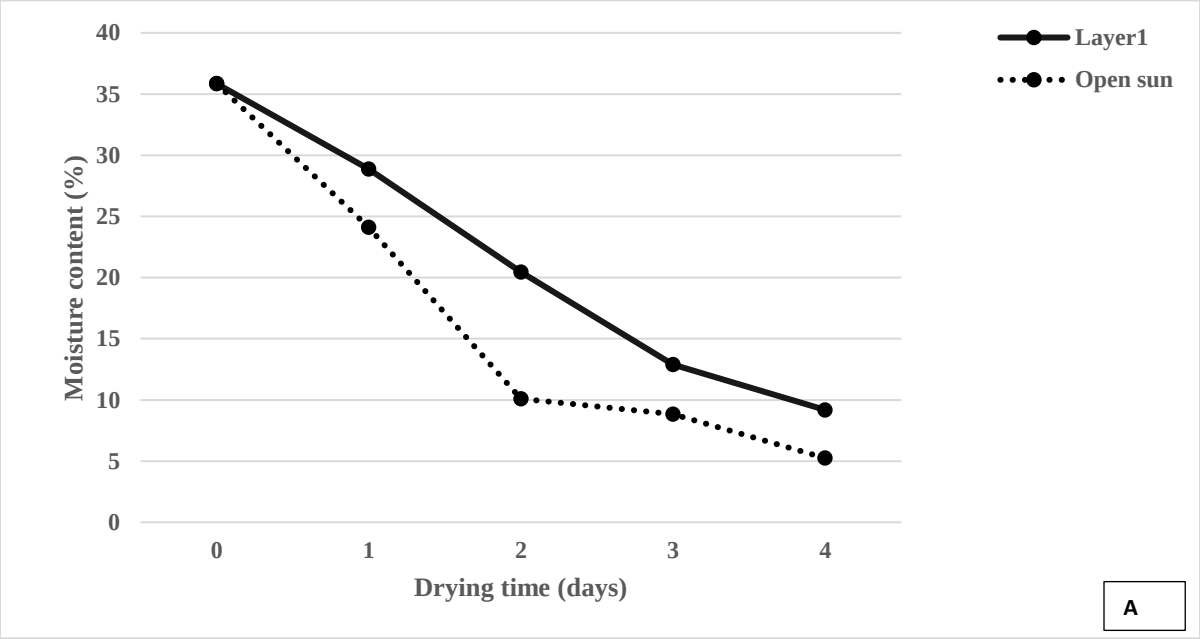

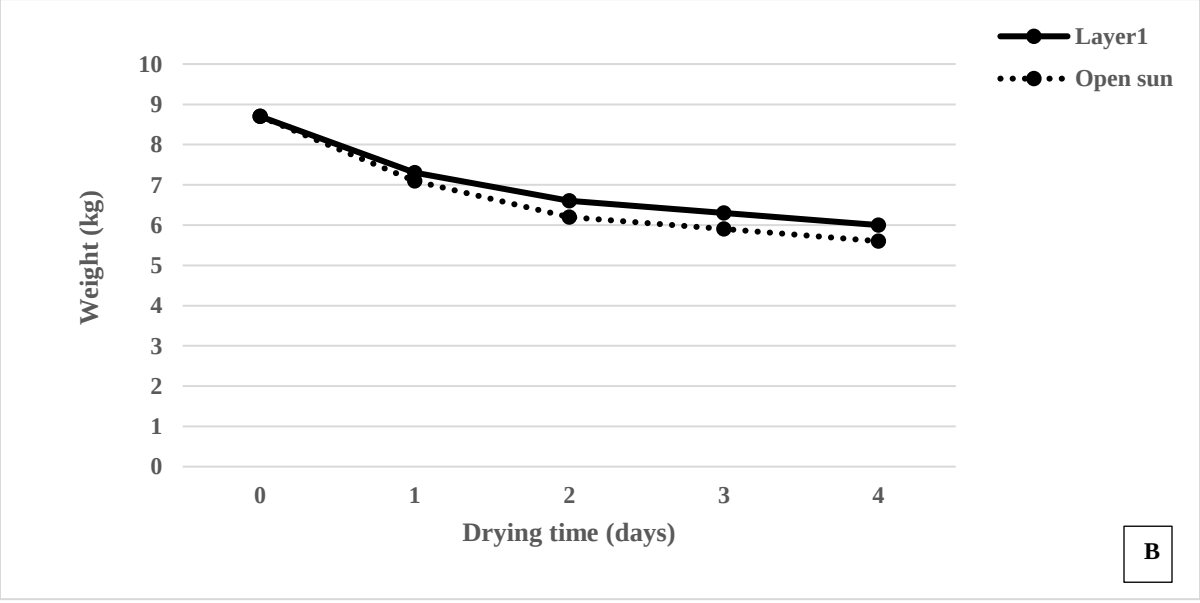

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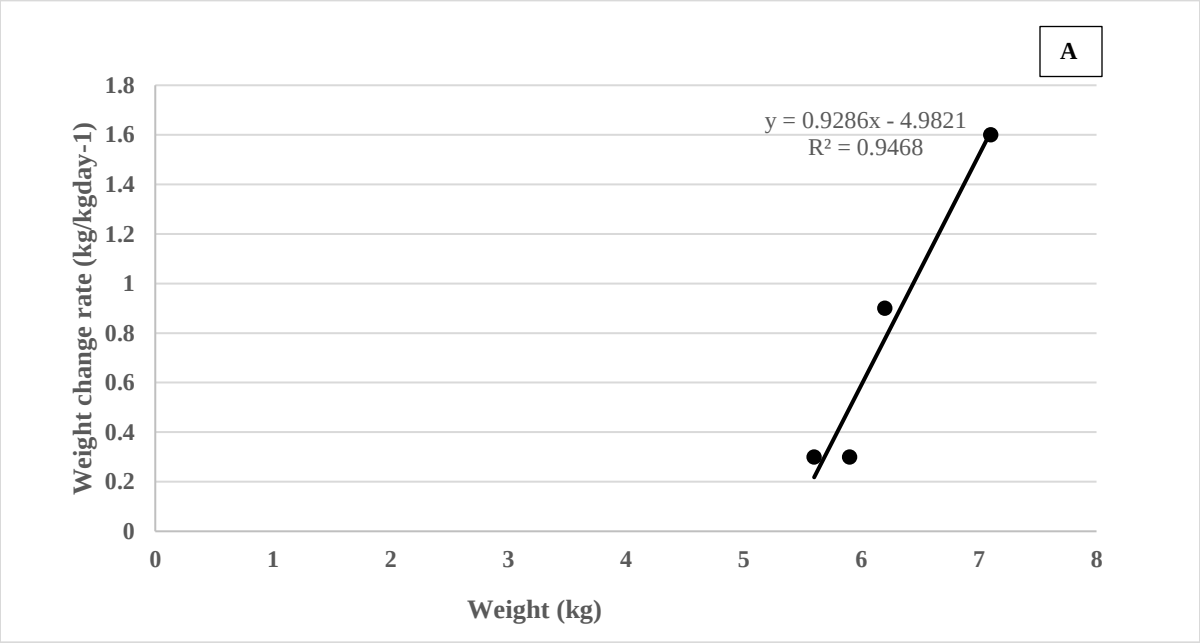

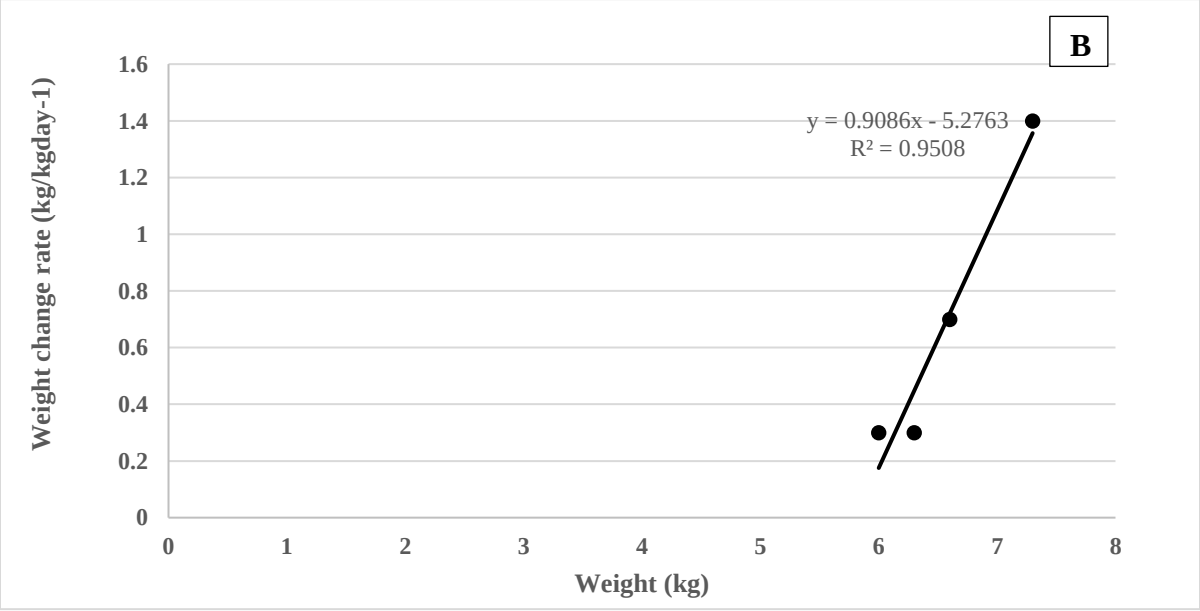

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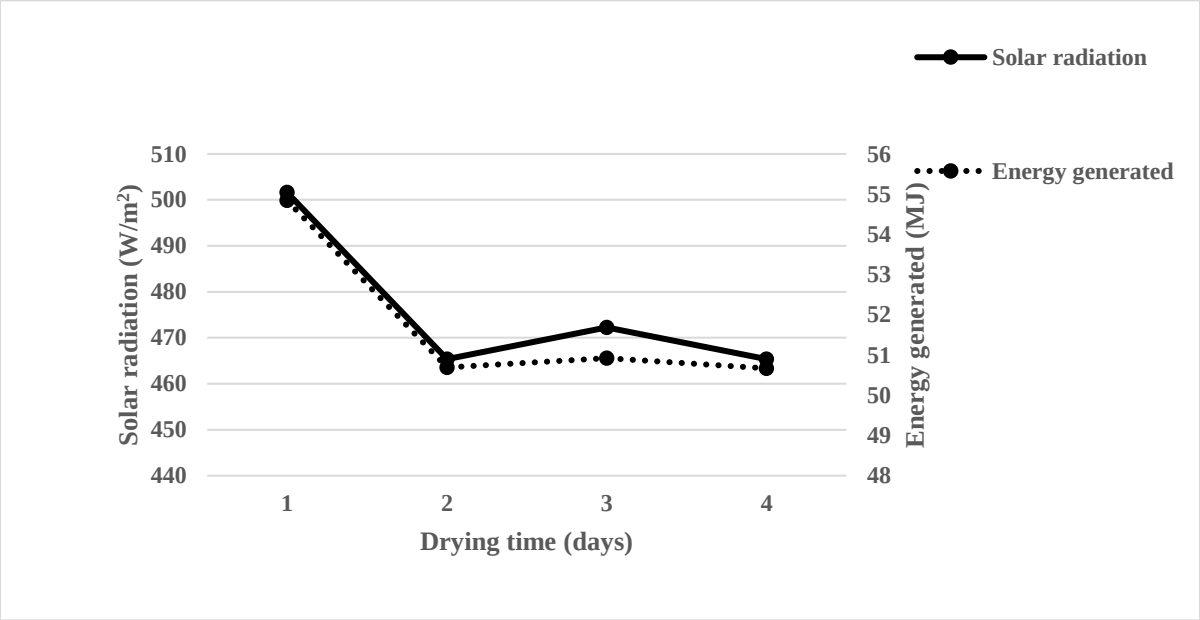

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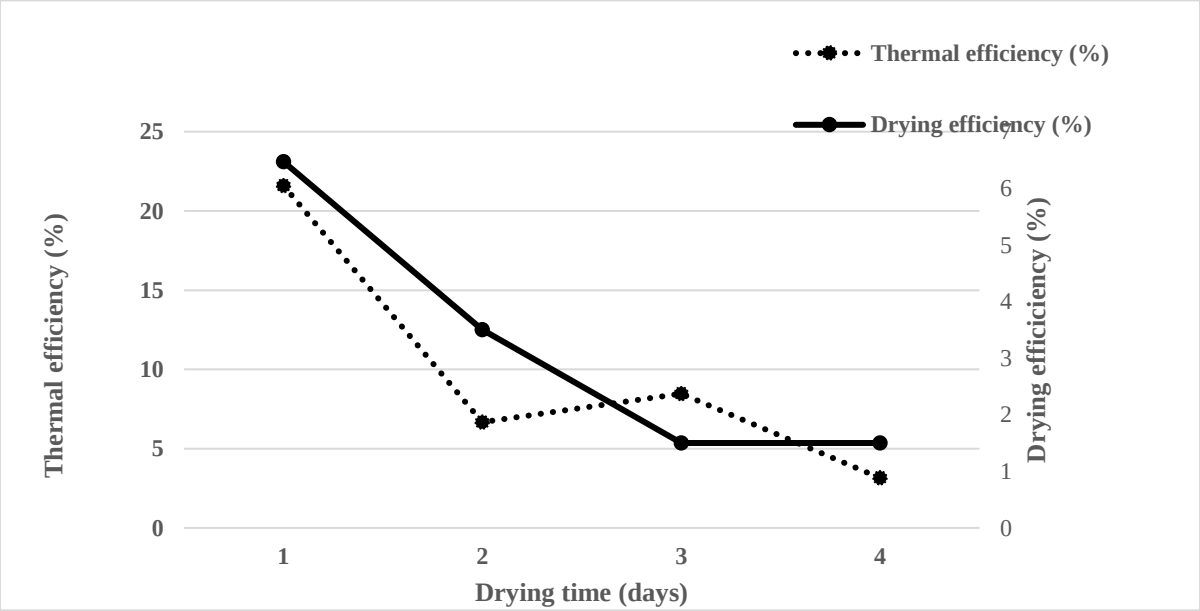

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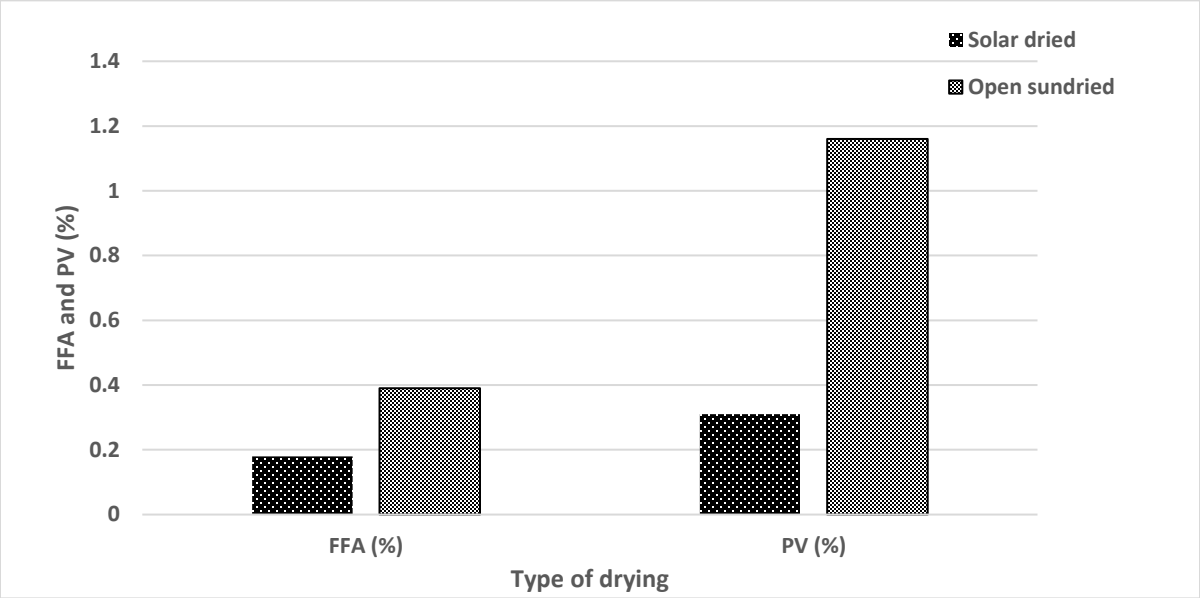

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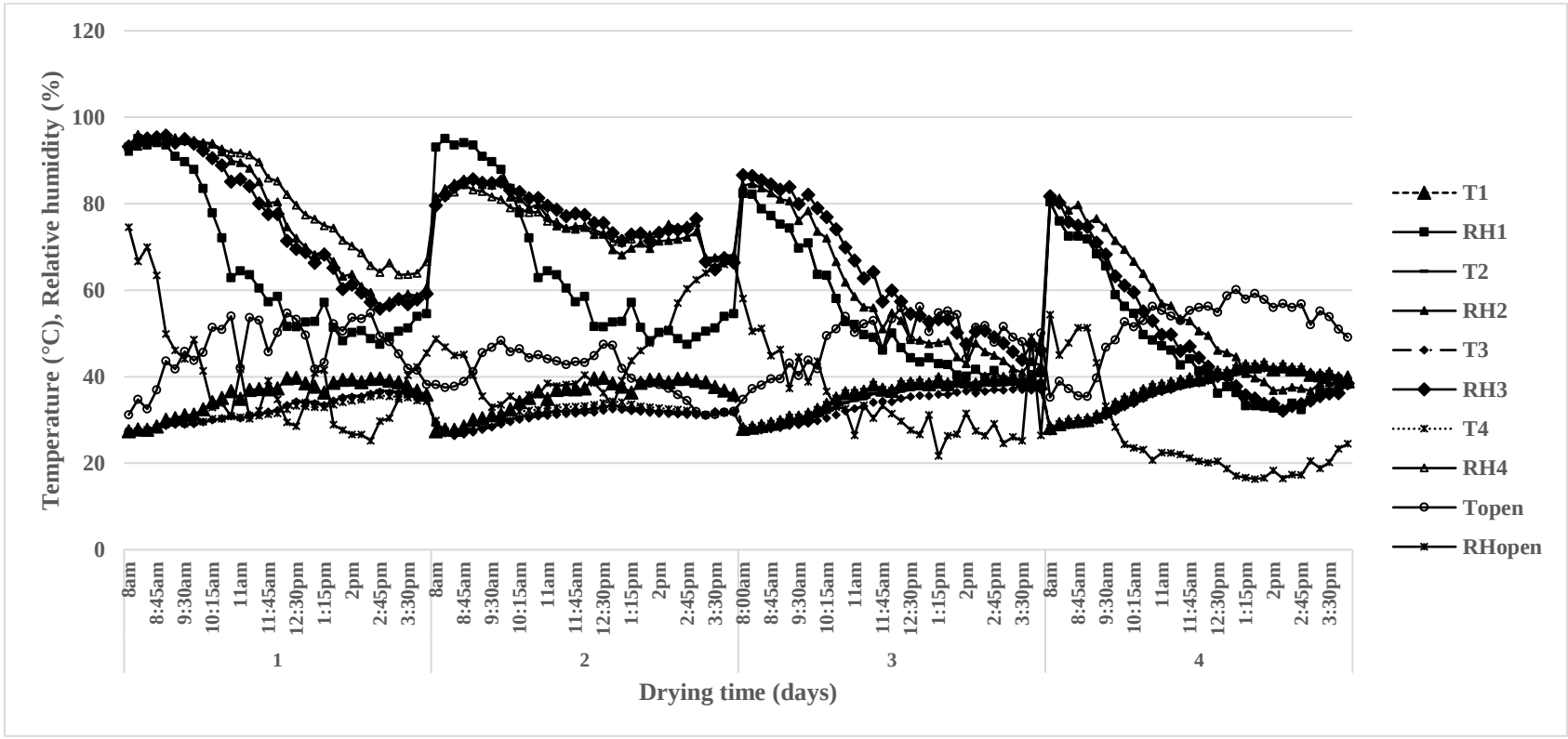
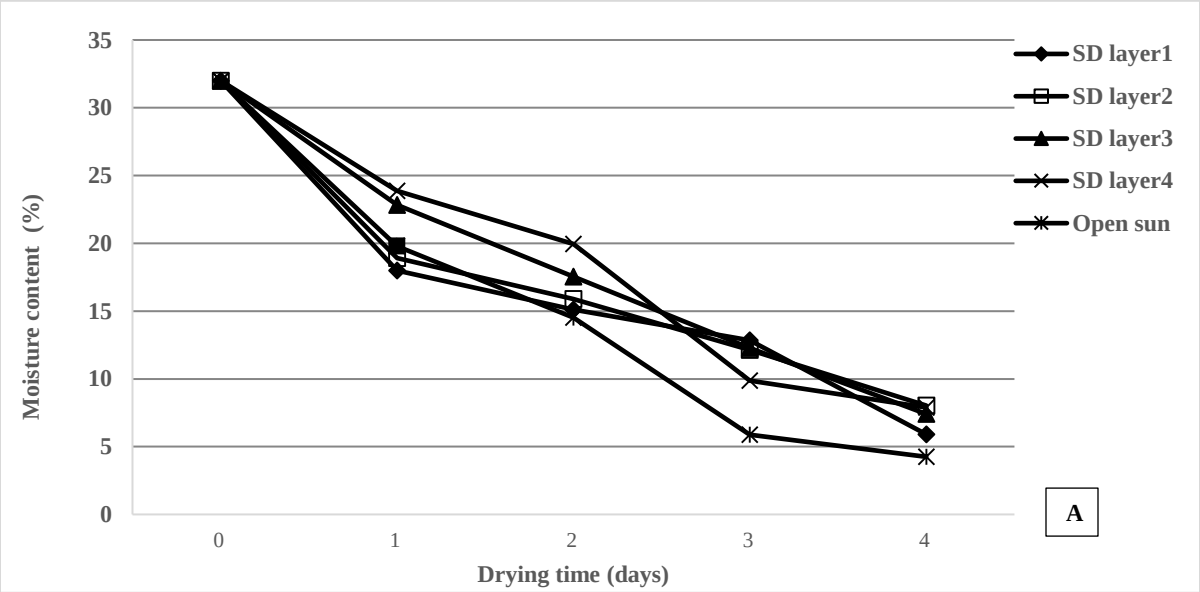
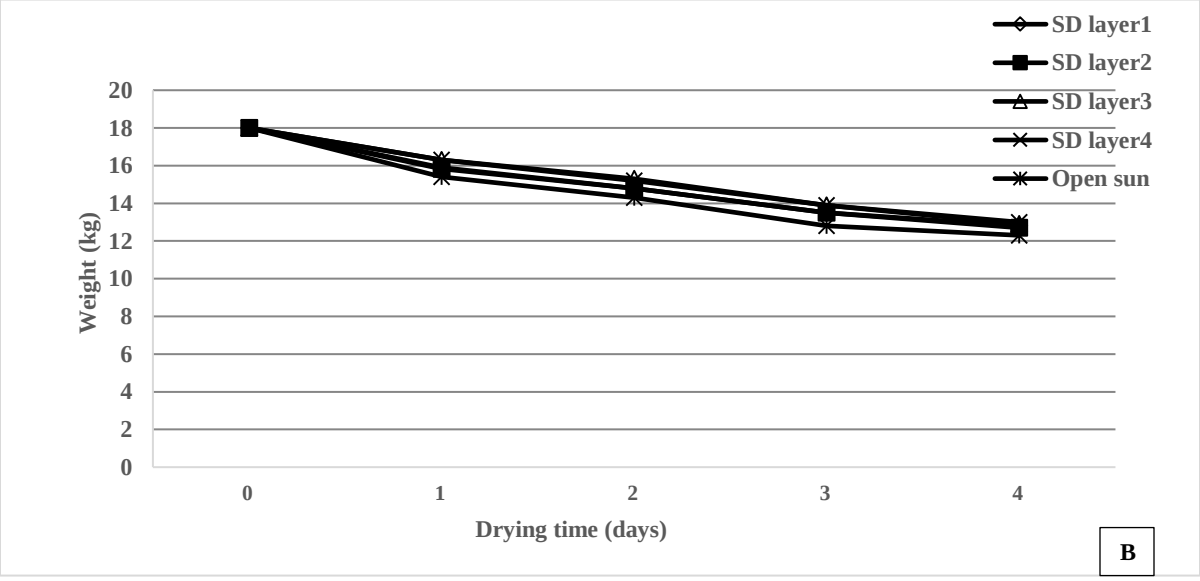


Fig. 4.9. Akoto et al.





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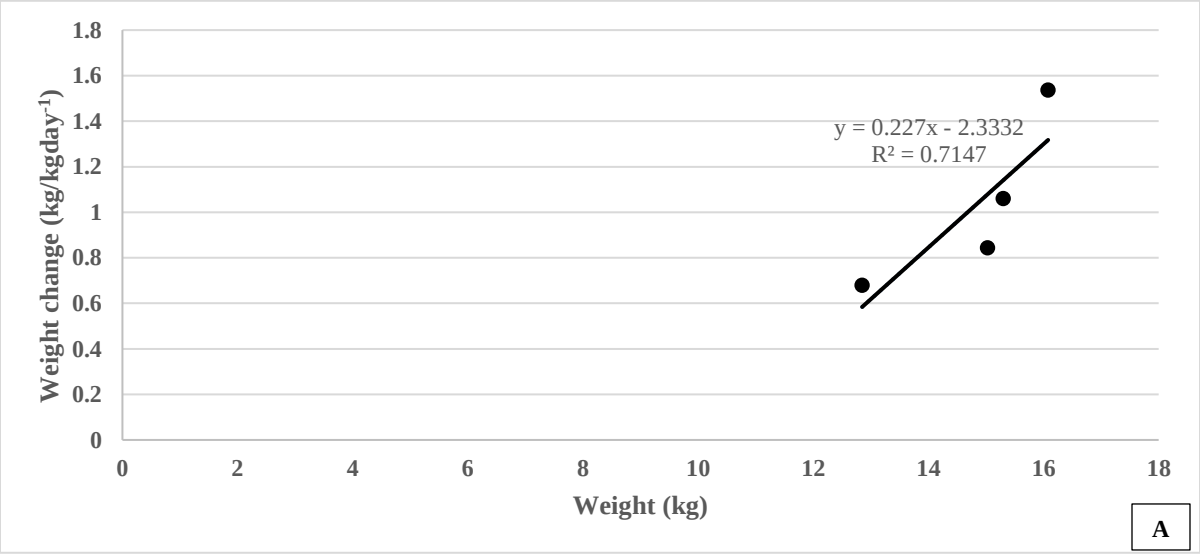

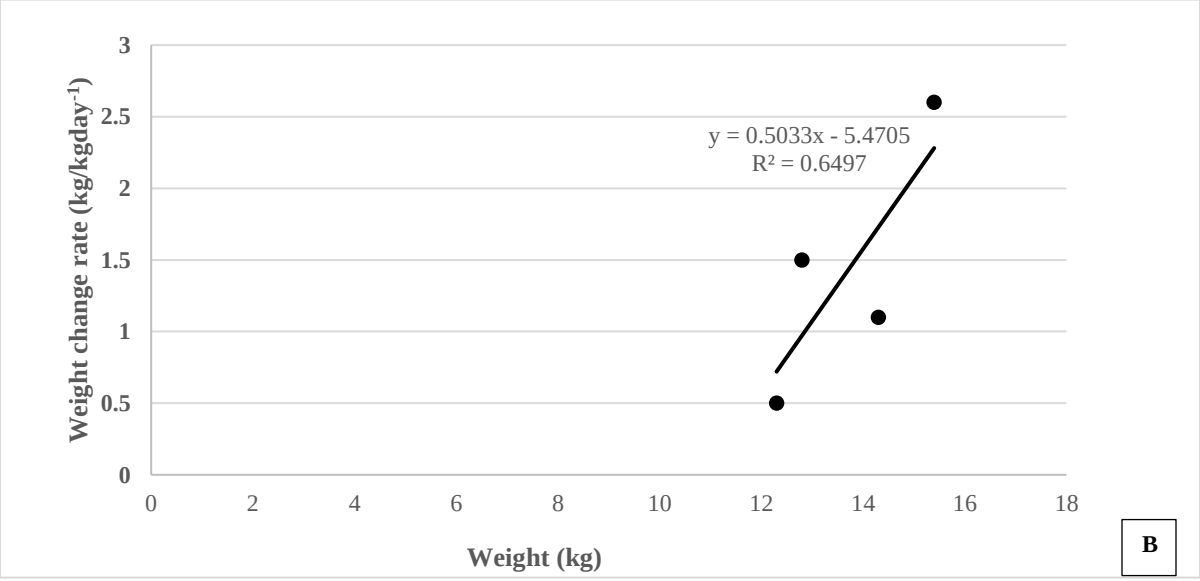

CHAPTER 5

CONCLUSIONS

1. Composting reduced aflatoxin levels in aflatoxin-contaminated peanut meal. Composting time and the type of starters used significantly influenced aflatoxin content, while the presence of accelerator did not affect aflatoxin levels during composting. The most toxin decontamination occurred in the first week when compost temperature and ammonia concentration were high. Significant aflatoxin reduction was also observed in an up-scale experiment using contaminated agricultural waste as raw materials. The results of the research suggest that composting can be employed by farmers in developing countries to convert agricultural wastes to safer soil amendments while controlling subsequent aflatoxin contamination of the soil.

2. Solar dried peanuts (single and four layers) attained moisture content below 10% in four days. In comparison, open sundried peanuts had a much more rapid moisture loss hence a faster drying rate. Peanuts in the solar dryer experienced much lower temperatures than those dried under the open sun. Faster drying rates were observed when peanuts had relatively higher moisture contents. Total energy generated by the solar collector positively correlated to the level of solar radiation. The drying and thermal efficiency observed in the study were comparable to those of similar dryers reported in literature. Solar dried peanuts had a lower level of lipid oxidation and a higher rate of germination compared to open sundried peanuts. Thus, solar drying has the potential for improving peanut safety and preserving peanut quality in Ghana.