EFFECT OF *Sitophilus zeamais* (MOTSCH.) INFESTATION ON PROTEIN CONTENTS OF STORED GRAINS OF QUALITY PROTEIN MAIZE VARIETIES

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DECLARATION

I declare that the work in this thesis entitled 'Effect of *Sitophilus zeamais* (Motsch.) infestation on protein contents of stored grains of quality protein maize varieties' has been carried out by me in the Department of Crop Protection. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree at this or any other Institution.

Maryam Shehu, USMAN	____________________	____________________
Name of Student	Signature	Date

CERTIFICATION

This thesis entitled 'EFFECT OF *Sitophilus zeamais* (MOTSCH.) INFESTATION ON PROTEIN CONTENTS OF STORED GRAINS OF QUALITY PROTEIN MAIZE VARIETIES' by Maryam Shehu USMAN meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Dr. L.J. Bamaiyi Chairman, Supervisory Committee	________________ Signature	____________________ Date
Prof. A.M. Oparaeke Member, Supervisory Committee	________________ Signature	____________________ Date
Prof. M.C. Dike Member, Supervisory Committee	________________ Signature	____________________ Date
Prof. A.B. Zarafi Head of Department	________________ Signature	____________________ Date
Prof. Adebayo A. Joshua Dean, School of Postgraduate Studies	________________ Signature	____________________ Date

DEDICATION

This valuable work is dedicated to my late daughter and my parents, Prof. Shehu Ado Garki and Hajiya Sa'adatu Atiku who were models for the five of us.

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ABSTRACT

The effect of *Sitophilus zeamais* infestation was evaluated on 10 maize varieties, comprising nine Quality Protein Maize (QPM) varieties (SAMMAZ 14, SAMMAZ 17, SAMMAZ 19, SAMMAZ 32, SAMMAZ 33, SAMMAZ 36, SAMMAZ 37, FLINT-Q and DENT-Q) and one non-QPM variety (SAMMAZ 20) which served as check. The experiment was conducted during two seasons; cold-dry and wet seasons (October – December, 2012 and June - August, 2013) respectively. The maize varieties were infested with ten pairs of newly emerged *S. zeamais* in seperate kilner jars containing 100 g of each maize variety. The number of F_1 and F_2 progeny, percentage damage, percentage weight loss, percentage germination and effect of kernel hardness were evaluated for each maize variety. The essential amino acid (tryptophan) and the protein contents of the maize varieties were determined before and after infestation with *S. zeamais* to determine the amount of losses incurred as a result of feeding by *S. zeamais*. The result from combined analysis of the two trials showed that at 45 days after infestation with *S. zeamais,* FLINT-Q (24.63) was the most susceptible variety with the highest mean number of F_1 progeny while SAMMAZ 17 (12.63) had the least amongst the QPM varieties. At 90 days after infestation with *S. zeamais*, DENT-Q (51.63) had the highest mean number of F_2 progeny whereas SAMMAZ 17 (19.25) had the least. The highest mean number of damaged grains with emergent holes were observed in FLINT-Q (36.50) followed by DENT-Q (34.88). The highest weight loss among the QPM varieties was also observed in FLINT-Q (7.78) followed by DENT-Q (7.59). The germination test conducted after infestation of the maize varieties indicated that SAMMAZ 14 (75 %) had the highest mean number of viable seeds amongst the QPM varieties, whereas DENT-Q (12.50 %) and FLINT-Q (12.50 %) had the least. A maximum reduction in tryptophan as a result of feeding by *S. zeamais* was found in FLINT-Q (42.86 %) which decreased from an initial value of 0.07 % to 0.04 %. Maximum losses in fraction I (albumin/globulin) proteins were observed in DENT-Q

(59.68 %) which decreased from an initial value of 0.62 % to 0.25 %. The maximum reduction in the amount of fraction II (zein) protein was observed in DENT-Q (55.36 %) which decreased from an initial value of 0.56 % to 0.25 %. The highest reduction in fraction III (glutelin) protein was in the variety SAMMAZ 19 (59.26 %) which decreased drastically from 0.81 % to 0.33 % at 12 weeks of storage. Minimum reductions in tryptophan (11.11 %), zein (22.22 %) and glutelin (43.85 %) proteins amongst the QPM varieties were observed in SAMMAZ 17 which decreased from 0.09 % to 0.08 %, 0.72 % to 0.56 % and 0.57 % to 0.32 % respectively. The results on the determination of grain hardness showed that SAMMAZ 17 appeared to be relatively harder than all the other QPM varieties. It can therefore be concluded that SAMMAZ 17 variety with relatively hard kernel is the most tolerant variety to *S. zeamais* infestation which can be stored for 90 days with minimum insect infestation and reduction in protein contents.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Maize

Maize (*Zea mays*) also known as corn belongs to the family Poaceae. It is the third most important cereal crop in the world after wheat and rice (FAO, 2002). In Nigeria, maize is known and called by different vernacular names depending on locality like 'agbado' (Yoruba), 'masara' (Hausa), 'oka' (Igbo), 'wyutara' (Kagoma) and 'kyureke' (Tiv) . Maize is one of the major staple food crops in West and Central Africa. These sub-regions have the greatest potential such as adequate moisture, abundant sunshine and relatively fertile soils for maize production (Badu-Apraku *et al.,* 2006). The area of land used for maize production in West and Central Africa increased from 3.2 million hectares in 1961 to 8.9 million hectares in 2005. The expansion of farm area devoted to maize resulted in increased production from 2.4 million metric tonnes in 1961 to 10.6 million metric tonnes in 2005 (FAO, 2006). Maize is grown in all the agro-ecological zones of Nigeria, more so in Northern Nigeria where it is cultivated both as rain fed and under irrigation (Ado, 1999; FAO, 2005). It was estimated that over 40 milllion metric tonnes of maize are produced in sub-saharan Africa annually (FAO Statistics, 2010). Over the years, maize has occupied the unique position of the "Hunger breaker" being the first crop to become available to consumers after the dry season (Lale, 1992). Maize has been of great importance in providing food for man, feed for livestock and raw materials for some agro-based industries. Doebley (1994) reported that maize can be boiled or roasted on the cob; the grains can be made to popcorn (*Guguru*) and eaten with roasted groundnuts.

The nutritional quality of maize is determined by the amino acid makeup of its protein. Amino acids serve as the building blocks for proteins. Maize contains all the ten essential amino acids in varying amounts. However, while maize may provide a rich source of some essential amino acids, it is a poor source of others. Normal maize (non-QPM) has poor nutritive value due to low concentration of two essential amino acids: lysine and tryptophan. Quality Protein Maize (QPM) confers the presence of high lysine and tryptophan, thus the use of QPM varieties helps to reduce nutritional related diseases and death among young children, pregnant and lactating mothers, the sickly and many low income families especially in developing countries including Nigeria (Bressani, 1992). In general, a sample with more than 0.070 % of tryptophan is considered QPM (Nurit and Palacios-Rojas, 2006).

Maize storage after harvest is affected by a number of problems including insect pests, moisture and moulds. The maize weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae) is cosmopolitan and polyphagous in feeding behavior. It causes maize kernel damage during storage. It makes holes in the grains, consumes a large portion of the endosperm, destroys the germ and thus reduces the nutritive value and viability of the grains. The chewing damage caused by the insect in the grains bring about increased respiration (hot spots), which promotes evolution of heat and moisture and in turn provide favourable condition for moulds growth leading to production of aflatoxin. Subsequently, bacteria growth is favoured which ultimately gives rise to depreciation and finally total loss (Maribet *et al.,* 2008). Some varieties of maize appear to be less suitable than others for insect development, and are often described as being "resistant" (less susceptible) to insect attack. Varietal resistance to storage insects is a potential means of reducing post-harvest losses of maize crop.

1.2 Justification

Normal (non-QPM) maize cultivars commonly grown and consumed are deficient in two essential amino acids, Lysine and Tryptophan. As a result, malnutrition due to inadequate protein intake is therefore widespread (Bjarnason and Vasal, 1992). Weight losses of 3-80 % in storage have been reported (De Lima, 1987). Heavy infestation caused by the maize weevil (*Sitophilus zeamais*) can cause weight losses of as much as 30-40 % (Casey, 1994). Maize grain losses contribute to food insecurity and low farm incomes in African countries. These losses are directly measurable in quantitative and qualitative (nutritional) terms. Quantitative loss involves reduction in weight of maize grains. Qualitative losses can occur as a result of changes in physical appearance and chemical constituents of maize. Insect pests are among the most important challenges posed to maize production and storage in Nigeria. Post-harvest losses due to storage insect pests such as the maize weevil, *S. zeamais* have been recognized as an increasingly important problem in Africa. Infestation by this weevil commences in the field (Demissie *et al.,* 2008), but most damage is done during storage. Maize is rich in carbohydrate but has little amount of proteins. If these proteins are depleted by insect pests during storage, nothing or very little amount of the protein will be left for the people to consume. The damage by storage pests will therefore inevitably tend to reduce the protein content of the grains. Infested grains are left with the insect's wastes, cast skins, unacceptable colour and unpleasant taste or odour thereby lowering the visual appearance and also rendering the grains undesirable for consumption (Mejia, 2007).

The widespread use of chemical insecticides for the management/control of stored-product insect pests is of global concern with respect to environmental hazards, insecticide resistance development, chemical residues in food, side effects on non-target organisms and the associated high costs (Cherry *et al*., 2005). To these effects, concern for the environmental safety, reduced protein contents and losses to storage insect pests has directed researches to the development of alternative management/control strategies such as the use of resistant or less susceptible maize varieties. A good knowledge of varietal resistance to maize weevils would therefore help to maintain an acceptably low insect population in stored maize grains, minimize the level of insect pest damage and extend the period that maize can be stored safely even without the use of insecticides.

1.3 Aim and Objectives

The aim of this work is to evaluate the susceptibility/resistance of Quality Protein Maize (QPM) varieties to *S. zeamais* infestation and to determine the effect of infestation on protein contents of the maize varieties after a storage period of three months.

The objectives of this study are:

1. To evaluate the response of Quality Protein Maize (QPM) varieties to *S. zeamais* infestation.

2. To determine the effect of *S. zeamais* infestation on the different protein constituents of the QPM varieties.

3. To determine the effect of seasons on the activities of *S. zeamais* on the QPM varieties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of Maize

Maize (corn) originated from central Mexico about 7000 years ago, starting from teosinte (*Zea mays parviglumis*) which was domesticated. Archaeological records and phylogenetic analysis suggest that domestication began at least 6000 years ago (Piperno and Flannery, 2001; Matsuoka *et al*., 2002). Maize (*Zea mays*) was essential in Mayan and Aztec civilizations. During the domestication of maize, every region in which it has been cultivated over the centuries has produced a selection of maize cultivars or land races. Farmers have maintained and improved these and they are adapted to local requirements and characteristics (Paliwal, 2000). The oldest maize was found in Teotihuacan, a valley near Mexico City (FAO, 1992). Maize was introduced to the South-East Asian archipelago probably in the 16^{th} century by the Portuguese. In the Northern territory, it was grown by the first white settlers in 1824 (O'Gara, 2007). The United States is the leading maize-growing country, with about 39 % of the world's production. Most of its crop is grown in the Midwestern region known as the Corn Belt, comprising Ohio, Indiana, Illinois, Iowa, Missouri, Kansas, and Nebraska. The other leading corn-growing nations are China, Brazil, Mexico, France, and Argentina. Maize requires an average temperature of about 24 ^{0}C during the day and 14 ^{0}C in the night. Rainfall should be fairly in abundance (about 460 – 600 mm) during the growing period (Miracle, 1966). Before the introduction of maize, millet and sorghum were the major cereal crops grown in West and Central Africa. The dramatic expansion of maize production started from 1970 onward (Smith *et al.,* 1994). Since its introduction into Europe by Columbus and other explorers, maize has spread to all areas of the world suitable to its cultivation.

2.2 Maize Production

Maize is the largest food crop of the United States, which is responsible for about 39 % of the world's production. The maize production leader in 2002 was United States with 39 % of world production, followed by China with 18.6 %. Specialty corns such as popcorn, sweet corn, high-protein corn, waxy corn, high oil corn and others, account for less than 5 % of the total U.S corn production; individually each has less than 1 % (Boyer and Hannah, 2001). According to Food and Agriculture Organization, Africa produces 7 % of the world's maize with South-Africa and Egypt being the main producers (FAO, 2007). The major States in Nigeria that grow maize and their statistics are shown in Table 2.1. Maize is a short duration crop in the tropics and can be cultivated twice in a year. About half of the world maize production is in the developing countries, where maize flour is the staple food for poor people. Many factors limit maize production; insects and mites being among the most important.

2.3 Insect Pests and Diseases of Maize

Insect pests severely limit the production of maize, one of the most important cereal crops worldwide. Maize is exposed to insect pest attack prior to harvest and in storage (Muyinza, 1998). Some of these insect pests include stem and ear borers, armyworms, cutworms, *Sitophilus zeamais, Sitophilus oryzae, Tribolium castaneum* and *Ephestia cautella*. Of these *S. zeamais* is the most predominant and destructive pest during storage (Peng and Morallo-Releisus, 1987). In storage, many insect species attack grain and the moisture that can accumulate from their activities provides ideal conditions for fungal activity. To avoid moisture and fungal contamination, it is essential that the numbers of insects in stored maize should be kept to a minimum. Fungal spoilage and mycotoxin contamination are of major concern. Maize has one of the most serious mycotoxin problems of all crops (Munkvold, 2003). Aflatoxin produced by *Aspergillus* species is one of the mycotoxins associated with maize pre-harvest, and mycotoxin contamination can increase if storage conditions are poorly managed. Insect infestation is considered to fascilitate mycotoxin contamination because insects act as vectors for fungal spores and insect damage leads to wounds in the plant through which fungal colonization can occur (Munkvold, 2003). Some diseases of maize include downy mildew, rust, leaf blight, stalk and ear rots, leaf spot, and maize streak virus.

2.4 Economic Importance of Maize

Maize is grown for many reasons. It is used as livestock feed, as human food, and as raw material in industries. Almost every part of maize plant is utilized (Romain, 2001). In industrialized countries, a larger proportion of the grain is used as livestock feed and as industrial raw material for food and nonfood uses. On the other hand, in developing world, about 50 % of all maize is consumed by humans as food while 43 % is fed to livestock and the remainder for industrial purposes (IITA, 2003). Maize is prepared and consumed in a multitude of ways which vary from region to region or from one ethnic group to the other. In the different regions of the world, maize is boiled or roasted on the cob, converted into corn meal (ground dried maize) and made into maize puddings. It is also used for popcorn and various manufactured cereal preparations. It is used as a replacement for wheat flour to make corn bread and other baked products. Drinks typically made from maize are fermented alcoholic or soft drink commonly drunk in Peru. Corn flakes are a common breakfast cereal in North America and the United Kingdom, and found in many other countries all over the world (FAO, 2010). Maize also serves as a basic raw material for the production of starch, oil, protein, alcoholic beverages, food sweeteners, crayons, soaps and absorbent materials for diapers. Other products of maize are livestock feed and other components such as fuel (Halm *et al*., 1996; Cardona *et al*., 2007).

Table 2.1: Maize Production Estimates from Three Major Producing States in Five Different Zones of Nigeria (× 1000 Metric Tonnes)

State	2010	2011	Zone
Bauchi	342.28	346.51	
Borno	494.38	498.98	North East
Gombe	190.77	203.00	
Kaduna	756.09	770.68	
Kano	536.39	546.82	North West
Katsina	270.85	273.13	
Niger	650.89	661.07	
Plateau	630.19	643.42	North Central
Kogi	371.34	375.91	
Ekiti	332.96	342.92	
Ogun	515.09	536.89	South West
Ondo	536.39	553.09	
Anambra	89.30	90.20	
Enugu	153.31	153.86	South East
Imo	170.24	171.78	

NAERLS and NPFS, 2011

2.5 Resistance and Susceptibility of Grains

It has long been known that resistance of grains to insect attack is strongly correlated with physical factors such as tight husk covers, kernel hardness and low moisture content. Chemical factors such as amylase (Rhine and Staples, 1968) and sugar contents (Singh and McCain, 1963) are also important resistance factors. More recently, Garcia-Lara *et al*. (2004) found that *Sitophilus zeamais* resistance is controlled by kernel hardness. For *Sitophilus oryzae,* grain hardness has been reported as the main resistance parameter (Bamaiyi *et al.,* 2007). Kelvin (2002) reported a relationship between seed hardness and thickness, both in the pericarp and the whole kernel by noting that maize with thick and hard pericarp was very hard to penetrate by the weevils. The same author observed a correlation between seed variety, the pericarp and kernel thickness. Bergvinson (2004) also revealed that maize with thicker husks or a harder kernel was insect resistant. Schoonhoven *et al.* (1975) reported that resistance was located in the undamaged pericarp, which act primarily against insects and so reduced the number of insect's progeny. International Maize and Wheat Improvement Centre in Mexico, CIMMYT (2001) reported that high moisture content makes grains susceptible to weevil damage. Dobie (1976) observed increased maize susceptibility to infestation after removal of the pericarp.

2.6 Damage and Losses in Stored Maize

Abraham (1991) indicated that the extent of damage during storage depends upon the number of emerging adult weevils during each generation and the duration of each life cycle, with grains permitting more rapid and higher levels of adult maize weevil emergence will be more seriously damaged. Bergvinson (2004) observed that maize weevils can consume as much as 15 % of a harvest in some months and have the ability to reduce maize quality. Several authors (Mutiro *et al.,* 1992; Pingali and Pandey, 2001; Gerald, 2008) reported that weevils were responsible for causing more than 20 % weight loss of hybrid maize stored in traditional structures, 40 % loss due to poor post-harvest storage and 80 % loss on farm stores in tropics.

2.7 Amino Acid and Protein Contents

The mature maize kernel is composed of 70-75 % starch, 9-12 % protein, 4.5 % oil, 1.3 % minerals and vitamins. Protein quality in maize depends on the amount and balance of the essential amino acids (Bressani, 1991). Proximate and tryptophan analyses of some maize varieties (QPM and Non-QPM) are shown in Table 2.2. Daniel *et al.* (1977) and Rajan *et al.* (1975) have both reported substantial losses in threonine of Quality Protein Maize (QPM) infested with *S. oryzae*. In the first study, threonine decreased after three months from an initial value of 1.30 to 0.91. In the second study, threonine decreased from 3.5 to 2.9 g per 16 g/N. These researchers also reported that the damaged maize was less efficient in complementing food legumes. Significant differences in the emergence of weevil progeny were noted however, between high lysine maize and normal endosperm maize of different lines. Tests performed by CIMMYT have indicated that as the level of tryptophan and lysine is increased, the numbers and weights of emerging *S. zeamais* correspondingly increased as well. Both tryptophan and lysine are important essential amino acids that have to be supplied by the diet. Tryptophan is required for the production of niacin thus helping to combat pellagra. It is used by the human body to produce serotonin, a major neurotransmitter that is important for normal nerve and brain function. Serotonin is involved in the control of mood, aggression, pain, anxiety, sleep, memory, eating behavior, addictive behavior, temperature, endocrine regulation and motor behavior (Sandik, 1992). Of all the essential amino acids, lysine is the most strongly conserved in humans (Flodin, 1997). L-lysine has a positive effect on Calcium metabolism in humans. Studies in animals and humans have shown that dietary supplements with L-lysine can increase intestinal calcium absorption and prevents an increase in calcium excretion in the urine after calcium load (Civitelli *et al.,* 1992). It is also involved in the cross linking process of bone collagen and in the biosynthesis of carnitine and elastin (Flodin, 1997). Therefore the addition of lysine into a lysine deficient diet will improve bone health in children and post-menopausal woman. Eventhough QPM varieties were more nutritious than normal maize; they were not accepted by farmers. Agricultural use of QPM was limited due to lower yield and undesirable kernel characteristics such as soft, chalky and less dense endosperm texture. Kernels dried slower at harvest and had higher incidence of ear rot. This contributed to greater susceptibility to diseases, insect infestation and aflatoxin contamination (Paiva *et al.,* 1991 and Yau *et al.,* 1999).

Chemical analysis of insect infested cereal grains has revealed substantial losses of nutrients like carbohydrates, vitamins and minerals, increase total protein, non-protein nitrogen and uric acid, but the true protein content of the infested grains decreased (Jood *et al.*, 1992). The maize kernel like that of other cereal grains includes pericarp (6 %), endosperm (82 %) and embryo (12 %). Both the endosperm and embryo (germ) of maize grain contain proteins. The proteins of maize can be divided into albumins, globulins, prolamins (zeins) and glutelins based on their solubility. Albumin proteins are soluble in water or low salt aqueous solution and globulins are soluble in high salt aqueous solution. Albumin and globulin proteins are abundant in the germ (Taylor and Schussler, 1986; Wilson, 1987), which is removed during the decortication and degerming process to produce endosperm flour. Zeins are a class of alcohol soluble proteins that are specific to endosperm of maize (Prassana *et al.,* 2001). They contain large amounts of the amino acids leucine (18.7 %), phenylalanine (5.2 %), isoleucine (3.8 %), valine (3.6 %), and tyrosine (3.5 %) but are very low in the essential amino acids threonine (3 %), histidine and cysteine (1 %), methionine (0.9 %), lysine (0.1 %) and are essentially devoid of tryptophan. A higher proportion of zein proteins are found in the endosperm flour. This is so, because the removal of the germ entails loss of protein material mostly albumin and globulins, but not prolamins (zein) which are located in protein bodies in the starchy endosperm (Taylor *et al.,* 1984; Lending and Larkins, 1989). Other proteins such as albumins, globulins and glutelins are collectively called non-zeins and they provide higher levels of tryptophan and lysine (FAO, 1992). Glutelins are seed proteins soluble in dilute alkali solution. They have been quantified as the amount of proteins remaining after sequential extraction with salt and aqueous alcohol. Glutelins are the second most abundant class of maize proteins after zein proteins.

2.8 Description of *Sitophilus* species

The maize weevil, *Sitophilus zeamais* (Plate 1A), is the most important post-harvest insect pest of maize in Nigeria (Ngamo *et al.,* 2004). It is the primary pest for maize, wheat, rice and sorghum. It has a length of 2.5 - 4 mm. *S. zeamais* appears similar to the rice weevil (*Sitophilus oryzae L.*), but has more clearly marked spots on the wing covers (elytra), and is somewhat larger (Plates 1A & B). To differentiate *S. zeamais* from *S. oryzae* on this basis of size is not accurate because the size of either of the two depends on whether its larvae developed in large or small grains. *S. zeamais* and *S. oryzae* are only distinguishable by their genitalia (Hill, 1987). Lale (2001) quoted Halstead (1963) as saying that the rostrums of male *S. zeamais* are distinctly shorter and wider than those of females. The rostrum of males is also rough while that of females is smooth and shiny. The larvae are light yellow in colour with a darker head and the pupae show a milky white colour. The rice weevil, *S. oryzae* (Plate 1B) is around 2 mm long. The rice weevil has four faint yellowish spots on the elytra. The wheat weevil, *Sitophilus granarius L*, also known as grain weevils or granary weevils are a common pest in temperate areas. Adult granary weevil is about 3-5 mm length and is uniformly colored with no spots.

Table 2.2: Proximate and Tryptophan Contents of Four Maize Varieties

	[1]SAMMAZ 14	[2]SAMMAZ 19	[4]SAMMAZ 20	[3]SAMMAZ 30
Protein (%)	10.7	10.06	9.54	10.81
Carbohydrate (%)	76.2	80.94	78.37	71.98
Fat (%)	2.1	3.86	5.29	7.90
Ash (%)	1.1	1.04	1.70	1.91
Moisture (%)	7.0	4.10	10.05	9.84
Tryptophan (%)	1.1	—	—	—

[1]Ado *et al*., 2005; [2]Ado *et al*., 2009; [3]Ajala *et al*., 2009; [4]Menkir *et al*., 2009

A. Maize weevil (*S. zeamais*)　　　　B. Rice weevil (*S. oryzae*)

Magnification: 400 X 600　　　　400 X 617

Adapted from goggle image

Plate 1: Some storage insect pests.

2.9 Life Cycle of *Sitophilus zeamais*

The life cycle of *S. zeamais* takes about 5 weeks (35 days) at 30 ^{0}C and 70 % relative humidity (Hill, 1983). The female chews through the surface of the grain, creating a hole, deposits egg singly, and covers the hole with a waxy secretion which is usually referred to as an "egg plug". The plug quickly hardens and leaves a small raised area on the seed surface. This provides the only visible evidence that the kernel is infested. The eggs hatch into tiny grubs in 4-9 days. Larval development last about 25 days under favorable conditions of temperature of 30 ^{0}C and 70 % relative humidity but under unfavorable environmental conditions, the larval stage may last for up to 98 days (Mattah, 2001). Upon hatching the larva feed exclusively on the grain. The larva will pupate while inside the grain and the pupal stage lasts for 3-6 days, then chews a circular exit hole and emerges as an adult beetle.

2.10 Control of *Sitophilus zeamais*

S. zeamais may be controlled by cultural, chemical, physical and biological methods in addition to plant resistance. Botanical products have played important roles in traditional storage pest control in the tropics (Hassanali *et al.*, 1990; Niber, 1994; Belmain *et al.*, 2001). Peasant farmers treat grains with plant products and oils, use cultural methods such as open sun drying and storing in barns, earthen pots, jars and airtight containers (Dobie, 1984). These are less cost effective for storage of large quantities of grains. Most of them are non toxic to consumers and are readily available (Hassanali *et al.*, 1990; Niber, 1994; Asawalam *et al.*, 2006). Ground hot pepper, *Capsicum frutescens* has been used to control the population of weevils in small quantities of stored grains. When mixed with grains, the pepper is thought to exert a suffocating and contact effect on the weevils, thus resulting in their death. Ivbijaro (1984) found that 5-20 ml/kg of maize of groundnut oil is very toxic to *S. oryzae*. In less than two days after oil treatment, 100 % of the weevils had died at 10 and 20 ml/kg and 63 % at 5 ml/kg. There is a progressive decline in oil toxicity and weevil mortality at every dose of groundnut oil with increase in storage period up to 21 weeks. He observed that eggs were laid only in the control and in the 1 ml/kg oil-treated grains.

Chemical control includes the use of insecticides to prevent or manage insect infestations. They have proved to be the simplest and most cost effective means of dealing with the pest. Eventhough synthetic chemicals continue to play important role in reducing storage losses due to insect pest activities (Niber, 1994), insecticide resistance (Perez-Mendoza, 1999), toxic residues in food and environmental pollution, adverse effects on beneficial and non target insects, increased risk to workers safety and the high cost of the chemicals (Niber, 1994; Asawalam *et al*., 2006) makes them less attractive. Some common insecticides used against storage pests are Carbon disulphide, Phostoxin, Pyrethrin, Permethrin, Malathion, Diazinon, Sumithion, Actellic dust, Ethylene dibromide (Evans, 1985).

Physical control storage measures involve manipulation of the storage atmosphere (temperature, relative humidity, oxygen etc). The environment may be altered to make it inimical to the pest. In small quantities of stored grains and at low infestation levels, *S. zeamais* can be removed physically by hand picking. Relative humidity helps in controlling insect populations in stored products. The death of insects under a carbondioxide rich atmosphere is largely due to excessive loss of water from their bodies caused by prolonged opening of their spiracles.

Biological control is the introduction or action of natural enemies (parasites, predators, etc) of pests to reduce pest populations to a level where economic losses are not possible. Reptiles like lizards feed on most storage pests including *S. zeamais* during drying process. The family

Pteromalidae contains the most frequently encountered parasitic wasps in tropical storage. *Anisopteromalus calandrae* (Howard) has been identified as one of the most promising candidates for biological control of a wide range of storage pests, including maize weevils, rice weevils, the angoumois grain moth and several bruchids in cowpeas. Species of Hymenoptera are mostly parasitoids but in the Prostigmata, both parasitoids and predators occur. The Pyemotidae (Prostigmata) represented by the genera, *Pyemotes* and *Acarophenax*, are ectoparasites of beetle and moth pests in tropical storage. The predaceous mite of *S. oryzae* is *Pyemotes ventricosus* (Newp.) (Schmutterer,1969).

Host plant resistance to insects is the genetic property that enables a plant to avoid, minimize, tolerate or recover from injury caused by insects. The use of resistant varieties is very crucial to successful grain preservation, especially in tropical storage. It is the cheapest and the most effective means of pest management requiring no use of chemicals, has no environmental hazards and does not require sophisticated skill or training for the farmer before use, but only the cultivation of the resistant cultivars.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Location

The experiment was conducted at the Storage Entomology Laboratory, Department of Crop Protection, Ahmadu Bello University, Zaria. The research was carried out during the cold-dry and wet seasons (October-December, 2012 and June-August, 2013) respectively. The mean laboratory temperature (27 ^{0}C for cold-dry season and 25 ^{0}C for wet season) and relative humidity (52 % for cold-dry season and 60 % for wet season) recorded daily during the period of the experiments varied slightly.

3.2 Culture of *Sitophilus zeamais*

A culture of *S. zeamais* was raised to supply large number of fresh weevils for the experiment. Unsexed *S. zeamais* were collected from already infested maize grains from the Storage Entomology Laboratory of Crop Protection Department, Ahmadu Bello University, Zaria. Two hundred and fifty grammes of maize grains were infested with 50 adult unsexed *S. zeamais* in a kilner jar. The kilner jar was covered with muslin cloth to allow ventilation and to prevent escape of the weevils. The jar was kept on the table in the laboratory at room temperature (21-25 ^{0}C). Two weeks after oviposition (egg laying), the adult weevils were sieved out and discarded. At 45 days, newly emerged F_1 generations of *S. zeamais* were used to infest the maize grains that were used for the experiment.

3.3 Collection of Maize Varieties

Ten (10) maize varieties, comprising 9 Quality Protein Maize (QPM) varieties (SAMMAZ 14, SAMMAZ 17, SAMMAZ 19, SAMMAZ 32, SAMMAZ 33, SAMMAZ 36, SAMMAZ 37, FLINT-Q and DENT-Q) and 1 non-QPM variety (SAMMAZ 20) which served as check were obtained from the Institute for Agricultural Research (I.A.R), Ahmadu Bello University, Zaria. Each maize variety was fumigated using one tablet of Aluminium phosphide (phostoxin) in an air tight drum for 96 hours (4 days) to disinfest any previous infestation by insect pests and thereafter spread on laboratory table for 48 hours (2 days) to allow dissipation of fumigant effect. The variety, source and description are presented in Table 3.1.

3.4 Evaluation of Maize Varieties

One hundred grammes of each maize variety was weighed using mettler balance and placed in a kilner jar. Ten pairs of newly emerged *S. zeamais* which were sexed using morphological characters were introduced into each of the kilner jars using an aspirator. The kilner jars were covered with muslin cloth to provide ventilation and prevent the weevils from escaping. This was repeated four times for each variety of maize. All kilner jars were labeled and arranged in a Completely Randomized Design (CRD) and allowed to stand for 12 weeks in the Laboratory.

3.4.1 Progeny emergence

Two weeks after oviposition, the adult weevils in all kilner jars were sieved out in order to eliminate mixing with F_1 generation and the maize samples were returned to their respective kilner jars. All kilner jars were examined 35 days after infestation so as to determine the F_1 progeny emergence, which were sieved out and counted. Sieving and counting the F_1 progeny continued up to the 45^{th} day when most F_1 progenies would have emerged. The numbers of F_2 progenies in all kilner jars were counted 35 to 45 days after F_1 emergence.

3.4.2 Percentage grain damage and emergent holes

At the end of 12 weeks, percentage damage was determined for each maize variety. Emergent holes on the grains were used as an indicator of the damage. One hundred grains were obtained at random and sorted into holed (damaged) and whole (undamaged) and the following formula was used for calculating the percentage damage (Golob and Webley, 1980):

$$\% \text{ Damage} = \frac{Number\ of\ damaged\ grains}{Total\ number\ of\ sampled\ grains} \times 100$$

3.4.3 Percentage weight loss

The percentage weight loss of each maize variety was determined using the count and weight method of Gwinner *et al*. (1996). The 100 grains used for the damage assessment were again used. The damaged and undamaged grains separated out were weighed and recorded appropriately. The results obtained were used to compute the percentage weight loss using the formula as follows:

$$\% \text{ Weight loss} = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu \times (Nd + Nu)} \times 100$$

Where:Wu= Weight of undamaged grains

Nu= Number of undamaged grains

Wd= Weight of damaged grains

Nd= Number of damaged grains

Table 3.1: Description of Maize Varieties

S/N	Variety	Source	Description
1	SAMMAZ 14	IAR	White Dent/Flint, QPM
2	SAMMAZ 17	IAR	White Dent/Flint, QPM Background
3	SAMMAZ 19	IAR	White Dent/Flint, QPM
4	SAMMAZ 32	IITA	Yellow, QPM
5	SAMMAZ 33	IITA	White, QPM
6	SAMMAZ 36	IAR	Yellow Dent/Flint, QPM
7	SAMMAZ 37	IITA	Yellow Flint, QPM
8	DENT-Q	IAR	White Dent, QPM
9	FLINT-Q	IAR	White Flint, QPM
10	SAMMAZ 20	IITA	White Flint, Non-QPM

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3.4.4 Percentage germination

Germination test was conducted before infestation of the maize varieties. At the end of the experiment, germination test was also conducted by bulking together each infested maize variety and randomly selecting 100 grains and placing them in separate petri dishes which were lined with moistened filter paper. While maintaining a wet set up, the grains were observed for germination at the seventh day. The percentage germination was calculated using the formula as follows (Bamaiyi *et al.,* 2006):

$$\% \text{ Germination } = \frac{Number\ of\ seeds\ germinated}{Total\ number\ of\ sampled\ seeds} \times 100$$

The percentage germination of non germinated seeds (germination loss) was determined using the formula:

$$\% \text{ Germination loss } = \frac{Before\ infestation - After\ infestation}{Before\ infestation} \times 100$$

3.5 Kernel Hardness

Kernel hardness test was determined based on the method suggested by Dobie (1974). Ten grammes of each maize variety was weighed and ground in a manually operated Maskiner mill. The resultant flour obtained was sieved using a 30 µ aperture sieve for 15 seconds in each case. The fractions of the maize passing through and retained by the sieve were weighed and recorded as 'filtrate' and 'residue' respectively (Dobie, 1974). This was repeated four times for each variety of maize. The data obtained were used to determine kernel hardness by observing that the finely crushed varieties produced more filtrate and fewer residues, and were thus considered as soft. Those that were simply fragmented produced less filtrate and more residues and were thus considered as hard. Those with equal filtrate and residues were considered as moderately hard.

3.6 Protein Contents Determination

Protein contents of the different maize varieties were determined before the maize weevils were introduced into the maize varieties. The same process was repeated after the termination of the experiment. This was done to determine the amount of protein loss due to feeding by *S. zeamais* and the following formula was used:

$$\% \text{ Protein loss} = \frac{Before\ infestation - After\ infestation}{Before\ infestation} \times 100$$

For all the maize varieties, tryptophan, albumin, globulin, prolamin (zein) and glutelin contents were determined. Tryptophan determination was carried out at the International Institute for Tropical Agriculture (IITA), Ibadan while albumin, globulin, zein and glutelin were determined at the Center for Biotechnology Research and Training (CBRT) and Multi-User Science Research Laboratory, Department of Chemistry, Faculty of Science, Ahmadu Bello University, Zaria.

3.6.1 Sample preparation

A random sample of whole maize grains were taken as representative of each maize variety. Each sample was ground at 0.5 mm setting of a cyclone mill. The samples were placed in a commercial filter paper envelope, defatted with hexane in a Soxhlet-type continuous extractor for six hours and air dried (CIMMYT, 2004).

3.6.2 Tryptophan determination

For each maize sample, 80 mg of finely ground, defatted whole maize grains were weighed into 15 ml falcon tubes and 3 ml papain solution was added. The tubes were closed to ensure no evaporation take place during incubation. Carefully, the tubes were shaken with vortex and were placed in an incubator oven at 65 ^{0}C for 16 hours. After one hour of incubation and one hour before completion of the 16 hour incubation time, the tubes were shaken with vortex again and returned back. The tubes were then taken out of the incubator oven, allowed to cool down at room temperature (21-25 ^{0}C) and were shaken by vortex before centrifuging them at 3600 x g for 10 minutes. Using micropipette, 1 ml of the hydrolysates (supernatant) was carefully transferred into new tubes. Slowly, 4 ml acid mixture (ferric chloride and sulfuric acid) was added by pouring it down the inner wall of the tubes. The tubes were shaken vigorously with vortex and were incubated at 65 ^{0}C for 30 minutes for color development. Samples were taken out of the incubator oven and were let to cool down at room temperature. Two tubes with just papain solution for use as blanks and four check samples with a known quantity of tryptophan (2 QPM, 2 Normal) were included for use throughout the experiment. The absorbance of the solutions was read in a spectrophotometer at 560 nm, which was adjusted with the blanks. A standard curve using known amounts of different tryptophan concentration was developed and plotted on the x-axis while the absorbance readings at 560 nm (optical density), was plotted on the y-axis and the slope of the standard curve was calculated. The percentage tryptophan content of each sample was estimated using the equation below (Nurit and Palacios-Rojas, 2006):

$$\%\,Tryptophan = \frac{\mathrm{OD560nm}}{slope} \times \frac{hydrolysis\ volume}{sample\ weight} \times 100\,\%$$

But this amount includes the tryptophan of the sample plus the tryptophan from the papain. To calculate the tryptophan content of the defatted samples, then the papain value needs to be subtracted. Therefore:

$$\%\,Tryptophan = OD560\,nm\,corrected \times Factor$$

Where: OD560 nm corrected = OD560 nm sample – OD560 nm average of papain blanks

$$Factor = \frac{1}{slope} \times \frac{hydrolysis\ volume}{sample\ weight}$$

3.6.3 Protein extraction

Maize grain proteins were sequentially extracted and fractionated into three fractions (Landry and Moureaux, 1970). Extraction buffers for the three fractions were 0.5M NaCl solution for albumin and globulin, 70 % ethanol and 2 % 2-Mercapto Ethanol (ME) for zein and 1 % Sodium Dodecyl Sulphate (SDS) and 2 % 2-ME for glutelin.

Fraction I

Albumin and globulin proteins were first extracted by weighing 500 mg of maize flour (1:5; flour-solvent) into test tubes. Each sample had two test tubes. Exactly 2.5 ml 0.5M NaCl solution was added into them and put into oscillatory water bath to shake the samples for 1 hour at 4 ^{0}C. Mixtures of sample and extraction buffer were centrifuged at 10,000 x g for 10 minutes at 25 ^{0}C. Supernatants (extracts) were decanted using micropipette into empty tubes. The pellets (residues) were treated again with the same volume of NaCl solution and the extraction was repeated for a second time. All the supernatants were pooled together as fraction I and were measured for concentration. The residues were used to obtain fractions II and III.

Fraction II

Zein protein was obtained by adding 2.5 ml mixture of 70 % ethanol and 2 % 2-Mercapto Ethanol to residues that were obtained in fraction I. These were put into oscillatory water bath to shake the samples for 1 hour at 22 ^{0}C. Mixtures of the sample and extraction buffers were centrifuged at 10,000 x g for 10 minutes at 25 ^{0}C. Supernatants (extracts) were decanted using micropipette into empty tubes. The pellets were treated again with the same volume of mixture of 70 % ethanol and 2 % 2-Mercapto Ethanol and the extraction was repeated for a second time. All the supernatants were pooled together as fraction II and were measured for concentration. The residues were used to obtain fraction III.

Fraction III

Glutelin protein was obtained by adding 2.5 ml mixture of 1 % Sodium Dodecyl Sulphate (SDS) and 2 % 2-Mercapto Ethanol solution to residues that were obtained in fraction II. These were put into oscillatory water bath to shake the samples for 1 hour at 22 ^{0}C. Mixtures of the sample and extraction buffer were centrifuged at 10,000 x g for 10 minutes at 25 ^{0}C. Supernatants (extracts) were decanted using micropipette into empty tubes. The pellets were treated again with the same volume of mixture of 1 % SDS and 2 % 2-Mercapto Ethanol and the extraction was repeated for a second time. All the supernatants were pooled together as fraction III and were measured for concentration.

Determination of protein concentration

The protein concentration of fractions I, II and III were determined for each maize variety as described by Bradford (1976). One hundred micro litre (100 μl) of the samples were pipetted into test tubes and followed by 1 ml of Bradford assay reagent. The contents of the test tubes were mixed either by inversion or vortexing and were incubated for five minutes at room temperature. The absorbance of the samples at 595 nm was measured using a spectrophotometer in 1 ml cuvette which was adjusted with a reagent blank prepared from 100 µl of distilled water and 1 ml of Bradford assay reagent. The protein concentrations of the samples were obtained from a standard curve equation using Bovine Serum Albumin (BSA) as the standard.

3.7 Statistical Analysis

Data obtained for progeny emergence, percentage damage, percentage weight loss, percentage germination, kernel hardness, tryptophan, albumin/globulin, prolamin (zein) and glutelin contents of the maize grains were subjected to Analysis of variance (ANOVA) and where there were significant differences, SNK was used to compare the means (SAS, 2003). Correlation between the various parameters was done.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of Quality Protein Maize (QPM) Varieties on Progeny Emergence of *Sitophilus zeamais*

At 45 days after infestation with *S. zeamais* (cold-dry season), the result of analysis of variance (ANOVA) showed that amongst the nine QPM varieties compared, FLINT-Q (25.00) had the highest mean number of F_1 progeny whereas SAMMAZ 17 (6.50) had the least. FLINT-Q (25.00) was found to be significantly different from all the QPM varieties except DENT-Q (21.25). Similarly, SAMMAZ 17 (6.50) showed significant difference ($p<0.05$) from all the QPM varieties except SAMMAZ 14 (11.00) and SAMMAZ 19 (12.00). The check SAMMAZ 20 (5.50) compared with the QPM varieties had the least mean number of F_1 progeny and showed significant difference from the QPM varieties except SAMMAZ 17 (6.50), SAMMAZ 14 (11.00) and SAMMAZ 19 (12.00). The highest and least mean number of F_2 emerged progeny amongst the QPM varieties at 90 days after infestation were also found in FLINT-Q (29.50) and SAMMAZ 17 (16.75) respectively. FLINT-Q and SAMMAZ 17 were significantly different ($p<0.05$) from each other. However, DENT-Q (26.00) was significantly different from SAMMAZ 37 (17.50), SAMMAZ 19 (17.25), SAMMAZ 14 (17.00) and SAMMAZ 17 (16.75). There was no significant difference observed between FLINT-Q, DENT-Q and SAMMAZ 33 from one another. Similarly, DENT-Q, SAMMAZ 33, SAMMAZ 32 and SAMMAZ 36 were also not significantly different from each other. The check SAMMAZ 20 (16.25) compared with all the QPM varieties had the least mean number of F_2 progeny (Table 4.1) and was not significantly different from the QPM varieties except FLINT-Q (29.50) and DENT-Q (26.00).

Table 4.1: Progeny Emergence of *S. zeamais* as Affected by Maize Varieties

	Mean Progeny Emergence			
	Cold-dry season		Wet season	
Variety	F_1 (45 DAI)	F_2 (90 DAI)	F_1 (45 DAI)	F_2 (90 DAI)
FLINT-Q	25.00^{a}	29.50^{a}	24.25^{a}	71.00^{ab}
DENT-Q	21.25^{ab}	26.00^{ab}	24.50^{a}	77.25^{a}
SAMMAZ 33	17.25^{bc}	23.50^{abc}	23.25^{a}	66.75^{abc}
SAMMAZ 32	16.00^{bc}	20.00^{bc}	22.25^{a}	49.75^{abcd}
SAMMAZ 36	14.00^{c}	18.25^{bc}	21.50^{a}	49.25^{abcd}
SAMMAZ 37	13.75^{c}	17.50^{c}	20.75^{a}	44.50^{bcd}
SAMMAZ 19	12.00^{cd}	17.25^{c}	20.50^{a}	42.00^{bcde}
SAMMAZ 14	11.00^{cd}	17.00^{c}	19.25^{a}	40.75^{cde}
SAMMAZ 17	6.50^{d}	16.75^{c}	18.75^{a}	21.75^{de}
SAMMAZ 20 (check)	5.50^{d}	16.25^{c}	15.75^{a}	14.25^{e}
S.E ±	2.38	2.79	3.47	10.34
CV (%)	33.43	27.62	32.88	43.30

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

DAI = Days After Infestation

The mean number of F_1 emerged progeny of *S. zeamais* (wet season) at 45 days after infestation compared amongst the QPM varieties and SAMMAZ 20 (check) ranged from 15.75 in SAMMAZ 20 to 24.50 in DENT-Q whereas the mean number of F_2 emerged progeny at 90 days after infestation ranged from 14.25 in SAMMAZ 20 to 77.25 in DENT-Q. The highest mean number of F_1 (24.50) and F_2 (77.25) progeny were found in DENT-Q while the least mean number of F_1 (15.75) and F_2 (14.25) progeny were found in SAMMAZ 20 (Table 4.1). The mean number of F_1 emerged progeny were not significantly different amongst the QPM varieties. Similarly, no significant difference was observed between SAMMAZ 20 (check) and the QPM varieties. The mean number of F_2 emerged progeny compared amongst the QPM varieties indicated that SAMMAZ 17 (21.75) showed significant difference from FLINT-Q (71.00), DENT-Q (77.25) and SAMMAZ 33 (66.75). However, DENT-Q, FLINT-Q, SAMMAZ 33, SAMMAZ 32 and SAMMAZ 36 were not significantly different from each other. The check SAMMAZ 20 (14.25) compared with the QPM varieties was significantly different ($p<0.05$) from DENT-Q (77.25), FLINT-Q (71.00), SAMMAZ 33 (66.75), SAMMAZ 32 (49.75), SAMMAZ 36 (49.25) and SAMMAZ 37 (44.50) but no significant difference was observed between SAMMAZ 20, SAMMAZ 17, SAMMAZ 14 and SAMMAZ 19 (Table 4.1).

4.2 Combined Results of Effect of Quality Protein Maize (QPM) Varieties on Progeny Emergence of *Sitophilus zeamais*

The combined results of both cold-dry and wet seasons showed that the mean number of F_1 progeny of *S. zeamais* that emerged from the check and QPM varieties at 45 days after infestation ranged from 10.63 in SAMMAZ 20 (check) to 24.63 in FLINT-Q whereas the mean number of F_2 progeny of *S. zeamais* that emerged at 90 days after infestation ranged from 15.25 in SAMMAZ 20 to 51.63 in DENT-Q. Therefore, the highest mean number of F_1 (24.63) and F_2 (51.63) progeny were found in FLINT-Q and DENT-Q respectively while the least mean number of F_1 (10.63) and F_2 (15.25) progeny were found in SAMMAZ 20. The mean number of F_1 emerged progeny of FLINT-Q (24.63) was therefore significantly different from that of SAMMAZ 20 (10.63). There was no significant difference observed amongst FLINT-Q, DENT-Q, SAMMAZ 33 and SAMMAZ 32 from each other but these were significantly different ($p<0.05$) from SAMMAZ 17 and SAMMAZ 20. The mean number of F_2 emerged progeny of *S. zeamais* in DENT-Q and FLINT-Q was significantly different from the other varieties except SAMMAZ 33. SAMMAZ 33 showed significant difference from SAMMAZ 19, SAMMAZ 14 and SAMMAZ 17. The check SAMMAZ 20 was significantly different from SAMMAZ 36, SAMMAZ 37, SAMMAZ 33, SAMMAZ 32, DENT-Q and FLINT-Q but was not significantly different from SAMMAZ 17, SAMMAZ 14 and SAMMAZ 19 (Table 4.2).

4.3 Effect of Seasons on Progeny Emergence of *Sitophilus zeamais*

The F_1 progeny emergence of the same maize varieties compared across the two experimental seasons showed that only SAMMAZ 17 and SAMMAZ 20 (check) varieties were significantly different ($p<0.05$) across the seasons (Table 4.3). In contrast, there were no significant differences in the F_2 progeny emergence of SAMMAZ 17 and SAMMAZ 20 (check)

Table 4.2: Progeny Emergence of *S. zeamais* as Affected by Maize Varieties (combined analysis)

	Mean Progeny Emergence	
Variety	F_1 (At 45 DAI)	F_2 (At 90 DAI)
FLINT-Q	24.63^{a}	50.25^{a}
DENT-Q	22.88^{a}	51.63^{a}
SAMMAZ 33	20.25^{ab}	45.13^{ab}
SAMMAZ 32	19.13^{ab}	34.88^{bc}
SAMMAZ 36	17.75^{bc}	33.75^{bcd}
SAMMAZ 37	17.25^{bc}	31.00^{bcd}
SAMMAZ 19	16.25^{bcd}	29.63^{cde}
SAMMAZ 14	15.13^{bcd}	28.88^{cde}
SAMMAZ 17	12.63^{cd}	19.25^{de}
SAMMAZ 20 (check)	10.63^{d}	15.25^{e}
S.E ±	2.10	5.35
CV (%)	33.67	44.57

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

DAI = Days After Infestation

Table 4.3: Seasonal Comparison of Progeny Emergence of *Sitophilus zeamais*

Variety	CDS F_1	WS F_1	CDS F_2	WS F_2
FLINT-Q	25.00[a]	24.25[a]	29.50[b]	71.00[a]
DENT-Q	21.25[a]	24.50[a]	26.00[b]	77.25[a]
SAMMAZ 33	17.25[a]	23.25[a]	23.50[b]	66.75[a]
SAMMAZ 32	16.00[a]	22.25[a]	20.00[b]	49.75[a]
SAMMAZ 36	14.00[a]	21.50[a]	18.25[b]	49.25[a]
SAMMAZ 37	13.75[a]	20.75[a]	17.50[b]	44.50[a]
SAMMAZ 19	12.00[a]	20.50[a]	17.25[b]	42.00[a]
SAMMAZ 14	11.00[a]	19.25[a]	17.00[b]	40.75[a]
SAMMAZ 17	6.50[b]	18.75[a]	16.75[a]	21.75[a]
SAMMAZ 20 (check)	5.50[b]	15.75[a]	16.25[a]	14.25[a]
S.E ±	2.97	2.97	7.57	7.57
CV (%)	33.26	33.26	41.47	41.47

Means followed by the same letter (s) in a row are not significantly different at $p<0.05$

CDS = Cold-dry Season WS=Wet Season

4.4 Effect of *Sitophilus zeamais* Infestation on Percentage Damage of the Quality Protein Maize (QPM) Varieties

Significant differences ($p<0.05$) were observed in the percentage of damaged grains caused by *S. zeamais* to the different maize varieties during the cold-dry season (Figure 4.1). The QPM varieties when compared amongst each other indicated that FLINT-Q (36.00) had the highest percentage grain damage which was significantly different from the other QPM varieties except DENT-Q (29.50). No significant differences were observed in the varieties DENT-Q (29.50), SAMMAZ 33 (26.50), SAMMAZ 32 (26.50), SAMMAZ 36 (25.50) and SAMMAZ 37 (25.00) but these were significantly different ($p<0.05$) from SAMMAZ 19 (13.75), SAMMAZ 14 (7.75) and SAMMAZ 17 (4.00). The check SAMMAZ 20 (3.50) compared with the QPM varieties was observed to have the least percentage grain damage but was not significantly different from SAMMAZ 17 (4.00) and SAMMAZ 14 (7.75).

In the wet season, it was observed that amongst the QPM varieties (Figure 4.2), DENT-Q (40.25) had the highest percentage grain damage and was significantly different from the other QPM varieties except FLINT-Q (37.00). No significant differences were observed amongst SAMMAZ 33 (30.75), SAMMAZ 32 (30.50), SAMMAZ 36 (28.00) and SAMMAZ 37 (25.25) but these were significantly different from SAMMAZ 19 (15.00), SAMMAZ 14 (13.50) and SAMMAZ 17 (12.75). The mean percentage of damaged grains amongst the QPM varieties and SAMMAZ 20 (check) ranged from 8.50 for SAMMAZ 20 to 40.25 for DENT-Q. SAMMAZ 20 (8.50) showed no significant difference from SAMMAZ 17 (12.75), SAMMAZ 14 (13.50) and SAMMAZ 19 (15.00) but was significantly different ($p<0.05$) from the other QPM varieties.

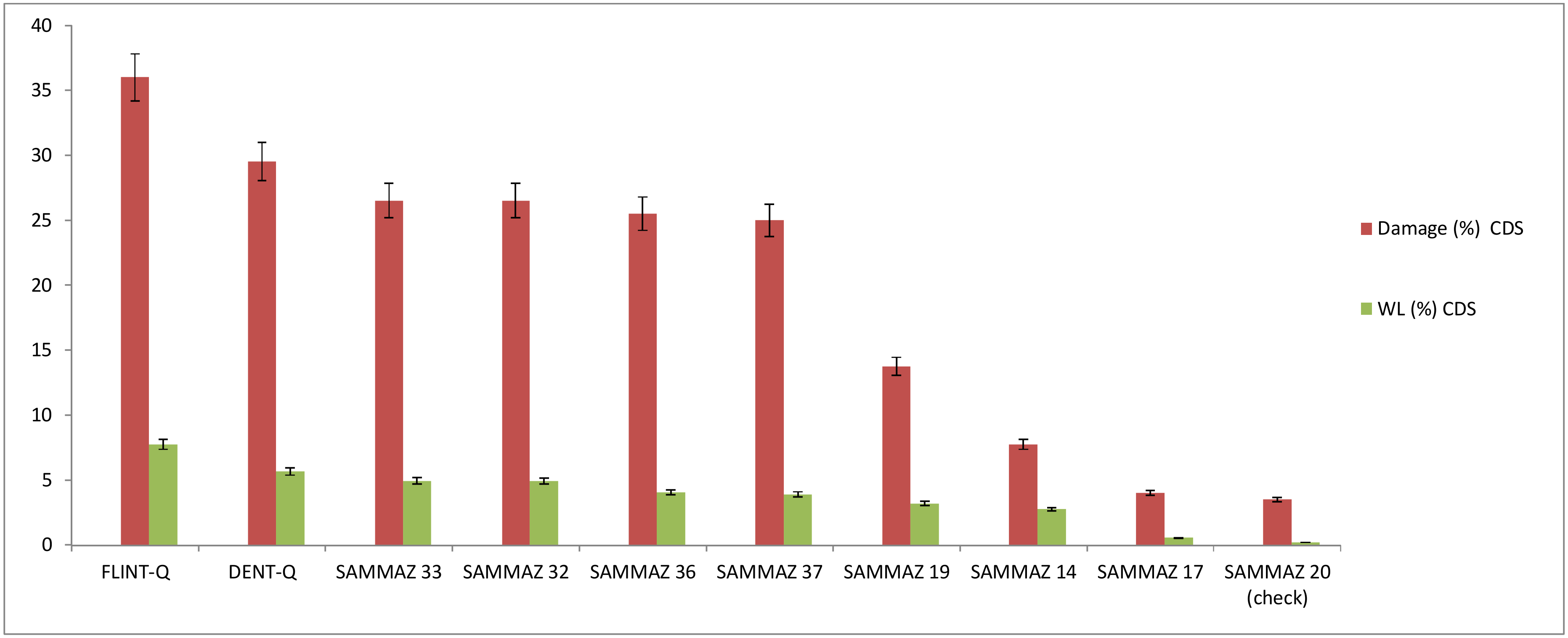

Figure 4.1: Percentage Damage and Weight Loss Caused by *S. zeamais* on Maize Varieties during Cold-Dry Season

WL = Weight Loss

CDS = Cold-Dry Season

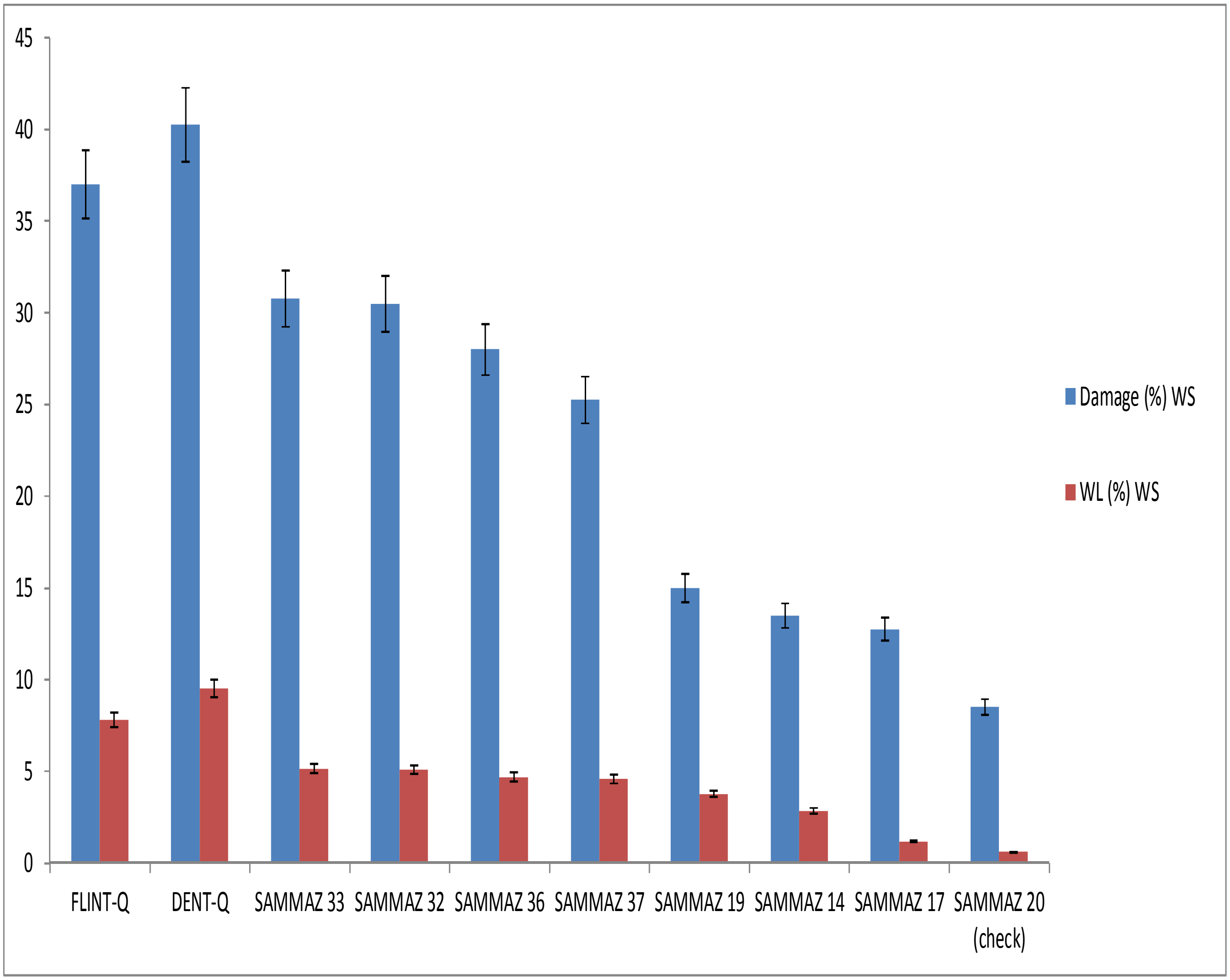

Figure 4.2: Percentage Damage and Weight Loss Caused by *S. zeamais* on Maize Varieties during Wet Season

WL = Weight Loss

WS = Wet Season

4.5 Effect of *Sitophilus zeamais* Infestation on Percentage Weight Loss of the Quality Protein Maize (QPM) Varieties

At the end of cold-dry season, the percentage loss in weight among the QPM varieties showed that FLINT-Q (7.77) was significantly different ($p<0.05$) from the other QPM varieties and suffered the highest weight loss whereas SAMMAZ 17 (0.54) suffered the least (Figure 4.1). The check SAMMAZ 20 (0.20) compared with the QPM varieties had the least percentage weight loss and was found not to be significantly different with SAMMAZ 17.

The wet season result indicated that amongst the QPM varieties, DENT-Q (9.52) had the highest percentage weight loss and was significantly different ($p<0.05$) from the other varieties except FLINT-Q (7.80). SAMMAZ 17 (1.18) was found to have the least percentage weight loss amongst the QPM varieties. However, SAMMAZ 20 (check) when compared with the QPM varieties was identified as having the least percentage weight loss but was not significantly different from SAMMAZ 17 and SAMMAZ 14 (Figure 4.2).

4.6 Combined Results for Effect of *Sitophilus zeamais* Infestation on Percentage Damage of the Quality Protein Maize (QPM) Varieties

The combined results for the two seasons of the experiment indicated that the mean percentage damage of the QPM varieties compared amongst each other showed that FLINT-Q and DENT-Q were not significantly different from one another. Similarly, SAMMAZ 33, SAMMAZ 32, SAMMAZ 36 and SAMMAZ 37 also showed no significant differences from each other. SAMMAZ 19 showed no significant difference from SAMMAZ 14 but it was observed to be significantly different ($p<0.05$) from all the other varieties. The check SAMMAZ 20 (6.00) showed significant difference from the QPM varieties when compared except from SAMMAZ 17 (8.38) and SAMMAZ 14 (10.63) which were not significantly different from one another. The mean percentage damage of the maize varieties ranged from

6.00 in SAMMAZ 20 to 36.50 in FLINT-Q (Figure 4.3). Therefore, the highest mean number of damaged grains with emergent holes was observed in FLINT-Q (36.50) followed by DENT-Q (34.88) whereas the least mean number of damaged grains with emergent holes was observed in the check SAMMAZ 20 (6.00) followed by SAMMAZ 17 (8.38).

4.7 Combined Results for Effect of *Sitophilus zeamais* Infestation on Percentage Weight Loss of the Quality Protein Maize (QPM) Varieties

The mean percentage weight loss of the two experimental seasons showed that the QPM varieties FLINT-Q and DENT-Q showed no significant difference from one another. No significant differences were also observed amongst SAMMAZ 36, SAMMAZ 37, SAMMAZ 19 and SAMMAZ 14 but these were significantly different ($p<0.05$) from SAMMAZ 17, FLINT-Q and DENT-Q (Figure 4.3). The check SAMMAZ 20 (0.40) compared with the QPM varieties was found to be significantly different from all the QPM except SAMMAZ 17 (0.86). The mean percentage weight loss of the maize varieties ranged from 0.40 in SAMMAZ 20 to 7.78 in FLINT-Q. The highest weight loss among the varieties therefore was observed in FLINT-Q (7.78) followed by DENT-Q (7.59) while the least weight loss was observed in SAMMAZ 20 (0.40) followed by SAMMAZ 17 (0.86).

4.8 Effect of Seasons on Percentage Damage and Percentage Weight Loss Caused by *Sitophilus zeamais* on the Quality Protein Maize (QPM) Varieties

The two experimental seasons (cold-dry and wet) showed no significant difference in the results of percentage damage and percentage weight loss of the Quality Protein Maize (QPM) varieties as a result of *Sitophilus zeamais* infestation when compared. Season therefore had no significant effect in the percentage damage and percentage weight loss caused by *S. zeamais* on the same maize varieties during storage.

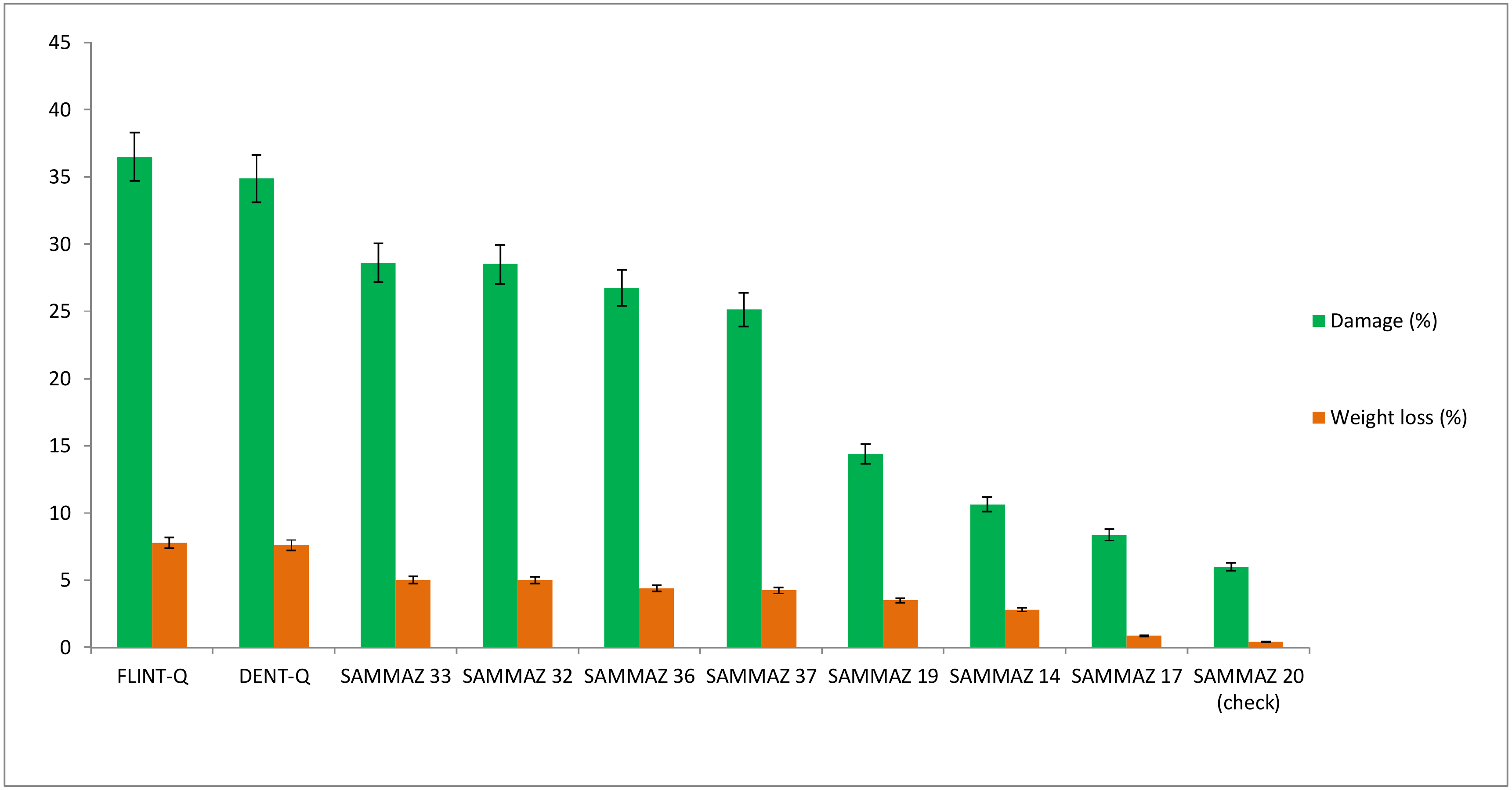

Figure 4.3: Percentage Damage and Weight Loss Caused by *S. zeamais* on Maize Varieties (combined analysis)

4.9 Percentage Germination of the Quality Protein Maize (QPM) Varieties Before and After *Sitophilus zeamais* Infestation

Before infestation of the maize varieties, the QPM varieties compared amongst each other showed that the percentage germination of SAMMAZ 19 (98.25), SAMMAZ 14 (94.50) and SAMMAZ 17 (94.50) were not significantly different from each other but these were significantly different from that of SAMMAZ 36 (82.50), SAMMAZ 33 (81.25), SAMMAZ 32 (80.00), FLINT-Q (80.00) and DENT-Q (60.00). However, all the QPM varieties showed significant difference ($p<0.05$) when compared with SAMMAZ 20 (check) except SAMMAZ 19, SAMMAZ 14 and SAMMAZ 17. SAMMAZ 20 (98.25) and SAMMAZ 19 (98.25) have the highest percentage germination while DENT-Q (60.00) had the least (Table 4.4).

The percentage germination of the maize varieties after infestation with *S. zeamais* during the cold-dry season (Table 4.4) indicated significant differences ($p<0.05$) amongst the QPM varieties. SAMMAZ 32, SAMMAZ 33, DENT-Q and FLINT-Q were not significantly different from each other but these were significantly different from SAMMAZ 36, SAMMAZ 37, SAMMAZ 19, SAMMAZ 14 and SAMMAZ 17. There was also no significant difference between SAMMAZ 36 and SAMMAZ 37 but these were significantly different from the other varieties. The highest and least percentage germination amongst the QPM varieties were recorded in SAMMAZ 17 (80.00) and FLINT-Q (10.00) respectively (Table 4.4). The check SAMMAZ 20 (85.00) compared with the QPM varieties had the highest percentage germination and was found to be significantly different ($p<0.05$) from the QPM varieties except SAMMAZ 17 (80.00) and SAMMAZ 14 (75.00).

The result of the wet season after *S. zeamais* infestation showed that amongst the QPM varieties, SAMMAZ 14 and SAMMAZ 19 were not significantly different from each other but were significantly different from SAMMAZ 17, SAMMAZ 37, SAMMAZ 33,

Table 4.4: Percentage Germination of Maize Varieties Before and After *S. zeamais* Infestation

	Germination (%)					
	Cold-dry season			Wet season		
Variety	BI	AI	Loss (%)	BI	AI	Loss (%)
FLINT-Q	80.00[c]	10.00[e]	87.50[a]	80.00[c]	15.00[de]	81.25[a]
DENT-Q	60.00[d]	15.00[e]	75.00[a]	60.00[d]	10.00[e]	83.33[a]
SAMMAZ 33	81.25[c]	20.00[e]	75.38[a]	81.25[c]	42.50[c]	47.69[b]
SAMMAZ 32	80.00[c]	25.00[e]	68.75[a]	80.00[c]	20.00[de]	75.00[a]
SAMMAZ 36	82.50[c]	45.00[d]	45.45[b]	82.50[c]	25.00[d]	69.70[a]
SAMMAZ 37	91.25[b]	60.00[cd]	34.25[bc]	91.25[b]	50.00[bc]	45.21[b]
SAMMAZ 19	98.25[a]	65.00[bc]	33.84[bc]	98.25[a]	80.00[a]	18.58[d]
SAMMAZ 14	94.50[ab]	75.00[abc]	20.63[cd]	94.50[ab]	75.00[a]	20.63[cd]
SAMMAZ 17	94.50[ab]	80.00[ab]	15.34[cd]	94.50[ab]	60.00[b]	36.51[bc]
SAMMAZ 20 (check)	98.25[a]	85.00[a]	13.49[d]	98.25[a]	85.00[a]	13.49[d]
S.E ±	2.24	5.92	7.02	2.24	5.23	5.83
CV (%)	5.20	24.65	30.06	5.20	22.59	23.77

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

BI = Before Infestation AI = After Infestation

SAMMAZ 36, SAMMAZ 32, FLINT-Q and DENT-Q. The highest percentage germination amongst the QPM varieties was recorded in SAMMAZ 19 (80.00) while DENT-Q (10.00) had the least. The check SAMMAZ 20 (85.00) compared with the QPM varieties had the highest percentage germination. No significant difference was observed between SAMMAZ 20 (check) with SAMMAZ 19 and SAMMAZ 14 (Table 4.4). The percentage of non germinated QPM varieties (germination loss) at the end of the experiment during the cold-dry season with no significant differences amongst them were observed in FLINT-Q (87.50), DENT-Q (75.00), SAMMAZ 33 (75.38) and SAMMAZ 32 (68.75) whereas during the wet season FLINT-Q (81.25), DENT-Q (83.33), SAMMAZ 32 (75.00) and SAMMAZ 36 (69.70) were observed to have the highest germination loss. The varieties that were least affected amongst the QPM were SAMMAZ 17 (15.34) during the cold-dry season and SAMMAZ 19 (18.58) during the wet season. The check SAMMAZ 20 (13.49) was least affected when compared with the QPM varieties in the two different seasons (Table 4.4).

4.10 Combined Results for Effect of *Sitophilus zeamais* Infestation on Percentage Germination of the Quality Protein Maize (QPM) varieties

Before infestation of the maize varieties, the percentage germination of the QPM varieties compared amongst each other showed that SAMMAZ 19 (98.25), SAMMAZ 14 (94.50) and SAMMAZ 17 (94.50) were not significantly different but these were significantly different from that of SAMMAZ 36 (82.50), SAMMAZ 33 (81.25), SAMMAZ 32 (80.00), FLINT-Q (80.00) and DENT-Q (60.00). SAMMAZ 20 (check) compared with the QPM varieties showed no significant difference ($p<0.05$) from SAMMAZ 19, SAMMAZ 14 and SAMMAZ 17 but was significantly different from the other QPM varieties. SAMMAZ 20 (98.25) and SAMMAZ 19 (98.25) were observed to have the highest percentage germination while DENT-Q (60.00) had the least (Table 4.5).

Table 4.5: Percentage Germination of Maize Varieties Before and After *S. zeamais* Infestation (combined analysis)

Variety	Germination (%) BI	AI	Loss (%)
FLINT-Q	80.00[c]	12.50[f]	84.38[a]
DENT-Q	60.00[d]	12.50[f]	79.17[a]
SAMMAZ 33	81.25[c]	31.25[de]	61.54[bc]
SAMMAZ 32	80.00[c]	22.50[ef]	71.88[ab]
SAMMAZ 36	82.50[c]	35.00[d]	57.58[c]
SAMMAZ 37	91.25[b]	55.00[c]	39.73[d]
SAMMAZ 19	98.25[a]	72.50[b]	26.21[e]
SAMMAZ 14	94.50[ab]	75.00[ab]	20.63[e]
SAMMAZ 17	94.50[ab]	70.00[b]	25.93[e]
SAMMAZ 20 (check)	98.25[a]	85.00[a]	13.49[e]
S.E ±	1.58	3.94	4.56
CV (%)	5.20	23.69	26.95

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

BI = Before Infestation AI = After Infestation

The combined results of the two seasons indicated that the percentage germination of the maize grains after *S. zeamais* infestation showed that SAMMAZ 37 was significantly different ($P<0.05$) from all the QPM varieties when compared amongst each other. The check SAMMAZ 20 (85.00) was also significantly different from the QPM varieties except SAMMAZ 14 (75.00) when compared. The germination test conducted after infestation indicated that SAMMAZ 20 (85.00) had the highest mean number of viable seeds followed by SAMMAZ 14 (75.00) whereas DENT-Q (12.50) and FLINT-Q (12.50) had the least (Table 4.5). At the end of both seasons of the experiment, FLINT-Q (84.38) which was not significantly different from DENT-Q and SAMMAZ 32 had the highest percentage of non germinated seeds (germination loss) whereas SAMMAZ 14 (20.63) had the least amongst the QPM varieties. The check SAMMAZ 20 (13.49) had the least percentage of germination loss.

4.11 Effect of Seasons on Percentage Germination of the Quality Protein Maize (QPM) varieties Before and After *Sitophilus zeamais* Infestation

The seasonal effect compared across both cold-dry and wet seasons showed no significant difference in the results of percentage germination of the same QPM varieties. Season therefore had no significant effect in the percentage germination of the maize varieties.

4.12 Kernel Hardness of Quality Protein Maize (QPM) Varieties

The results on grain hardness (residue) showed that SAMMAZ 17 (5.05) was significantly different ($p<0.05$) from all the QPM varieties. DENT-Q (3.20) and FLINT-Q (3.20) were not significantly different from each other but these were significantly different from the other QPM varieties. The QPM varieties compared with the check SAMMAZ 20 (5.23) were found to be significantly different ($p<0.05$) from the check except SAMMAZ 17 (5.05). SAMMAZ 20 and SAMMAZ 17 appeared to be harder than all the other varieties (Table 4.6).

Table 4.6: Relative Kernel Hardness of Quality Protein Maize Varieties

	Kernel Hardness		
Variety	Filtrate (g)	Residue (g)	Category
FLINT-Q	5.75^{a}	3.20^{d}	Soft
DENT-Q	5.60^{ab}	3.20^{d}	Soft
SAMMAZ 33	5.45^{b}	4.20^{c}	Soft
SAMMAZ 32	5.50^{b}	4.20^{c}	Soft
SAMMAZ 36	5.40^{bc}	4.33^{c}	Soft
SAMMAZ 37	5.23^{cd}	4.35^{c}	Soft
SAMMAZ 19	5.20^{cd}	4.40^{bc}	Soft
SAMMAZ 14	5.08^{d}	4.58^{b}	Soft
SAMMAZ 17	4.68^{e}	5.05^{a}	Hard
SAMMAZ 20	4.25^{f}	5.23^{a}	Hard
S.E ±	0.07	0.08	
CV (%)	3.42	3.43	

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

4.13 Tryptophan Content of Quality Protein Maize (QPM) Kernels Before and After *Sitophilus zeamais* Infestation

Before infestation of the maize samples, it was observed that amongst the QPM varieties, SAMMAZ 14 (0.10) had the highest percentage amount of tryptophan which was significantly different ($p<0.05$) from the other QPM varieties. There was no significant difference between SAMMAZ 32, SAMMAZ 37, SAMMAZ 19 and SAMMAZ 17 from each other. Similarly, SAMMAZ 36 and SAMMAZ 33 showed no significant difference between them. However, FLINT-Q (0.07) and DENT-Q (0.07) were also not significantly different from one another and were found to have the least percentage amount of tryptophan amongst the QPM varieties. The check SAMMAZ 20 (0.06) was observed to have the least percentage amount of tryptophan compared to the QPM varieties (Table 4.7).

After infestation of the maize samples, the result of cold-dry season indicated that, amongst the QPM varieties, there was no significant difference between SAMMAZ 19, SAMMAZ 32 and SAMMAZ 37 from each other. Similarly, SAMMAZ 17 and SAMMAZ 14 also showed no significant difference between them. SAMMAZ 33 and SAMMAZ 36 were also found not to be significantly different from one another. However, FLINT-Q and DENT-Q showed significant difference ($p<0.05$) from each other and from the other QPM varieties (Table 4.7). The percentage tryptophan of the check SAMMAZ 20 (0.06) was found to be significantly different from those of the QPM varieties except SAMMAZ 33 (0.06) and SAMMAZ 36 (0.06). The QPM varieties compared amongst each other showed that FLINT-Q, SAMMAZ 14 and SAMMAZ 17 were significantly different from each other and from the other varieties in the percentage amount of tryptophan loss. The percentage amount of tryptophan loss as a result of infestation by *S. zeamais* ranged from 0.00 % in SAMMAZ 20 (check) to 42.86 % in FLINT-Q. The highest percentage amount of tryptophan loss when compared amongst the QPM varieties was observed in FLINT-Q (42.86 %) whereas SAMMAZ 17 (11.11 %) had

Table 4.7: Percentage Tryptophan of Maize Kernels Before and After *S. zeamais* Infestation

	Tryptophan (%)					
	Cold-dry season			Wet season		
Variety	BI	AI	L (%)	BI	AI	L (%)
FLINT-Q	0.07^{d}	0.04^{e}	42.86^{a}	0.07^{d}	0.04^{e}	42.86^{a}
DENT-Q	0.07^{d}	0.05^{d}	28.57^{b}	0.07^{d}	0.04^{e}	42.86^{a}
SAMMAZ 33	0.08^{c}	0.06^{c}	25.00^{bc}	0.08^{c}	0.05^{d}	37.50^{b}
SAMMAZ 32	0.09^{b}	0.07^{b}	22.22^{c}	0.09^{b}	0.08^{a}	11.11^{e}
SAMMAZ 36	0.08^{c}	0.06^{c}	25.00^{bc}	0.08^{c}	0.06^{c}	25.00^{c}
SAMMAZ 37	0.09^{b}	0.07^{b}	22.22^{c}	0.09^{b}	0.07^{b}	22.22^{cd}
SAMMAZ 19	0.09^{b}	0.07^{b}	22.22^{c}	0.09^{b}	0.07^{b}	22.22^{cd}
SAMMAZ 14	0.10^{a}	0.08^{a}	20.00^{d}	0.10^{a}	0.08^{a}	20.00^{d}
SAMMAZ 17	0.09^{b}	0.08^{a}	11.11^{e}	0.09^{b}	0.08^{a}	11.11^{e}
SAMMAZ 20 (check)	0.06^{e}	0.06^{c}	0.00^{f}	0.06^{e}	0.06^{c}	0.00^{f}
S.E ±	0.001	0.001	1.54	0.001	0.001	3.28
CV (%)	2.35	3.22	20.56	2.35	3.10	9.65

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

BI = Before Infestation AI = After Infestation L (%) = Percentage Amount of Tryptophan Loss the least. The check SAMMAZ 20 (0.00 %) was found to be significantly different ($p<0.05$) from all the QPM varieties and no reduction was observed (Table 4.7).

The result from the wet season showed that after infestation of the maize samples, the QPM varieties SAMMAZ 33 (0.05) and SAMMAZ 36 (0.06) were significantly different ($p<0.05$) amongst them and from the other QPM varieties. No significant differences were observed between SAMMAZ 32, SAMMAZ 14 and SAMMAZ 17; SAMMAZ 37 and SAMMAZ 19; DENT-Q and FLINT-Q from each other (Table 4.7). The percentage tryptophan of the check SAMMAZ 20 (0.06) was significantly different from those of the QPM varieties except SAMMAZ 36 (0.06). The varieties with the highest percentage amount of tryptophan losses that showed no significant differences amongst them but were significantly different from the other varieties were observed in FLINT-Q (42.86 %) and DENT-Q (42.86 %). The least percentage losses were found in SAMMAZ 17 (11.11 %) and SAMMAZ 32 (11.11 %) but there was no reduction observed in the check SAMMAZ 20 (0.00 %).

4.14 Combined Results for Tryptophan Content of Quality Protein Maize (QPM) Kernels Before and After *Sitophilus zeamais* Infestation

At the beginning of the experiment, before infestation of the maize varieties, the result for both cold-dry and wet seasons showed significant differences in the percentage amount of tryptophan (Table 4.8). The QPM varieties compared amongst each other indicated no significant differences between SAMMAZ 32, SAMMAZ 19, SAMMAZ 37 and SAMMAZ 17. Similarly, SAMMAZ 33 and SAMMAZ 36 also showed no significant difference from one another. However, SAMMAZ 14 (0.10) was observed to be significantly different ($p<0.05$) from all the varieties but FLINT-Q and DENT-Q were not significantly different from each other. The check SAMMAZ 20 (0.06) was found to be significantly different from the QPM varieties. The highest

Table 4.8: Percentage Tryptophan of Maize Kernels Before and After *S. zeamais* Infestation (combined analysis)

Variety	Tryptophan (%)		
	BI	AI	Loss (%)
FLINT-Q	0.07^{d}	0.04^{e}	42.86^{a}
DENT-Q	0.07^{d}	0.05^{d}	28.57^{b}
SAMMAZ 33	0.08^{c}	0.06^{c}	25.00^{c}
SAMMAZ 32	0.09^{b}	0.08^{a}	11.11^{e}
SAMMAZ 36	0.08^{c}	0.06^{c}	25.00^{c}
SAMMAZ 37	0.09^{b}	0.07^{b}	22.22^{d}
SAMMAZ 19	0.09^{b}	0.07^{b}	22.22^{d}
SAMMAZ 14	0.10^{a}	0.08^{a}	20.00^{d}
SAMMAZ 17	0.09^{c}	0.08^{a}	11.11^{e}
SAMMAZ 20 (check)	0.06^{e}	0.06^{c}	0.00^{f}
S.E ±	0.001	0.001	0.96
CV (%)	2.35	3.17	14.02

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

BI = Before Infestation AI = After Infestation

amount of tryptophan was observed in SAMMAZ 14 (0.10) while the least was observed in the check SAMMAZ 20 (0.06).

At the end of the experiment, the percentage amount of tryptophan after infestation compared amongst the QPM varieties showed that SAMMAZ 33 and SAMMAZ 36 were not significantly different from each other but were significantly different from the other varieties (Table 4.8). Similarly, there was no significant difference between SAMMAZ 37 and SAMMAZ 19 from one another but these were significantly different from the other varieties. SAMMAZ 32 and SAMMAZ 14 were also not significantly different from each other. However, FLINT-Q and DENT-Q were significantly different ($p<0.05$) from each other and from the other QPM varieties. The comparison indicated that FLINT-Q (42.86 %) had the greatest loss in percentage amount of tryptophan whereas SAMMAZ 32 (11.11 %) and SAMMAZ 17 (11.11 %) had the least (Table 4.8). The check SAMMAZ 20 (0.00 %) compared with the QPM varieties showed significant difference and no reduction in tryptophan was observed in both seasons.

4.15 Effect of Seasons on Tryptophan Content of the Quality Protein Maize (QPM) Kernels

The two experimental seasons (cold-dry and wet) were not significantly different in the results of percentage amount of tryptophan content of the Quality Protein Maize (QPM) kernels before infestation. Season therefore had no significant effect in the percentage amount of tryptophan content of the uninfested QPM varieties during storage. After infestation, the results of the same maize varieties of FLINT-Q, DENT-Q, SAMMAZ 33 and SAMMAZ 32 compared across the two experimental seasons showed significant difference across the seasons. Season therefore had significant effect in them during storage (Table 4.9). The other maize varieties were not significantly different in the percentage amount of tryptophan across both seasons and therefore season had no significant effect on them.

Table 4.9: Seasonal Comparison of Percentage Amount of Tryptophan in the Quality Protein Maize Kernels After *S. zeamais* Infestation

	Tryptophan (%)	
Variety	Cold-dry season	Wet season
FLINT-Q	0.04[a]	0.04[a]
DENT-Q	0.05[a]	0.04[b]
SAMMAZ 33	0.06[a]	0.05[b]
SAMMAZ 32	0.07[a]	0.08[b]
SAMMAZ 36	0.06[a]	0.06[a]
SAMMAZ 37	0.07[a]	0.07[a]
SAMMAZ 19	0.07[a]	0.07 [a]
SAMMAZ 14	0.08[a]	0.08[a]
SAMMAZ 17	0.08[a]	0.08[a]
SAMMAZ 20 (check)	0.06[a]	0.06[a]
S.E ±	0.001	0.001
CV (%)	3.17	3.17

Means followed by the same letter in a row are not significantly different at $p<0.05$

4.16 Protein Contents of Quality Protein Maize (QPM) Kernels Before and After *Sitophilus zeamais* Infestation

The mean percentage protein of the three fractions obtained before infestation indicated that albumin and globulin (fraction I) proteins of DENT-Q, FLINT-Q and SAMMAZ 37 had no significant difference between them. DENT-Q (0.62) and FLINT-Q (0.62) had the highest percentage amount of albumin and globulin proteins whereas SAMMAZ 36 (0.45) had the least amongst the QPM varieties (Table 4.10). However, the check SAMMAZ 20 (0.26) which was significantly different ($p<0.05$) from all the QPM varieties had the least percentage of albumin and globulin proteins. The prolamin/zein (fraction II) protein of the QPM varieties SAMMAZ 17, SAMMAZ 14 and SAMMAZ 19 had no significant difference amongst each other but SAMMAZ 17 (0.72) was observed to have the highest percentage amount of zein protein. On the other hand, FLINT-Q (0.50) which was not significantly different from SAMMAZ 36, SAMMAZ 32, SAMMAZ 33, SAMMAZ 37 and DENT-Q had the least. The check SAMMAZ 20 (1.08) was found to have the highest percentage of zein protein when compared with the QPM varieties and was significantly different ($p<0.05$) from the QPM varieties. The highest and least percentage amount of glutelin (fraction III) protein amongst the QPM varieties was observed in SAMMAZ 19 (0.81) and SAMMAZ 17 (0.57) respectively. Both SAMMAZ 19 and SAMMAZ 17 were found to be significantly different from each other. The check SAMMAZ 20 (0.53) showed significant difference when compared with the QPM varieties and had the least percentage amount of glutelin protein.

The result from the cold-dry season showed that after infestation of the maize varieties, the nine QPM varieties compared amongst each other showed no significant differences ($p>0.05$) in the percentage amount of albumin and globulin (fraction I) proteins. In contrast, the check SAMMAZ 20 (0.18) was found to be significantly different when compared with the QPM varieties. However, the percentage amount of prolamin/zein (fraction II) protein compared

Table 4.10: Comparison of Protein Fractions of Maize Kernels Before and After *S. zeamais* Infestation

	Protein fraction (%)																	
	Cold-dry season									Wet season								
	Albumin+ Globulin			Zein			Glutelin			Albumin+ Globulin			Zein			Glutelin		
Variety	BI	A I	L (%)	BI	A I	L (%)	BI	A I	L (%)	BI	A I	L (%)	BI	A I	L (%)	BI	A I	L (%)
FLINT-Q	0.62^{a}	0.35^{a}	43.55^{a}	0.50^{e}	0.30^{d}	40.00^{a}	0.79^{ab}	0.45^{ab}	43.04^{a}	0.62^{a}	0.19^{a-d}	69.35^{a}	0.50^{e}	0.16^{ef}	68.00^{a}	0.79^{ab}	0.30^{ab}	62.03^{de}
DENT-Q	0.62^{a}	0.36^{a}	41.94^{a}	0.56^{de}	0.33^{cd}	41.07^{a}	0.79^{ab}	0.44^{ab}	44.30^{a}	0.62^{a}	0.14^{d}	77.42^{a}	0.56^{de}	0.18^{f}	67.86^{a}	0.79^{ab}	0.31^{a}	60.76^{e}
SAMMAZ 33	0.51^{cd}	0.30^{a}	41.18^{a}	0.56^{de}	0.33^{cd}	41.07^{a}	0.76^{bc}	0.43^{b}	43.42^{a}	0.51^{cd}	0.18^{bcd}	64.71^{abc}	0.56^{de}	0.19^{de}	66.07^{a}	0.76^{bc}	0.28^{ab}	63.16^{cd}
SAMMAZ 32	0.53^{bc}	0.31^{a}	41.51^{a}	0.60^{cde}	0.35^{cd}	41.67^{a}	0.76^{bc}	0.43^{b}	43.42^{a}	0.53^{bc}	0.19^{a-d}	64.15^{abc}	0.60^{cde}	0.19^{de}	68.33^{a}	0.76^{bc}	0.27^{b}	64.47^{c}
SAMMAZ 36	0.45^{d}	0.28^{a}	37.78^{a}	0.60^{cde}	0.35^{cd}	41.67^{a}	0.77^{bc}	0.43^{b}	44.16^{a}	0.45^{d}	0.21^{abc}	53.33^{bcd}	0.60^{cde}	0.20^{d}	66.67^{a}	0.77^{bc}	0.28^{ab}	63.64^{cd}
SAMMAZ 37	0.59^{ab}	0.34^{a}	42.37^{a}	0.51^{e}	0.31^{cd}	39.22^{a}	0.79^{ab}	0.44^{ab}	44.30^{a}	0.59^{ab}	0.20^{a-d}	66.10^{ab}	0.51^{e}	0.15^{def}	70.59^{a}	0.79^{ab}	0.31^{a}	60.76^{e}
SAMMAZ 19	0.50^{cd}	0.30^{a}	40.00^{a}	0.67^{bcd}	0.39^{cd}	41.79^{a}	0.81^{a}	0.45^{ab}	44.44^{a}	0.50^{cd}	0.24^{ab}	52.00^{cd}	0.67^{bcd}	0.21^{d}	68.67^{a}	0.81^{a}	0.21^{c}	74.07^{a}
SAMMAZ 14	0.55^{bc}	0.33^{a}	40.00^{a}	0.69^{bc}	0.40^{c}	42.03^{a}	0.74^{c}	0.42^{b}	43.24^{a}	0.55^{bc}	0.19^{a-d}	65.45^{abc}	0.69^{bc}	0.25^{c}	63.77^{a}	0.74^{c}	0.23^{c}	68.92^{b}
SAMMAZ 17	0.54^{bc}	0.32^{a}	40.74^{a}	0.72^{b}	0.61^{b}	15.28^{b}	0.57^{d}	0.43^{b}	24.56^{b}	0.54^{bc}	0.25^{a}	53.70^{bcd}	0.72^{b}	0.50^{b}	30.56^{b}	0.57^{d}	0.21^{c}	63.16^{cd}
SAMMAZ 20	0.26^{e}	0.18^{b}	30.77^{a}	1.08^{a}	0.99^{a}	8.33^{b}	0.53^{e}	0.47^{a}	11.32^{b}	0.26^{e}	0.15^{cd}	42.31^{d}	1.08^{a}	0.88^{a}	18.52^{b}	0.53^{e}	0.28^{ab}	47.17^{f}
S.E ±	0.02	0.03	6.11	0.04	0.03	6.89	0.01	0.01	3.60	0.02	0.02	4.92	0.04	0.01	3.60	0.01	0.01	0.74
CV (%)	7.55	16.85	30.60	11.89	13.04	40.09	1.18	11.97	18.75	7.55	19.56	15.51	11.89	8.42	12.25	1.18	3.95	2.35

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

BI = Before Infestation AI = After Infestation L (%) = Percentage Amount of each Protein Loss amongst the QPM varieties showed that SAMMAZ 17 (0.61) was significantly different from the other varieties. Similarly, SAMMAZ 14 (0.40) and FLINT-Q (0.30) showed significant difference from each other. On the other hand, the check SAMMAZ 20 (0.99) was found to be significantly different in the percentage zein protein compared to those of the QPM varieties. The mean percentage amount of glutelin (fraction III) protein in all the QPM varieties showed no significant difference amongst each other. However, the check SAMMAZ 20 compared with all the QPM varieties also showed no significant differences from SAMMAZ 19, FLINT-Q, DENT-Q and SAMMAZ 37 (Table 4.10). The maximum percentage reduction (percentage loss) in the amount of albumin and globulin (fraction I), zein (fraction II) and glutelin (fraction III) proteins as a result of infestation by *S. zeamais* were observed in FLINT-Q (43.55 %), SAMMAZ 14 (42.03 %) and SAMMAZ 19 (44.44 %) respectively. The minimum losses amongst the QPM varieties were observed in SAMMAZ 36 (37.78 %) for albumin and globulin, SAMMAZ 17 (15.28 %) for zein and SAMMAZ 17 (24.56 %) for glutelin proteins. On the other hand, the check SAMMAZ 20 compared with the QPM varieties had the least percentage loss in albumin and globulin (30.77 %), zein (8.33 %) and glutelin (11.32 %) proteins (Table 4.10).

During the wet season, the result of the mean percentage proteins of the three fractions obtained after infestation showed that, the QPM varieties when compared showed no significant differences amongst SAMMAZ 17, SAMMAZ 19, SAMMAZ 36, SAMMAZ 37, FLINT-Q, SAMMAZ 32 and SAMMAZ 14 from each other in the percentage amount of albumin and globulin (fraction I) proteins. SAMMAZ 17 (0.25) was observed to be significantly different from SAMMAZ 33 (0.18) and DENT-Q (0.14). The check SAMMAZ 20 (0.15) was not significantly different from the QPM varieties except SAMMAZ 17(0.25) and SAMMAZ 19 (0.24) when compared. The percentage amount of prolamin/zein (fraction

II) protein in all the QPM varieties showed that SAMMAZ 17 (0.50) and SAMMAZ 14 (0.25) were significantly different ($p<0.05$) from each other and from the other varieties. The check SAMMAZ 20 (0.88) was found to be significantly different when compared with all the QPM varieties. The percentage amount of glutelin (fraction III) protein of the QPM varieties indicated that DENT-Q (0.31) was significantly different ($p<0.05$) from SAMMAZ 32 (0.27), SAMMAZ 14 (0.23), SAMMAZ 19 (0.21) and SAMMAZ 17 (0.21). The check SAMMAZ 20 (0.28) compared with the QPM varieties was found to be significantly different ($p<0.05$) from SAMMAZ 14, SAMMAZ 19 and SAMMAZ 17. However, SAMMAZ 20 showed no significant difference from DENT-Q, FLINT-Q, SAMMAZ 37, SAMMAZ 36, SAMMAZ 32 and SAMMAZ 33 QPM varieties (Table 4.10). Amongst the QPM varieties, the greatest and least percentage losses in albumin and globulin proteins were observed in DENT-Q (77.42 %) and SAMMAZ 19 (52.00 %) respectively, that of zein protein were observed in SAMMAZ 37 (70.59 %) and SAMMAZ 17 (30.56 %) respectively whereas that of glutelin protein were also observed in SAMMAZ 19 (74.07 %) and SAMMAZ 37 (60.76 %) respectively. The QPM varieties compared with the check SAMMAZ 20 indicated that the least percentage losses in albumin and globulin (fraction I), zein (fraction II) and glutelin (fraction III) proteins were found in SAMMAZ 20 (42.31 %, 18.52 % and 47.17 %) respectively (Table 4.10).

4.17 Combined Results for Albumin and Globulin Proteins of Quality Protein Maize (QPM) Kernels Before and After *Sitophilus zeamais* Infestation

Before infestation of the maize varieties, significant differences were observed from the combined results of the two seasons of the experiment. Amongst the QPM varieties, DENT-Q, FLINT-Q and SAMMAZ 37 showed no significant differences from each other. Similarly, SAMMAZ 14, SAMMAZ 17 and SAMMAZ 32 also showed no significant difference from one another. No significant difference was also observed between SAMMAZ 33 and SAMMAZ 19.

In contrast, SAMMAZ 36 (0.45) showed significant difference ($p<0.05$) from the QPM varieties (Table 4.11). The check SAMMAZ 20 (0.26) compared with the QPM varieties was significantly different from all the QPM varieties. The least amount of albumin and globulin proteins determined amongst the maize varieties before infestation was observed in SAMMAZ 20 (0.26) whereas the highest amount was observed in DENT-Q (0.62) and FLINT-Q (0.62).

After infestation of the maize varieties, the mean percentage amount of albumin and globulin proteins from the result of combined analysis of the two experimental seasons indicated that, SAMMAZ 17 was significantly different from SAMMAZ 33 and SAMMAZ 36 but was not significantly different from the other QPM varieties when compared amongst each other. SAMMAZ 20 (check) showed significant difference ($p<0.05$) when compared with the QPM varieties (Table 4.11). The percentage losses in the amount of albumin and globulin proteins of DENT-Q (59.68 %) were significantly different from that of SAMMAZ 17 (48.15 %), SAMMAZ 19 (46.00 %) and SAMMAZ 36 (46.67 %) which showed no significant difference amongst them. In contrast, the check SAMMAZ 20 (34.62 %) showed significant difference from the QPM varieties in the percentage amount of albumin and globulin losses (Table 4.11).

4.18 Combined Results for Zein (Prolamin) Protein of Quality Protein Maize (QPM) Kernels Before and After *Sitophilus zeamais* Infestation

Before infestation of the maize varieties, the combined results from both cold-dry and wet seasons (Table 4.11) showed that the mean percentage amount of zein protein compared amongst the QPM varieties indicated SAMMAZ 14, SAMMAZ 17 and SAMMAZ 19 were not significantly different from each other but these were significantly different from SAMMAZ 33, SAMMAZ 37, DENT-Q and FLINT-Q. It was observed that SAMMAZ 32 and SAMMAZ 36 also showed no significant difference amongst each other. The check SAMMAZ 20 (1.08) compared with the QPM varieties showed significant difference from the QPM varieties. The

Table 4.11: Protein Fractions of Maize Kernels Before and After *S. zeamais* Infestation (combined analysis)

	Protein fraction (%)								
	Albumin+ Globulin			Zein			Glutelin		
Variety	BI	AI	L (%)	BI	AI	L (%)	BI	AI	L (%)
FLINT-Q	0.62^{a}	0.27^{ab}	56.45^{ab}	0.50^{e}	0.23^{f}	54.00^{a}	0.79^{b}	0.37^{a}	53.16^{b}
DENT-Q	0.62^{a}	0.25^{ab}	59.68^{a}	0.56^{de}	0.25^{ef}	55.36^{a}	0.79^{b}	0.37^{a}	53.16^{b}
SAMMAZ 33	0.51^{cd}	0.24^{b}	52.94^{ab}	0.56^{de}	0.26^{ef}	53.57^{a}	0.76^{d}	0.35^{abc}	53.95^{b}
SAMMAZ 32	0.53^{bcd}	0.25^{ab}	52.83^{ab}	0.60^{cd}	0.27^{de}	55.00^{a}	0.76^{d}	0.35^{abc}	53.95^{b}
SAMMAZ 36	0.45^{e}	0.24^{b}	46.67^{b}	0.60^{cd}	0.28^{de}	53.33^{a}	0.77^{c}	0.36^{ab}	53.25^{b}
SAMMAZ 37	0.59^{a}	0.27^{ab}	54.24^{ab}	0.51^{de}	0.23^{f}	54.90^{a}	0.79^{b}	0.37^{a}	53.16^{b}
SAMMAZ 19	0.50^{d}	0.27^{ab}	46.00^{b}	0.67^{bc}	0.30^{cd}	55.22^{a}	0.81^{a}	0.33^{bc}	59.26^{a}
SAMMAZ 14	0.55^{b}	0.26^{ab}	52.73^{ab}	0.69^{bc}	0.32^{c}	53.62^{a}	0.74^{e}	0.33^{bc}	55.41^{ab}
SAMMAZ 17	0.54^{bc}	0.28^{a}	48.15^{b}	0.72^{b}	0.56^{b}	22.22^{b}	0.57^{f}	0.32^{c}	43.85^{c}
SAMMAZ 20	0.26^{f}	0.17^{c}	34.62^{c}	1.08^{a}	0.94^{a}	12.96^{b}	0.53^{g}	0.38^{a}	28.30^{d}
S.E ±	0.01	0.01	3.92	0.03	0.01	3.88	0.003	0.01	1.83
CV (%)	7.55	18.14	21.45	11.89	12.06	23.62	1.18	10.75	10.25

Means followed by the same letter (s) in a column are not significantly different at $p<0.05$

BI = Before Infestation AI = After Infestation L (%) = Percentage Amount of each Protein Loss highest mean percentage zein protein was found in the check SAMMAZ 20 (1.08) while FLINT-Q (0.50) had the least (Table 4.11).

The combined results for zein protein after infestation of the maize varieties (Table 4.11) indicated that, the QPM varieties compared amongst each other showed no significant differences between SAMMAZ 32, SAMMAZ 33, SAMMAZ 36 and DENT-Q from each other. SAMMAZ 17 (0.56) was found to be significantly different from all the QPM varieties. The check SAMMAZ 20 (0.94) showed significant difference ($p<0.05$) from the nine QPM varieties compared. The greatest loss in zein protein was observed in DENT-Q (55.36 %) and was not significantly different from the other QPM varieties except SAMMAZ 17. On the other hand, SAMMAZ 17 (22.22 %) had the least loss and showed significantly difference ($p<0.05$) from the QPM varieties. The check SAMMAZ 20 (12.96 %) showed no significant difference only from SAMMAZ 17 (22.22 %) when compared with the QPM varieties (Table 4.11).

4.19 Combined Results for Glutelin Protein of Quality Protein Maize (QPM) Kernels Before and After *Sitophilus zeamais* Infestation

Before infestation, the mean percentage amount of glutelin protein from the result of combined analysis of the two seasons indicated that, amongst the QPM varieties, only SAMMAZ 14 (0.74), SAMMAZ 17 (0.57), SAMMAZ 19 (0.81) and SAMMAZ 36 (0.77) showed significant differences ($p<0.05$) from each other and from the other maize varieties (Table 4.11). The other varieties comprising FLINT-Q, DENT-Q and SAMMAZ 37 showed no significant differences amongst them but these were significantly different from SAMMAZ 33 and SAMMAZ 32. The check SAMMAZ 20 (0.53) was significantly different from all the QPM varieties. The mean percentage amount of glutelin protein observed before infestation of the maize varieties ranged from 0.53 to 0.81 in SAMMAZ 20 (check) and SAMMAZ 19 respectively.

After infestation of the maize varieties, the result of combined analysis of the two experimental seasons indicated that, the mean percentage amount of glutelin compared amongst the QPM varieties were not significantly different in DENT-Q, FLINT-Q, SAMMAZ 37, SAMMAZ 36, SAMMAZ 33 and SAMMAZ 32 from each other. Similarly, SAMMAZ 19, SAMMAZ 14, SAMMAZ 17, SAMMAZ 33 and SAMMAZ 32 were also not significantly different amongst each other (Table 4.11). However, the check SAMMAZ 20 (0.38) compared with the QPM varieties showed no significant difference from DENT-Q (0.37), FLINT-Q (0.37), SAMMAZ 37 (0.37), SAMMAZ 36 (0.36), SAMMAZ 33 (0.35) and SAMMAZ 32 (0.35) but was significantly different ($p<0.05$) from SAMMAZ 19 (0.33), SAMMAZ 14 (0.33) and SAMMAZ 17 (0.32) varieties. The highest and least percentage losses in the amount of glutelin protein when compared between the QPM varieties were observed in SAMMAZ 19 (59.26 %) and SAMMAZ 17 (43.85 %) respectively. SAMMAZ 17 (43.85 %) was significantly different from SAMMAZ 19 (59.26 %) and the other varieties. The check SAMMAZ 20 (28.30 %) showed significant difference ($p<0.05$) from all the QPM varieties and had the least amount of glutelin loss (Table 4.11).

4.20 Effect of Seasons on Protein Contents of the Quality Protein Maize (QPM) Kernels

The two experimental seasons (cold-dry and wet) showed no significant difference across the seasons in the percentage protein contents of the QPM varieties before *Sitophilus zeamais* infestation. The protein Contents (albumin, globulin, zein and glutelin) of the same maize varieties compared across the two experimental seasons after *S. zeamais* infestation showed that the varieties were significantly different across the two seasons (Table 4.12). Season therefore had significant effect in the infested QPM varieties during storage.

Table 4.12: Seasonal Comparison of Protein Fractions of Maize Kernels After *S. zeamais* Infestation

	Protein fraction (%)					
	Albumin+ Globulin	Albumin+ Globulin	Zein	Zein	Glutelin	Glutelin
Variety	Cold-dry season	Wet season	Cold-dry season	Wet season	Cold-dry season	Wet season
FLINT-Q	0.35[a]	0.19[b]	0.30[a]	0.16[b]	0.45[a]	0.30[b]
DENT-Q	0.36[a]	0.14[b]	0.33[a]	0.18[b]	0.44[a]	0.31[b]
SAMMAZ 33	0.30[a]	0.18[b]	0.33[a]	0.19[b]	0.43[a]	0.28[b]
SAMMAZ 32	0.31[a]	0.19[b]	0.35[a]	0.19[b]	0.43[a]	0.27[b]
SAMMAZ 36	0.28[a]	0.21[b]	0.35[a]	0.20[b]	0.43[a]	0.28[b]
SAMMAZ 37	0.34[a]	0.20[b]	0.31[a]	0.15[b]	0.44[a]	0.31[b]
SAMMAZ 19	0.30[a]	0.24[b]	0.39[a]	0.21[b]	0.45[a]	0.21[b]
SAMMAZ 14	0.33[a]	0.19[b]	0.40[a]	0.25[b]	0.42[a]	0.23[b]
SAMMAZ 17	0.32[a]	0.25[b]	0.61[a]	0.50[b]	0.43[a]	0.21[b]
SAMMAZ 20 (check)	0.18[a]	0.15[b]	0.99[a]	0.88[b]	0.47[a]	0.28[b]
S.E ±	0.01	0.01	0.02	0.02	0.02	0.02
CV (%)	17.11	17.11	8.93	8.93	4.23	4.23

Means followed by the same letter in a row are not significantly different at $p<0.05$

4.21 Correlation Results for Resistance / Susceptibility Parameters of Stored Maize grains to *Sitophilus zeamais* Infestation

The combined results of the cold-dry and wet seasons showed that the number of F_1 adult progeny emergence was significant and positively correlated with the number of F_2 adult emergence ($r = 0.51$, $p<0.05$), percentage damage ($r = 0.59$, $p<0.05$) and percentage weight loss ($r = 0.50$, $p<0.05$). Similarly, F_2 adult emergence was also significant and positively correlated with percentage damage ($r = 0.56$, $p<0.05$) and percentage weight loss ($r = 0.55$, $p<0.05$). However, the correlation between percentage damage and percentage weight loss ($r = 0.75$, $p<0.05$) was highly significant and positively correlated. On the other hand, the percentage germination of infested maize grains was highly significant and negatively correlated with percentage damage ($r = -0.78$, $p<0.05$) but was significant and also negatively correlated with percentage weight loss ($r = -0.69$, $p<0.05$). A highly significant negative correlation also existed between grain hardness with percentage damage ($r = -0.79$, $p<0.05$) and percentage weight loss ($r = -0.81$, $p<0.05$) whereas a highly significant positive correlation existed between grain hardness with percentage germination of the maize grains after infestation (Table 4.13). The zein protein of the infested maize varieties was significant and negatively correlated with F_1 adult emergence ($r = -0.52$, $p<0.05$), F_2 adult emergence ($r = -0.54$, $p<0.05$), percentage damage ($r = -0.69$, $p<0.05$) and weight loss ($r = -0.66$, $p<0.05$) but the zein protein was found to be significant and positively correlated with percentage germination of infested maize grains ($r = 0.57$, $p<0.05$) and grain hardness ($r = 0.67$, $p<0.05$). A non significant correlation existed between tryptophan, albumin/globulin and glutelin proteins of the infested maize varieties with the various parameters.

Table 4.13: Correlation of Resistance / Susceptibility Parameters of Stored Maize Grains to *Sitophilus zeamais* Infestation

	F_1	F_2	D	wtloss	gerinf	gh	trypinf	a+ginf	zeininf	gluinf
F_1	1.00									
F_2	0.51^{*}	1.00								
D	0.59^{*}	0.56^{*}	1.00							
Wtloss	0.50^{*}	0.55^{*}	0.75^{**}	1.00						
Gerinf	-0.46^{NS}	-0.38^{NS}	-0.78^{**}	-0.69^{*}	1.00					
gh	-0.52^{*}	-0.46^{NS}	-0.79^{**}	-0.81^{**}	0.78^{**}	1.00				
trypinf	-0.24^{NS}	-0.30^{NS}	-0.36^{NS}	-0.29^{NS}	0.32^{NS}	-0.35^{NS}	1.00			
a+ginf	-0.13^{NS}	-0.36^{NS}	-0.03^{NS}	0.00^{NS}	-0.11^{NS}	-0.17^{NS}	0.40^{NS}	1.00		
zeininf	-0.52^{*}	-0.54^{*}	-0.69^{*}	-0.66^{*}	0.57^{*}	0.67^{*}	-0.17^{NS}	-0.10^{NS}	1.00	
gluinf	-0.35^{NS}	-0.43^{NS}	-0.10^{NS}	-0.04^{NS}	-0.07^{NS}	-0.08^{NS}	0.04^{NS}	0.63*	0.33^{NS}	1.00

* Significant ** Highly significant ^{NS} Not significant

F_1	=	F_1 Adult emergence
F_2	=	F_2 Adult emergence
D	=	Percentage Damage
Wtloss	=	Percentage weight loss
Gerinf	=	Percentage Germination after infestation of maize grains
Gh	=	Grain Hardness
Trypinf	=	Tryptophan after infestation of maize grains
a+ginf	=	Albumin/Globulin after infestation of maize grains
zeininf	=	Zein after infestation of maize grains
gluinf	=	Glutelin after infestation of maize grains

CHAPTER FIVE

5.0 DISCUSSION

The outcome of this work has shown considerable variation between the check and Quality Protein Maize (QPM) varieties with respect to F_1 and F_2 adult emergence, damaged grains, weight loss of the grains, grain hardness, tryptophan and other protein contents. With increasing number of F_1 and F_2 adult progeny, there was increasing grain damage and weight loss. Out of the nine QPM varieties infested with *S. zeamais*, SAMMAZ 17 had the least damage and number of adult insects; therefore it is relatively less susceptible to *S. zeamais* attack compared to the other QPM varieties. In contrast, the QPM varieties FLINT-Q and DENT-Q had the greatest damage and supported more *S. zeamais*, therefore may be regarded as susceptible. The check had the least damage and number of progeny when compared with the QPM varieties. The greatest damage observed in FLINT-Q and DENT-Q varieties was probably because more adult F_1 and F_2 progeny were found in them whereas SAMMAZ 17 which had the least grain damage amongst the QPM varieties had few F_1 and F_2 adult progeny emergence. This agrees with the report of Abraham (1991) which indicated that the extent of damage during storage depends upon the number of emerging adult weevils during each generation and the duration of each life cycle. Grains that had more adult maize weevil emergence were more seriously damaged. There was less number of *S. zeamais* progeny observed in the maize varieties during the cold-dry season compared with the wet season which had more progeny emergence. This probably may be as a result of dryness of the pericarp of the grains during the cold-dry season due to low moisture content which makes it difficult for the insects to bore and penetrate into the grains thus affecting the insects emergence. On the other hand, more number of *S. zeamais* progeny was observed in the maize varieties because of high moisture content during the wet season. Findings in this study agrees with CIMMYT (2001) that reported high moisture content makes grains susceptible to weevil damage.

The percentage weight loss and percentage damage of all the stored maize varieties were significant and positively correlated with the number of F_1 and F_2 adult emergence. Any maize variety that supported and allowed many *S. zeamais* to develop in it would be expected to suffer more damage and weight loss. The only QPM variety considered to be less susceptible and had the least weight loss in this study is SAMMAZ 17. The check SAMMAZ 20 (non-QPM) was also considered less susceptible. SAMMAZ 17 and SAMMAZ 20 varieties were significantly different in their tryptophan and protein contents but were observed to have hard kernels (corneous endosperm). The minimum losses in tryptophan, zein and glutelin proteins were observed in SAMMAZ 17 and SAMMAZ 20. These two varieties supported few *S. zeamais* in them and thus suffered less weight loss as a result of infestation by *S. zeamais.* Although more damage and weight loss as a result of *S. zeamais* infestation was observed during the wet/rainy (June-August) season than the cold-dry (October-December) season, there was no significant difference observed across the two experimental seasons. This may be probably because the two experiments were carried out in the same laboratory during the two seasons and the temperature and relative humidity of the laboratory only slightly varied. Result for the germination test revealed a decrease in percentage germination of all the infested stored maize varieties. The reduced percentage germination of these stored grains as a result of *S. zeamais* infestation agrees with Lale (2002) who reported that damage to the embryo of the seed causes loss of viability. The result is also in agreement with the findings of early workers like Mensah (1986) that reported decrease in seed viability with time in seeds of cowpea.

The QPM variety (SAMMAZ 17) identified as having hard kernel (corneous endosperm) in this research work fragmented on grinding and was also found to be relatively less susceptible to *S. zeamais* attack. Those varieties identified as having soft kernels (floury endosperm) became finely crushed during grinding and they were also found in the present study to be relatively susceptible to *S. zeamais* as compared with SAMMAZ 20 (check). Out of the 10 maize varieties evaluated for grain hardness, only one QPM variety, SAMMAZ 17 and the non-QPM variety, SAMMAZ 20 (check) were identified as having hard kernels compared to the other varieties. The fact that the other QPM varieties were not found to have hard kernels may be attributed to the possession of softer floury endosperms compared to the check and thus making the grains relatively susceptible to storage insect pests. The result obtained agrees with Garcia-Lara *et al*. (2004) that reported *S. zeamais* resistance was controlled by kernel hardness. The result is also in agreement with the findings of Bamaiyi *et al.,* (2007) that reported grain hardness has been the main *S. oryzae* resistance parameter. Kelvin (2002) also reported a relationship between seed hardness and thickness, both in the pericarp and the whole kernel by noting that maize with thick and hard pericarp was very hard to penetrate by the weevils. The same author observed a correlation between seed variety, the pericarp and kernel thickness. Bergvinson (2004) also revealed that maize with thicker husks or a hard kernel has more resistance to insect damage which is also in line with the findings of this study.

The tryptophan and protein contents of the maize grains evaluated in this study were observed to decrease with increasing grain damage as a result of feeding by *S. zeamais*. The tryptophan and protein contents were determined before and after infestation with *S. zeamais*. The results indicated that the amount of tryptophan in the whole kernels of the QPM varieties was higher than in the non-QPM variety (check). Findings in this study were in agreement with Ado *et al*., (2005) that reported normal maize (non-QPM) has poor nutritive value due to low concentration of two essential amino acids: lysine and tryptophan whereas Quality Protein Maize (QPM) conferred the presence of high lysine and tryptophan. A maximum reduction in tryptophan was found in FLINT-Q which decreased from an initial value of 0.07 % to 0.04 % within 12 weeks of storage. This result agrees with the work of Daniel *et al.* (1977) and Rajan *et al.* (1975) that reported substantial losses in threonine content of Quality Protein Maize (QPM) infested with *S. oryzae*. In the first study, threonine decreased after three months from an initial value of 1.30 to 0.91. In the second study, threonine decreased from 3.5 to 2.9 g per 16 g/N. These researchers also reported that the damaged maize was less efficient in complementing food legumes.

Protein fractionation studies based on the procedure of Landry-Moureaux (1970) showed that, the QPM varieties before infestation had more albumin and globulin (fraction I) proteins than the check (non-QPM) variety. The prolamin/zein (fraction II) protein of the check (non-QPM) was more than that of the QPM varieties. All the QPM varieties were higher in glutelin (fraction III) protein compared to that of the check. This is in line with the work of Gentinetta *et al*. (1975), Ortega and Bates (1983), that demonstrated QPM genotypes were higher in fraction III protein. The combined analysis of the protein fractions showed that maximum losses in albumin and globulin (fraction I) proteins as a result of infestation caused by *S. zeamais* were observed in DENT-Q (59.68 %). This variety decreased from an initial value of 0.62 % to 0.25 % but the minimum loss amongst the QPM varieties was found in SAMMAZ 19 (46.00 %) which reduced from an initial value of 0.50 % to 0.27 %. A maximum reduction in zein (fraction II) protein was found in DENT-Q (55.36 %) which decreased from an initial value of 0.56 % to 0.25 %. The minimum reduction in this fraction amongst the QPM varieties was found in SAMMAZ 17 (22.22 %) which reduced from an initial value of 0.72 % to 0.56 %. The highest loss in glutelin (fraction III) protein was in the variety SAMMAZ 19 (59.26 %) which decreased drastically from 0.81 % to 0.33 % within 12 weeks of storage. The decrease was comparatively less in SAMMAZ 17 (43.85 %) compared amongst the QPM varieties. This variety decreased from an initial value of 0.57 % to 0.32 %.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The results from the experiments conducted showed that at 45 days after infestation with *S. zeamais,* FLINT-Q (24.63) was the most susceptible variety with the highest mean number of F_1 progeny while SAMMAZ 17 (12.63) had the least amongst the QPM varieties. At 90 days after infestation with *S. zeamais*, DENT-Q (51.63) had the highest mean number of F_2 progeny whereas SAMMAZ 17 (19.25) had the least. The highest percentage damage and percentage weight loss amongst the QPM varieties were also observed in FLINT-Q. The germination test conducted after infestation of the maize varieties revealed a decrease in percentage germination of all the infested maize varieties. Reduction in the essential amino acid (tryptophan) and other proteins as a result of feeding by *S. zeamais* was determined. FLINT-Q (42.86 %) had the maximum reduction which decreased from an initial value of 0.07 % to 0.04 %. Maximum losses in fraction I (albumin/globulin) proteins were observed in DENT-Q (59.68 %) which decreased from an initial value of 0.62 % to 0.25 %. The maximum reduction in the amount of fraction II (zein) protein was observed in DENT-Q (55.36 %) which decreased from an initial value of 0.56 % to 0.25 %. The greatest reduction in fraction III (glutelin) protein was in the variety SAMMAZ 19 (59.26 %) which decreased drastically from 0.81 % to 0.33 % at 12 weeks of storage. Minimum reductions in tryptophan (11.11 %), zein (22.22 %) and glutelin (43.85 %) proteins amongst the QPM varieties were observed in SAMMAZ 17 which decreased from 0.09 % to 0.08 %, 0.72 % to 0.56 % and 0.57 % to 0.32 % respectively. The results on the determination of grain hardness showed that SAMMAZ 17 appeared to be relatively harder than all the other QPM varieties.

6.2 Conclusion

Amongst the Quality Protein Maize (QPM) varieties evaluated in this work, only SAMMAZ 17 had relatively hard kernel (corneous endosperm) possibly making it less susceptible to *Sitophilus zeamais* attack. This variety (SAMMAZ 17) supported few *S. zeamais* and thus suffered less damage (8.38 %) and weight loss (0.86 %) as a result of feeding by *S. zeamais.* The other QPM varieties evaluated had softer floury endosperms suggesting that they were more susceptible to attack by *S. zeamais*. The minimum losses in tryptophan (11.11 %), zein (22.22 %) and glutelin (43.85 %) proteins were also found in SAMMAZ 17. It can therefore be concluded that SAMMAZ 17 variety with relatively hard kernel is the most tolerant variety to *Sitophilus zeamais* infestation which can be stored for 90 days with minimum insect infestation and reduction in protein contents.

6.3 Recommendation

Based on the findings of this study, although the QPM varieties have higher amount of the essential amino acid (tryptophan), which makes them more nutritious than the non-QPM variety (check), they were found to be relatively susceptible to the maize weevil *S. zeamais*. It is thus recommended that breeders should develop more QPM varieties with hard kernels to obtain longer storage periods.

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Appendix I: Daily Record of the Laboratory Temperature and Relative Humidity During the Experimental Periods

	Cold-dry season		Wet season	
Day	Temperature (^{0}C)	Relative Humidity (%)	Temperature (^{0}C)	Relative Humidity (%)
1	26	52	29	65
2	26	51	29	61
3	27	66	24	61
4	27	61	29	66
5	28	52	27	77
6	27	52	24	70
7	26	64	26	73
8	27	73	29	64
9	26	64	24	64
10	27	52	24	77
11	27	52	29	76
12	27	76	24	73
13	27	73	24	78
14	28	69	28	71
15	27	68	24	68
16	26	71	24	69
17	27	63	27	63
18	27	52	27	77
19	27	52	24	78
20	26	76	27	76
21	27	73	24	73
22	29	52	28	77
23	27	52	24	77
24	27	60	29	60
25	26	52	24	92
26	27	68	26	68
27	27	52	26	71
28	27	63	24	63
29	26	50	27	50
30	27	52	24	39
31	27	39	27	40
32	26	52	24	45
33	27	33	25	35
34	27	45	24	33
35	27	40	24	39
36	27	37	26	37
37	26	32	24	38
38	27	22	24	28
39	27	28	26	21
40	26	31	27	32
41	27	52	24	23

42	27	38	24	31
43	28	20	25	20
44	27	20	25	16

	Cold-dry season		Wet season	
Day	Temperature (^{0}C)	Relative Humidity (%)	Temperature (^{0}C)	Relative Humidity (%)
45	27	16	24	20
46	27	23	24	23
47	26	21	25	20
48	27	25	27	20
49	28	20	24	21
50	27	23	27	23
51	27	20	24	23
52	27	23	24	20
53	27	20	25	20
54	27	20	26	25
55	27	23	24	38
56	28	52	25	83
57	27	52	24	83
58	27	69	24	69
59	27	52	26	83
60	27	52	27	83
61	27	52	24	88
62	28	52	24	83
63	27	52	25	79
64	26	78	26	78
65	27	69	24	69
66	27	52	26	85
67	27	84	24	84
68	26	85	25	85
69	27	52	26	84
70	27	76	24	76
71	27	84	24	84
72	27	52	24	90
73	26	52	25	82
74	26	52	26	81
75	27	52	24	83
76	27	52	24	81
77	26	52	27	66
78	26	61	26	61
79	27	77	24	67
80	27	52	24	70
81	26	64	27	64
82	26	73	26	73
83	27	64	25	64
84	25	52	24	63

85	25	77	24	60
86	26	77	24	77
87	27	60	23	60
88	27	52	25	92
89	27	65	24	65
90	26	61	24	61

Appendix II: First trial: Mean Progeny Emergence of *S. zeamais,* Percentage Damage, Percentage Weight Loss and Percentage Germination After Infestation of Maize Varieties

Variety	F_1	F_2	% damage	% weightloss	% germination
FLINT-Q	25.00	29.50	36.00	7.77	10.00
DENT-Q	21.25	26.00	29.50	5.65	15.00
SAMMAZ 33	17.25	23.50	26.50	4.92	20.00
SAMMAZ 32	16.00	20.00	26.50	4.91	25.00
SAMMAZ 36	14.00	18.25	25.50	4.06	45.00
SAMMAZ 37	13.75	17.50	25.00	3.88	60.00
SAMMAZ 19	12.00	17.25	13.75	3.20	65.00
SAMMAZ 14	11.00	17.00	7.75	2.75	75.00
SAMMAZ 17	6.50	16.75	4.00	0.54	80.00
SAMMAZ 20	5.50	16.25	3.50	0.20	85.00

Appendix III: Second trial: Mean Progeny Emergence of *S. zeamais,* Percentage Damage, Percentage Weight Loss and Percentage Germination after Infestation of Maize Varieties

Variety	F_1	F_2	% damage	% weightloss	% germination
FLINT-Q	24.25	71.00	37.00	7.80	15.00
DENT-Q	24.50	77.25	40.25	9.52	10.00
SAMMAZ 33	23.25	66.75	30.75	5.14	42.50
SAMMAZ 32	22.25	49.75	30.50	5.09	20.00
SAMMAZ 36	21.50	49.25	28.00	4.69	25.00
SAMMAZ 37	20.75	44.50	25.25	4.59	50.00
SAMMAZ 19	20.50	42.00	15.00	3.77	80.00
SAMMAZ 14	19.25	40.75	13.50	2.85	75.00
SAMMAZ 17	18.75	21.75	12.75	1.18	60.00

SAMMAZ 20	15.75	14.25	8.50	0.60	85.00

Appendix IV: Combined Analysis of Variance for F_1 Progeny Emergence of *S. zeamais* on Maize Varieties

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	1343.950	149.328	4.23	0.0003
Trial	1	938.450	938.450	26.58	<.0001
Trial*Var	9	235.300	26.144	0.74	0.6705
Error	60	2118.500	35.308		
Corrected Total	79	4636.200			

Appendix V: Combined Analysis of Variance for F_2 Progeny Emergence of *S. zeamais* on Maize Varieties

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	10582.513	1175.835	5.13	<.0001
Trial	1	15152.513	15152.513	66.14	<.0001
Trial*Var	9	4847.613	538.624	2.35	0.0240
Error	60	13746.250	229.104		
Corrected Total	79	44328.888			

Appendix VI: Combined Analysis of Variance for Percentage Damage of Maize Varieties After *S. zeamais* Infestation

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	8989.200	998.800	34.51	<.0001
Trial	1	378.450	378.450	13.08	0.0006
Trial*Var	9	207.800	23.089	0.80	0.6196
Error	60	1736.500	28.942		
Corrected Total	79	11311.950			

Appendix VII: Combined Analysis of Variance for Percentage Weight Loss of Maize Varieties After *S. zeamais* Infestation

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	429.818	47.758	16.89	<.0001
Trial	1	10.871	10.871	3.85	0.0545
Trial*Var	9	22.881	2.542	0.90	0.5317
Error	60	169.619	2.827		
Corrected Total	79	633.189			

Appendix VIII: Combined Analysis of Variance for Percentage Germination of Maize Varieties After *S. zeamais* Infestation

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	54751.250	6083.472	48.83	<.0001
Trial	1	61.250	61.250	0.49	0.4859
Trial*Var	9	3351.250	372.361	2.99	0.0052
Error	60	7475.000	124.583		
Corrected Total	79	65638.750			

Appendix IX: Analysis of Variance for Grain Hardness of the Maize Varieties

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	31.515	3.502	163.50	<.0001
Trial	1	0.000	0.000	0.00	1.0000
Trial*Var	9	0.000	0.000	0.00	1.0000
Error	60	1.285	0.021		
Corrected Total	79	32.799			

Appendix X: Combined Analysis of Variance for Tryptophan Content of Maize Varieties Before Infestation with *S. zeamais*

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	0.014	0.000	422.44	<.0001
Trial	1	0.000	0.000	0.00	1.0000
Trial*Var	9	0.000	0.000	0.00	1.0000
Error	60	0.000	0.000		
Corrected Total	79	0.014			

Appendix XI: Combined Analysis of Variance for Tryptophan Content of Maize Varieties After Infestation with *S. zeamais*

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	0.018	0.002	472.17	<.0001
Trial	1	0.001	0.001	185.39	<.0001
Trial*Var	9	0.001	0.000	17.04	<.0001
Error	60	0.000	0.000		

Corrected Total	79	0.020

Appendix XII: Combined Analysis of Variance for Albumin and Globulin Proteins of Maize Varieties Before Infestation with *S. zeamais*

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	0.792	0.088	58.01	<.0001
Trial	1	0.000	0.000	0.00	1.0000
Trial*Var	9	0.000	0.000	0.00	1.0000
Error	60	0.091	0.002		
Corrected Total	79	0.883			

Appendix XIII: Combined Analysis of Variance for Albumin and Globulin Proteins of Maize Varieties After Infestation with *S. zeamais*

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	0.132	0.015	7.42	<.0001
Trial	1	0.288	0.288	145.21	<.0001
Trial*Var	9	0.044	0.005	2.48	0.0178
Error	60	0.119	0.002		
Corrected Total	79	0.584			

Appendix XIV: Combined Analysis of Variance for Zein (prolamin) Protein of Maize Varieties Before *S. zeamais* Infestation

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	2.033	0.226	38.28	<.0001
Trial	1	0.000	0.000	0.00	1.0000
Trial*Var	9	0.000	0.000	0.00	1.0000
Error	60	0.354	0.006		
Corrected Total	79	2.387			

Appendix XV: Combined Analysis of Variance for Zein (prolamin) Protein of Maize Varieties After *S. zeamais* Infestation

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	3.575	0.397	209.08	<.0001

Trial	1	0.426	0.426	224.38	<.0001
Trial*Var	9	0.009	0.001	0.51	0.8633
Error	60	0.114	0.002		
Corrected Total	79	4.124			

Appendix XVI: Combined Analysis of Variance for Glutelin Protein of Maize Varieties Before *S. zeamais* Infestation

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	0.682	0.076	1034.06	<.0001
Trial	1	0.000	0.000	0.00	1.0000
Trial*Var	9	0.000	0.000	0.00	1.0000
Error	60	0.004	0.000		
Corrected Total	79	0.687			

Appendix XVII: Combined Analysis of Variance for Glutelin Protein of Maize Varieties After *S. zeamais* Infestation

Source of variation	Df	Sum of square	Mean Square	F value	Pr > F
Var	9	0.034	0.004	2.61	0.0131
Trial	1	0.602	0.602	419.54	<.0001
Trial*Var	9	0.024	0.003	1.86	0.0760
Error	60	0.086	0.001		
Corrected Total	79	0.746			