EVALUATION OF SORGHUM CULTIVARS (*Sorghum bicolor* L. Moench) FOR BIRD PREFERENCE AND NUTRITIONAL PROPERTIES

BY

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ABSTRACT

The study was conducted at Agriculture Research Institute (ARI)-Ilonga with the objective of identifying less bird preferred cultivars and associated physical and chemical properties. It involved two field experiments laid in a Randomized Complete Block Design. A total of 18 local and improved sorghum varieties were used. Analysis of nutritional properties included Ether Extract, Proteins, Minerals, Crude Fibres, Carbohydrates and Tannin in the Laboratory at Sokoine University of Agriculture was conducted. Data obtained were analysed using MSTATC software followed by separation of the means using Duncan's Multiple Ranges Test (DMRT). The study observed no influence of physical properties on bird preference, but, there was very little influence of nutritional qualities as follows:- Crude protein was positively correlated with yield loss, crude fibre, fat content, grain weight, and tannin levels. Crude fibre had positive correlation of 0.47 with tannins and was statistically ($P \leq 0.5$) significant but was negatively correlated with yield losses. There was strong significantly different ($P \leq 0.01$) correlation of 0.65 between tannin and yields losses. Khalidii, Mnyambi, Gafembee and Selemani ranked high in crude protein, crude fibre and tannin contents with less yield losses and were classified as less bird preferred. However, Khalidi outperformed all the cultivars and hence most promising cultivar for crop improvement to curb bird attack problem. The influence of crude protein, fibre and tannin on bird preference was not established and no single parameter was identified to have contributed to less bird preference. Intensive screening and biotechnological evaluation of the genetic potentials on bird preference is recommended.

DECLARATION

I, Robertson Michael Simbagije, do here by declare to the senate of Sokoine University of agriculture that, this dissertation is the result of my own original work and that, it has never been nor concurrently being submitted for a higher degree award in any other university.

.... 10.11.2009.

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The above declaration is confirmed

.... 11.11.2009

Prof. Robert N. Misangu — Date

(Supervisor)

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DEDICATION

This work is dedicated first and foremost to the Almighty God Jehovah who made me survive to date through difficult times, to my beloved mother Dorothea Ntira, who has been my personal lawyer in all aspects from infancy to date and whose prayers for my success have not been in vain, to my beloved wife, Severa for her moral support and Innocent, Queen and Sonia my beloved children for their patience.

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LIST OF ABREVIATIONS AND SYMBOLS

ANOVA	-	Analysis of Variance
AOAC	-	Association of Official methods for Analytical Chemists
ARI	-	Agriculture Research Institute
CC	-	Catechin Concentration
CE	-	Catechin Equivalent
CHO	-	Carbohydrates Contents
Conc	-	Concentrated
CP	-	Crude Protein
CRD	-	Completely Randomized Design
CV	-	Coefficient of variation
DMB	-	Dry matter bases
EE	-	Ether Extract (Fat content)
FAO	-	United Nations Food and Agriculture Organization
GQE	-	Grain Quality Evaluation
HCL	-	Hydrochloric acid
IBPGR	-	International Board for Plant Genetic Resources
ICRISAT	-	International Crop Research in Semi-Arid and Tropics
MAFC	-	Ministry of Agriculture, Food and Cooperative
MC	-	Moisture Content
RCBD	-	Randomized Complete Block Design
r.p.m	-	Revolutions per minute

SMIP	-	Sorghum and Millet Improvement Programme
SUA	-	Sokoine University of Agriculture
VE	-	Volume of extract
VM	-	Volume Made up
^{o}C	-	Degree Centigrade
pH	-	Hydrogen ions concentration

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Average food production per capita has been declining over the past 40 years in Africa causing a wide spread of hunger and poverty. Slow economic growth continues to work against efforts of poverty alleviation. However, agriculture stands a good chance to reverse the declining productivity and stimulate vibrant economic growth in Africa, because agriculture remains the most dominant sector in almost all economies of African countries.

Among other crops, sorghum (*Sorghum bicolor* L. Moench) can play a big role in alleviating poverty and food insecurity due to its ability to perform well in semi arid areas, where there is a wide spread of crop failure for many crops. Sorghum is the most important crop grown by low and resource-poor farmers largely as a staple food. This is because sorghum can thrive better than other crops in drought- prone, marginal areas and with poor soil fertility (Poehlman and Borthakur, 1977).

Sorghum is an amazingly diverse group of plants, probably more diverse genetically than any other crop plant (Poehlman and Borthakur, 1977). It is adapted to a wide range of ecological conditions and can produce useful yields of grain under conditions, which are unfavourable for most other cereals. The crop is essentially a plant of hot and warm climate areas. It can also tolerate hot and dry conditions, but can also be grown in areas with high rainfall in which waterlogged conditions may occur. In some countries, such as Sudan, it can be grown under irrigation. The optimum temperature for growth is about 30°C and it is killed by frost. The great merit of sorghum is its drought-resistance. The xerophytic characters of the crop allow it to survive physiological drought produced by water logging when root functions are temporarily impaired (Purseglove, 1975).

Sorghum is grown on approximately 10 million hectares worldwide and accounts for about 56% of cereal acreage and 41% of cereal production. However, the yields realized by resource-poor farmers have remained considerably lower than that obtained by breeders even for improved varieties that have shown to produce high yield between 2.0-3.0t/ha on the research stations. This is mainly due to inadequate dissemination of the improved varieties, variation of genotype performance over varying environments, yield losses from insect pests and diseases. Doggett (1972) optimistically, considered that 'it is probably reasonable to set a yield of 20 tons of grain per hectare as a target for sorghum yield when planning for crop improvements. Intensive screening for high yielding potentials and stability followed by improvement of identified sorghum genotypes is inevitable. There is certainly much scope for yield improvement in the crop, should commercialization, technology adoption and constraining factors improve.

The sorghum grain is a staple cereal with important dietary components in many semi arid African countries. It is consumed in many forms including but not limited to leaven bread, soft and stiff porridge, non-alcoholic and alcoholic beverages. Proper processing and storage of sorghum will maintain nutritional values, minimize grain losses and improve marketability of the end products. Despite the relative importance of sorghum in the food system of many semi arid countries, a small proportion of produced sorghum grain is commercially processed and marketed. There are potential sorghum grain processing opportunities in different forms such as decorticated sorghum grain as rice substitute, composite sorghum bread, cookies, pop sorghum breakfast cereals and snake food products.

1.2 Problem statement and justification

Sorghum yields have remained historically very low, adversely affecting the nutritional status of the poor and limiting their potential income. The progressive decline in yield of sorghum crop over time has been due to drought and bird scaring costs in terms of time and cash, which have led farmers to shift to cultivation of other crops whose production costs are relatively low, but which cannot thrive well in such dry regions. This shift has reduced sorghum yield tremendously, increased food insecurity and income poverty in the regions.

Grain eating birds are the most serious pest of sorghum in almost all sorghum and millet growing areas. The most notorious type is Sudan dioch (*Quelea quelea*), which are highly mobile migrants causing high economic loss and in some years disastrous. Other important birds include various species of weavers (*Ploceus spp*), sparrows (*Passer spp*), parakeets (*Psitacula spp*), pigeon (*Columba spp*), crows (*Corvus*), and Deves (*Streptopelia*) (Sharma and Daves, 1988). They are able to inflict heavy losses causing economic damage of up to 40 percent (SMIP, 2001). The impact of birds on agricultural production has led to the formation of several regional and international organizations for bird control in Africa (Bruggers and Jaeger, 1982).

Although the impact of bird pest on grain production is generally recognized, until very recently, only little quantitative information on losses is available. In Senegal, annual cereal losses due to birds were valued at $4-5million, with sorghum and millets suffering more than 78% of the total losses (Brugger and Ruelle, 1981).

Source: Jonathan Gressel (2007).

Plate1: Thousands of *Quelea quelea* in one of their breeding sites

In Sudan, bird damage has been estimated to cause a loss of $6.3 million annually (FAO, 1981). In India, nearly 10% of sorghum grains are estimated to be destroyed by birds yearly (Jain and Prakash 1983).

Pigeons have been found to destroy 10-100% of pearl millet at sowing, while sparrows account for up to 29% of grain loss in Punjab (Toor 1982). Secondary effect of bird attack is that fungi and storage insect pests easily infest sorghum grains previously attacked by birds (Syngenta Foundation, 2005).

In Tanzania, the Ministry of Agriculture, Food Security and Cooperatives (MAFSC, 2006) reported the most affected regions to include Mwanza, Arusha, Mbeya, Shinyanga, Morogoro, Dodoma, Singida and Kilimanjaro. *Quelea quelea* is the main avian sorghum pest, which breeds annually between March and May. The breeding adults normally migrate with rains from Southern to Northern Tanzania, synchronizing the nest building, egg laying and brooding almost at the same time. This accounts for the seasonal population explosion to thousands of birds (Plate 1). *Quelea* seasonal reproduction normally coincides with the maturity of traditional small grain cereals like millets, paddy, sorghum and wheat.

Further more, the ministry's report also mentioned that large areas of many regions in Tanzania are grown maize, where sorghum would produce better and high yields than maize. This is because sorghum is a more reliable crop with better and consistent yields across the seasons had it not been bird attack and associated bird scaring costs. The bird pest is not peculiar to sorghum but since sorghum is more of a poor- peasant crop than maize, repeated incidences of birds attack on sorghum exacerbate food insecurity problem among poor families that heavily depend on it for their livelihoods (Dendy and Dobraszczyk, 2001).

The sorghum programme in Tanzania has developed some excellent cultivars with good quality grains. However it was demonstrated that these could not be grown in fields without numerous bird scaring operations. According to SMIP survey (2001), the adoption of improved cultivars of sorghum in Tanzania is only 36%. The report further points out, that bird attack is one of the major constraints affecting adoption rates of technologies. Farmers have continued to grow their local sorghum cultivars because the improved ones are heavily damaged by birds resulting into total loss of the crop yields if bird scaring is not done. The fact that farmers have continued to grow landraces means that, they contain particular important attributes, which are not available in the improved cultivars. This is what the study was geared to explore and establish a bench mark information/data for a detailed study on possible conventional and biotechnological breeding programme to address the bird attack problem on sorghum in semi- arid areas in the long run. The goal is to provide resource-poor farmers with effective but affordable technologies to combat these problems of low yields, food insecurity and poverty. In the absence of cost effective bird control measures, growing of sorghum cultivars that are less bird preferred seems economically viable and most effective method.

In order to improve sorghum production for ensured food security and poverty alleviation in semi arid areas of Tanzania, it is better to screen among local and improved sorghum cultivars for less bird preferred sorghum cultivars as a base for future comprehensive breeding program.

1.3 Failure of methods in use for bird control in sorghum

Efforts to reduce grain losses due to bird damage seem to be far from reaching satisfactory results, although many traditional and newly developed techniques like traditional bird scaring, plant phenology, bioacoustics and chemical method are in use to combat the menace of sorghum and millets grain eating birds.

1.3.1 Traditional bird scaring

The traditional bird scaring methods includes frightening the birds through shouting, beating empty tins or can, throwing stones or mud bullets at the bird flocks, planting of trap crop, destruction of nesting sites, covering the crop heads with bags, piece of cloth and use of fish and nylon nets (Dogget, 1957). It is the commonly used method but very tedious and costly in terms of labour and accounts for about 75 percent of production costs of sorghum. It consumes a considerable amount of farmers' productive time, which could be used for other income generating activities (SMIP, 2001).

It should be noted that, in the sorghum growing areas the level of performance in primary schools has always been low because children who are supposed to be in school are the ones who do the bird scaring. As the acreage under sorghum increases, therefore, a large number of children is involved in bird scaring leading to low school attendance and consequently high dropout due to low performance (Gressel, 2007).

1.3.2 Plant phenology

The sorghum plant is planted such that the flowering is during the period of low bird's influx. However, this is complicated by the length of the crop-growing period to maturity as it is affected by sunshine duration and the amount of rainfall received which is almost inconsistent in most of sorghum growing areas. Plant characteristics such as bristles and anther covering of the grain have been reported to be associated with resistance to birds (Beri *et al.*, 1969) and Singh (1980) has suggested the cultivation of varieties with awns.

1.3.3 Bioacoustics method

Distress alarm or warning calls have also been exploited for bird control. These calls are recorded and replayed at regular intervals. The method is effective in scaring some bird species such as parakeets. However many bird species do not produce distress calls and therefore the method cannot be used to such bird species.

1.3.4 Chemical methods

Use of synthetic repellents such as thiram is reported to be an effective bird repellent (Metzer and Royal, 1961). Other chemicals like quelea toxin, Methiocarb, methyl parathion, Avitrol 100(R), tetramethyl thirum disulphite and anthraquinone have been used through spraying of the whole field or in spots and edges. These are however, environmental hazardous chemicals because they kill or affect both targeted and non-targeted birds and other organism. None of the above methods have proven to be effective and efficient in the control of birds essentially because these methods are very expensive.

1.4.0 Research questions and hypothesis

1.4.1 Research questions

In addressing the bird attack problem there are a number of research questions, which must be answered. These include but not limited to the following:-

a) Is there any less bird preferred sorghum cultivar(s)?

b) What are the levels of bird preference across sorghum cultivars?

c) What are correlations of less bird preference and nutritional qualities in sorghum?

d) What are the nutritional qualities constraints associated with bird preference?

1.4.2 Hypothesis: Bird damage levels of sorghum in field varies from cultivar to cultivar

1.5 Objectives

1.5.1 Overall objective

To evaluate sorghum varieties for less bird preference to increase sorghum yields and reduce yield losses caused by bird damage in order to improve food security among small holder farmers in semi-arid regions of Tanzania.

1.5.2 Specific objectives

(i) To determine levels of bird preference among selected sorghum cultivars in

Tanzania.

(ii) To determine physical and chemical properties that might have influence on bird preference in sorghum.

(iii) To determine nutritional quality differences between highly and less bird preferred sorghum cultivars.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Economic importance of sorghum production

According to FAO (1996) report, sorghum is an important staple cereal in the drier parts of Africa and Asia and occupies the fourth place among the world's cereals after wheat, rice and maize. The report points out that, the declining sorghum production in areas where the crop is a key to food security raises an issue of major concern among decision and policy makers. That, the increase in population growth has forced the expansion of sorghum acreage into drier and marginal lands; due to re-allocation of the more productive land to other competing enterprises, such as livestock production and cultivation of cereals like maize. It also mentions most of marketing policies to have encouraged commercial trade and processing of the food commodities with less emphasis on sorghum and millet products.

Doggett (1972) considers that sorghum will become of increasing importance as populations in the tropics and subtropics require the less fertile and agriculturally more difficult land to be brought into cultivation. It is also equally stated by Dendy (1997) that sorghum constitutes the major sources of dietary energy for millions of people in Africa and Asia and will become increasingly important not only for rural but also urban populations in semi arid tropics. When assessed in terms of total production as percentage of all cereals based on the order of its importance, sorghum is first in West Africa, second in East Africa and third in Southern Africa.

It was also reported by Dendy and Dobraszczyk (2001) that sorghum and millets together represented approximately 70 percent of total cereals production in West Africa, 30 percent of total cereals production in East Africa and 10 percent of total cereals production in Southern Africa.

Sorghum is a very important cereal crop in Tanzania after maize and rice. It is grown in all agro-ecological zones and is a subsistence crop in the semi-arid and frequently drought prone areas. The crop supports about 80 percent of the population in drought prone, marginal areas with poor soil fertility of Shinyanga, Mwanza, Singida, Mara, Dodoma regions and parts of Morogoro region in Tanzania, where other crops cannot thrive well (MAFSC, 2006).

2.2 Sorghum morphology

Sorghum is always grown from seed. However, it can be propagated by cuttings if desired due to the presence of root primordial at the nodes. The radicle produced during germination is later replaced by adventitious roots; arising from the lowest nodes of the stem. The seedlings appear above ground in about 7 days. Sorghum is a vigorous annual grass growing to a height between 0.5-6.0 m, often with a single stem. Tillers are produced in some varieties early or late after flowering and may be grown as a ratoon crop (Purseglove, 1975).

Purseglove (1975) mentioned different morphological and physiological properties that make sorghum drought-resistance to include:- (a) the plant above ground grows slowly until the root system has become well established; (b) sorghum produces twice as many secondary roots as maize; (c) silica deposits in the endodermis of the roots prevent collapse during drought stresses; (d) the leaf area is about half that of maize; (e) the leaves have a waxy coating and in rolling property in times of drought; (f) Loss of water through sorghum leaves is about half that of maize; (g) sorghum requires about 20 per cent less water than maize to produce the equivalent amount of dry matter; (h) sorghum can compete well with weeds once it has become well established and (i) the plant can remain dormant during periods of drought and resume growth when conditions become favourable.

It is this last property that is of prime importance, permitting the production of grain under conditions of limited or uncertain rainfall. Maize subjected to wilting for a week or more suffers permanent damage to the stomata; sorghum stomata are scarcely affected by wilting for fourteen days and quickly resume the diurnal rhythm of change in stomata opening.

Both Purseglove (1975) and House (1985) when independently studied the flowering in sorghum, they observed that, inflorescence begins to flower when the peduncle has completed its elongation and it may take a period of 30 to 100 days depending on the cultivar. The first flowers to open are at the top of the uppermost panicle branch and opening continues downwards; flowers in the same horizontal plane in the panicle open about the same time. The pedicel spikelet bloom 2-4 days after the sessile spikelet on the same branch and flowering is spread over a period of 6-15 days. Grain weight, colour, taste and hardness vary between cultivars. The growth duration to maturity varies greatly among varieties, some early types taking only 100 days or less, while long-term sorghums require 5-7 months to maturation.

2.3 Ecological requirements

Sorghum is grown between 40° N and S of the Equator. The crop is most extensively cultivated in the drier savannas and grasslands of Africa, the plains of India and the southern Great Plains of the United States. It is grown in areas, which are too hot and too dry for maize. In many parts of Africa, maize has replaced sorghum, but where conditions are border-line and in some years maize may fail with disastrous results (Purseglove, 1975).

2.4 Soil requirement

Sorghum can tolerate a wide range of soil conditions. The crop will grow well on heavy soils, especially the deep-cracking valley-bottom and black-cotton soils of the tropics, even when subjected to temporary waterlogged conditions (Purseglove, 1975). In the Sukuma land of Tanzania, sorghum is the principal crop of the clay black mbuga soils in the valley bottoms, bulrush millet or maize being grown on the lighter soils of the hillsides. Sorghum is equally at home on light sandy soils. It can be grown with a wide range of soil pH from 5.0-8.5 and tolerates salinity better than and will produce a crop on soils too poor for many other crops (Ackland, 1971).

Increased yields due to manure application depend upon the moisture status of the soil and the conditions of cultivation. When water is limiting and husbandry is poor, a response to fertilizers is negligible. When moisture conditions are more favourable the application of 23 kg N/ha has often given increase in yields. Where there is an assured water supply or the crop is grown under irrigation, 45 kg N/ha is recommended. The N-application should be done in splits by putting enough on the seedbed to ensure a good start, but using most of it as a top dressing 1-2 weeks before floral initiation (Anderson and Ingram, 1989).

2.5 Sunshine and photoperiod requirements

Sorghum is a short-day plant, but varieties vary in their sensitivity to the photoperiod and this character is genetically controlled. The expression to photoperiod response is influenced by temperature and can only be fully realized when certain minimum temperature requirements have been fulfilled. Some varieties such as the broomcorn are relatively insensitive to photoperiod. Tropical varieties may fail to set seed in high latitudes. Curbs (1968), cited by Purseglove (1975) noticed that locally adapted varieties in Nigeria always flowered towards the end of the rains and thus escaped damage from moulds and sucking bugs, which would attack them if they flowered earlier. This could not be explained entirely by responses to photoperiod and temperature as they flowered over a wide range of latitudes if planted in May or June. The stimulus may have been the number of successively shorter days after June 21 rather than their absolute length. From the above, it can be concluded that the maturity length of sorghum is determined by the interaction between genotype, photoperiod and temperature.

2.6 Chemical composition

Like other cereals, sorghum is predominantly starchy; with high fibre content and poor digestibility of nutrients, which severely influences consumer choices. Whole grains are important sources of vitamin B-complex, which are mainly concentrated in the outer layer of the grain. Purseglove (1975) estimated chemical properties of air-dried whole grain sorghum to be about 8-16% moisture, 8-15% protein, 2-5% fat, 68-74% carbohydrate, 1-3% fibre and 1.5-2.0 % Ash.

Rooney and Serna-Salvidar (1991) observed sorghum grains to contain no vitamin A and C, although certain yellow endosperm varieties contained small amount of ß-carotene, a precursor of Vitamin A. Obilana (2001) emphasizes critical evaluation of sorghum grain quality with various end uses in mind that should be paid to the traits; like grain hardness determines grain storability and processing quality.

Sorghum is unique among cereals in the sense that some cultivars contain tannins (polyphenols) in both leaves and grains. The tannins in sorghum are condensed tannins called pro-anthocyanidins and react with vanillin in the presence of HCL to give bright red colour. This is the basis for the colour metric vanillin-HCL procedures (Hahn *et al.*, 1984). Price and Butler (1980) attributed deleterious nutritional properties of less bird preferred sorghums to several possible tannin-related effects. This include the suspected tannin-protein binding effects in the digestive tract expressed as indigestible complexes with dietary protein, deactivation of digestive enzymes, and "tanning" of some areas within the digestive tract. The problem with most high-tannin sorghums is that there is no uniform polymerization in all of the tannin molecules during ripening and some retain protein binding properties which are nutritionally deleterious in the ripened grain. However, tannin content in sorghum has agronomic advantages such as protecting the seed from attack by moulds, insects and pre-harvesting germination (Dendy and Dobraszczyk, 2001).

The aerial shoots of sorghum contain the hydrocyanic acid (HCN) which in just small amount of 0.5 g HNC is sufficient to kill a cow and more than 750 ppm is regarded as dangerous to stock. The quantity of HCN varies with the cultivar and the growth condition and it usually diminishes with age. Small plants and young tillers have a high dhurrin content, most of which occurs in leaves. During drought, ratoon fresh plants are a dangerous source of poisoning. Nitrogenous manure application increases the HCN content. However, the poison is destroyed when the fodder is made into hay or silage (Purseglove, 1975).

2.7 Crop husbandry

Traditionally, in the Lake and Central regions of Tanzania sorghum is dry planted on the black clay mbuga soils before the advent of the rainy season. This involves the minimum cultivation and is facilitated by the treading of the cattle when grazing down the dry stalks of the previous crop. The pulverized clay covers the broadcasted seeds effectively, in a way that could not be done by other means (Ackland, 1971).

In modern cultivation, sorghum is often planted on hills or ridges with several seeds per hole, of which at 14 days after emergence are thinned to 2-3 seedlings. The time of planting is governed to some extent by the time taken to maturity. Generally, however, in dry climates the crop should be planted during the first onset of the rains, as delayed planting can result in substantial yield losses. The optimum plant population depends upon the height, stem thickness and tillering capacity of the cultivar, the available moisture and the soil fertility. The usual spacing is 60-90 x 20-60 cm between and within a row respectively. In very dry areas the seed-rate is about 2-3 kg/ha, in more favoured areas is 5-7 kg/ha and when the crop is to be irrigated is 10-15 kg/ha. Forage sorghums are planted at closer spacing. Seed dressing against smut and other diseases is advisable (Purseglove, 1975).

2.8 Pests and diseases

Weed control is important in the early stages of growth. When sorghum is well established it can tolerate weeds better than most cereal crops. The parasitic *Striga* is the most serious weed in cereals, and should be removed before seed setting (Purseglove, 1975).

Sorghum is very susceptible to bird damage, particularly by *Quelea qualea*. Bird control is usually by scaring. Children particularly who are supposed to be in school, are extensively used for bird scaring. Sorghum cultivars with red kernels are claimed to be less preferred and hence not much affected by bird. The less preference is said to be associated with high tannin levels, which makes sorghum grain bitter at milky stage. The bitterness of the sorghum at milky stage is said to deter bird attack, and that as the grains mature and reach less than 16 percent moisture content; the tannin content declines to levels suitable for human consumption (Sharma and Davies, 1988).

2.9.1 Yield potentials

Globally, the production of sorghum expanded from 40 million tones during early1960s to 66 million tones in early 1980s. By early 1990s, it had fallen to 58 million tones. In the same periods, the acreage under sorghum declined marginally from about 45.6 million hectares to 44.4 million hectares. The global growth of area under sorghum has shown a general slight decline of about -0.2% per year and yield of -0.5% per year before the year 2000. Expansion acreage in Africa increased at about 3.6% per year, although yields declined at about -0.1% per year (FAO, 2004). An average productivity estimates show that, the mean yield in Africa is about 800kg/ha, 1200kg/ha in Asia, 4000kg/ha in America; and 5000kg/ha in Europe (FAO, 1996). The degree of commercialization and corresponding low levels of adoption of new technologies in developing countries cause this disparity. Yields of threshed grain per hectare also vary widely depending upon the cultivar and the location.

2.10 Crop improvement

As stated above, sorghum is an extremely variable crop. The botanical varieties of both grain and wild sorghums can cross readily. Thus, there is considerable scope for improvement by hybridization and selection. Most of the African varieties are tall and often late-maturing types. Although the crop is grown principally for grain for human consumption, the straw is a useful by-product. It is necessary to consider palatability preferences of the local people. Where the crop is combine-harvested, uniformity is essential and dwarf, evenly and early maturing varieties are required (House, 1985).

In many areas local varieties have become adapted to their environment, particularly in regard to climatic conditions and resistance to local diseases and pests. Cultivars introduced into a different environment seldom perform well. Modern hybrids from the United States have often been of little value in our tropical environments. Similarly, varieties from the tropics may not do well in the United States of America. They usually grow tall and late maturing, and those, which are markedly photoperiodic, completely fails to flower. However, introduced varieties, particularly where male sterility or other specific gene is required, have proved valuable in breeding programmes. It is desirable therefore; that a country or groups of countries should have their own breeding programmes for the production of improved varieties suited to local conditions. The crop is often naturally self-pollinated, but an average of about 6 per cent cross-pollination does take place, this varies with the cultivar, local conditions and compactness of the inflorescence (House, 1985).

2.9.1 Processing, utilization and marketing

Sorghum is mainly utilized as food and feed for livestock. Cultivars with a red pericarp are also used for brewing alcoholic beverages both locally and industrially (Mansuetus, 1995). The physical and chemical qualities of sorghum influence the end product qualities, which in turn affect the market value. It is important to record grain colour because it influences the colour of any product made from that grain. For instance, if it is to be milled for porridge meal, a white or light colour is generally preferred (Asante, 1995). The testa is a heavily pigmented layer containing tannins, found just under the pericarp in high tannin brown sorghum (Hahn *et al.*, 1984). It is purple or brown and is thick at the crown of the grain and thin near the germ region. The testa closely adheres to the endosperm and affects the flour colour in milled products. A thick, light coloured pericarp may mask a dark endosperm, giving a false impression of the grain colour. Pericarp color or pigmentation is not necessarily related to tannin content or biochemical activity (Bullard and Elias, 1980), but endosperm colour affects the colour of the milled products while texture affects hardness and hence the milling yields. Pericarp thickness affects dehulling losses and milling yield and hardness. On the other hand, it can influence milling quality and water absorption capacity, which in turn affects diastatic enzyme activity. Harder grains generally give a higher milling yield than soft grains due to dehulling losses. Dehulling losses is thus inversely related to grain milling yield and both are determined by grain hardness. Grain hardness also influences water absorption, which in turn affects diastase enzyme activity (IBPGR and ICRISAT, 1993).

It is important to know the Moisture Content (MC) of grain because it affects storage period of the grains. Grains with MC higher than 12% are more susceptible to mould infection than those with lower MC. The MC affects grain-quality parameters such as density and milling yield. The MC of sample for laboratory analysis is determined and standardized to a MC recommended range of 11.0 $\pm$ 0.5%. This method of MC determination has been standardized and calibrated against the oven-drying method

(AOAC, 1980) by regression analysis. The Steinlite moisture value (x) is thus converted to oven % MC (y) by substitution in the equation: $y = 3.89 + 0.58x$. High MC reduces impedance of flow of current through the sample leading to higher meter reading.

The weight of 1000 grains indicates the grain density. Because the sorghum grain is small and there is variation in grain weight within a cultivar, one cannot just take one or two seeds and weigh them to establish the grain weight; many seeds must be selected randomly, counted out and weighed together to provide a representative average grain weight (Gomez *et al.*, 1997).

Crude protein content is useful to determine grain protein content in order to ascertain the grain's nutritional value, or to observe the effect of different treatments on its protein content (Asante, 1995). Because crude protein content does not guarantee protein availability, digestible protein and digestible available protein contents should also be determined (AOAC, 2000). Pepsin digestibility is useful in determining digestibility differences between sorghum cultivars and other cereal crops. It is important in comparing digestibility levels of different sorghum food preparations to remember that the tannins in the testa affect taste, digestibility, and other functional properties of the grain (Mertz *et al.*, 1984).

Tannins have anti nutritional effects. Sorghum cultivars with high tannin contents are bitter and have low protein digestibility (Dendy and Dobraszczyk, 2001). They bind strongly to and precipitate proteins, increase saliva secretion and endogenous protein excretion and inhibit protein metabolism once digested and absorbed (Serna-Saldivar and Rooney, 1995). Polyphenols also act as trypsin inhibitors (Dendy and Dobraszczyk, 2001).

Mineral content is inorganic residue resulting from the incineration of organic matter to ash. Burning to ash is useful when preparing samples for mineral analysis and determination of the proportion of bran to endosperm in selected grain varieties. Since the mineral content of bran is 20 times that of endosperm, ash product indicates the thoroughness of separation of the bran from the rest of the grain during decortications (McLaughlin *et al.*, 1987).

Utilization and demand issues involve proving diversified and convenient sorghum product to consumer groups. These could be in form of fortified nutrient supplements for specific target consumer (Asante, 1995). Sadly, about 40% of sorghum produced in East and Central Africa is sold as it has a local market near areas of production and between households. Domestic markets for sorghum are characterized by low and variable volumes, high transaction costs in terms of transportation of bulky materials ending at low market price that could not meet all the transaction costs. There are no organized marketing infrastructures for sorghum products in many countries due to irregular and unpredictable supplies (FAO, 1996). Approximately 60% of sorghum produced in East and Central Africa is consumed at farm households while 40% is sold in domestic markets. Some countries like Ethiopia, Eritrea, Sudan, Kenya and Somalia are importers of sorghum. Generally the East and

Central Africa region is a net importer of sorghum importing about 350,000 tonnes annually (FAO, 1996).

Nutritionally, sorghum compare well with other cereal grains although it is regarded as an inferior good in many countries. Per capita consumption of sorghum is high in countries or areas where the climate does not allow economic production of other cereals and where per capita incomes are relatively low (Asante, 1995). In many countries consumption of sorghum as food is relatively small or negligible than other cereals (FAO, 1996). The decline in per capita consumption of sorghum has been influenced by changes in consumers' traditional food habits, urbanization, time and energy required to prepare sorghum for food, conditions of marketing facilities, processing techniques, stability of supplies and relative availability of sorghum products in urban areas (FAO, 1996). Opportunity for commercialization of sorghum will require major investments in production, marketing and policy environments.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experiment I: Determination of qualitative and physical properties of selected sorghum cultivars

3.1.1 Field experiment

Three field experiments were conducted at the Eastern Agricultural Research Zone headquarters (ARI- Ilonga). The experiments were conducted from November, 2006 to May, 2007. Eighteen sorghum cultivars collected from farmers in Shinyanga, Singida and ARI-Ilonga were used.

The experimental plots were planted on 10th November such that the maturity occurred when there were no other crops in fields to provide an alternative feeding niche. The second planting was on 14th February 2007 which is the normal cropping season for sorghum in the Eastern Agro-ecological Zone and the third planting was done on 26th March, 2007 so that the crop matures during off- season.

The Randomized Complete Block Design (RCBD) was used with three replications. The plot size of 5m x 5m and plants were at 75cm x 25cm apart, giving six rows and a population of 120 plants per plot. The influence of head type and shape was studied by visual observation of bird's landing and bird damage differences in form of yield losses. The experiments were conducted without bird scaring, but 40 plants per cultivar per plot were protected from bird attack by covering the panicles with pollination bags. Two central rows were harvested for each plot to determine grain yield and two border rows from sides of each plot were left. After establishment of the qualitative grain quality parameters, the bird damage levels were determined by weighing the average grain weight of 40 undamaged heads and average grain weight of 40 damaged sorghum heads from each test cultivar. Statistical analysis of recorded data was performed using MSTATC soft ware and means separation was done using Duncan's Multiple Range Test (DMRT) as described by Gomez and Gomez (1984)

3.1.2 Grain-quality evaluation for qualitative properties

The objective of the grain quality evaluation (GQE) was to investigate for possible information on the qualitative and quantitative data most relevant for bird less preference in sorghum and that might be highly associated with bird preference and product end user selection necessary for breeding purpose.

Rapid screening procedures as outlined by Gomez *et al.* (1997) in the Instruction Manual of Laboratory procedures for quality evaluation of sorghum and pearl millet were used. All laboratory tests were performed accordingly using whole, healthy grains from a representative sample in the food nutrition laboratory of Sokoine University of Agriculture.

The GQE involved analysis of grain colour, grain hardness, panicle (head) compactness, head type, taste of the grain at dough stage and grain weight on the bases of 1000 grain weight in grams. No single parameter could serve as a criterion, nor can it be a condition for selection thus several traits were considered together in evaluating the cultivar.

3.1.2.1 Grain colour determination

Differences in grain colour were effectively observed by placing a few samples of grains on a sheet of white paper. The base for classification of grain colour was on the pericarp colour (outer coat of grain) that was recorded with descriptors as white, yellow, red, brown, gray, or a combination, of these colours, according to the IBPGR and ICRISAT (1993).

3.1.2.2 Testa presence or absence determination

Scalpel was used to scrape off the pericarp at the crown of the grain. If a dark layer was observed, presence of testa was confirmed and recorded or vice versa.

3.1.2.3 Grain hardness determination

Grain hardness was measured visually on a scale of 1 to 5 based on proportion of floury to vitreous endosperm and hardness scores recorded. To verify the scores, quantitative dehulling loss was used. Ten sound grains were selected, held firmly on the paper with the forceps and each grain was cut longitudinally into two symmetrical halves using the scalpel. One-half from each grain was pressed, cut side up, onto a strip of masking tape that was placed, sticky side up, on the paper. Then, with the aid of the seed magnifier, examination of each grain for hardness score based on the following scale was done:

Table 1: Classification of grain hardness

Scale	Score (%)	Description
1	<25	Very soft
2	25	Soft
3	50	Intermediate
4	75	Hard
5	>75	Very hard

Source: Gomez *et al.* (1997).

Each final score was recorded and then the average calculated.

3.1.2.4 Grain weight determination

The grains were counted in three replications of 1000 grains for each cultivar and weight in grams of each cultivar recorded and then statistically analysed.

3.2 Experiment II: Determination of nutritional and chemical properties

This section describes how moisture content (oven-drying method); ash content; fat content; crude protein content and tannin content parameters for sorghum were determined in laboratory.

Nutritional and chemical qualities evaluation was done using a Completely Randomized Design (CRD) with three replications (Gomez and Gomez, 1984). Proximate analysis procedures for determination of crude protein, mineral content, crude fibre, ether extract, moisture content and carbohydrates was conducted according to association of official methods for analytical chemistry (AOAC, 2000). Assay by Vanillin-Hydrochloric acid method was performed to determine tannin content quantitatively.

3.2.1 Oven drying method for determination of moisture content (MC)

It was important to determine the moisture content (MC) before carrying out any analysis because the results of analyses are more reliable when reported on a dry-matter basis (DMB).

The total of 54 samples of tested sorghum cultivars with weight of 5grams each were heated to remove the moisture at a temperature of 105°C overnight and then reweighed to get the difference between the initial and final weights. The later equal to the weight of free moisture in the sample.

Equation used for calculations was done using the

% MC=B—A/B x 100.

Where, **A** = the final weight of the dish + sample, and

B = the initial weight of the dish + sample.

To express the results of analyses on a DMB, the final result was multiplied by factor: **100/ 100—% MC.**

3.2.2 Determination of ash content (ash)

Total of 54 samples of sorghum flour weighing 5grams for each of the tested cultivars were heated to 550°C to burn off all the organic material and leave an inorganic residue. Ash content was then calculated using the following equation:

% Ash = B—A/B x 100,

Where **A** = weight (g) of the sample and crucible after incineration, and

B = weight (g) of the sample and crucible before incineration.

3.2.3 Determination of fat content (ether extract)

Each sample weighing 5grams was used to determine fat content by the gravimetric extraction method followed by recovery of the fat by evaporation of the solvent. The monitoring system was carefully done and heat adjusted until the solvent was in moderate boiling and then solvent condensed to drip off the cold droplets at a rate of 16-20 drops per minute. After 4 hours of heating, the unit was turned off and then left to cool. The rotary evaporator was used to evaporate the major portion of the solvent. The last traces of the solvent were evaporated by drying the flasks in the drying oven at (103°C) for 30 minutes. The flasks was then cooled in the desiccators and reweighed. The flasks returned to the oven for 10-15 min, cooled again and reweighed. The drying, cooling, and weighing process was repeated until the difference between consecutive weights is within range of 10 mg. The last weight was used in the following equation to determine the fat content.

% FC= B – A/Sample weight x 100

Where, **A** = the flask weight (g), and

B = the flask weight + fat (g).

3.2.4 Micro-Kjeldahl nitrogen determination

Kjeldahl nitrogen analysis, which is the most common technique for measuring protein nitrogen, was used. Organic nitrogen in the sample weighing 0.25 grams was converted to ammonium sulphate by digestion with concentrated sulphuric acid, using copper sulphate as a catalyst. The ammonium was determined from the amount of ammonia liberated by distillation of the digest with alkali. The ammonia liberated was collected in a volume of boric acid and determined by titration with standard sulphuric acid.

The percent crude protein (% CP) in the sample was calculated using the following formula;

% CP = (A) (B) (14) (6.25) (100) x 6.25/C

Where, **A** = normality of the acid,

B = volume of standard acid used (mL), corrected for the blank

(i.e., the sample titre minus the blank titre);

C = sample weight (mg), and

6.25 = conversion factor for protein from % nitrogen (AOAC, 2000).

Table 2: Selected indicative chemical composition ranges of sorghum from the world germplasm collection at ICRISAT

Ranks	Protein (%)	Fat (ether extract) (%)	Ash (mineral) (%)	Crude fibre (%)	Starch (%)
Low	4.4	2.1	1.3	1	55.6
Medium	11.4	3.3	1.9	1.9	69.5
High	21.1	7.6	3.3	3.4	75.2

Source: Jambunathan and Subramanian (1988).

3.2.5 Tannin content determination

The quantitative analytical procedure assay by Vanillin-Hydrochloric acid method was used. The assay method is a more accurate measure of tannin content although it is more time consuming than the Rapid Semi-quantitative method. The absorbance of standard solutions, sample extracts, and sample blanks in the spectrophotometer reading was taken at the wave length of 500 nm at exactly 20 min after adding vanillin-HCI reagent to the standard solutions and sample extracts. A standard curve of absorbance (y) against catechin concentration (x) from the catechin standard solution readings was made. The intercept and slope of this curve was found and then the sample blank absorbance subtracted from the sample absorbance. The corrected absorbance was substituted into the regression equation y = a + bx in order to find the concentration of the sample extracts;

Where a = intercept and b = the slope of the graph.

Concentration (in g mL^{-1}) was converted into mg catechin mL^{-1}

A percent catechin equivalent (% CE) was calculated according to Gomez and Gomez (1976) using the formula:

$$\% \ CE = \frac{CC \times VM}{VE \times wt} \times 100,$$

Where CC = catechin concentration (mg mL^{-1});

VM = volume made up, i.e., 25mL;

VE = volume of extract, i.e., 1mL;

wt = weight of sample (i.e., = 250mg) and tannin classified accordingly following levels established by Price and Butler (1977 and 1978) as indicated in Table 3.

Table 3: Tannin classification

Tannin group	Catechin equivalents (%)	Tannin level
I	0.00-0.09	None
I	0.10 – 0.25	Low
II	0.26 – 0.99	Intermediate
III	1.00 and above	High

Source: Price and Butler (1977, 1978).

Techniques adopted for quality evaluation of sorghum and pearl millet from the manual of laboratory procedures (Gomez *et al.*, 1997) was incapable in evaluating sorghum grain qualities at dough stage which is the critical period for birds attack on sorghum. All tannin classification was done according to Price and Butler (1977, 1978) as outlined in Table 3 and 7

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Qualitative and physical properties of selected sorghum cultivars and their relationship with bird preference

4.1.1 The relationship between panicle architecture and bird preference.

Generally the panicle shape of fifteen out of eighteen studied cultivars as shown in Tables 4 and 5 was erect; except for Gafembee and Nsukunu varieties which had goose necked panicles and Mjinga mfutu with droopy panicle. There were no direct indication that panicle disposition had any influence on bird preference in sorghum (Tables 4 and 5). For example while Gafembee is goose necked; Mnyambi, Selemani and Khalidi had erect panicles and were both less preferred by birds with yield losses of 46.07% for gafembee which was much comparable to 45.48% for Mnyambi. Among these less preferred cultivars Selemani had the highest yield loss of 60.13 % and Khalidii had the lowest yield loss of 22.24%. Further more, Nsukunu with goose panicle disposition was highly preferred by birds than all of the tested local cultivars with a yield loss of about 85 percent and there were not statistically different from improved cultivars in terms of yield loss levels (Table 4 and 5). This may have been due to sweetness of Nsukunu grains as opposed to Gafembee with bitter grains while Selemani and Khalidi had sour tastes.

4.1.2 The relationship between head type and bird preference

Among the 18 studied sorghum cultivars on head type as listed in Table 3, eleven cultivars had semi-compact heads except for Mjinga mfutu, Gafembee and Fara which had compact heads, Langalanga manyeangombe, Langalanga nyekundu and langalanga nyeupe had loose heads and Khalidi which had loose to semi- compact heads.

The influence of head type on bird preference in sorghum was not clearly established because, while Gafembee had compact head and less bird preferred, Mnyambi and Selemani which are both semi-compact headed were less bird preferred. Khalidi is loose to semi-compact and was as well less preferred by birds. This indicated that sorghum head type did not influence bird damage.

General understanding is that, bird perching is difficult on loose heads (Sharma and Daves, 1988) but loose-headed sorghum like Langalanga manyeangombe, Langalanga nyeupe and langalanga nyekundu were observed to be highly bird preferred resulting in grain losses between 65-83 percent. This was greater than in some compact and semi compact headed cultivars like Gafembee, Mnyambi and Selemani with yield losses of 46, 45 and 60 % respectively (Table 4 and 5).

It is therefore clear that head type has very little influence on birds' preference in sorghum and hence breeding for specific head type may not have much effect in bird control. However, semi-compact headed sorghums are recommended for a good distribution of pesticides when spraying for disease and pest control; and post harvest processing like drying and threshing.

Table 4: Qualitative and physical properties

Cultivar Names	Panicle Shape	Head type	Taste at Dough	Grain Colour	Grain Hardness	Yield Loss
Seleman	Erect	Semi- compact	Sour	Brown	Intermediate	60.13
M. Mfutu	Droopy	Compact	Sour	White	Intermediate	63.00
Manyea-Ng'ombe	Erect	Loose	Sweet	Tan	Hard	82.94
Mnyambi	Erect	Semi-compact	Sweet	Brown	Intermediate	45.48
Gafembee	Goose	Compact	Bitter	Brown	Intermediate	46.07
Ntora	Erect	Semi-Compact	Sweet	White	Hard	83.28
Nsunkunu	Goose	Semi-Compact	Sweet	Tan	Hard	84.62
L Nyekundu	Erect	Loose	Sour	Red	Intermediate	65.00
L. Nyeupe	Erect	Loose	Tasteles s	White	Hard to intermediate	71.37
Fara	Erect	Compact	Sweet	Brown	Intermediate	77.45
Nkhasa	Erect	Semi-Compact	Sweet	Brown	Intermediate	74.91
Ufemba	Erect	Semi-Compact	Sweet	Brown	Intermediate	81.45
Pato	Erect	Semi –Compact	Sweet	White	intermediate	97.17
Macia	Erect	Semi- Compact	Sweet	White	Hard	98.51
Wahi	Erect	Semi- Compact	Sweet	White	Hard	97.91
Hakika	Erect	Semi- Compact	Sweet	White	Intermediate	97.76
Tegemeo	Erect	Semi- Compact	Sweet	White	Intermediate	96.61
Khalidi	Erect	Semi- Compact	Sour	Brown	Intermediate	22.24

4.1.3 The relationship between grain taste and bird preference

Among the eighteen evaluated cultivars, twelve cultivars had sweet taste (Table 4). Cultivars Selemani, Langalanga nyekundu, Mjinga mfutu and Khalidi had sour taste, Langalanga nyeupe was tasteless and only Gafembee had a bitter taste.

The relationship between bird preference and grain taste did not indicate whether birds preferred a particular seed taste, because while one would expect that all sweet sorghum cultivars would be highly bird preferred; exception for Mnyambi which is sweet and relatively less bird preferred with grain loss of 45.48% only. In contrary, Langalanga nyekundu and Mjinga mfutu, which had sour taste, were more preferred by birds resulting into grain loss of 65% and 63% respectively.

4.1.4 The relationship between grain colour and bird preference

Out of the 18 studied sorghum varieties, seven cultivars were classified as brown sorghum based on the testa colour or pericarp colour (Table 4). These include Selemani, Mnyambi, Gafembee, Langalanga nyeupe, Fara, Nkhasa and Khalidi. However, three cultivars; Selemani, Langalanga nyeupe and Khalidi had white pericarp with small brown spots. This masks the brown coloured testa and may give wrong impression about the colour of the sorghum grain should selection be done based on seed coat colour. Langalanga manyea ng'ombe and Ntora were classified as tan coloured, whereas red sorghum was Langalanga nyekundu only and the remaining eight cultivars were classified as white sorghum.

The study confirmed, however, that there was some association between brown colour and high tannin content in sorghum (Tables 4 and 8). For instance:- Fara, Nkhasa and Ufemba are both brown with high tannin levels of 5.45%, 4.36% and 3.79% CE. Hahn *et al.* (1984) report on the relationship between sorghum grain pigment and Tannin concentration agree with these findings.

While it is generally claimed by some authors that brown sorghum is less preferred by birds (resistant to bird) (Sharma and Davies, 1988); Fara, Nkhasa and Ufemba which are brown coloured were highly preferred by birds with grain losses of 77.45%, 74.91% and 81.45% respectively.

The study also revealed that sorghum grain colour was not well developed during dough stage, the time when birds attacked the sorghum. At dough stage almost all sorghum grains were pale green regardless of the cultivars. This made the use of colour criterion in studying bird preference and efficiency evaluation of relationship of sorghum grain colour and bird damage unreliable.

4.1.5 The influence of grain hardness on bird preference

The results for grain hardness are presented in Table 4. Thirteen out of the eighteen cultivars had intermediate to soft grains. The cultivars Langalanga manyeang'ombe, Macia, Wahi, Ntora and Nsukunu had hard grains.

The results also indicated that there was little influence of grain hardness on bird preference in sorghum. This is because all sorghum cultivars with hard grains like

Langalanga manyeang'ombe, Macia, Wahi, Ntora and Nsukunu were highly preferred by birds with bird damage ranging from 83% - 99%. The cultivars Khalidi, Mnyambi, Gafembee and Selemani possessing intermediate grain hardness, were less bird preferred with bird damage ranging between 20% and 60% (Table 5).

It may, however, be due to differences in stage of growth and time of grain hardness analysis. Bird attack on sorghum is serious during dough stage of reproductive phase and hardness analysis is done on harvested dry grain mainly for determination of losses of dehulled grains. Lack of available technological recommendation for determination of grain hardness when sorghum is at dough stage was one of the draw back to this study. It should be born in mind that, birds have no teeth and therefore sorghum grain hardness may not be good criterion for evaluation of bird preference unless it is related to digestibility, nutrients availability and absorption.

4.1.6 The relationship between days to 50% flowering and bird damage

The results on period taken to attain 50% flowering in sorghum cultivars varied between 60 and 85 days (Table 5). Generally these results are within the normal range of sorghum flowering period of 30 to 100 days as reported by Purseglove (1975) and House (1985). Among the eighteen tested cultivars, Khalidi was the earliest maturing cultivar than all the cultivars, attaining 50% flowering in 45 days after emergence. It was followed by the improved cultivars, which took 61days for Tegemeo, Hakika and Wahi; 62 days for Pato and 63 days for Macia. The latest maturing cultivar was Langalanga nyeupe, which took 88 days to 50% flowering (Fig. 1 and Table 5).

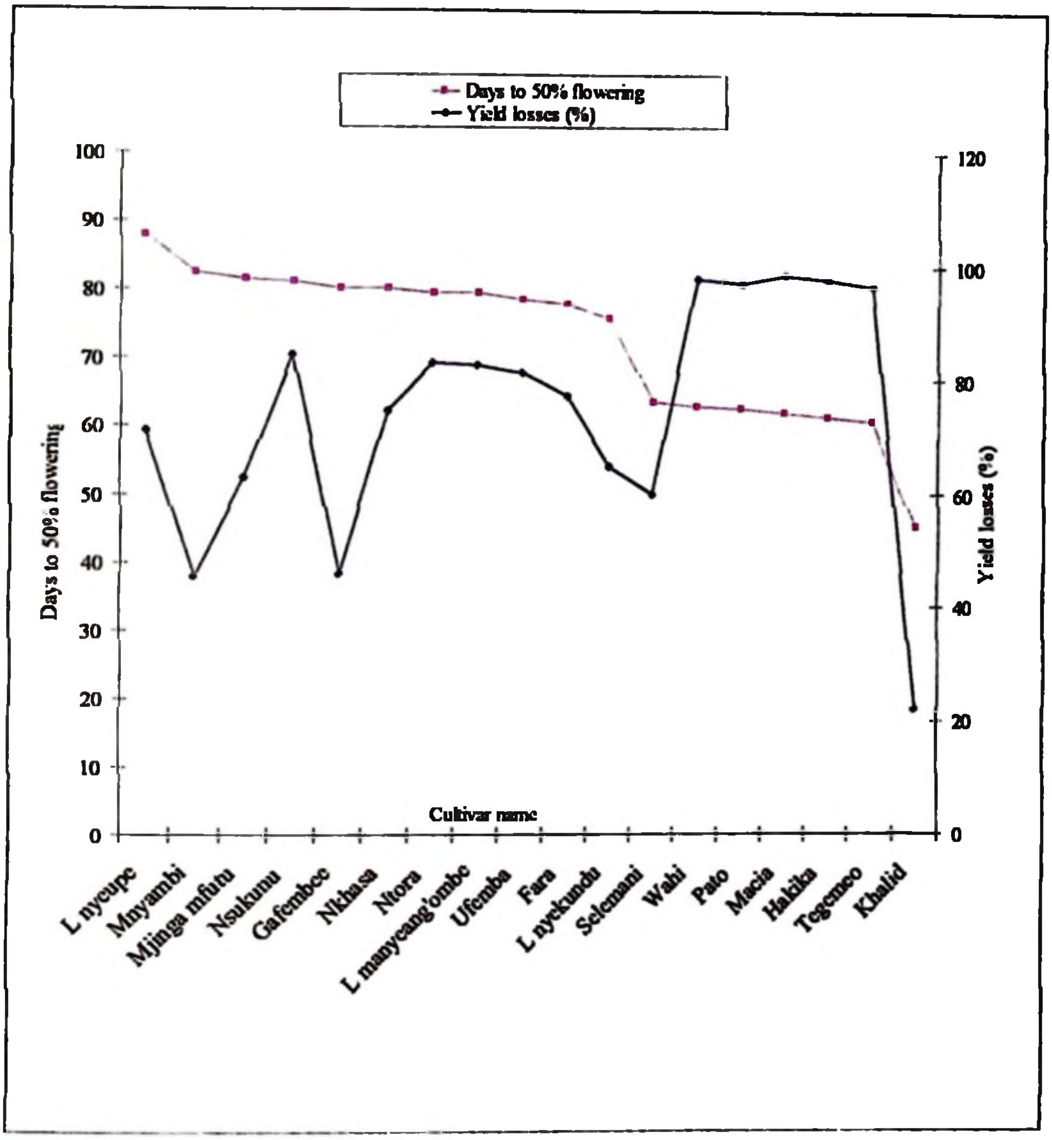

Figure 1: The relationship between numbers of days to 50% flowering and yield losses due to birds' attack

The attribute of period to 50% flowering gave no clear linkage with respect to bird damage levels. There was a negative correlation with no significant statistical differences between the duration to 50% flowering and yield losses due to bird damage (Table 7 and Fig. 1). For example, while Khalidi matured earliest, was less preferred by birds with the lowest yield loss of 22.24% than all sorghum cultivars studied. Langalanga nyeupe was the latest to mature taking 88 days and was among the highly preferred cultivars by birds with high yield loss of 71.37%. Gafembee which took slightly less period to mature than Langalanga nyeupe was not severely damaged by birds showing yield loss of 45% and was the third less bird preferred sorghum cultivar after Khalidi and Mnyambi (Table 5).

Generally, there was slight relationship between days to 50% flowering and bird damage variation among cultivars. Cultivars that flowered earlier had more yield losses than the late flowering cultivars due to delayed harvesting time. For example Tegemeo, Hakika Wahi, Pato and Macia which are early maturing had high yield losses, with exception of Khalidi which had the lowest yield loss than all other cultivars (Table 5). Relay planting intervals with respect to flowering period of each cultivar may minimize grain losses through synchronized flowering,

4.1.7 The influence of grain weight and bird damage in sorghum

Results for grain weight are indicated in Table 6, in which most of cultivars had grain weights ranging between 2.0 and 3.5g with exception of Mjinga mfutu which had high grain weight of 6.18g/1000 seeds followed by Tegemeo with 3.49g/1000 seeds and Mnyambi with 3.39g/1000 seeds. The lowest grain weight was that of Gafembee which is 1.46g /1000 seeds (Fig. 3).

Generally, the study showed stable yield losses irrespective of the grain weight (Fig. 3), thereby making the relationship between grain weight and bird damage unpredictable. For example while Mjinga mfutu had the largest grain weight

(6.18g/1000seeds) and was observed to be highly preferred by birds, Gafembee with the smallest grain weight (1.46g/1000seeds) was relatively less preferred by birds. On the other hands, Macia with grain weight slightly large (1.61g/1000seeds) than Gafembee which was highly affected by birds with a loss of 98.91% (Fig. 2).

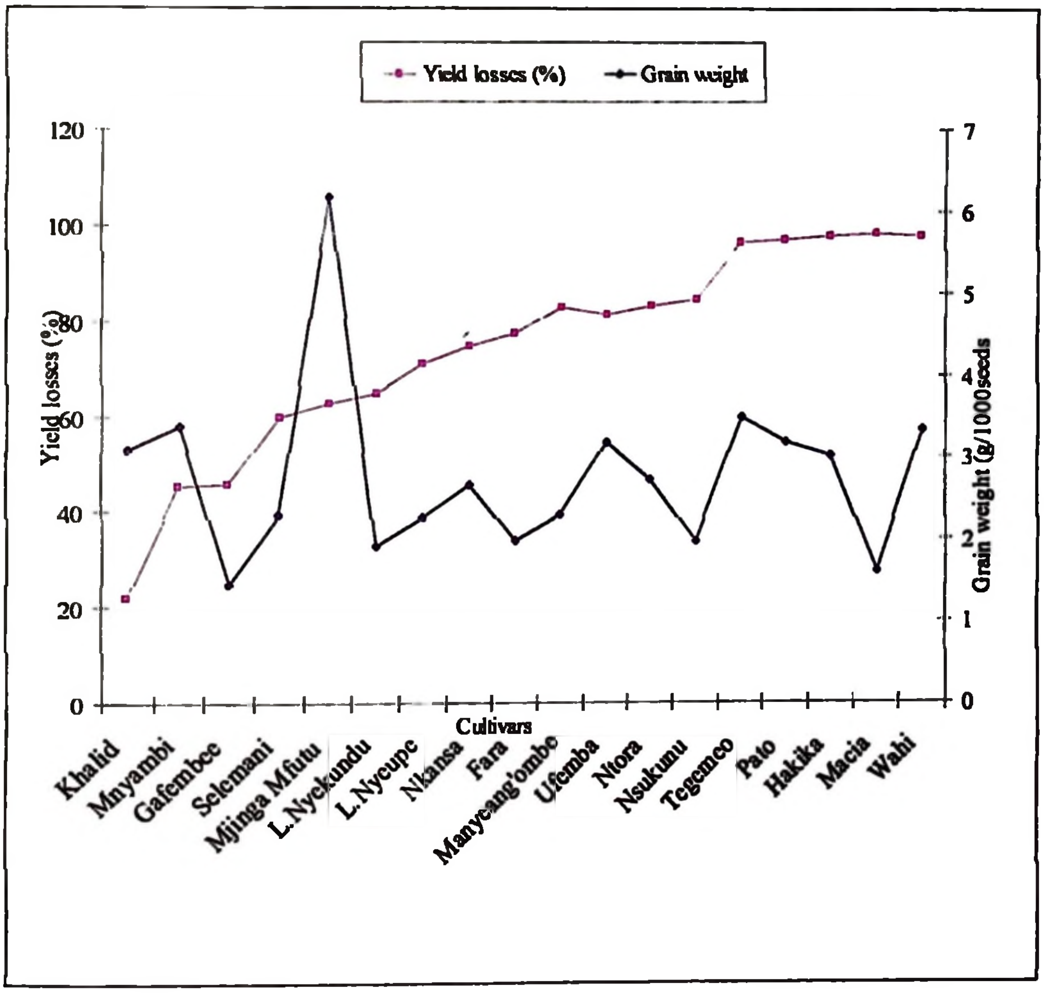

Figure 2: Relationship between grain weight and yield losses due to bird damage

The grain weight was measured on whole grain with an assumption that birds consume the whole grain. It was observed later that at dough stage grains are still

Table 5: Maturity, grain weight and yield losses due to bird attack

Cultivar names	Days to 50% flowering	Grain weight (%)	Yield with bird control (Kg/ha)	Yield without bird control (Kg/ha)	Yield Loss (%)
Macia	62.00 d	1.61 h	2 673 a	39.71 gh	98.51
Pato	62.67 d	3.18 cd	2 515 b	71.09 fgh	97.17
Tegemeo	60.67 d	3.49 b	2 488 b	84.33 fgh	96.61
Hakika	61.33 d	3.03 d	1 963 c	43.97 gh	97.76
Selemani	63.67 d	2.31 f	1 726 d	688.10 b	60.13
Wahi	63.00 d	3.34 bc	1 664 d	34.72 h	97.91
Mnyambi	82.67 ab	3.39 bc	1 362 e	742.50 b	45.48
Gafembee	80.33 bc	1.56 h	1 317 ef	710.20 b	46.07
Langa nyeupe	88.00 a	2.28 f	1 281 fg	366.80 cd	71.37
Mjinga mfutu	81.67 bc	6.18 a	1 258 fg	465.30 c	63.00
Langa nyekundu	76.00 c	1.93 g	1 251 fg	438.10 c	65.00
Khalidii	45.33 e	3.10 cd	1 248 fg	970.40 a	22.24
L.manyeang'ombe	79.67 bc	2.31 f	1 225 gh	208.80 ef	82.94
Fara	78.00 bc	1.99 g	1 165 hi	262.70 de	77.45
Ntora	79.67 bc	2.73 e	1 126 ij	188.30 efgh	83.28
Ufemba	78.67 bc	3.19 d	1 075 jk	199.40 efg	81.45
Nkansa	80.33 bc	2.67 e	1 072 jk	269.00 de	74.91
Nsukunu	81.33 bc	1.98 g	1 036 k	159.40 efgh	84.62
Coefficient of Variations	3.45%	5.70%	2.57%	19.03%	

Means followed by the same letter (s) are not statistically different according to mean separation by DMRT.

soft and birds do not necessarily feed on the whole grain but break the grain to access the soft juicy endosperm. This suggests that neither large grain weight nor small size determined the level of bird damage or preference in sorghum (Table 7).

4.1.8 Sorghum grain yield potentials from bird controlled plots.

Among the evaluated eighteen sorghum cultivars on yielding potential, Macia was observed to be the highest yielder with a mean yield of 2 673 kg/ha followed by Pato and Tegemeo with mean yields of 2 515 kg/ha and 2 488 kg/ha respectively. Both cultivars are improved varieties. There were no statistical ($P \leq 0.01$) yield difference between Pato and Tegemeo; Selemani and Wahi; Langalanganyeupe, Mjinga mfutu, Langalanga nyekundu and Khalidii; and between Ufemba and Nkhansa (Table 5). Among the thirteen local cultivars studied, Selemani outperformed all the others by producing 1 726 kg/ha grain yield followed by Mnyambi with 1 362kg/ha and Gafembee 1 317 kg/ha. It was the fifth among the high yielding cultivars after Macia, Pato Tegemeo and Hakika (Table 5 and Fig 3). It compared with the improved cultivar Wahi whose average yield was 1 664 kg/ha. This implies that, crop improvement of the Selemani cultivar may make it more productive than all of the current improved varieties in use.

The lowest yield of 1 664kg/ha among the improved cultivars was produced by Wahi and among the local cultivars, Nsukunu gave the lowest yield of 1 036 kg/ha of all cultivars in the trial. These results are in consistent with the yield estimates given by FAO (1996) for Africa and Asia regions, which are estimated between 800kg/ha and 1 200 kg/ha for improved and unimproved cultivars respectively.

4.1.9 Sorghum grain yields without bird control and yield losses estimates.

Different types of birds attacked sorghum indiscriminately at dough stage to maturity by eating seeds. Among these included Sudan dioch (*Quelea quelea*) Sparrows (*Passers spp*), pigeons (*Columba spp*), Crows (*Corvus spp*), weavers (*Ploceus spp*) and Doves (*Streptopelia spp*). They either consumed the whole seed or broke seeds by eating portions and leaving half of the seed on the panicle hence opening a window for moulding. This damage was easily recognized through broken and exposed white endosperm of the seed when inspected shortly after the attack before growing of moulds and oxidation processes.

From the results in Table 5, comparing levels of bird damages among evaluated cultivars, local cultivars generally outperformed the improved cultivars, where Khalidii cultivar emerged as the least bird preferred cultivar with highest grain yield of 970.40 kg/ha followed by Mnyambi, Gafembee and Selemani, with yield of 742 kg/ha; 710.20 kg/ha and 688.1 kg/ha respectively. However, there were no statistical difference in bird preference between Mnyambi, Gafembee and Selemani. Other local cultivars that outperformed the improved cultivars in terms of yield loss are Mjinga mfutu with 465.30 kg/ha and Langalanga nyekudu that yielded 438.10 kg/ha and were not statistically different.

Generally, all the improved cultivars had low yield levels when subjected to indiscriminate birds attack. For example; the improved cultivar Wahi had the lowest yield of 34.72 kg/ha followed by Macia with 39.71 kg/ha and Hakika with 43.97

kg/ha (Fig.4) despite that there were no statistical difference between Macia and Hakika. According to the results in Table 5, these cultivars were highly affected by birds with yield losses ranging from 98 to 99 % while the local cultivars Khalidi, Mnyambi, Gafembee and Selemani were less bird preferred and had yield losses ranging between 20-61%.

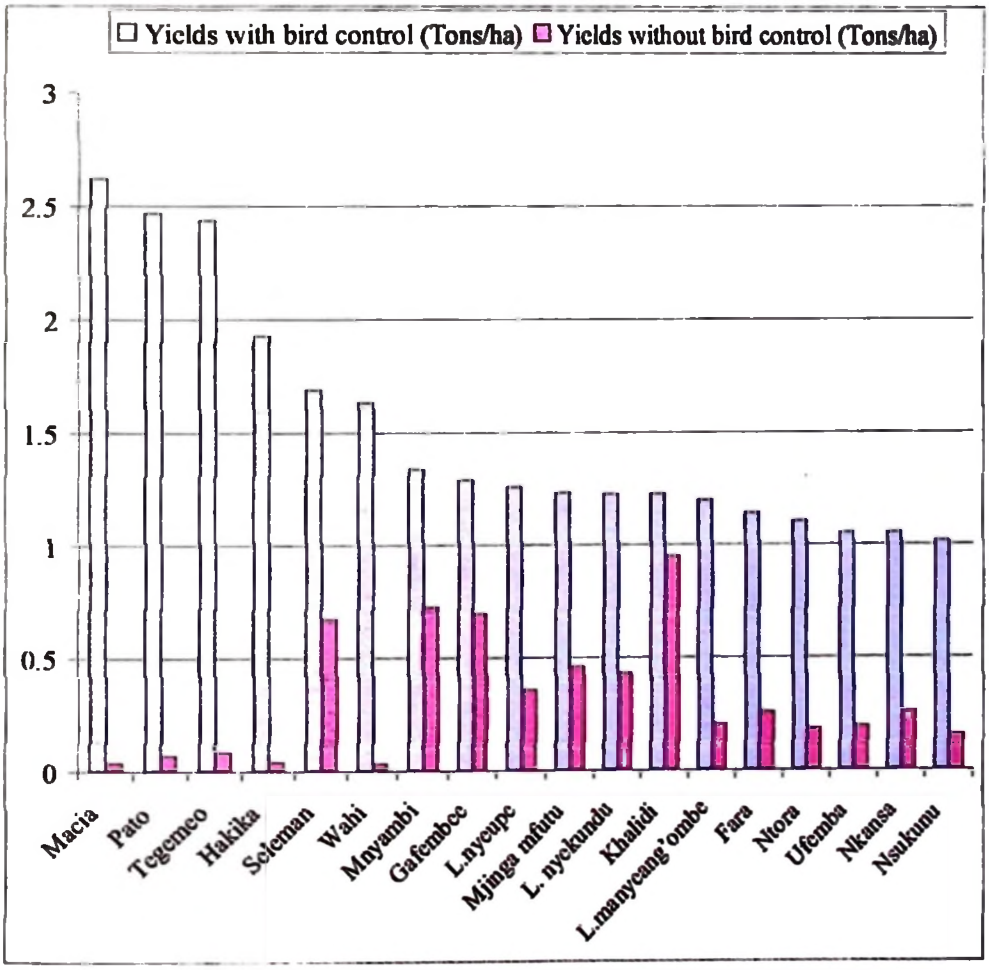

Figure 3: Differences in yield levels of cultivars between bird controlled and uncontrolled sorghum plots

For better comparison of the yield differences the results have been presented in Fig.3. In terms of yield losses percentage; Khalidi had the lowest grain loss of 22.2% followed by Mnyambi with 45.5%, Gafembee with 46.1% and Selemani with 60.1% (Table 5 and Fig. 4). Because these are less bird preferred cultivars and given the competitive nature of crops diversification and management by farmers in terms of time and economic importance, farmers would still prefer having little harvest without bird scaring in years of heavy infestation. This implies that these cultivars although are low yielding may still be preferred by farmers than the improved cultivars with high yields but with high production costs in terms of bird scaring.

Although Macia, Pato, Tegemeo, Hakika are improved and high yielding (Table 5) the cultivars were highly affected by birds with yield losses of 99%, 97%, 97%, and 98% respectively. These grain losses are too high suggesting that cultivation and production of these cultivars will require bird scaring. These yield losses are similar to yield losses reported by Brugger and Ruelle (1981), who recorded yield losses of more than 75 % caused by bird attack in Senegal.

4.2 Relationship between nutritional properties and grain yield losses

4.2.1 Ether extracts (Fat content)

The fat content for the eighteen cultivars (Table 6) falls within the range of 2.0-3.0 % a range within the data reported by Purseglove (1975). The variety Mjinga mfutu ranked the highest with 3.2% followed by Tegemeo, Langalanga nyeupe, and Khalidi with 3.1%, 3.0% and 2.9% fat contents respectively. There were no statistical differences between these cultivars. Hakika, Ufemba and Nkhasa ranked the third and had fat content of 2.4%, 2.3 and 2.3% respectively with no significant differences between them. The cultivars Pato, Ntora, Fara, Wahi, Langalanga manyeang'ombe, Langalanga nyekundu and Nsukunu ranked fourth in terms of fat contents and were not significantly different. The cultivars Selemani, Mnyambi and Gafembee had the lowest fat content of about 2.0%

Fat content (Table 7) had a negative correlation with tannin and grain losses and with no significant differences. However, fat content was positively correlated with yield loss, crude fibre, and crude proteins but with no statistical differences. Fat content correlated positively by correlation coefficient of 0.59 with significant statistical ($P \leq 0.05$) differences to grain weight. This implies that any breeding improvement with respect to fat content will lead to direct improvement in crude fibre, crude protein and grain weight (Table 7).

Considering bird preferences in sorghum on basis of fat content influence, there was no direct relation observed because while Mjinga mfutu, Tegemeo and Langalanga nyeupe are highly preferred by birds; Khalidii, with the same range of fat content was least preferred among all 18 evaluated cultivars. In addition, Selemani, Mnyambi and Gafembee had very low fat content and were both less preferred by birds. Therefore fat had no influence on birds' preference in sorghum.

4.2.2 Crude protein contents

The results indicated in Table 6 and Fig 4; show that sorghum cultivar Khalidi had the highest crude protein (12.2% CP) and was significantly different ($P \leq 0.01$) from others. Hakika was second with crude protein of 12.0% and was statistically different ($P \leq 0.01$) from other cultivars. However, the cultivars Mjinga mfutu with 11.4% CP and Wahi 11.2% CP were not statistically different. Mnyambi and Fara had equal crude protein content (10.7 % CP) and were not statistically different. The lowest crude protein was obtained from cultivar Nkhasa (8.4 %CP) followed by Ntora and Langalanga nyeupe with 8.9% and 9.1% CP respectively and were not statistically different. These results for crude proteins in sorghum are similar to that reported by Purseglove (1975) who obtained approximately 8-15 per cent protein. Further more, crude protein results obtained by Jambunathan and Subramanian (1988) generally ranked sorghum cultivars as being medium (Table 2).

Khalidi, although is a local cultivar, outperformed both improved and unimproved cultivars in terms of crude protein content. In addition to being less preferred by birds, this is another very important attribute for this cultivar in breeding programmes. Other cultivars; Mnyambi, Gafembee and Selemani which contained 10.7%, 10.5% and 9.4% crude protein respectively, are also promising cultivars because these cultivars are less preferred by birds (Table 6 and Fig. 4).

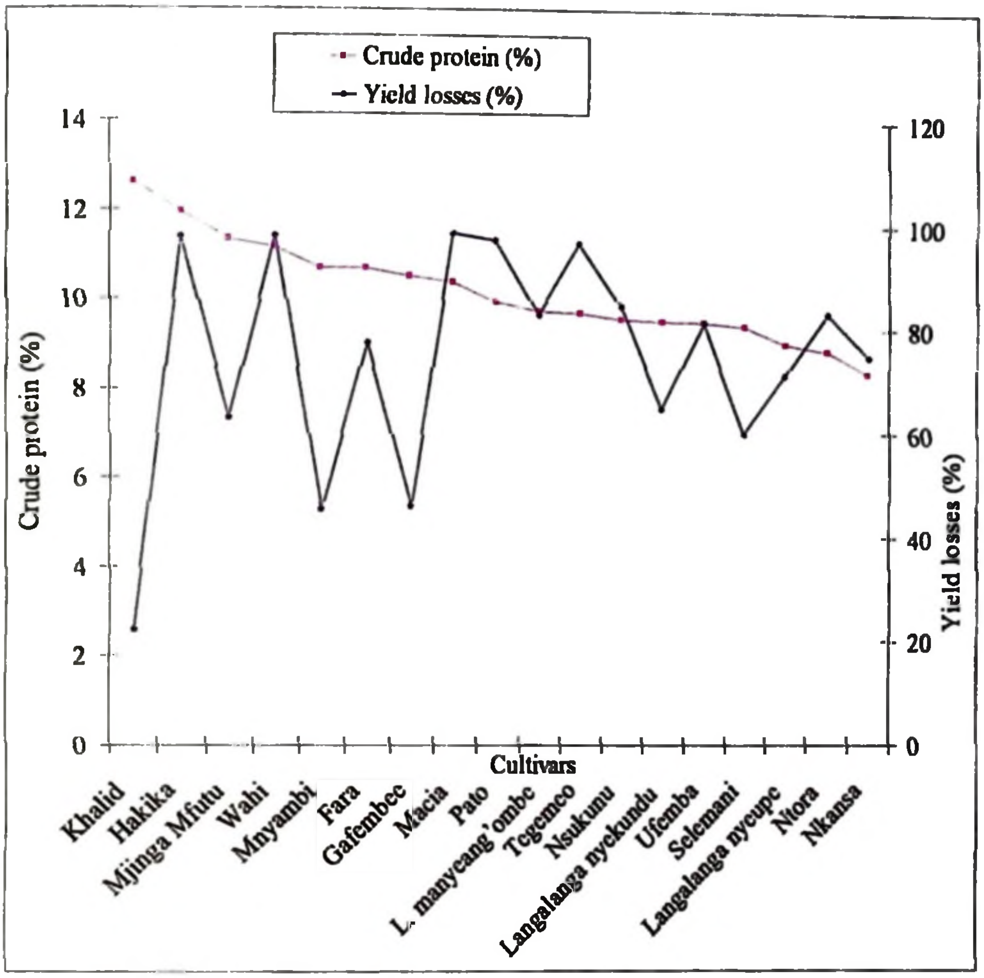

Figure 4: The relationship between crude protein contents and sorghum grain yield losses (%).

Crude protein was positively correlated to yield loss, crude fibres, fat content, grain weight, and tannin levels with no significant statistical ($P \leq 0.05$) differences (Table 7). Again the positive correlation between crude protein, yield loss and tannin is of demerit nutritionally, although it explains why Khalidi outperformed all other cultivars with respect to both nutritional and less preferred by bird qualities. This is because tannins have anti-nutritional properties through binding protein thus rendering proteins indigestible and unavailable in sorghum (Burns, 1971). This could be the reason for certain sorghum cultivars being less preferred by birds.

Crude protein was found (Table 7) to be negatively correlated with coefficient of -0.83 and there were high significant ($P \leq 0.001$) differences for carbohydrates, days to 50% flowering by correlation coefficient of -0.55 and statistically significant ($P \leq 0.05$) with yield losses. This implies that breeding for improvement of crude protein in sorghum will negatively affect the carbohydrate content, yield losses and growth duration (50% FLW). This may be an advantage of escaping the bird influx because plants will mature early before bird breeding season and thus reduces bird damage.

Khalidi, however, was observed to be of nutritional improvement merit, because while sorghums are generally low in protein content, the cultivar had the highest crude protein content which could be used to improve the trait in other sorghum cultivars. Sorghum grows well in semi arid region where some protein rich crops do not perform very well and thus breeding for protein quality sorghum using Khalidi cultivar may be a sustainable opportunity for alleviating protein related malnutrition in such areas.

4.2.3 Ash (mineral) content

Ash content results of the eighteen evaluated cultivars ranged between 1.0 and 1.6%, and were compared to normal ash content ranges of 1.5-2.0 % in sorghum as reported by Purseglove (1975). Variation among the studied cultivars shows that, Hakika cultivar had the highest ash content of 1.60 % followed by Khalidi with 1.58 %, but were not significantly different ($P \leq 0.01$). Nsukunu and Langalanga nyeupe ranked the second with ash content level of 1.48%. Mjinga mfutu, Selemani and Ufemba with 1.46%, 1.44% and 1.44% ash content levels respectively were ranked third and were not significantly different. Langalanga manyeang'ombe, Tegemeo and Fara had the lowest ash content of 1.20%, 1.16% and 1.15 % respectively and were not statistically different. These results for mineral content were generally low (Table 2) based on ranking given by Jambunathan and Subramanian (1988) may be due to sand soils and water logging in areas where the crop was grown which might have experienced nutrient leaching. On the other hand, keeping in mind that Hakika is an improved cultivar and Khalidi is a local cultivar, Khalidi stands a good chance of improvement with respect to mineral content.

4.2.4 Crude fibre

As indicated in Table 6, evaluated cultivars had crude fibre ranging between 2.0 and 3.81%. These results agreed with the reported range of 1-3 % (Purseglove, 1975). Out of the eighteen evaluated cultivars, Gafembee had significantly the highest amount of crude fibre of about 3.81 % compared to other cultivars.

Second in rank included Khalidi with 3.39 %, Mjinga mfutu with 3.33 %, Pato with 3.30 % and Mnyambi with 3.29 %, all of which were not statistically different. Nsukunu ranked the third with 3.09 % and was statistically different from other cultivars.

Table 6: Selected nutritional properties for studied sorghum cultivars

Cultivar name	Ether extract	Crude Protein	Ash content	Crude fibres	CHO Content
Khalidi	2.96a	12.64a	1.58a	3.39b	68.08i
Hakika	2.420b	11.97b	1.60a	2.07i	70.47gh
Mjinga mfutu	3.15a	11.36c	1.46bc	3.33b	69.73h
Wahi	2.25bc	11.18c	1.32fg	2.74efg	70.61g
Mnyambi	2.02cd	10.70d	1.39cdef	3.29b	1.84def
Fara	2.28bc	10.70d	1.15h	2.89de	72.94bc
Gafembee	2.09cd	10.53de	1.34efg	3.81a	70.30gh
Macia	2.10cd	10.41e	1.30g	2.47h	71.89def
Pato	2.30bc	9.96f	1.40cde	3.30b	71.87def
L. Manyeangombe	2.25bc	9.76g	1.20h	3.00cd	71.13efg
Tegemeo	3.12a	9.71gh	1.16h	3.02cd	71.05fg
Nsukunu	2.23bc	9.58ghi	1.48b	3.09c	72.51cd
L. nyekundu	2.25bc	9.54hi	1.42bcd	2.59gh	71.98de
Ufemba	2.32b	9.52hi	1.44bc	3.00cd	73.40b
Selemani	2.01d	9.42i	1.44bc	3.03cd	72.51cd
L. nyeupe	2.97a	9.04j	1.48b	2.62fgh	72.57 bcd
Ntora	2.29bc	8.87j	1.36defg	2.96cd	72.65bcd
Nkhasa	2.44b	8.38k	1.39cdef	2.78ef	75.20a
CV values	3.55%	0.84%	2.24%	2.43%	0.50%

Means followed by the same letter (s) are not statistically significant different according to mean separation by DMRT.

The fourth group included Selemani, Tegemeo, Langalanga manyeang'ombe, Ufemba and Ntora with crude fibre content that were not statistically different. Hakika had the lowest crude fibre content of 2.07% of all cultivars. Correlation analyses (Table 7) shows that, crude fibre has positive correlation of 0.47 with Tannin and were statistically significant ($P \leq 0.05$). The trait was also positively correlated with crude protein, ether extract and grain weight but not statistically different. There was also a negative correlation of -0.58 between fibre content levels and yield losses in sorghum with significant negative statistical difference ($P \leq 0.05$). Gafembee, Khalidii and Mnyambi ranked high in crude protein, crude fibre and tannin contents and are relatively less bird preferred and therefore they are more superior for these parameters compared to the rest of the cultivars tested.

4.2.5 Carbohydrates (CHO)

Results in Table 6 show that carbohydrates ranged between 68 to 75% which was a normal carbohydrate range for sorghum when compared to the range of 68- 74% established by Purseglove (1975). Comparing carbohydrate content among cultivars, Nkhasa had the highest CHO content (75.2 %) followed by Ufemba (73.4 %) and were statistically different ($P \leq 0.01$). Fara with 72.9% CHO which was statistically different ($P \leq 0.01$) from the other cultivars and Khalidi had the lowest CHO content (68.1 %).

Carbohydrate levels had positive correlation with Tannin, yield losses and days to 50% flowering and had statistical significant differences ($P \leq 0.05$) (Table 7).

Carbohydrate was very highly statistically significant ($P \leq 0.001$) correlation (-0.83) with crude protein. It also had a positive correlation (0. 53) to days to 50% flowering which was statistically significant ($P \leq 0.05$). Nkhasa, Fara and Ufemba were highly preferred by birds and were affected by birds resulting in yield losses of 74.9%, 77.5% and 81.5% respectively. These results indicate that there was some direct relationship between CHO content and bird preference in sorghum.

Table 7: Simple correlation between selected physical and chemical properties as they influence intensity of bird attack in sorghum

Rows	CHO %	Crude fibres %	Crude Protein %	Days to 50% Flower	Ether extract %	1000 grain weight	Tannin %
CHO %	1						
Crude Fibres %	-0.29NS	1					
Crude Protein %	-0.83 ***	0.09 NS	1				
Days to 50% Flower	0.53*	0.10NS	-0.55*	1			
Ether Extract %	-0.37NS	0.04NS	0.20 NS	-0.14NS	1		
1000 grain weight	-0.34NS	0.18NS	0.37NS	-0.05NS	0.59**	1	
Tannin %	0.12NS	0.47*	0.07 NS	-0.01NS	-0.29NS	-0.24NS	1
Yield losses %	0.35	-0.58*	-0.29NS	-0.02NS	-0.10NS	-0.04NS	-0.63**

Note: * ($P \leq 0.05$) = significant at 5%; ** ($P \leq 0.01$) = highly significant at 1%;

*** ($P \leq 0.001$) = very highly significant at 0.1% and NS= not significant

Table 8: Sorghum grain yield losses (%) and tannin levels in percent Catechin Equivalent (%CE)

Cultivar name	Yield losses (%)	Tannin (%CE)	Tannin classification
Macia	98.52	0.139	Low
Pato	97.17	0.828	Intermediate
Tegemeo	96.61	0.032	None
Hakika	97.76	0.064	None
Selemani	60.13	5.621	High
Wahi	97.92	0.223	Low
Mnyambi	45.48	3.885	High
Gafembee	46.07	6.242	High
Langalanga nyeupe	71.37	0.016	None
Mjinga mfutu	63.00	0.080	None
Langalanga nyekundu	65.00	0.446	Intermediate
Khalidii	22.27	4.554	High
Langalanga manyeang'ombe	82.96	0.143	Low
Fara	77.45	5.446	High
Ntora	83.29	0.096	None
Ufemba	81.45	3.790	High
Nkansa	74.91	4.363	High
Nsukunu	84.62	0.000	None

4.2.6 The influence of tannin content on bird preference in sorghum

Out of the 18 evaluated cultivars for tannin content (Table 8), six were classified as high tannin and brown sorghum. These included Gafembee, Selemani, Fara, Khalidii, Nkansa, Mnyambi and Ufemba. Among high tannin sorghum, Gafembee had the highest tannin content and Ufemba the lowest. Langalanga nyekundu and Pato had intermediate tannin levels. Macia, Wahi and Langalanga manyeangombe were classified as low tannin sorghums. The remaining cultivars were classified as having no tannin.

Based on the results presented in Table 8; Gafembee, Selemani, Fara, Khalidi, Nkhasa, Myambi and Ufemba cultivars were identified to have high tannin levels and were brown sorghums . The result of correlation coefficient indicated a strong positive correlation of 0.63 between tannin levels and yield loss and Tannin had positive correlation coefficient of 0.47 with crude fibres and all were statistically and significantly different ($P \leq 0.05$). This implies that increase in crude fibre will increase in tannin but decrease yield losses in sorghum. Tannin, on the other hand, was negatively correlated with days to 50% flowering; ether extract and grain weight (Table 7).

Table 8 shows that cultivars with low tannin content generally had high grain yield losses than those with high tannin content. There are some exceptions however, because Nkhasa, Ufemba and Fara, had higher tannin contents than Khalid and Mnyambi, but they were much affected by birds than the later. Only Gafembee had highest tannin content and equally less bird preferred by birds, indicating some direct relationship between the two parameters.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

The study has not generated exhaustive information to answer some of the research questions and objectives. No single parameter was identified to be specific as factor for either less or high bird preference in sorghum.

Generally Khalidi, Mnyambi, Gafembee and Selemani were the less bird preferred sorghum. Khalidi outperformed all of the eighteen studied cultivars and compared well with other cultivars in days to maturity, yield loss (less preferred by bird) levels, crude protein content, ash content and fat content. Although Khalidi exhibited high tannin, crude proteins, ash content, fat content and crude fibre levels, these parameters did not uniquely contribute to it being less preferred by birds. These parameters however, made Khalidi the most promising cultivar for improvement and use in improving other cultivars with regards to nutritional qualities and efforts in addressing the bird attack problem in sorghum growing areas.

The study observed no influence of physical and chemical properties on bird preference in sorghum. However, there was some relationship between grain colour and tannin contents which showed that all brown sorghum cultivars had high tannin contents. Most of cultivars with high tannin content were less preferred by birds than those with low tannin content. However these results are not enough to conclude that tannin had influence on bird preference in sorghum. Farther exploration of the actual factors that might be associated with bird preference in sorghum is needed. Tannin was positively correlated with crude fibre and negatively correlated to yield losses; Tannin and crude fibre were observed to be more associated with less bird preference than any other parameters. There was strong negative correlation between protein and carbohydrates and days to 50% flowering. On the other hand, Fat content significantly correlated positively with crude protein, crude fibre and grain weight. A breeding programme to improve fat content in sorghum will also lead to direct nutritional improvement in crude fibre, crude protein and grain weight.

The results revealed no significant difference in nutritional qualities between less and highly bird preferred sorghum cultivars. Intensive screening and biotechnological research involving many cultivars need to be done to have a wide range of statistical comparison. Multiple testing across different locations and seasons (years) to account for bird's influx, bird type and sorghum damage variations is recommended. Influences of nutritional parameters like proteins, fats, mineral and crude fibres on birds' sorghum preference need further investigation especially using live caged birds to assess digestibility and nutrients availability; factors that might have contribution to bird preference in sorghum.

Studies on techniques of evaluating bird preference in sorghum are needed and could take into consideration of applicability at dough (milky) stage at which the birds seriously attack the crop.

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7.0 APPENDIXES

APPENDIX 1: ANOVA table for grains yield from bird controlled sorghum

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	4622.71	2311.355	1.50	0.2367
Entry (1-18)	17	14567994.87	856940.875	557.53	0.0000
Error	34	52259.12	1537.033		
Non-additivity	1	796.42	796.417	0.51	
Residual	33	51462.70	1559.476		
Total	53	14624876.70			

Grand Mean= 1524.774 Grand Sum= 82337.786 Total Count= 54

Coefficient of Variation= 2.57%

APPENDIX 2: ANOVA table for grains yield from bird uncontrolled sorghum

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	15550.05	7775.025	1.97	0.1550
Entry (1-18)	17	4062795.06	238987.944	60.57	0.0000
Error	34	134150.10	3945.591		
Non-additivity	1	14993.55	14993.555	4.15	0.0497
Residual	33	119156.54	3610.804		
Total	53	4212495.20			

Grand Mean= 330.159 Grand Sum= 17828.598 Total Count= 54

Coefficient of Variation= 19.03%

APPENDIX 3: ANOVA table for grain weight in grams per 1000 seeds

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	0.19	0.094	3.72	0.0347
Entry (1-18)	17	57.22	3.366	133.35	0.0000
Error	34	0.86	0.025		
Non-additivity	1	0.00	0.001	0.03	
Residual	33	0.86	0.026		
Total	53	58.26			

Grand Mean= 2.786 Grand Sum= 150.430 Total Count= 54

Coefficient of Variation= 5.70%

APPENDIX 4: ANOVA table for days to 50% flowering

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	0.11	0.056	0.01	0.9912
Entry (1-18)	17	6568.83	386.402	61.81	0.0000
Error	34	212.56	6.252		
Non-additive	1	1.25	1.250	0.20	
Residual	33	211.31	6.403		
Total	53	6781.50			

Grand Mean=72.500 Grand Sum=3915.000 Total Count=54

Coefficient of Variation= 3.45%

APPENDIX 5: ANOVA table for ether extract (fat content)

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	0.04	0.022	2.95	0.0661
Entry (1-18)	17	7.02	0.413	56.14	0.0000
Error	34	0.25	0.007		
Non-additive	1	0.00	0.000	0.00	
Residual	33	0.25	0.008		
Total	53	7.31			

Grand Mean= 2.414 Grand Sum=130.350 Total Count=54

Coefficient of Variation= 3.55%

APPENDIX 6: ANOVA table for crude protein contents

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	0.00	0.001	0.14	0.8733
Entry (1-18)	17	62.55	3.680	507.96	0.0000
Error	34	0.25	0.007		
Non-additive	1	0.01	0.008	1.09	0.3037
Residual	33	0.24	0.007		
Total	53	62.80			

Grand Mean= 10.181 Grand Sum= 549.800 Total Count= 54

Coefficient of Variation= 0.84%

APPENDIX 7: ANOVA table for mineral contents

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	0.01	0.003	3.64	0.0371
Entry (1-18)	17	0.81	0.048	49.59	0.0000
Error	34	0.03	0.001		
Non-additivity	1	0.00	0.001	1.06	0.3110
Residual	33	0.03	0.001		
Total	53	0.85			

Grand Mean= 1.384 Grand Sum= 74.730 Total Count= 54

Coefficient of Variation= 2.24%

APPENDIX 8: ANOVA table for crude fibre

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	0.00	0.000	0.00	0.9968
Entry (1-18)	17	8.00	0.471	90.43	0.0000
Error	34	0.18	0.005		
Non-additive	1	0.00	0.002	0.33	
Residual	33	0.18	0.005		
Total	53	8.18			

Grand Mean= 2.966 Grand Sum=160.140 Total Count=54

Coefficient of Variation= 2.43%

APPENDIX 9: ANOVA table for carbohydrate contents

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Replication (1-3)	2	0.13	0.067	0.52	0.5986
Entry (1-18)	17	126.61	7.448	57.61	0.0000
Error	34	4.40	0.129		
Non-additive	1	0.02	0.022	0.17	
Residual	33	4.37	0.133		
Total	53	131.15			

Grand Mean=71.707 Grand Sum= 3872.190 Total Count= 54

Coefficient of Variation= 0.50%