Effects of Deterioration Parameters on Storage of Maize: A Review

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Abstract

Maize (Zea mays L), commonly known as corn in the United States, is the third most important cereal grain worldwide, after wheat and rice. It is a basic staple grain for large groups of people in Africa, Latin America, and Asia. In tropical countries, a large proportion of the maize is harvested and stored under humid and warm climatic conditions, which subsequently results in rapid deterioration of the grains, mainly because of growth of molds and pests. This study reviewed the main factors that lead to deterioration of maize in tropical countries and suggests ways of preventing the identified causes. This paper also reviews world production, varieties, climatic and storage conditions of maize. Deterioration of maize is mainly affected by moisture content, temperature (grain and air), relative humidity, storage conditions, fungal growth, and insect pests. Fungal growth, especially Aspergillus flavus and Fusarium sp in maize, facilitated by hot and humid conditions, poses a major risk through production of mycotoxins. In order to maintain high quality maize for both short- and long-term storage, maize must be protected from weather, growth of microorganisms, and pests.

Keywords: Maize, corn, relative humidity, temperature, fungal growth, storage.

1. Introduction

Maize (Zea mays L) commonly known as corn in the United States and Canada, is the third most important cereal grain worldwide after wheat and rice (Golob et al., 2004). It is referred to as the cereal of the future for its nutritional value and utilization of its products and by-products (Lee, 1999). The demand for maize has been estimated to increase by 50%, from 558 million metric tons in 1995 to over 800 million metric tons in 2020 (Martinez et al., 2011). This enormous increase is due to diverse uses of corn, from food and animal feed to ethanol production (FAO, 2006). It is a basic staple food grain for large parts of world including Africa, Latin America, and Asia (Yaouba et al., 2012).

In tropical and subtropical countries, a large proportion of the grain (such as maize) is harvested and stored under hot and humid conditions, and most farmers lack proper knowledge, equipment and methods of drying grains (Weinberg et al., 2008). Subsequently, the maize is stored while still relatively moist and warm; both warmth and high moisture contents can result in rapid deterioration of the grains and promote the growth of microorganisms (e.g. fungi and bacteria) and insects in the grains (Ekechukwua and Norton, 1999). Maize, like other stored products is hygroscopic in nature and tends to absorb or release moisture. Even if properly dried after harvest, exposure to moist and humid conditions during storage will cause the kernel to absorb water from the surroundings (Devereau et al., 2002), leading to increase maize moisture contents, which result in enhanced deterioration.

To maintain high quality maize during storage, maize should been protected from weather (including relative humidity and temperature), growth of microorganisms, and insects (Oyekale et al., 2012). According to Campbell et al., (2004), the current estimates of the cost of grain loss due to insect and microorganism damage of grain stored in developing countries each year ranged from $500 million to $1 billion (Tuite and Foster, 1979) Also reported that insects in grain enhance mold development because they increase moisture content and temperature, and open areas of the grain for attack.

Fungal growth in maize is facilitated by hot and humid conditions (Egal et al., 2005). It has been reported by several researchers that fungal infestation in maize results in color change, decreases in nutritional values, and reduction of overall quality and quantity of the maize. Major fungi associated with grain storage, including maize, are Aspergillus flavus, Fusarium sp, and others. Fungal growth in maize presents a major risk for humans and animals, through production of mycotoxins (especially Aflatoxins).

The objective of this article was to review the published literature and discuss the main factors that lead to deterioration of maize in tropical countries, and to suggest ways of preventing the identified causes.

2. World Production

Maize is among a few crops grown on almost every continent. According to FAO (2006), global maize production has increased by nearly 50 percent over the pasts ten years. The total global production for 2011/12 fell due to severe drought in some part of the US, which is the biggest producer of maize (Hoff and O'Kray, 2012). The total world production for 2011/12 was 0.8 billion metric tons; the US contributed 36.19 % of the overall world’s total. Other major producers of maize are China (22.1 %), EU-27 (7.44 %), Brazil (7.15 %), Argentina (2.54 %), India and Mexico (2.48 % and 2.36 % respectively), Ukraine (2.59 %), South Africa (1.38 %), and other (15.77 %) (USDA, 2012).

2.1. Origin

Maize is one of the oldest human-cultivated crops. The center of origin is believed to be the Mesoamerica region, at least 7000 years ago when it was grown as a wild grass called teosinte in the Mexican highlands (FAO, 2006). Maize spread around the globe after European discovery of the Americas in the 15th century (OGTR, 2008). Maize has tremendous variability in kernel color, texture, composition and appearance. Botanically, maize belongs to the grass family gramineae (Poaceae); it is an annual plant with an extensive fibrous root system. It is a diploid species, with a chromosome number of 2n = 2x = 20 (Cai, 2006).

2.2. Maize Varieties

The kernel, or seed, of a maize plant consists of three main parts; the pericarp, endosperm and embryo (Belfield and Brown, 2008). Maize grain is subdivided into distinct types based on endosperm and kernel composition, kernel color, environment in which it is grown, maturity, and its use (Paliwal et al., 2000). There are six major varieties that are commercially grown specifically for human consumption, including Zea mays var. dent (indurate Sturt), flint (indurate Sturt), popcorn (everta Sturt), waxy, and sweet (saccharata Sturt) (Nuss and Tanumihardjo, 2010).

2.2.1. Dent Corn (indurate Sturt)

Dent corn (indurate Sturt) also referred as "field" corn, is the most common type of corn grown for grain, silage and biofuel in the United States and around the World. The main features that distinguish this from other types of corn is the presence of corneous, horn endosperm at the sides and back of the kernels; generally the central part is soft and floury (Johnson, 1991). During drying, the soft endosperm collapses to form an indentation; this central core or crown is unique to the dent types and originated the name “dent” corn (PE/AI, 2012). Due to the soft endosperm dents, this type of corn is more susceptible to grain insects and molds, both in the field and in storage (Paliwal et al., 2000). Two common types of dent have been identified as white and yellow (Figure 1); normally white is more preferred in the food processing industry.

2.2.2. Flint Corn (indurate Sturt)

Flint corn is a type of corn with short, rounded or flat kernels, surrounded by a hard outer layer (hull), starchy and soft endosperm in the middle. Other features that distinguish flint from other corns are long, slender ears with few rows, relatively high protein and lipid contents, and the ability to produce high-quality flour (Gangaiah, 2008; Ruiz de Galarreta and Álvarez, 2010; OGTR, 2008). The hardness of the flint corn outer layer makes it less prone to damage by grain mold and insects, both in the field and in storage (Paliwal et al., 2000). It is a multicolored grain, ranging from pale-orange to dark red (Figure 2). Flint corn is extensively grown in Central and Southern America, Asia, and Southern Europe for human consumption and industrial purposes (OGRT, 2008). It is not grown extensively in the US.

2.2.3. Popcorn (everta Sturt)

Popcorn is a popular type of corn (Figure 3); it is characterized by a very hard outer layer, corneous endosperm and small portion of soft starch (reviewed in Brown and Dallah, 1995). The shape of popcorn is either pointed (rice-like) or round (pearl-like) (Johnson, 1991). Compared to other types of corn (such as dent), popcorn is a minor crop. It is used to make popped corn, or as the basis of popcorn snacks (Brown and Dallah, 1995).

2.2.4. Waxy corn (waxy maize)

Waxy (corn) maize looks like flint corn in appearance, except it has a thick, transparent waxy endosperm (Kereliuk and Sosulski, 1996). Research has shown that waxy corn starch resembles potato starch in properties (Boutard, 2012). It contains approximately 99 % amylopectin, very small quantities of amylose, high transmittance and low retrogradation properties (Zhou et al., 2013). Nutritionists have found that waxy corn may be a suitable source of carbohydrate for maintaining glucose control in insulin sensitive individuals (Sands et al., 2009). Waxy corn is extensively used in food processing as thickening and emulsifying agent, as well as remoistening adhesives in paper, gummed tape, and the textile industry (Sandhu et al., 2007).

2.2.5. Sweet Corn (saccharata Sturt)

The production and consumption of sweet corn has increased dramatically in the past decade in the US, Brazil, Canada, and Europe, for both fresh vegetables and for food processing (Williams, 2012). Sweet corn (Figure 4) originated from a mutation in the Peruvian race Chullpi. The entire endosperm in sweet corn is translucent, and the starch has been partially converted to sugar (Boutard, 2012; Najeeb et al., 2011). They are white or yellow in color, but yellow sweet corn is more preferred by the consumer because of high amount of vitamin A and C (Gangaiah, 2008). According to Coskun et al., (2006), sweet corn contains approximately 221 g of carbohydrates, 3.35 g of protein and about 10 g of oil. It is an attractive crop for many farmers because these plants can grow very quickly and harvest can be mechanized (Johnson, 1991).

2.3. 6. Chemical Composition and Nutritional Value of Maize

The importance of cereal grains in human nutrition is widely recognized, as they provide substantial amounts of energy and protein to millions people, especially in developing countries (FAO, 2011). Cereal provides an estimated 10 % and 15 % of the world’s calories and protein, respectively (Nuss and Tanumihardjo, 2010). Typical proximate compositions of the main parts of the maize kernel (yellow dent corn) are shown in Table 1. Chemically, dried maize kernel contains about 10.4 % moisture, 6.8 % to 12 % protein, 4% lipid, 1.2 % ash, 2.0 % fiber and 72 % to 74 % carbohydrate (Kulp and Joseph, 2000). It also contains macro and micronutrients such as calcium, phosphorus, iron, sodium, potassium, zinc, copper, magnesium, and manganese, with 7 mg/100 g, 210 mg/100 g, 2.7 mg/100 g, 35 mg/100 g, 287 mg/100 g, 2.2 mg/100 g, 0.3 mg/100 g, 127 mg/100 g, and 0.45 mg/100 g each, respectively in dry matter basis (db) (Nuss and Tanumihardjo, 2010). These will vary due to geographic location, variety, hybrid, growing season, and soil types and conditions.

3. Factors Affecting Storage

Temperature and moisture content of the cereal grains are the two key features affecting the resulting quality of the grain, biochemical reactions, dry matter losses, allowable storage times and overall storage management of the grain (Gonzales et al., 2009; Lawrence and Maier, 2010).

3.1. Moisture Content

Biological and biochemical activities occur only when moisture is present. Hence, for safe storage of grain, both the moisture content of the grain and that of the surrounding air should be reduced and monitored (Jayas and White, 2003). Maize grains, like other stored products, are hygroscopic materials (i.e. they absorb and release water). They consist of a constant amount of dry matter but water content will vary (Devereau et al., 2002). Moisture content plays a significant role in the storage of grain; when grain has more moisture, it heats up and can have mold spoilage (Brewbaker, 2003). As a general expression, the higher the moisture content, the more susceptible the maize grain is to mold and insect deterioration.

3. 2. Interactions between Temperature and Relative Humidity

Relative humidity can be described as the amount of water vapor that is contained in the air as a proportion of the amount of water vapor required to saturate the air at the same temperature (Lawrence, 2005). Several studies have been conducted to examine the relationship between temperature and relative humidity (RH) in grain storage in the tropics, and results have revealed a direct relationship between them, that is, as temperature increases, grain will lose moisture to the surrounding air, thereby increasing the relative humidity (Devereau et al., 2002) In has been observed that in most cereal grains, every 10 ℃ rise in temperature causes an increase of about 3 % in relative humidity (ACDI/VOCA, 2003). Shah et al., (2002), explained that changing temperature and relative humidity not only promotes molds growth, but also causes considerable nutrient losses of grain. For the case of nutrients, reported by Rehman et al., (2002), after six months of maize storage at 45 ℃ and 12 % RH, result showed significant decreases in protein soluble sugars, up to 20.4 %.

Moreover, according to Samuel et al., (2011), even after drying, maize grain harvested in tropical countries retained a certain amount of moisture, and when exposed to air, exchanges of moisture between the maize grains and surrounding occur until the equilibrium is reached (Samuel et al., 2011), beside this, fluctuation of temperature and relative humidity in tropical countries accelerates rapid multiplication of molds and insects, which facilitate further spoilage of grain (Yakubu, 2009).

4. Maize Storage Losses and Deterioration

4.1 Respiration and Dry Matter Loss

The viable grain kernels, insects, molds, mites and other organisms in the stored grain are living organisms and they are respire; during the respiration process (eq.1), oxygen is consumed and carbon dioxide, water and heat are produced (Bern et al., 2013); The carbon dioxide, moisture, and heat produced through respiration of the grain causes an increase in temperature and dry matter loss of the stored grain. Carbon dioxide has been used by many researchers as one way of quantifying the deterioration of maize grain over time (Muir et al., 1985).

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2834\ \text{kJ} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The carbon dioxide, moisture, and heat produced through respiration of the grain causes an increase in temperature and dry matter loss of the stored grain (Lee, 1999). A two-month trial conducted by Reed et al., 2007), at three different levels of moisture content (low 15.0 %, medium 16.6 % and high 18.0 %) showed gradual increases in moisture content of 15.1 ± 0.01 %, 16.6 ± 0.04 %, and 18.2 ± 0.03 %, for low, medium, and high moisture content maize, respectively. The respiration activity of stored grain is also considerably influenced by the condition, or soundness of the product.

4.2. Molds and Fungi

Mold and fungal species can develops on grains, in the field as well as in storage (Table 2); contamination of maize grain with mold and fungi is regarded as one of the most serious safety problems in the tropical countries and throughout the world (Kaaya and Kyamuhangire, 2006). Toxigenic fungi invading maize are divided into two distinct groups, field fungi and storage fungi (Barney et al., 1995).

Field fungi invade maize and produce toxins before harvest or before the grains are threshed, and can develop under high relative humidity of over 80 %, with moisture content of 22 % to 33 % and wide range of temperature (10 ± 35 ℃) (Williams and Macdonald, 1983; Montross et al., 1999). These usually die out in storage, but some can live under storage conditions (Sanchis et al., 1982), cause significant damage reducing the yield and quality, especially in warm humid climates (Moturi, 2008). Conversely, storage fungi invade grain primarily during storage and require moisture content in equilibrium with relative humidity of 70 % to 90 %. In both circumstances, fungi originated from the field. Storage molds replace field molds that invade/ contaminate the maize before harvest (Reed et al., 2007).

There are several key fungal species associated with stored grains, including Fusarium spp., Penicillium spp., Rhizopus spp., Aspergillus spp and Tilletia spp. (Williams and MacDonald 1983; and Barney et al., 1995). Infection of maize grain by storage fungus results in discoloration, dry matter loss, chemical and nutritional changes and overall reduction of maize grain quality (Chuck-Hernández et al., 2012). It has been reported by Fandohan et al., (2003) that storage fungi contributes to loss of more than 50 % of maize grain in tropical countries, and ranks second after insects as the major cause of deterioration and loss of maize. According to Williams and McDonald (1983), when storage molds invade maize grain they cause rot, kernel discoloration, loss of viability, vivipary, mycotoxin contamination, and subsequent seedling blights. It was revealed by Sone (2001), that broken maize and foreign materials promote development of storage molds, because fungi more easily penetrate broken kernels than intact kernels. Similarly, Dharmaputra et al., (1994) reported that mechanical damage during or after harvesting on maize grains can provide entry points to fungal spores. Likewise, Fandohan et al., (2006) reported that increases in grain damage and cracking create an opportunity for fungi to grow and penetrate the maize grain.

Moisture content and temperature are the two key environmental factors that influence growth of molds and fungi (Alborch et al., 2011). Maize grain is generally harvested with moisture content of around 18 % to 20 % and then dried. If inadequately dried the conditions are favorable for molds and fungi to grow, which can result in a significant decreases in grain quality and quantity (Mar ń et al., 1998). Also Barney et al., (1995) and Rees (2004), report that fungal growth in stored grain in the tropical countries is mainly associated with increases in grain moisture contents, and fluctuation in temperatures, resulting in unsafe storage of high-moisture grain and moisture migration and condensation.

Furthermore, a study conducted by Reed et al., (2007) on the effect of moisture contents and temperature on storage molds, found that the higher the initial moisture contents the greater the infection of maize kernels. According to Miller (1995), the growth and development of storage fungi in grain are governed by three main factors, crop (nutrients), physical (temperature, moisture) and biotic (insects, interference competition) factors.

4.3. Mycotoxins

Molds growing on maize grains present a great threat, especially through production of secondary metabolites (mycotoxins) (Weinberg et al., 2008). Mycotoxins are a chronic problem for maize grown in warm, humid, tropical, and sub-tropical regions (Kaaya and Kyamuhangire, 2006). Molds and fungal infections can result in mycotoxin contamination in all stage from growing, harvesting, storage to processing (Chulze, 2010). The most important mycotoxins that frequently occur in cereal grains are aflatoxins, ochratoxins, fumonisins, trichothecenes, and zearalenone (Pitt, 2000). The two most common and toxic mycotoxin compounds encountered on maize in tropical and subtropical regions are aflatoxins and fumonisins (Krska, 2008).

According to Miller (1995), aflatoxin is predominantly a problem in cereal grains, particularly in maize; it is produced by three main species of fungi, Aspergillus flavus, A. parasiticus, and A. nomius. These fungi tolerate and resist a wide range of conditions, and can be found everywhere such as in soil, in plant and animal remains, milk, and in grains and seeds such as peanuts and maize (Pitt, 2000). They generate four significant aflatoxins: B1, B2, G1, and G2 (Figure 5) and they can produce toxins during storage, transportation, and during processing. The hierarchy of toxicity are in the order of B1>G1>B2>G2. At present, aflatoxin B1 is a considered to be among the strongest natural known carcinogens (Widstrom, 1996), and regarded as a quadruple threat, i.e., as a potent toxin, carcinogens, teratogen, and mutagen (Waliyar et al., 2003). World Health Organization (WHO) categorizes aflatoxins as class number 1 carcinogens, as they are highly poisonous, toxic substances (Martinez et al., 2011).

Aflatoxin contamination has been associated with stunting in children, immune suppression, micronutrient deficiencies, and higher prevalence of cancers in sub-Saharan Africa, East Asia, and China (Smith et al., 2012; Moturi, 2008. Hell (2010) found a strong relationship between aflatoxin exposure and liver cirrhosis. Because of the carcinogenic properties of aflatoxins, many countries around the world have set regulatory limits on allowable aflatoxin levels in foods and feeds (Table 3) (Liu et al., 2006).

Several researchers report that aflatoxin contamination in grain increases with storage period and environmental conditions. Aflatoxins contamination is facilitated by long-term storage under unhygienic and unventilated conditions (Egal et al., 2005). Research conducted Liu et al., (2006) in China showed a significant increase in aflatoxins with storage length (i.e. 0.84 μg/kg in twelve months to 1.17 μg/kg in twenty four months). Aflatoxin contamination and A. flavus infection are often associated with high temperature and drought conditions (Kaaya and Kyamuhangire, 2006), found higher levels of aflatoxins in moist regions of Uganda than in dry regions (Table 4).

Many researches consistently found high temperature to be a major factor influencing aflatoxin contamination and fungal growth (Widstrom, 1996; Kaaya and Kyamuhangire, 2006; Tubajika and Damann, 2001). Alborch et al., (2011) revealed that temperature and water activity (aw) influence not only rate of fungal spoilage, but also the production of mycotoxins.

Mycotoxins produced by Fusarium moniliforme and closely related species, growing on maize and other grains are serious problems throughout the world (Pitt, 2000). There are widespread in tropical and subtropical regions (Afolabi et al., 2006), cause symptomless infections throughout the plant and in maize grain, and it is presence mostly ignored because it does not cause visible damage to the plant (Fandohan et al., 2003). The U.N Food and Agricultural organization (FAO) estimated that about 25 % of the world food crops are lost due to mycotoxin contamination with Fusarium (Fareid, 2011). Fusarium is considered field fungi as it invades over 50 % of maize grains before harvest (Fandohan et al., 2003). It is regarded as most prevalent fungi associated with maize, and can cause asymptomatic infection (Scott, 1993).

There are many reports which suggest that Fusarium toxins (Fumonisins) can affect livestock and humans (Miller et al., 1983). It has been statistically associated with an increased risk of esophageal cancer in humans who consumed contaminated maize in the Transkei part of South Africa, North East Italy, Iran and Central China (Doko et al., 1995; Kimanya et al., 2009); it is also associated with a possible cause of neural tube defects in newborns along the Texas-Mexico border (Stack, 1998).

It is also reported by Pitt (2000) that Fumonisins are a major cause of leukoencephalomalacia, a fatal brain disease of horses, donkeys, mules, and rabbits, and pulmonary edema in swine. However, research conducted by Kimanya et al., (2010) in rural Tanzania, showed that the exposure of fumonisins to infants negatively affected growth. There are six common types of fumonisins; A1, A2, B1, B2, B3, and B4 (Figure 6). According to Cawood et al., (1991), fumonisin B1, B2, and B3 are most important ones found in naturally-contaminated maize and in maize fungal cultures, and produce the highest amounts of toxins (up to 17900 µg/g) (Fandohan et al., 2003).

Toxins from Fusarium moniliforme is categorized as Class 2B, possibly carcinogenic to humans (Munkvold and Desjardins, 1997). Even if the effects are not well established/understood in humans, many countries including the USA have set the maximum level of fumonisin in maize and maize-based foods (Fandohan et al., 2003). The Joint FAO/WHO Expert Committee on Food Additives (JECFA) set maximum tolerable daily intake (PMTDI) of 2 µg/g for B1, B2, and B3, while The US Food and Drug Administration (FDA) set 4 µg/g for all types of fumonisins (WHO, 2002; and Marasas, 2001).

Afolabi et al., (2006) report fusarium contamination and growth are favored by warm and dry conditions. Typical symptoms of maize kernels infected by fusarium are white or pinkish-white color on maize kernels (Figure 7). The optimum conditions required for fumonisin production are still unknown (Robertson-Hoyt et al., 2007), but the occurrence of F. moniliforme is related to drought stress and climatic conditions (Scott, 1993).

Furthermore, a study conducted by Fareid (2011), revealed that temperature and water contents are key factors for the growth and mycotoxinogenesis of Fusarium species, the results shows linear relationships between temperature and levels of fumonisin B1 production; maximum production was observed at 25 ℃. Similar research conducted by Mar ń et al., (1998) showed growth rates of Fusarium species and other fungal species are critically dependent on water activity and temperature; research found higher growth rate of Fusarium species at 0.995 water activity. In connection to this, Mar ń et al., (1998), found the best temperature for production of fumonisin B1 in maize is 30 ℃ and 0.98 aw.

As opposed to aflatoxin, fumonisins are only concentrated in the pericarp and germ of the maize grain, so removing those outer parts can significantly reduce the level of toxin in the maize (Charmley and Prelusky, 1994). Similarly, research conducted by Fandohan et al., (2006), showed significant decreases in fumonisins after dehulling (removing hulls), as shown in (Figure 8).

There is a close relationship between storage fungi and insect infestation, Jian and Jayas (2012) report that some storage fungi attract insects and promote their growth, but other prevent through secretion of toxic metabolites. In connection to this, Burns (2003) found direct association between insect feeding activity, fungal growth and mycotoxin production. Likewise, Setamou et al., (1997), detected low levels of mycotoxin for less damaged maize (2%) than in higher damaged maize.

4.4. Insects and Pests

It has been observed that globally, the greatest losses of grains in storage are due to insect infestation. Grain storage provides the ideal environment for several insects to flourish, consume grain nutrients, and contaminate it with insect fragments and feces (Boxall, 1991; Paliwal, 2000). According to White and Sinh (1980), grain storage systems are ecologically unstable, containing varieties of species with high reproductive potential that can damage grain over a short period of time.

It is estimated that 1% to 5% of stored grain in developed countries and 20% to 50% of stored grain in developing countries are lost due to insect damage (Ileleji et al., 2007; Nukenine, 2010); more than 500 insect species are reported to be associated with grain, among which 250 are directly linked to maize grain, both in field and in storage (Jian and Jayas, 2012); and Mathur, 1987). Montross et al., (1999) described how stored-grain insects are classified into two main groups (internal and external feeders), where internal feeds are those insects developed inside the kernels, while, external are those whose eggs hatch and live on the surface of grain kernels. Among the key insects in maize storage is the maize weevil Sitophilus zeamais. S. zeamais (Figure 9) is classified as a primary or major pest due to its ability to destroy a whole grain kernel (Kanyamasoro et al., 2012); other major species found in grain storage are shown in Table 5.

When maize grains are stored they are exposed to a broad range of complex ecological factors; the most important factors that affect grain quality and pest development are temperature and moisture (Maier et al., 1996). They described that the grain storage conditions such as temperature and moisture content, and environmental conditions, such as temperature and relative humidity, play an important part in how fast insects and pests develop and threaten the quality and quantity of stored grain.

According to Montross et al., (1999), propagation and development of insects depends on several factors, including, moisture content and temperature of the grain, the level of damage and foreign-material of the grain, and atmosphere around grain (Hayma, 2003) found that favorable conditions for most grain storage insects to develop is between 25 ℃ to 30 ℃, and relative humidity between 70 % and 80 %. Conversely, research conducted by Yakubu et al., (2011), showed that insect infestation problems can be controlled under hermetic storage conditions at moisture and temperature ranges of 6 % and 16 % and 10 ℃ and 27 ℃, respectively.

5. Maize Storage

Stored grains are considered an ecological system. Jian and Jayas (2012) described it as an approach by which grain integrated with other factors such as relative humidity and temperature to promote protection of grain and environments to deliver good quality grain at the end of storage time. Practice of grain storage has direct effects on quality of stored grain. According to Nukenine (2010), “storage is a way or process by which agricultural products or produce are kept for future use”. In maize storage ecosystems, the most important factors that influence molds and insects infestation are water activity, temperature and air (Montross et al., 1999). In addition, grain temperature and moisture content affects grain quality in storage and promotes growth and development of molds, insects, mites and dry matter losses (Maier et al., 1996). Maize and grain storage systems are classified into three main types; crib, bags, and bulk storage (Yakubu, 2009; and Montross et al., 1999).

The allowable storage time for maize is the time until 0.5 % of dry matter decomposition is reached (Hellevang, 2005). The dry matter loss of corn is directly related to the carbon dioxide (CO2) production (eq.1), and Bern et al., (2002), found about 7.33 g of CO2 per kg of dry matter was required to lose 0.5 % of the dry matter.

According to Steele (1967) and Thompson (1972) cited by Bern et al., (2002), the amount of CO2 can be easily predicted under certain conditions (T= 15.6 oC, M = 25 % and D = 30 %) using equation 2, where ts is the time in hours, and (t_n) for non-reference conditions can be computed by equation 3, where MM, MT and MD are multipliers for moisture, temperature and mechanical damage respectively.

$$Y = 1.3(e^{0.006 t_s} - 1) + 0.015 t_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$t_n = t_s M_M M_T M_D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. 3$$

Allowable storage time is cumulative term and functions of temperature and corn moisture contents; maize at 20 % moisture content and 60 ℉ has an allowable storage time of 29 days. If after five days, the maize is dried to 18 %, the allowable storage time at 18 % and 60 ℉ will be ((29-5))/29×56= 46days (Hellevang, 2005; and Bern at el., 2013).

6. Conclusion

In conclusion, for the proper storage of maize grain, environmental factors such as temperature and moisture content must be controlled. Such factors are the major influences of maize deterioration, because they affect molds, insects, and other pest, which can result in huge losses of maize grain in a very short time. To avoid mycotoxin contamination, maize should be monitored regularly to assure safe storage conditions, hence, maize contaminated by fungi and molds not only render grains unfit for human consumption by discoloration, but can also lead to toxin production such as aflatoxins and fumonisins.

7. Recommendations

Based on the findings, the following recommendations are made:

- Proper monitoring of temperature and relative humidity of maize grain and surrounding atmosphere on storage especially in the initial stage of storage to maintain the highest possible quality of stored grain; in general, the lower the temperature and moisture content the longer it can be stored without being infected by mold and insects;
- To avoid deterioration of maize in tropical and subtropical regions, maize should be dried to moisture contents below 14% immediately after harvest;
- Hygiene and sanitation from harvest to storage are key factors in eliminating sources of infection and reducing levels of contamination;
- Sorting or separating foreign materials and broken corn kernels produced during harvesting from clean maize; those promote development of grains pest and molds;
- Maize should be stored in a sealed, airtight container or structure, to reduce oxygen concentration, which will limit the presence of aerobic organisms.
- Clean, fumigate, or separate maize grain immediately after discovery of insects and molds.
- Remove or separate old grain from new grain to avoid contamination and transfer of pests from one lot to another.

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Figure 1: Yellow and white dent corn.

Figure 2: Orange, Indian and red flint corn.

Figure 3: Yellow and white popcorn.

Figure 4: White sweet corn.

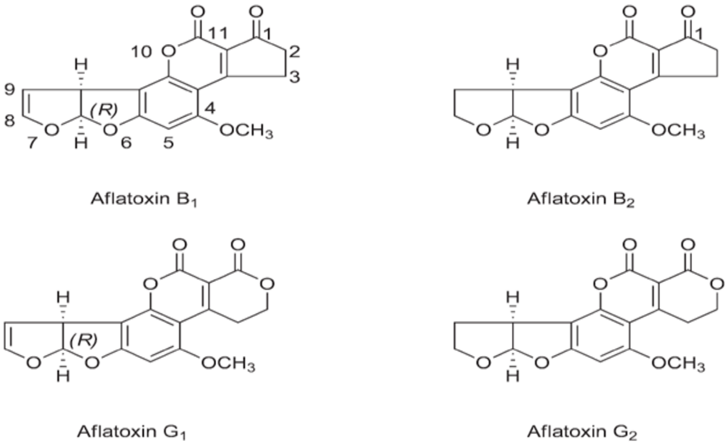
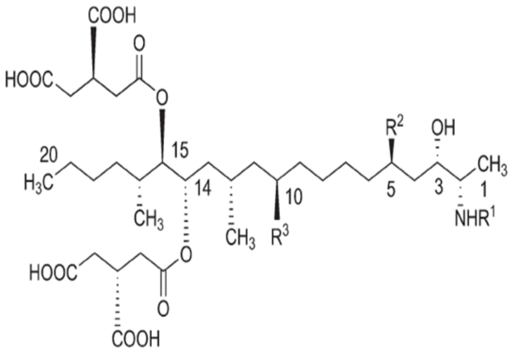


Figure 5: Chemical structures of aflatoxins B1, B2, G1, and G2 (Fujimoto, 2011**).**



Fumonisin A_1 R^1=Ac, R^2=OH, R^3=OH
Fumonisin A_2 R^1=Ac, R^2=OH, R^3=H
Fumonisin B_1 R^1=Ac, R^2=OH, R^3=OH
Fumonisin B_2 R^1=Ac, R^2=OH, R^3=H
Fumonisin B_3 R^1=R^2=H, R^3=OH
Fumonisin B_4 R^1=R^2=R^3=H

Figure 6: Chemical structures of fumonisins (Fujimoto, 2011**).**

Figure 7: Furasium infections on maize kernels.

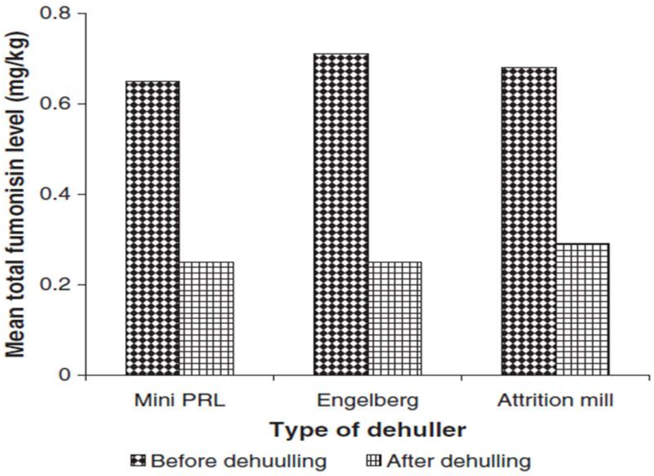


Figure 8:Mean fumonisin level in maize before and after dehulling using different dehulling methods (Fandohan et al., 2006**)**

Figure 9: Maize weevil (*Sitophilus Zeamais***).**

Table 1: Proximate chemical composition of main parts of maize kernels (% db) (Nuss and Tanumihardjo, 2010)

Chemical component	Pericarp	Endosperm	Germ
Protein	3.7	8.0	18.4
Fat	1.0	0.8	33.2
Crude fiber	86.7	2.7	8.8
Ash	0.8	0.3	10.5
Starch	7.3	87.6	8.3
Sugar	0.34	0.62	10.8

Table 2: Optimum conditions for growth of common storage molds on cereals and grains at 25°C to 27°C (Montross et al., 1999)

	Relative humidity (%)	Moisture content (% w.b)
Asperigullus halophilieus	68	12-14
A. restrictus	70	13-15
A.glaucus	73	13-15
A.candidus, A. ochraeus	80	14-16
A.flavus, parssiticus	82	15-18
Penicillium spp	80-90	15-18

Table 3: Maximum amount of aflatoxins B1 allowed in foodstuffs in different countries in ppb (Liu et al., 2006)

Australia/New Zealand	Brazil	Canada	China	EU	India	Japan	Malaysia	Mexico	South Africa	UK	USA
15	30	15	20	2	30	10	35	20	15	10	20

Table 4: Aflatoxin B1 contaminations of maize kernels stored for two to six months in three agroecological zones of Uganda (Kaaya and Kyamuhangire, 2006)

Agroecological zone	No of samples	% positive	Aflatoxin content (ppb)	
			Range	Mean
Mid-Altitude (moist)	80	87.5	0-32	20.54
Mid-Altitude (dry)	80	77.5	0-22	18.02
High land	80	68.8	0-15	12.35
LSD ($p \leq 0.05$)				5.022
CV (%)				22.4

Table 5: Common insect species found in grain storage and optimal growth conditions (Montross *et al.*, 1999**)**

Insects species	**Relative Humidity (%)**	**Temperature (◦C)**
Sitophilus zeamais (maize weevil)	70	27-31
Sitophilus oryzae (rice weevil)	70	26-31
Prostephanus truncatus (larger grain borer)	80	25-32
Rhyzopertha dominica	50-60	32-34
Sitotroga cerealella (Angoimois grain moth)	75	26-30
Plodia interpunctella (Indian meal moth)	70	26-29
Tribolium castaneum (red flour beetle)	70-75	32-35
Cryptolesters ferrugineus (rusty flour beetle)	70-80	33
Oryzaephilus surinamenis (sawtoothed grain beetle)	31-34	90
Trogoderma granarium (khapra beetle)	33-37	25

Abbreviations

Term	Description
a_w	Water activity
$C_6H_{12}O_6$	Carbohydrates
CO_2	Carbon dioxide
db	Dry basis
Eq	Equation
EU	European Union
FAO	Food and Agriculture Organization
H_2O	Water
O_2	Oxygen
RH	Relative humidity
t_s	Time in hours for reference conditions
t_n	Time in hours for non-reference conditions
ppb	Part per billion
US	United States of America
USDA	United States Department of Agriculture
wb	Wet basis
WHO	World Health Organization