THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Science (Tropical Agriculture)
DEGREE

Tropical Agriculture
FIELD

Interdisciplinary Graduate Program
PROGRAM

TITLE: Effects of Seeding Rates and Harvesting Dates on Yield, Oil and Protein Contents and Aflatoxin Incidence in Sesame Seed (*Sesamum indicum* L.)

NAME: Mrs. Mya Thandar

THIS THESIS HAS BEEN ACCEPTED BY

.... **THESIS ADVISOR**

(Associate Professor Ed Sarobol, Ph.D. **)**

.... **THESIS CO-ADVISOR**

(Associate Professor Jindarath Verawudh, Ph.D. **)**

.... **PROGRAM CHAIRMAN**

(Associate Professor Yingyong Paisooksantivatana, Ph.D. **)**

APPROVED BY THE GRADUATE SCHOOL ON ....

.... **DEAN**

(Associate Professor Gunjana Theeragool, D.Agr. **)**

THESIS

EFFECTS OF SEEDING RATES AND HARVESTING DATES ON YIELD, OIL AND PROTEIN CONTENTS AND AFLATOXIN INCIDENCE IN SESAME SEED (*SESAMUM INDICUM* L.)

MYA THANDAR

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science (Tropical Agriculture)
Graduate School, Kasetsart University
2009

Mya Thandar 2009: Effects of Seeding Rates and Harvesting Dates on Yield, Oil and Protein Contents and Aflatoxin Incidence in Sesame Seed (*Sesamum indicum* L.). Master of Science (Tropical Agriculture), Major Field: Tropical Agriculture, Interdisciplinary Graduate Program. Thesis Advisor: Associate Professor Ed Sarobol, Ph.D. 79 pages.

To determine the effects of different seeding rates and harvesting dates on yield of sesame and improvement of seed quality, the field experiment was conducted at the National Corn and Sorghum Research Center, Pak Chong, Nakhon Ratchasima Province during rainy season 2008. A split-plot in RCB design was used and replicated four times. Treatments consisted of four seeding rates (4, 6, 8 and 10 kg ha^{-1}) as main plots and different harvesting dates (52, 56 and 60 days after flowering, DAF) as sub-plots, respectively.

Results revealed that all growth and yield parameters were significantly affected by the seeding rates and harvesting dates. The interaction of seeding rates and harvesting dates significantly affected on all parameters studied, while 1000-seed weight showed no significant interactions. For each seeding rate, delay harvesting increased plant height at harvest, height to first capsule, node numbers per plant, capsule numbers per plant and capsule length, but reduced seed numbers per capsule. Most importantly, for each seeding rate, the greater seed yield was obtained from the early harvest (52 DAF) and the greatest seed yield was from 4 kg ha^{-1} seeding rate. Low seeding rate reduces seed cost. Therefore, it could be suggested that 4 kg ha^{-1} seeding rate application was optimum for high sesame yield.

Aflatoxins are considered a potential hazard to human and animal health, due to their toxicity and carcinogenicity. Aflatoxin contamination in seed occurred at 7.58 ppb which was less than 20 ppb maximum limit. Although the concentration was not toxic level, it is considered unfit for human consumption and trade and may reduce seed quality for consumption. The average oil and protein contents in sesame were 37.46% and 26.36%, respectively.

___________________________ ___________________________ ___ / ___ / ___

Student’s signature   Thesis Advisor’s signature

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation and gratefully acknowledged to my thesis advisor, Associate Professor Dr. Ed Sarobol, for his invaluable suggestions, patient guidance and encouragement throughout the course of this study and completion of thesis. I would like to sincerely thank to my thesis co-advisor, Associate Professor Dr. Jindarath Verawudh, for his kind advice, valuable comments and suggestions. Special thanks are due to Associate Professor Dr. Isara Sooksathan for her valuable advice, suggestion and serving as external examiner and also to Associate Professor Dr. Prapa sripichitt for her comments and being Chairperson for my thesis exam.

I am greatly indebted to Professors, students and staff of Agronomy Department for their kindness and necessary supporting, Mr. Surapol Chowchong and all of the staff of the National Corn and Sorghum Research Center for providing facilities and field assistance. Thanks are due to the Post-harvest and Products Processing Research and Development Office, Department of Agriculture, Chatuchak, Bangkok, for assistance in chemical analysis and aflatoxin determination.

I am deeply indebted to Myanmar Agriculture Service, Ministry of Agriculture and Irrigation, Myanmar and FAO for the financial support to study the master course. I am most grateful to all of my teachers both formal and informal education who teach me valuable knowledge and education from kindergarten up to present.

I am deeply appreciated to both of my parents and parents-in-law who give me heartfelt love and kindly encouragements. My greatest appreciation devotes to my beloved husband and two sons for their eternal love, patience, understanding, encouragement and moral supports. Without them, the study would have never been successful.

Mya Thandar

November 2009

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

Appendix Table **Page**

LIST OF ABBREVIATION

CV	=	Coefficient of Variation
DAF	=	Days After Flowering
DAS	=	Days After Sowing
LSD	=	Least Significance Difference
ppb	=	Parts per billion
RH	=	Relative Humidity
ICRISAT	=	International Crops Research Institute for the Semi-Arid Tropics

EFFECTS OF SEEDING RATES AND HARVESTING DATES ON YIELD, OIL AND PROTEIN CONTENTS AND AFLATOXIN INCIDENCE IN SESAME SEED (*SESAMUM INDICUM* L.).

INTRODUCTION

One of the world's most important and oldest oilseed crops known to man (Gharbia-Abou *et al*., 2000) is sesame (*Sesamum indicum* L.) which is grown throughout the tropical and subtropical regions of the world. In Myanmar sesame has been planted from ancient time and is said to have reached here from India. Myanmar is one of the major sesame producers in the world and occupies the largest growing area, 53% of total oilseed crop area, especially in the Central Myanmar. The oil seed crops grown in Myanmar are groundnut (*Arachis hypogaea* L.), sesame (*Sesamum indicum* L.), sunflower (*Helianthus annuus* L.), soybean (*Glycine max*), mustard (*Brassica* species), niger (*Guizotia abyssinica*) and oil palm (*Elaeis guineensis*). Sesame is grown in all three seasons as (i) the rain crop (ii) the winter crop and (iii) the irrigated (pre-monsoon) crop. It is the major source of edible oil for local consumption and is rich in oil and other nutrient ingredients. Hence, the cultivation of sesame for domestic self-sufficiency particularly, as an edible oil, and as an attractive high quality commodity for export has commended major attention.

Most of the sesame is grown under rainfed conditions and is very dependent on soil moisture in those central dry zone areas. Annually, the production can vary up or down depending on rainfall. Due to the vagaries of weather, over 40 % is damage, and management constraints leading to additional loss of yield and lack of good quality seed for the following season. Broadcasting is still common and practiced at various seed rates with the average of 15 kg ha^{-1} resulting in lower yield. Farmers normally used much more seeds to get good germination, since the seeds are small, and uproot young seedlings for optimum plant population. Therefore, waste seed and more labor requirement resulted. Broadcast planting always resulted in non-uniform plant spacing in the field. Broadcast sowing also prevents mechanization during further management practices. Uniform plant stands universally have yield advantage over non-uniform plant spacing. Significant yield reductions due to non-uniform plant spacing were recorded in several crop species such as sunflower, corn, and sorghum, but little is known on sesame.

The major obstacle to the expansion of sesame is its capsule shattering when mature and costly harvest. The shattering in sesame remains the problem of sesame production in the world. Seed loss may reduce yield by 60% (Boyle and Oemcke, 1995). Because sesame has an indeterminate growth habit, therefore, timing of harvest is important. Sesame seeds typically give greater oil content than many other oilseeds, ranging from 37 to 63%. It contains about 51% oil, 17-19 % protein and 16-18 % carbohydrate (Yermanos *et al.*, 1972). The oil content and composition is markedly influenced by genetic, climatic, and agronomic factors and varies considerably within variety (Yoshida *et al.*, 2007). Various studies have reported the effect of genetic and environmental factors on the quality of seed, but few have reported on date of harvest. Aflatoxins are considered a potential hazard to public health, due to their toxicity and carcinogenicity. Under favorable environmental conditions, insect attack, and substrate, aflatoxin-producing fungal species can grow in certain foods and feeds. Research works, in Myanmar, on seeding rates and harvesting dates in sesame are limited. Therefore, the present study was undertaken to find out optimum seeding rate and harvesting date for high yield and good quality sesame seed with no or low incidence of aflatoxin contamination.

OBJECTIVES

This research aimed at evaluating the effects of different seeding rates and harvesting dates on yield of sesame and seed quality. The specific objectives were as follows :

1. To investigate the productivities in different plant population.

2. To determine the oil and protein contents of sesame seed.

3. To find out the relationship between seed rates and times of harvesting effect on aflatoxin contamination in seed.

LITERATURE REVIEW

1. Background Information

Sesame, also known as sesamum, gingelly, beniseed, sim-sim and till, is an important annual oilseed crop. It has been cultivated for centuries, particularly in Asia and Africa, for its high content in edible oil and protein. Sesame is probably the most ancient oilseed used by man, and its domestication lost in the mists of antiquity. Indian botanists argue that sesame originated in India (Bedigian *et al*., 1985). Ashri (1998) felt that settling the debate on the origin of sesame will require more detailed cytogenetic and suitable DNA comparisons. From whatever origin, sesame spread into Africa, the Mediterranean and into the Far East. In the Middle East a tremendous amount of sesame is consumed as tahini (sesame butter or sesame paste). Tahini mixed with ground chickpea kernels becomes hummus. In China, Japan, and Korea, sesame is widely used as cooking oil, and it is consumed for its medicinal qualities. In these countries, grandmothers advise, "Eat sesame for health". In recent years the Japanese have been identifying and quantifying the medicinal benefits of sesame. *In vitro* and animal studies have verified several antioxidant properties, and initial unpublished results in human studies further verify that stories passed down through generations have merit (Namiki, 1995). In the West, sesame is primarily used in the confectionary trade in rolls and crackers. In India sesame is used in many religious ceremonies (Joshi, 1961).

2. World Sesame Production and Situation

Today, India, Myanmar, China and Sudan are the world's largest producers of sesame. In 2007, the major producers (in 1000 t increments) were India (739), Myanmar (661), China (615), Sudan (287), Uganda (185), Ethiopia (181), Nigeria (110), Paraguay (58), Bangladesh (55), Tanzania (51), Thailand (47), Central African Republic (44), Egypt (41) and Pakistan (41). The increase in production in China is due to improved cultivars. Although China has played a major role in the export market, some traders predict that China will become a net importer in the next 10 years as consumption increases (Langham and Wiemers, 2002). Of the fourteen countries, six countries were in Asia, seven in Africa and one in Latin America. In total they collectively account for 84 % of the total world sesame production (3.7 million tons). Asia produces 64 % of the world supply of seed and Africa grows 31 % of the total of 95 %, with Sudan, Uganda, and Nigeria being key producers (FAO, 2005). The majority of sesame in the world is produced in semi-arid regions where rainfall is relatively limiting. This confirms the attribute of sesame as a crop that is drought tolerant and could be widely cultivated in areas where most grain crops cannot survive. Asia exports 17 % of sesame crop; it imports twice as much it exports. Asia imports oilseed quality sesame from Africa. In Asia most sesame is consumed within 160 km of where it is grown since farmers grow very small plots for their extended families (FAO, 2005). World production areas have remained generally stable over the years, although in some countries the crop is being marginalized. Competition from more remunerative crops and a shortage of labor have pushed sesame to the less fertile land and to areas of higher risk (Bennett, 1998). In 2007, world exports of sesame seed were 1,042 million tons, with Japan being the largest importer. The European Community, Korea and the United States are the other major importers of sesame seed (Anonymous, 2008). It is forecast that imports of sesame seed will grow at between 6% and 8% per annum until the year 2012 (Bennett, 1998).

3. Sesame Production in Thailand

Sesame is an economical oil crop which is grown as a supplementary to other main crops such as rice and corn. The world demand of sesame has exceeded production capacity and is reflected in the high national farm price for sesame seeds of 1 US \$ kg^{-1} in 1995. Sesame exports from Thailand (seed and oil) are worth about US \$ 8 - 12 million annually. The national sesame production is about 27,000 to 32,000 tons per annum, of which 45% is used for domestic consumption and 55% is exported. The production area in Thailand is, about 0.12% of the whole country area, between 32000 and 60320 ha (Suddhiyam and Maneekhao, 2005).

There are three types of sesame seeds: white, black and red or brown which occupy 10, 25 and 65% of the sesame growing area, respectively. The brown and white seeded types are grown in the North and Central regions while the black seeded type is mainly grown in the Northeast. Seventy percent of sesame production comes from the North (Suddhiyam and Maneekhao, 2005). Sesame is normally grown in the rainfed areas of Thailand whereby in upland and mid lowland sites (before rice growing). In the upland sites of the North and Central regions, the growing times are in the early rainy season (March - May) and late rainy season (July). In the mid lowland sites of the Northeast and some parts of the North, farmers grow sesame in the early rainy season (February - April) before rice. Broadcasting is practical for farmers approximately 6 - 12 kg ha^{-1} rate since it keeps population high enough for controlling weeds and less time consuming. The optimum population density is about 200,000 plants ha^{-1} with row spacing of 50 cm and plant spacing of 10 cm, 1 plant $hill^{-1}$. The average yield is around 500 - 630 kg ha^{-1}. In Thailand sesame production areas are reduced year by year. It is due to seed shattering and it is costly at harvest and manual labor is becoming scarce. The new varieties of non shattering would be potential for increasing seed yield per unit area and the mechanical production system would be accepted by grower as the major crops such as rice and maize (Suddhiyam and Maneekhao, 2005).

4. Sesame Production in Myanmar

Myanmar is the second largest country in South East Asia and is covered by total land area of 676, 577 square kilometer, stretching for 2276 kilometer along the sea coasts of Bay of Bengal and the Andaman Sea (MOAI, 2009). The country is bordered with Bangladesh on the west, India on the northwest, People’s Republic of China (PRC) on the northeast, the Lao People’s Democratic on the east and Thailand on the southeast. The western, northern and eastern parts of the country are hilly regions with altitude varying from 915 to 2134 meters above the mean sea level (MOAI, 1998). Myanmar climate is tropical and sub-tropical with three general seasons (i) the rainy season (mid-May to mid-October), (ii) the dry cold season (mid-October to mid-February) and (iii) the hot season (mid-February to mid-May). The average annual rainfall varies over the country, ranging from 2480 mm to 5690 mm in the coastal and hilly regions and 657 mm to 1220 mm in the central core of Myanmar. The temperature in the southern part of the country differs slightly during the different seasons. In the central plain of the country seasonal temperature variation is 34.1°C-40.2°C in hot season and 10°C -13.2°C in cold season. It is considerably cooler in hilly regions where the average daily maximum temperature is 29.2°C and the minimum 7.9°C. Myanmar was second largest producer sesame crop in the year 2007. Its production was 661,000 tons on an area of 1.582 million hectares. The central dry zone region of Sagaing, Mandalay and Magway are the major producing divisions.

Sesame is only one oilseed crop allowed to export and one of the major oilseed crops in Myanmar as a source of edible oil. Myanmar sesame has comparative advantages in the oil crop sector for the export markets. Sesame is an important source of food in Myanmar’s diet such as cooking oil, snacks, and ingredients for other foods and additionally serves as animal fodder, inorganic fertilizer for plants and an export commodity. Sesame oil has been premium one in upper Myanmar since immemorial time. For those reasons, sesame also has important role, like rice, in Myanmar’s various traditional cultures and customs. Oilseed crops are the second most important items after paddy in Myanmar’s diet and national requirement. Among the principal oilseed crops, sesame is adaptable and feasible to different seasons and growing conditions occupies the largest growing area since many years ago. Currently, the area under sesame in Myanmar, constitutes about 12 % of the world’s total area while in the year 2004-2005, the rain crops covered 1.17 million hectares and the winter crop was 0.22 million hectares. And among the Myanmar’s various oil crops, sesame tops the list at 51.3% and with groundnuts just about 22% (Myanmar Sesame, 2005). Sesame occupies 44 % (1.426 million hectare) of all oilseed crops area and supplies 30 % of domestic edible oil in 2006-2007. Major growing area of sesame is central Dry Zone Area, the central tropical region of the country and is characterized by semiarid climate with less annual rainfall about 700-900 millimeters. The climate in this area is suitable for oilseed crop especially for sesame and groundnut. Actually, sesame production in Myanmar encounters many constraints that lead to low yield and yield instability. Therefore Myanmar should step up her production to meet the ever increasing demand for sesame particularly in the export market.

5. Nutritional Values and Uses

As early as 1927, Jones and Gersdorff (1927) reported that sesame seeds were rich in both protein and oil. Later, Chartfield (1934) and Yermanos *et al*. (1964) indicated that besides the high protein content of the seeds their nutritive value was also high and the amino acid composition was similar to that of meat. Natural sesame seeds, those that are unhulled, are high in calcium. Both natural and hulled sesame seeds contain high amounts of the B vitamins riboflavin, thiamine, and niacin. Duhoon (2004) stated that sesame is the ‘queen’ of oilseeds because of its oil and protein are of very high quality, and it has tremendous potential for export. Sesame seed is a rich source of oil, protein, phosphorus and calcium and high in antioxidants and other healthful features. The seeds typically contain a greater amount of oil than many other oilseeds. However, wide ranges of oil contents, from 37 to 63%, have been reported for sesame seed. The oil content may vary from as low as 35% to as high as 57% according to Eckey (1954). Average seed content is 53.4% oil and 26.3% protein on a moisture-free basis, iodine value of 110.0, and the variation in oil content due to location is 6%, that for protein content 7.3% and iodine value 9.2 units. In addition, sesame oil contains two important natural antioxidants or lignans, which are both oil and water –soluble, believed to promote cell integrity and the healthy function of body tissues in the presence of oxidizing compounds: sesamolin and sesamol. These antioxidants maintain fats and cholesterol and increase vitamin E activity dramatically. Sesame oil has a long shelf life because of an antioxidant called sesamol and also contains oleic and linoleic acid (Jin *et al*., 2001). Many cosmetics include sesame oil because of its antioxidant properties. These antioxidative compounds preserve the stability of sesame seed and oil. Furthermore, they are biologically active and provide a variety of health benefits upon ingestion. Sesame oil is used in cooking, salad oils, margarine and raw material for the production of some industrial materials including paints, varnishes, soaps, perfumes, cosmetics, bath oils, pharmaceuticals (vehicle for drug delivery) and insecticides. Sesame oil cakes contain 34% to 55% of protein and are used as animal fodder and as a fertilizer. Sesame oil can also be replaced olive oil. Medicines containing sesame oil are said to reduce aches and paces and relieve depressions, while it also lessens weariness and builds up stamina. Its other attribute is the use as oil massage before bed time, for curing insomnia and hence sesame remains a popular commodity in global markets (Walton, 2008).

6. Botanical Classification

Sesame belongs to the division *Spermatophyta*, the sub-division *Angiospermae*, the class *Dicotyledoneae*, the order *Tubiflorae*, and the family *Pedaliaceae*, consisting of 16 genera and about 60 species in this family (Kobayashi, 1991). There are approximately 38 species in the genus *Sesamum* and most of them are wild (Kobayashi, 1991). Out of these, *S. indicum* L. is cultivated extensively. The other 6 partially cultivated species include *S. radiatum* (India, Africa, Sri Lanka), *S. angustifolium* (Congo, Mozambique, Uganda), *S. occidentale* (Africa, Sri Lanka, India), *S. calycinum* (Angola, Mozambique), *S. bauymii* (Angola). All other species are wild and found in tropical African countries. Nine wild species have been found in peninsular India. Linnaeus classified sesame in two different species, *Sesamum indicum* and *Sesamum orientale*, but De Candolle combined the two species to one and used the name *Sesamum indicum*. There are many different varieties of *Sesamum indicum* L. that differ considerably in size, form, growth habit, corolla color, and seed size, color and composition (Weiss, 2000). Stem height usually ranges from 60 to 120 cm (Weiss, 2000), but plants can be as short as 22 cm (Bisht *et al*., 1998) and as tall as 245 cm. Plants with a height of 300 cm have been reported (Weiss, 2000). Sesame have somatic chromosome number is 2n=26. Sesame is grown in tropical to temperate zones, mostly between latitudes 40°N and 40°S. Sesame is a short day plant and flowers in 42-45 days when exposed to 10 hours day length (Weiss, 1983). The crop can tolerate dry conditions, but will respond to good rainfall as long as water logging does not occur. Some varieties can thrive on 450 mm of rainfall. The crop requires only 500-650 mm of rainfall per annum. Small amount of the rain (zero to

127mm) is critical to sesame in the 70 days during reproductive and ripening phases (Langham, 2008). Sesame is drought tolerant and will do better with more moisture. There are two types of sesame, those used in dry areas or seasons and those used in high moisture or wet season. Generally, wet sesame does not do well in dry areas but dry sesame may do well in wet areas. The dry lines generally have a strong root that will penetrate deep into the soil to stay in the moisture. The wet lines generally have shallow root. There are intermediate lines that are productive in wet or dry but will not do well in the extremes.

7. Factors Affecting on Growth and Seed Yield

Yield of sesame is generally poor compared with other crops due to genetic and environmental factors (Ashri, 1998). The environmental factors that influence sesame productivity include climatic factors such as temperature, rainfall and day length, soil types and management practices such as plant densities, time of sowing, irrigation, fertilizers, herbicides and fungicides, some of which may partially mitigate others (Geleta *et al.*, 2002 and Adebisi, 2004). Low grain yield could be occurred due to the inappropriate planting method, seeding rate and crop management. Sesame yield is very low due to poor management practices (Rahman *et al.*, 1994) and commonly grown in small-scale farms with low input and less mechanization in most of the major sesame producing countries. Sesame yield could be improved by increasing plant productivity using better management practices and/or by increasing seed retention by capsules (Ashri, 1998 and Caliskan *et al.*, 2004). Low yield had been attributed to cultivation of low yielding dehiscent varieties with low harvest index values, significant yield loss during threshing and lack of agricultural inputs such as improved varieties, fertilizers and other agro-chemicals (Ashri, 1994, 1998; Weiss, 2000; Uzun and Cagirgam, 2006). For successful production of crop many factors, such as, quality seed, weed control, proper fertilization, irrigation, method of sowing, optimum sowing time, seeding rate and time of harvest are indispensable. Yield decreases progressively with the delay in planting from optimum time of sowing (Cane, 1949).

Yields are highly correlated with plant height and main stem length. Mulkey *et al*. (1987) also reported that delayed sowing affected plant height. The time of harvesting also have significant influence on plant height (Alam Sarkar *et al.*, 2007). Imoloame *et al.* (2007) stated that plant height decrease with increase in seed rate, the interaction between seed rate and sowing method on plant height are not significant, the number of flowers produced per plant decrease with increase in seed rate. Stand establishment is the biggest challenge in profitable sesame production. Since seeds are small, 220 seeds g^{-1} (Martin *et al*., 1976), seedlings lack the emergence vigor of larger-seeded agronomic crops, therefore, soil crusting can be a severe problem in stand establishment. Plant sesame seed 2.54 cm depth when soil temperatures reach 21°C (Johnson and Croissant, 1986). Given space, sesame will branch excessively. Branching delays maturity and is less effective in compensating for poor stands. Shallow cultivation may be an acceptable method of weed control. Several shallow tillage operations kill early germinating weeds before planting, with between the row cultivation after emergence (Johnson and Croissant, 1986).

Sesame is extremely sensitive to water logging and salinity. Even short periods of water logging will result in significant reductions in plant numbers and seed yield. High phosphorus levels in saline soils may decrease sesame yields. Excessive moisture is not beneficial and extended periods of rainfall and/or high humidity may cause leaf diseases. Although, irrigation raises yield in arid and desert areas, plants standing in water for more than a few hours will be killed. Increasing number of irrigations for growing sesame plants at different growth stages increased seed yield (Ayasmy and Kulandivelu, 1992; Mathew and Kunju, 1993). The crop is fairly drought-tolerant, and once established is capable of withstanding a higher degree of moisture stress than many fields crops. The dry conditions are advantageous for ripening and producing high quality seed (Bennett and Conde, 2003). Dry periods during germination and fruit formation are detrimental to the crop (Kumar *et al.*, 1996). Sesame requires a minimum growing season of 90 days. Early fall frosts may discolor the seed or produce shrunken seed of unacceptable quality. Some varieties are susceptible to leaf spot diseases. These usually do not cause problems in dry areas, but in humid high rainfall areas, severe losses may occur.

Other diseases that may infect sesame include fusarium wilt, charcoal rot and verticillium wilt. Aphids, stink bugs, red spiders, grasshoppers and cutworms are commonly observed on sesame and may cause economic yield loss. Cultivars resistant to diseases, pests, and abiotic stresses would be most important, especially because in developing countries other means of control are often unavailable. Charcoal rot (*Macrophomina phaseolina spp. sesamica*) is widespread and destructive, and attacks other crops. Sesame phyllody, caused by a mycoplasma-like organism that is transmitted by leaf hoppers (*Orosius albicinctus* Distant) induces vegetative proliferation of the flower buds and can be most destructive.

8. Seeding Rates Affect on Yield

A wide range of plant densities for optimum yields in sesame can be found in literature. However, most of previous studies indicate that different plant densities were obtained by manipulating inter- and intra-row spacing although sesame were sown as broadcast in many sesame producing countries. It is well known that broadcast planting always resulted in non-uniform plant spacing. Significant seed yield reduction due to non-uniform plant spacing were reported in several crop species such as sunflower, corn and sorghum, but little information about the effect of non-uniform plant population due to broadcast planting on sesame. Broadcast sowing also prevents the use of mechanization during the later growth stages. There is little information on plant density of sesame sown only as row-spacing. Regarding weed control, row planting is superior to broadcasting, resulting in increased yield (Weiss, 1971), while wide spacing favor higher weed competition in crops (Akobundu, 1987). The row planting caused more uniform distribution of plants in the field as well as allowed better cultivation and irrigation. Consequently, abundant plant growth occurred with row planting. Broadcasting not only requires higher seed rate but also results in lower plant population, whereas drill sowing method is recommended because of its uniform seed distribution and sowing at desired depth, which usually results in higher germination and uniform stand. In Australia, Bennett and Conde (2003) showed that the highest seed yields were achieved if sesame was sown in row spacing between 32 cm to 50 cm, wider rows resulted in decreased weed control and yield, while narrower rows resulted in a yield reduction. Also, increased number of seeds per capsule, number of capsules per plant, and dry matter production increased when the intra-row spacing increased from 30 to 90 cm (Weiss, 1983; Olowe and Busari, 1994). A seeding rate of 1.12 kg ha^{-1} is recommended for 75cm rows. Other row spacing requires adjustments in seeding rate. Ideal populations are 617,750 to 741,300 plants ha^{-1} (Johnson and Croissant, 1986).

The effect of plant population on yield and yield components have been reported by several researchers. For example, seed yield per unit area increases with increased population density from 80,000 to 160,000 plants ha^{-1} and beyond this density it becomes counterproductive (Delgado and Yermanos, 1975). Plant population refers to the number of plants emerged and established in the field which can contribute to overall crop performance (yield, competition with weeds, moisture use, etc.). It is usually expressed in terms of plants per hectare or plants per linear meter of row. In particular, population density plays a key role in determining seed yield. Adeyemo *et al*. (1992) reported that optimal population of sesame is between 133,333 and 266,667 plants ha^{-1}. However, Olowe and Busari (1994) recommended 166,667 and 333,333 plants ha^{-1} for the semi-arid regions of Northern Nigeria. Population density might bring about micro-environmental variations, which may affect the agronomic traits of sesame. Genotypic differences also may play an important role in this respect. Therefore, achieving higher agronomic performance requires management practices such as seeding rate to be carefully adjusted considering varietal characteristics (Geleta *et al*., 2002). This observation suggests that, in sesame, population effects on yield $plant^{-1}$ are mainly controlled by changes in capsule weight $plant^{-1}$, capsule numbers $plant^{-1}$, seed numbers $capsule^{-1}$ and seed production efficiency. The results are in conformity with that of Carpenter and Board (1997) for soybean. Yield potential is maintained with high populations since there are more plants per hectare. Generally, as population density increases, yield per unit area increases to an upper limit. After this maximum is reached, only minor improvements in yield are achieved, or decreases in yield are realized. When grown under high populations, individual plants produce fewer pods, fewer branches, grow taller, and pod higher off the soil surface than when grown at low populations. The optimum plant density for sesame is influenced by several factors such as temperature, soil fertility, water availability and genotype. Optimizing plant density is also very important for improving seed yield in a particular environment.

9. Harvesting Dates Effect on Yield and Yield Components

Globally, sesame is still harvested manually. Alam Sarker *et al*. (2007) stated that the highest number of seeds capsule^{-1} was produced when the crop was harvested at 40 DAF and the lowest number of seeds was produced when the crop harvested at 30 DAF, during the crop period from February to June. It was observed that the number of seeds capsule^{-1} increased progressively from the crop harvested at 30 up to 40 DAF and thereafter reduced when the crop was harvested at 45 DAF. The reduction in the number of seeds might be due to shattering of capsule as a result of allowing the crop standing in the field after maturity. Similar result was also reported by Mondal *et al*. (1995) they suggests that delayed harvesting reduced the number of seeds per capsule. The maximum weight of 1000 seeds was obtained when the crop was harvested at 40 DAF and minimum at 30 DAF. Harvesting at 30 DAF, 35 DAF and 40 DAF produced statistically different results. The 1000-seeds weight increased with the delay in harvesting up to 40 DAF. The crop harvested at 40 DAF gave the statistical1y similar weight of 1000-seeds as that of crop harvested at 45 DAF. The maximum weight of 1000-seeds was observed when the crop was harvested at 40 DAF and it might be due to optimum maturity and accumulation of maximum dry matter. The minimum weight of 1000-seeds was produced when the crop was harvested at 30 DAF. It might be due to immaturity of the seeds. The highest seed yield was produced at 40 DAF and the lowest seed yield was produced at 30 DAF. Yield losses can be heavy due to the indeterminate growing characteristic which prevents all the seeds in a crop maturing at once. Furthermore, early harvesting can reduce seed quality and late harvesting can enhance seed loss. Desiccation with herbicides is a method used for crop stands with heterogeneous ripeness and high weed density. It can be a way of limiting seed losses and improving seed quality (Bowerman, 1984).

10. Relation Between Nature of Growth Habit and Harvest

The seed capsules of normal dehiscent (shattering) sesame varieties open at maturity. Considerable care is required to prevent excessive seed loss. The shattering of the capsule is desirable in China and India where an adequate supply of cheap labor enables hand harvesting and threshing. The lack of uniform ripening of capsules has further complicated mechanical harvesting techniques and breeding efforts. Capsules at the base of the plant may be opening while the upper part of the plant is still flowering. Where mechanization is the basis for successful crop production, as in North America, the lack of a mechanical harvesting procedure is the principal obstacle to widespread commercial production. The development of indehiscent varieties is one means to facilitate mechanical harvesting. Langham in 1943 discovered a single indehiscent plant which has led to the development of a number of indehiscent varieties. A single Mendalian recessive gene controls the shattering characteristics, although, there is a strong genotype-environment interaction so that temperature and soil moisture affect genotypic expression. Although sesame is widely used for different purposes it is generally grown in small holdings. Sesame production has been limited due to a lack of mechanized sowing and harvesting. Sesame is usually sown and harvested by hand causing yield losses. Seed loss is a major problem for sesame producers. The primary reason for this problem is that harvesting time cannot be adjusted. It is rather difficult to decide when to harvest a sesame crop for maximum yield because plant growth is indeterminate and capsules dehisce (shatter) when mature. According to Ashri (1989) the crop continues to produce leaves, flowers and capsules as long as the weather and soil moisture conditions permit due to its indeterminate growth habit. So, it is common to have several mature capsules on the lower parts of the stem and recently developed capsules near the top of the plant. Therefore, if plants are harvested too early, the seed quality of the whole crop is reduced by the inclusion of immature seed from near the top of the plant. On the other hand, if plants are harvested too late, then yield may be reduced by seed loss through seed fall from the earliest maturing capsules (Day, 2000). Therefore, maturation of seeds at the same time is important to prevent harvest loss and enable mechanized harvesting.

11. Reasons to Prevent Mechanization

There is a limited amount of mechanization in some countries. Without mechanization, sesame will only persist in those niches where no other crop can be grown. In the mid 1940s, Langham and Rodriguez (1949) laid out the major requirements for mechanizing sesame: (1) the plants should terminate flowering, (2) the plants should drop their leaves, (3) the seed in the capsules should mature before the capsules open, (4) the capsules should retain their seed until the plant is in the combine, and (5) the capsules should release the seed in the combine. The first 3 requirements were solved in the 1940s and improved in the 1950s/1960s through extensive breeding and exchange of materials between D.G. Langham, M.L. Kinman, and J.A. Martin. Sesame is classified as an indeterminate crop which will continue flowering as long as moisture and nutrients are available. As the flowering continues, the early capsules dry down, open, and lose their seed. Many lines in Asia have this character, and it is quite a problem because the plants are cut as the lower capsules open. As a result, there is a continuum from mature seed to immature seed on the plants. However, there are many lines from all parts of the world where the flowering stops. In most of the world, maturity is defined as the time that the first capsule begins to dry down. These farmers want to cut the plant and move it into shocks prior to that seed being lost. At first dry capsule, there is a full range of cultivars where the seed close to the top of the plant is mature to where the top of the plant is still flowering. In the late 1950s, Kinman found that if a plant was cut when the seed was mature at ¾ of the capsule zone, that there was little loss in potential yield. The majority of the seeds in the upper ¼ would still mature into viable seeds. This is defined as physiological maturity (PM). In the early days of mechanization where sesame was swathed, the objective was to have the plant reach PM before the first capsule dried down. The time between those two points was defined as the swathing window (SW). Since that time cultivars have been developed where SW exceeds three weeks and the seed at the top is fully mature.

12. Factors Effecting Oil and Protein Contents of Sesame Seed

The oil content of seed was slightly decreased with increasing plant population. In contrast to oil content, the protein content was significantly increased with increasing population density (Caliskan *et al*., 2004). Because oil and protein contents are inversely proportional, seeds with increase oil content have decreased protein content. The oil content of sesame seed tends to increase with increasing length of photoperiod (Calil, 1965). Early planting dates tended to increase the seed oil content (Arzumanova, 1963). Short growing season plants have higher oil content than plants with a medium long growing cycle (Yermanos, 1978). The high rates of nitrogen fertilizer application reduced the oil content of sesame seeds (Singh *et al*., 1960). Majumdar and Pal (1988) found that the delay of irrigation from flowering to capsule development when two irrigation treatments were applied did not affect oil content. Kumar *et al*. (1996) also reported that two irrigations resulted in the maximum oil and that moisture stress caused a significant reduction in oil content in the sesame seed. The protein content was also influenced by irrigation and increased at higher temperatures. Many studies have found that ecological condition, variety, maturity, growing season and location affect the oil content of sesame. Bahkali and Hussain (1998) reported that dark sesame seed has significantly higher oil but lower protein content than white seeds. As indicated by many researchers, the variation in fatty acid composition of vegetable oils depends on agronomic and climatic factors during the growing season. Early sown plants had higher percentage of oleic acid and late sown plants had higher percentage of linoleic acid (Gupta *et al*., 1993). In addition, the determinate genotypes were found to be of higher oleic acid content and lower linoleic acid content (Uzun *et al*., 2002).

13. Chemical Composition in Sesame Seed

13.1 Oil Content

Sesame seed contains greater oil content than many other oil crops (Salunkhe *et al*., 1991). Sesame seed is composed of 40-60% of oil. Sesame oil content is related to seed color, although this is specific to geographic location. For example, the white-seeded varieties in the Sudan have a lower oil content than the red-seeded varieties (Bedigian and Harlan, 1983), but in Ethiopia white or light-colored seeds usually have more oil than dark-colored seeds (Seegeler, 1989). Seed color differences are also economically significant. In West Bengal, white-seeded sesame is sold at a price at least 30 % higher than that of brown-seeded or black-seeded varieties because of its higher oil content and greater culinary utility (Chakraborty *et al.*, 1984). In a collection of sesame plants from around the world (Yermanos *et al.*, 1972), the mean oil content in 721 samples was 53.1%, the oil was clear and colorless in 47.4% of the samples and light green in 37.2%, with the remaining samples were dark green or brown. Short plants tended to have colorless oil, whereas tall plants had light green oil, and early plants had higher seed oil content. Most oilseeds show a negative correlation between oil and protein content; sesame is no exception. For each 1% average increase in protein content, there is a corresponding average decrease in oil content of 0.85% (Kinman and Stark, 1954).

13.2 Fatty Acid

Sesame oil contains about 80% unsaturated fatty acids, with oleic and linoleic acid, that are rich in omega 6, predominating and present in approximately equal amounts (Lyon, 1972). The saturated fatty acids account for less than 20% of the total fatty acids. Palmitic and stearic acids are the major saturated fatty acids in sesame oil. The oil contains more unsaturated fatty acids than many other vegetable oils. The high proportion of unsaturated fatty acids renders sesame oil an important source of essential fatty acids in the diet (Langstraat *et al.*, 1976). Linoleic acid is required for cell membrane structure, cholesterol transportation in the blood and for prolonged blood clotting properties (Vles and Gottenbos, 1989). Smith (1971) reported 44% linoleic and 42% oleic acids, respectively, and 13% saturated fatty acids in sesame oil. Arachidic and linolenic acids are present in very small quantities (Rao and Rao, 1981). The crude oil contains a relatively low amount of free fatty acids.

13.3 Antioxidants Compounds

Sesame oil is remarkably stable because of its natural antioxidants, sesamin and sesamolin, two compounds not found in any other oil (Bedigian *et al*., 1985). These are phenylpropanoid lignans and serve to protect against rancidity (Weiss, 1971), which may be one reason that sesame is nicknamed the "Queen of Oilseeds". In addition to the sesame lignans identified in the 1950s, recently the Japanese have identified sesaminol, and they are looking at sesaminol glucosides. The latter are significant because they are water-soluble and travel with the meal whereas the lignans are oil soluble and travel with the oil. As a result, the meal when processed as flour has also shown stability due to antioxidants. Other unsaponifiable substances in sesame oil include sterols, triterpenes, pigments and tocopherols. Tocopherols are natural antioxidants that inhibit oil oxidation. Tocopherols act as biological kidnappers of free radicals and could prevent diseases, besides possessing an important nutritional function for human beings as a source of vitamin E (Monahan *et al*., 1993 and Brigelius-Flohe *et al*., 2002). The outstanding characteristic of sesame oil is its long shelf life and rich source of protein, carbohydrates, minerals, calcium and phosphorus. Sesame oil is rich in vitamin E but is deficient in vitamin A.

13.4 Protein Content

Proteins in the seed are mostly located in the outer layer of the seed. Most of the proteins present in sesame seeds are storage proteins found as albumins (8.9%), globulins (67.3%), prolamins (1.3%) and glutelins (6.9%) on the basis of their solubility (Rivas *et al*., 1981). In general, Indian varieties tend to be lower in protein and higher in oil than Sudanese varieties which generally appear in the export market. The water-insoluble 11S globulin and the soluble 2S albumin, conventionally termed α-globulin and β-globulin, respectively, are the two major storage proteins and constitute 80-90% of the total seed proteins in sesame. The major fraction is α-globulin which has a high molecular weight and accounts for about 60-70% of the total seed proteins (Nath and Giri, 1957). A minor component is β-globulin contributing to about 25% of the sesame seed proteins and has low molecular weight and is rich in acidic and hydrophobic amino acids (Rajendran and Prakash, 1988). Very little is known about the third major sesame storage protein, i.e., 7S globulin as a minor constituent approximately 5% of the total storage proteins in sesame has briefly been reported in several investigations (Prakash and Nandi, 1978; Prakash, 1986; Tai *et al.*, 2001 and Beyer *et al.*, 2002).

One of the unique aspects of sesame protein is the high content of sulphur-containing amino acids, particularly methionine and cysteine (Smith, 1971 and Brito, 1981) and also tryptophan which is limiting in many oil seed protein (Johnson *et al*., 1979 and Yen *et al*., 1986). Sesame proteins are deficient in lysine (Sawaya *et al*., 1985). Sesame seed has been increasingly associated with food allergy, probably because of its use in international fast-food and bakery products. Seed storage proteins are known food allergens in peanut, walnut, Brazil nut, and soybean. According to recent investigations, the storage proteins appear to be the major allergens of sesame (Beyer *et al*., 2002 and Wolff *et al.*, 2003). Furthermore, despite the 7S vicilin-type globulin only accounting for 5% of the total sesame proteins, a 45 kDa polypeptide corresponding to the 7S globulin has recently been shown to be a major allergen for a group of twenty individuals with sesame allergy (Beyer *et al*., 2002).

13.5 Other Components in Sesame Seed

The carbohydrate content of sesame is comparable to that of groundnut seeds and is higher than that of soybean seeds (Joshi, 1961). Sesame seeds contain 21-25% carbohydrates. The seeds contain about 5% sugars, most of which are of reducing type. Dey and Friedmann (1951) suggested that sesame seeds contain a high proportion of oxalate, at least a part of the calcium would be unavailable physiologically. Black varieties of sesame contain higher levels of oxalic acid and fiber and lower protein levels than white varieties (Johnson and Raymond, 1964). Sesame seeds are reported to contain 3-6% crude fiber (Ramachandra *et al*., 1970; Gopalan *et al*., 1982 and Taha *et al*., 1987). The crude fiber is present mostly in husk or seed coat (Narasinga Rao, 1985). In addition, Sesame seed is also a rich source of niacin, folic acid, vitamin E, certain minerals, calcium, phosphorus, and iron but lacking in vitamin A.

Yermanos *et al*. (1972) reported an oil content of 40.4-59.8% in sesame seeds from various world areas, and of 47-54.6% in Japanese sesame lines. El-Tinay *et al.* (1976) reported an oil content of 42.2-52.2% in the exotic type, and that of 41.3-49.6% in the local type, and also reported protein content of 45.0-53.7% in the introduced type, and that of 45.0-60.0% in the local type. Kinman and Martin (1954) reported an oil content of 45.29-63.38% (moisture-free) and protein content of 16.69-25.69% (moisture-free) in sesame seeds. The composition is markedly influenced by genetic, climatic, and agronomic factors and varies considerably within variety. Shorter-season varieties tend to have higher oil content than longer-season varieties. The dark-colored seeds generally have higher oil content. Smaller seeds contain more oil than larger seeds (Seegeler, 1983). Rough-seeded cultivars generally have lower oil content than smooth-seeded types (Yermanos *et al*., 1972). The oil yield is from 50% to 57%, depending on growing condition and seed variety.

14. Aflatoxin Occurrence and Carcinogenicity

Many agricultural commodities such as cereals (maize, sorghum, pearl millet, rice, etc.), oil seeds (groundnut, sesame, soybean, sunflower), spices (chillies, black pepper, turmeric, ginger, coriander), fruits nuts (almonds, pistachio) and feeds are vulnerable to be manifested by a group of fungi that are able to produce toxic metabolites called mycotoxins (Jelinek *et al*., 1989; Vasanthi and Bhat, 1998 and Reddy *et al*., 2001). Among various mycotoxins, aflatoxin contamination of agricultural products has gained significant global interest as a result of their deleterious effects on human as well as animal health and, thus, its importance to international trade. *Aspergillus flavus* is the most common species in Africa and Asia, while *A. parasiticus* is predominant in America. Both species belong to a group of fungi that produces highly toxic mycotoxins known as aflatoxins. Molds can grow and mycotoxins can be produced pre-harvest, post-harvest or during storage, transport, processing, or feeding. In general, environmental conditions- heat, water, and insect damage -cause plant stress and predispose plants in the field to mycotoxin contamination. Because feedstuffs can be contaminated pre-harvest, control of additional mold growth and mycotoxin formation is dependent on storage management. After harvest, temperature, moisture content, and insect activity are the major factors influencing mycotoxin contamination of feed grains and foods (Coulombe, 1993). Field applications of fungicides may reduce mold growth, in turn reducing the production of mycotoxins. However, the stress or shock of the fungicide to the mold organism may cause increased mycotoxin production (Boyacioglu *et al*., 1992; Gareis and Ceynowa, 1994). The FAO has estimated that approximately 25% of the world's food crops are contaminated by mycotoxins annually (CAST, 1989). And also crop loss due to aflatoxins contamination costs US producers more than $100 million per year on average including $ 26 million to peanuts ($69.34 ha^{-1}). Awareness of the potential danger posed by aflatoxins contamination of foodstuffs has been increase in recent times. The filamentous fungus *A. flavus* causes approximately 30% of the cases of aspergillosis, a serious human disease.

Aflatoxins are found in many countries of the world, especially in tropical and subtropical regions where the warm and humid weather provides optimal conditions for the growth of aflatoxigenic molds. The optimum temperature for growth of the molds is 24 – 35°C and equilibrium relative humidity of above 70% (Williams *et al*., 2004 and Farombi, 2006). Thus food and feed crops grown under tropical and subtropical conditions are more prone to aflatoxin contamination than those in temperate regions. Myanmar, being a tropical country, her conditions of temperature and humidity are favorable for growth of the molds and for the production of the toxin. The formation of aflatoxins is influenced by physical, chemical and biological factors. The physical factors include temperature and moisture. The chemical factors include the composition of the air and the nature of the substrate. Biological factors are those associated with the host species (Hesseltine, 1983).

15. Factors Effecting Aflatoxin Contamination

Aflatoxin contamination can occur pre-harvest in the field, post-harvest in drying and storage of different foods and feeds, and shipment. Grains are infested by this fungus results in large agricultural and economic losses. The aflatoxin problem is closely linked with end-of-season drought stress, where the *Aspergillus* fungus favors drought stressed conditions in the plant to produce aflatoxins. Warm temperature with drought-like condition causes grain to become more susceptible to aflatoxin formation in the field. In addition, insect damage before and after harvest can allow the organism to access individual kernels, thereby increasing the chance of aflatoxin contamination in an infested crop. The toxins may also be formed under poor storage conditions in which the grains are kept in a high temperature, high moisture environment or are inadequately dried. Crop husbandry practices, climatic conditions, and soil factors, in addition to host-plant susceptibility, significantly influence aflatoxin contamination.

15.1 Pre-harvest Contamination

Pre-harvest *A. flavus* colonization and aflatoxin contamination also occur, and several environmental factors have been associated with fungal infection. The development of aflatoxin in field is influenced by factors that increase plant stress, particularly during the pollination and grain filling stage of development (Jones *et al*., 1981). Aflatoxin incidence and levels were positively related to location and crop year, but not to genotype (Stoloff and Lillehoj, 1981). Relative humidity above 86% also favors colonization and aflatoxin production in the field (Davis and Deiner, 1983). Field infection of corn with *A. flavus* (Wicklow, 1983) is expected when temperatures, including nighttime temperature, are high and there is drought stress. Drought-stressed plants also have a higher incidence of infection by *A. flavus*. Early harvest and a decrease in late-season irrigation may reduce contamination (Russell *et al*., 1976). Detached and over-mature pods are also highly vulnerable to invasion by soil insects, *Aspergillus* fungi and consequently aflatoxin contamination (Cole *et al*., 1989). Rachaputi *et al*. 2001 showed that aflatoxin contamination was significantly reduced by harvesting the crop early in sites where soil water deficit and soil temperatures were conducive to aflatoxin production. Therefore, aflatoxin contamination could be minimized by harvesting the crop earlier than the current practice. Pre-harvest control has involved agronomic practices that minimize mycotoxin accumulation in the field. These include proper irrigation, pesticide application, resistant or adapted hybrids, proper tillage and fertilization. Unfortunately, breeding for mycotoxin resistant hybrids has been only partially successful. The most practical and economical action to reduce aflatoxin levels is to prevent *A. flavus* colonization and aflatoxin production in the field. Therefore there is an urgent need to minimize its incidence at the farm level, through agronomic or genetic means.

15.2 Post-harvest Contamination

Initially, *A. flavus* and other *A. spp*. were considered exclusively storage fungi because they can grow at low water activities (Christensen *et al*., 1977) and aflatoxin contamination was believed to be primarily a storage problem that is very severe in many rural areas that lack the infrastructure for drying and other appropriate storage conditions. Post-harvest approaches for management of mycotoxin contamination include mycotoxin analysis of feedstuffs and diversion of contaminated lots; ammoniation of corn and cottonseed to destroy aflatoxin; dilution; and storage technology (Trail *et al*., 1995). Mycotoxin-contaminated grains can be used for ethanol production, and in some cases these grains can be diluted with clean feeds (Desjardins *et al*., 1993). The USFDA does not allow dilution of aflatoxin-contaminated feeds, which is considered adulteration. The best strategy for post-harvest control of mycotoxins is proper storage and handling of feed grains. Post-harvest aflatoxin contamination is most attributable to improper storage of the pods and seed. Conditions important for aflatoxin formation during storage are high humidity and high temperature (Xue *et al*., 2004). Crops entering storage may contain foreign materials such as sticks, soil, rocks and weeds collected during the harvesting process. These foreign materials may rewet surrounding kernels and provide moisture for growth of *A. flavus* (Dowell and Smith, 1995). Good storage practices will reduce the effect of initial contamination. However, poor storage practices will increase contamination even during non-drought periods. Natural accumulation of CO_2 and decreased level of oxygen in closed storage reduce fungi development (Jackson and Press, 1967 and Landers *et al*., 1967).

The invasion of sesame by *A. flavus* and aflatoxin contamination occur before harvest, during postharvest field drying and storage. The main factors influencing the growth of *A. flavus* and other storage fungi are moisture (relative humidity), temperature, time, and gaseous composition of the atmosphere, rain water leakage, condensation and insect infestation and aeration. The minimum moisture level for aflatoxin production at 30°C by *A. flavus* is equal to the moisture content of a product in equilibrium with 83% relative humidity or higher, depending on the nature of the substrate and the duration of storage. For starchy cereal seeds such as maize and wheat, the limiting moisture level for growth of *A. flavus* is about 18.5% whereas in oily seeds such as peanuts it is 8 or 9%. Controlled atmosphere in storage with high CO_2 and low O_2 appears to inhibit the *Aspergillus* growth (Moseley *et al*., 1971 and Wilson and Jay, 1976). Aeration is necessary to reduce aflatoxin contamination in storage. Landers *et al*. (1967) stated that aflatoxin production decreased in CO_2 level ranging from 20-80% and not produced at 100% CO_2 and O_2 reduced from 5 to 1% level.

16. Cultural Practices for Reducing Contaminations

Waliyar *et al*. (2000) reported that aflatoxin contamination can be reduced by varying degrees with treatment as follows:

16.1 Preharvest

As the end-of-season drought favors aflatoxin contamination, several management practices have been developed to improve water retention at the end of the rainy season.

- Lime application can reduce aflatoxin contamination by 72%
- Farm Yard Manure (FYM) by 47%
- Cereal crop residue by 28%
- Combination of FYM and lime by 84%
- Combination of lime and residue by 82%
- Combination FYM, and residue by 53% and
- Combination of FYM, residue, and lime by 85%

16.2 Postharvest

Postharvest practices are:

- Avoid damage to pods during harvest
- Avoid end-of-season drought with irrigation (if possible)
- Harvest the crop at maturity
- Eliminate damaged pods
- Dry the pods to 8% moisture level
- Avoid rehumidification of pods during storage
- Store pods under insect-free and low humidity conditions

17. Effects of *A. flav*us and Aflatoxins Contamination

Deterioration in grain quality due to *A. flavus* growth becomes unfit for marketing and consumption. In groundnut, seed and non-emerged seedling decay and aflaroot disease was observed due to fungus attack. Aflatoxins contamination in grain poses a great threat to human and livestock health as well as international trade. The increased concern in the microbiological safety of food has led to the use of several methods, including artificial preservatives to prevent or reduce the incidence of mycotoxins in food commodities. Ogunsanwo *et al.* (2004) reported that mere roasting at 150°C for 30 minutes reduced the aflatoxin content of Nigerian peanut by 70% while Onilude *et al.* (2005) reported that certain lactic acid bacteria isolates from indigenously fermented cereal gruels inhibited the growth of aflatoxigenic mould.

The fungi which produce aflatoxins can be grouped into 3 classes according to their moisture requirements. The first class contains the field fungi which need 22-25% moisture. The second includes storage fungi which need 13-18% moisture and the third, advanced decay fungi, require over 18% moisture (Christensen, 1965). Specific nutrients, such as minerals (especially zinc), vitamins, fatty acids, amino acids and energy source (preferably in the form of starch), are required for aflatoxins formation (Wyatt, 1991). Large yield of aflatoxins are associated with high carbohydrate concentrations, such as are found in wheat and rice and to a lesser extent in oilseeds such as cottonseed, soybean and peanuts (Diener and Davis, 1968). The limiting temperatures for the production of aflatoxins by *A. flavus* and *A. parasiticus* are reported as 12 to 41°C, with optimum production occurring between 25 and 32°C (Lillehoj, 1983).

18. Aflatoxin Testing Methods

In order to conduct the incidence of aflatoxins, it is essential to develop cost-effective and rapid methods for their quantitative estimation (ppb or ppm reading). ICRISAT has been investigating the problem of aflatoxin contamination for over 20 years. Aflatoxin concentrations are typically measured quantitatively using ELISA (enzyme-linked immunosorbent assays) technology, HPLC (high-performance liquid chromatography), TLC (thin-layer chromatography plates), GLC (gas-liquid chromatography), Near Infrared Spectroscopy (NIRS), spectrophotometrically, or fluorometric test kits. ELISA is a biochemical technique used mainly in immunology to detect the presence of an antibody or an antigen in a sample and often requires long incubation times, skilled analysts, and is more conductive to analysis of batches of samples rather than simple samples. The ELISA has been used as a diagnostic tool in medicine and plant pathology, as well as a quality control check in various industries.

MATERIALS AND METHODS

Materials

1. KU-18 sesame variety
2. Chemical fertilizer (15-15-15)
3. Bamboo sticks and tags
4. Insecticides, fungicides and sprayer
5. Plastic bags
6. Paper bags
7. Moisture meter
8. Electric and weight balance
9. Electrical Oven
10. Materials and chemicals for oil and protein content determination
11. Chemicals and equipment for aflatoxin testing

Methods

The field experiment was carried out at the National Corn and Sorghum Research Center (Suwan Farm), Nakhon Ratchasima Province during the 2008 rainy season (June-September). A split plot in RCB design was used with four replications. The main plots were four seeding rates (4, 6, 8 and 10 kg ha^{-1}) and the sub-plots were three harvesting dates (52, 56 and 60 days after flowering, DAF). Black sesame cultivar KU-18 was selected for this study. KU-18, the black seed sesame variety was developed under the KU Sesame Breeding Project in 1992. Its unique quality is taste and flavor for edible seed (Takada and Uno, 2001). Seeds were obtained from the seed production field of the National Corn and Sorghum Research Center, Nakhon Ratchasima Province. KU-18 is a small-seeded sesame cultivar (4g/1000 seeds in this study) and has black color seed coat. The site was ploughed, harrowed and leveled properly. The plot size was 4m x 5m leaving a distance of 1 m between replications and the center 2 m between two adjacent sub-plots and each sub-plot consisted of 8 rows. Sesame was drilled by hand keeping 50 cm distance between rows on June

2008. Compound fertilizer (15-15-15) was applied at the rate of 155 kg ha^{-1} at 1 week after planting and weeding was carried out by hand two times while thinning was not carried out. Sprinkler irrigations and chemicals were applied whenever necessary during the growth period of the crop. All other agronomic practices were kept normal and uniform for all the treatments. The total amount of rainfall for 2008 was 1285.00 mm. The cultivated area is situated at longitude 101° 25'18" E, latitude 14° 24'42" N and 387.92 m above mean sea level. In the experimental site, a total rainfall of 553.3 mm was received during the sesame planting period in wet season. The average minimum and maximum temperatures for the cropping season were 22.4°C and 31.3℃, respectively.

At 30 days after planting (DAP) ten plants from each plot were randomly selected within the middle rows to record plant height at flowering and harvest time, plant height to first capsule, number of nodes per plant, number of capsules per plant, capsule length, average number of seeds per capsule and 1000 seed weight. At maturity, four centered-rows in an area of 6 m^2 were harvested to obtain seeds for seed yield and chemical analysis. The ten earlier tagged plants were harvested separately and used for yield component determination. The crop was carefully hand cut to avoid capsule shattering. After harvesting, plants were placed in plastic bags for transport to the silo and air-dried for about three days then threshed. After complete threshing and cleaning, the seeds were sun dried to eight per cent moisture level. Seed yield was calculated over all plants in the plot. After drying and cleaning to remove foreign materials, seeds were stored at 13°C and 70 % RH and, later, were analyzed for oil contents (%) by using Soxtex System and protein contents by Kjeltex System. Aflatoxin contamination was determined by ELISA (Enzyme Linked Immuno Sorbent Assays) method. Chemical analysis and aflatoxin determination were done at the Post-harvest and Products Processing Research and Development Office, Department of Agriculture, Chatuchak, Bangkok. IRRI Statistics method was used for analysis of variance (ANOVA) and among treatment mean differences were determined by Fisher’s LSD.

1. Chemical Determination for Oil Content

The moisture content was measured by a vacuum oven drying method (130 ± 3°C for 3 hours) using a forced-draft oven (LCV-242, Espec, Osaka). The oil content was determined by the Sohxlet method using a Soxtex, System HT 1043 Extraction Unit (Tecator Co., Ltd., Sweden) produced by Tecator. Total oil was determined by extracting the ground seeds in a Soxtec apparatus with petroleum ether for 12 hr (David, 1989).

2. Chemical Determination for Protein Content

Grain protein is rarely measured directly because of the difficult analytical procedures involved. Therefore, total nitrogen was measured in dry grain by the Kjeltex and then converted to crude grain protein using a conversion factor (5.30) for sesame. The protein content was calculated by multiplying the obtained total nitrogen percentage by the protein factor: 5.30 and expressed as moisture-free basis (David, 1989).

3. Aflatoxin Determination by ELISA Method

There were four major types of aflatoxins as B_1, B_2, G_1, and G_2, of which B_1 type is the most potent carcinogen (Squire, 1981). In this study, aflatoxin B_1 was determined using the ELISA technique. However, the total aflatoxin would be greater. In order to determine the presence and level of aflatoxins in sesame seed with ELISA method, aflatoxin is extracted from a ground-sample by shaking with methanol solution. Free toxin in the sample and controls, was allowed to compete with enzyme-labeled toxin (conjugate) for the antibody binding site. After the particular incubation time, the content of the wells were removed and wash to remove any unbound toxin or enzyme-labeled toxin. A substrate was then added which reacts with the bound enzyme conjugate to produce the blue color. More blue color means fewer toxins and colorless means more toxins. Read the optical density of the test by microwell reader. Optical densities of standard toxin were used to form the standard curve and the sample optical densities were plot against the curve to calculate the exact amount of aflatoxin present in the sample.

Data Collection

The following data were collected.

(a) Plant population at emergence (plants)

(b) Plant height at flowering (cm)

(c) Plant height at harvest (cm)

(d) Height to1st capsule (cm)

(e) Number of nodes per plant (nodes)

(f) Number of capsules per plant (capsules)

(g) Capsule length (cm)

(h) Plant population at harvest (plants)

(i) Number of seeds per capsule (seeds)

(j) 1000-seed weight (g)

(k) Seed yield (kg ha^{-1})

(l) Oil and protein contents (%)

(m) Aflatoxin level (ppb)

Experimental Site

Field study was conducted at the National Corn and Sorghum Research Center, Nakhon Ratchasima Province. Chemical analysis and aflatoxin determination were done at the Post-harvest and Products Processing Research and Development Office, Department of Agriculture, Chatuchak, Bangkok, Thailand.

Duration

The study periods started from June to September 2008 rainy season for field experiment followed by laboratory works from January to February, 2009.

Meteorological Data

Meteorological data for the period of experimentation were obtained from Pak Chong Agromet Station, Pak Chong, Nakhon Ratchasima and presented in Appendix Tables (1-4).

RESULTS AND DISCUSSION

1. Seeding rates effect on growth, yield and yield components

After complete emergence, the number of plant population was recorded. During the growing period, it was observed that different seeding rates resulted in different plant population (Table 1). Drilling the seed at the rate of 4, 6, 8 and 10 kg ha^{-1} resulted in plant densities, at seedling stage, of 658,083, 962,667, 1,136,420 and 1,468,830 plants ha^{-1}, respectively. Final plant population was determined one week before harvest. However, at harvesting time, final plant populations were 493,583, 585,917, 671,750 and 712,083 plants ha^{-1}, respectively. Reduction of plant population was due to interplant competition for growth factors. The plant losses of 25, 39, 41 and 52% respectively, were noted from the seeding rates 4, 6, 8 and 10 kg ha^{-1}. These degrees of losses were also reported elsewhere (Mazzani, 1966 and Weiss, 1971). Mazzani (1966) recorded that plant losses of 22-26 % during the period from 80-100 days after sowing and Weiss (1971) stated that the plant losses of 25-34 % occurred between emergence and harvest time. Using the high seed rates may compensate for often substantial losses of seed and plants during the period from sowing till harvesting (Weiss, 1971). Additional seed is a form of insurance for a good stand because there is no agronomic practice that can improve a poor stand other than replanting (Langham, 2008). The environment from the emergence through the juvenile stage is more important for final plant number than the seeding rate (Langham, 2007). One positive aspect of a higher population is that it forces the sesame to grow faster and shade out competing weeds. In Texas, Kinman and Martin (1954) found that there was slight difference in yield between 25,250 - 495,750 plants ha^{-1} because of high stand tolerance. In Australia, Bennett (1998) strived for 303,500 to 354,000 plants ha^{-1} and Sapin *et al*. (2000) recommended 202,250 to 404,750 plants ha^{-1}. In Venezuela, Avila (1999) found small difference between 303,500 and 354,000 plants ha^{-1}.

Table 1 Effects of seeding rates on plant population at emergence and harvest time of sesame.

Seeding rates (a) (kg ha^{-1})	Plant population at emergence (plants ha^{-1})	Plant population at harvest (plants ha^{-1})
4	658,083 b	493,583 b
6	962,667 b	585,917 ab
8	1,136,420 ab	671,750 ab
10	1,468,830 a	712,083 a
LSD (5%)	367,685	213,408
CV (a) (%)	26.24	23.33

Within each column, means followed by the same letter or letters are not significantly different at $P<0.05$ as determined by Fisher's LSD.

Table 2 showed that different seeding rates did not affect plant height at flowering stage, but at harvest time. Plant height among 4, 6 and 8 kg ha^{-1} seeding rate were not significantly different, while 6 kg ha^{-1} seeding rate produced the tallest plants. Further increase beyond this seeding rate led to the decrease in plant height and the height was gradually shortened with increasing seeding rate. Imoloame *et al.* (2007) stated that plant height decrease with increase seeding rate. It was suggested that low seeding rate resulted in vigorous plant growth due to less inter- and intra-plant competition for growth resources such as soil moisture and nutrients because the root penetrates deep into the soil for moisture. Plant height to first capsule in different seeding rates showed similar result. Delgado and Yermanos (1975) reported plant height and height to first capsule were only slightly affected by changes in plant density. The final height of the plant is influenced more by the vegetative phase than the reproductive phase (Langham, 2007). The population density affects the phenotype and the length of time of the phases and stages. As the plants compete for light, plants in high population grow taller and faster than low population. However, unless there is considerable moisture and fertility, the final height is usually lower in high populations. High populations will use up the present moisture and fertility sooner and will go through the whole cycle faster from the mid bloom to the late dry down stage. High populations will lose lower leaves faster since the light will not penetrate the canopy (Langham, 2007).

Different seeding rates significantly affected number of nodes and number of capsules per plant (Table 2). The number of nodes and capsules per plant decreased with increasing seeding rates. The highest number of nodes (21.4) and capsules (35.8) per plant were obtained from the lowest seeding rate (4 kg ha^{-1}) while the lowest values (17.9 nodes and 26.4 capsules, respectively) were obtained from the highest seeding rate (10 kg ha^{-1}). These results indicated that plants grown at low seeding rate received more light intensity as compared with higher seeding rate. Furthermore, competition for nutrients and water between plants was less with decreasing population. A greater number of nodes and capsules per plant were important factors in improving sesame seed yield. Capsules number per plant values generally agreed with several earlier reports (Kutlu *et al.*, 1991; Bullock *et al.*, 1998; Christmas, 2002 and Yilmaz, 2003).

Different seeding rates showed no significantly difference in length of capsule. However, the longest capsule length (3.88 cm) was obtained from 4 kg ha^{-1} seeding rates and the shortest capsule length (3.73 cm) was found at 10 kg ha^{-1} seeding rates. Although different seeding rates did not cause a difference in number of seeds per capsule, the highest seeds per capsule were marked in 8 kg ha^{-1} seeding rate whereas 10 kg ha^{-1} seeding rate showed the lowest number of seeds per capsule (Table 2). Similarly, different seeding rates showed no significant difference in 1000-seed weight, but sesame seed weight was gradually decreased with increasing seeding rate (Table 2). This result was in line with Majumdar and Roy (1992) who reported the insignificant reduction in 1000-seed weight with increasing plant population.

Sesame seed yield was significantly affected by different seeding rates. The highest seed yield (966 kg ha^{-1}) was obtained from 4 kg ha^{-1} seeding rate, and then seed yield was gradually decreased with increasing seeding rates. The lowest seed yield (786 kg ha^{-1}) was found in 10 kg ha^{-1} seeding rates. The reason for yield reduction due to increased seeding rates can be attributable to reduced node numbers and capsule numbers per plant (Table 2). This result agreed with the earlier findings by Mazzani and Cobo (1956), Bleasdale (1966), Menon (1967), Gerakis and Tsangarakis (1971) and Delgado and Yermanos (1975) who reported that sesame yield increased with increasing population up to a certain level and further increase in plant population led to yield reduction. Imoloame *et al.* (2007) also reported that the highest seed yield was obtained from the seeding rate of 6 kg ha^{-1}. When seeding rate increased, plant population density increased, which might have caused greater competition for available water, nutrients and lights, thus leading to lower seed yield. At the lower seeding rates, numbers of plants per unit area are fewer than the higher seeding rates. When the seeding rates increased, the competition among plants also increased in terms of usage of light, water and nutrient elements. However, plants in the low seeding rates produced the highest number of nodes per plant, number of capsules per plant and seed yield in comparison with the high seeding rates. Population density plays triple roles in determining seed yield (Adebisi *et al.*, 2005). A better distribution of small plants derived from higher populations most likely compensated for the higher growth rates of less densely distributed plants derived from low populations. High plant population can have some advantages, canopy closure is quicker, light interception is greater, and weed competition is lower. However, yield does not always increase as plant population increases. As the number of plants per unit area increases, each plant captures less light, which limits each plant's growth. Too high plant populations also increase competition for nutrients and water, may promote lodging.

Seeding rates did not affect the height of plant at flowering, the height to first capsule, capsule length, number of seeds per capsule and 1000-seed weight but affected plant population at emergence and at harvest time, plant height at harvest, number of nodes and capsules per plant and seed yield.

Table 2 Effects of seeding rates on plant height at flowering and harvest, height to 1st capsule, number of nodes and capsules per plant, capsule length, number of seeds per capsule, 1000-seed weight and seed yield of sesame.

Seeding rates (a) (kg ha^{-1})	Plant height at flowering (cm)	Plant height at harvest (cm)	Height to 1st capsule (cm)	Nodes number per plant	Capsules number per plant	Capsule length (cm)	Seeds number per capsule	1000 seed weight (g)	Seed yield (kg ha^{-1})
4	90.51	121.37ab	46.14	21.43a	35.81 a	3.88	73.72	3.36	966 a
6	90.95	121.68 a	44.66	20.55a	33.53ab	3.86	73.53	3.28	907ab
8	95.23	121.63ab	49.12	19.26ab	30.16bc	3.77	74.49	3.34	903ab
10	91.87	116.01 b	48.24	17.90b	26.43 c	3.73	71.67	3.25	786 b
LSD (5%)	ns	5.63	ns	2.24	4.50	ns	ns	ns	123.31
CV (a) (%)	19.14	20.12	14.84	13.44	16.12	5.43	8.53	7.28	16.44

Within each column, means followed by the same letter or letters are not significantly different at $P<0.05$ as determined by Fisher's LSD.

2. Harvesting dates effect on growth, yield and yield components

Delay harvesting tended to increase nodes number per plant and significantly increased capsules number per plant (Table 3). Harvesting date 60 DAF yielded the greatest number of nodes (20.59) and number of capsules per plant (34.21) while the lowest number of nodes and capsules per plant were obtained from harvesting date 52 DAF. The indeterminate growth nature of sesame may be the cause of this increment. However, the longest capsule length (3.95cm) was obtained from 56 DAF. The highest number of seeds per capsule was obtained from harvest date 52 DAF but it was not statistically different from harvest date 60 DAF (Table 3). Harvesting date 56 DAF yielded the lowest number of seeds per capsule. This results was closely supported by Mondal *et al*. (1995), they reported that delay harvesting reduced the number of seeds per capsule. No conspicuous difference in 1000-seed weight between different harvesting dates was resulted. The 1000-seed weight tended to decrease when harvesting was delayed. Different harvesting dates affected on the seed yield (Table 3). The maximum seed yield of sesame (1,163 kg ha^{-1}) was observed in harvesting date 52 DAF and lowest seed yield was obtained from harvesting date 60 DAF. Delay harvesting reduced yield due to capsules opened and shattering of the seeds during harvesting time. Furthermore, early harvesting can reduce seed quality and late harvesting can enhance seed loss. Delayed harvest, however, increases the risk of seed shattering. Due to its indeterminate growth, it cannot be harvested at once as seeds are formed and ripened chronologically. Therefore, it is essential to harvest the plant by choosing the optimum period for varieties and locations. According to this experiment, an appropriate harvest time was at 52 DAF.

3. Interaction effects of seeding rates x harvesting dates

Table 4 and 5 showed that the interaction of seeding rates x harvesting dates affected all parameters measured but 1000-seed weight which was constant. It can be concluded, to illustrate the potential that, for each seeding rates delay harvesting increased plant height at harvest (Table 4). Delay harvesting allowed sesame plants to grow taller because of indeterminate growth habit of sesame. Consequently, delay harvesting increased nodes number per plant, but not for 10 kg ha^{-1} seeding rate, and tended to increase capsule number per plant.

For table 5, the pattern was that, for each seeding rates delay harvesting shortened capsule length, reduced seeds number per capsule and reduced seed yield. According to the result, it was obviously pointed that the higher seed yield could be expected by using seeding rate 4 kg ha^{-1} or any other seeding rates with harvest date 52 DAF. The seeding rate of 10 kg ha^{-1} with harvest date 60 DAF gave the lowest seed yield.

Table 3 Effects of harvesting dates (days after flowering, DAF) on number of nodes and capsules per plant, capsule length, number of seeds per capsule, 1000-seed weight and seed yield of sesame.

Harvest dates (b) (DAF)	Nodes number per plant	Capsules number per plant	Capsule length (cm)	Seeds number per capsule	1000-seed weight (g)	Seed yield (kg ha^{-1})
52	19.05	28.24 b	3.74 b	75.81 a	3.34	1163a
56	19.71	32.00ab	3.95 a	70.24 b	3.34	829 b
60	20.59	34.21 a	3.74 b	74.00ab	3.25	679 c
LSD (5%)	ns	3.90	0.15	5.41	ns	106.79
CV (b) (%)	13.41	16.98	5.28	10.11	7.62	16.44

Within each column, means followed by the same letter or letters are not significantly different at P<0.05 as determined by Fisher's LSD

Table 4 Effects of interaction of seeding rates (kg ha^{-1}) and harvesting dates (days after flowering, DAF) on plant height at harvest, height to 1st capsule, number of nodes and capsules per plant of sesame.

Interaction (a x b)	Plant height at harvest (cm)	Height to 1st capsule (cm)	Nodes number per plant	Capsules number per plant
4 x 52	121ab	47ab	20ab	32 b
x 56	120ab	46ab	21ab	35ab
x 60	123 a	46ab	23 a	40 a
6 x 52	118ab	45ab	19 b	27bc
x 56	125 a	40 b	21ab	35ab
x 60	122 a	49 a	22ab	38ab
8 x 52	122 a	50 a	18 b	27bc
x 56	125 a	47ab	21ab	34ab
x 60	118ab	51 a	19 b	30bc
10 x 52	117ab	46ab	20ab	27bc
x 56	112 b	46ab	16 b	24 c
x 60	119ab	53 a	18 b	28bc
LSD (5%)	9.75	8.61	3.87	7.80

Within each column, means followed by the same letter or letters are not significantly different at $P<0.05$ as determined by Fisher's LSD.

Table 5 Effects of interaction of seeding rate (kg ha^{-1}) and harvesting date (days after flowering, DAF) on capsule length, number of seeds per capsule, 1000-seed weight and seed yield of sesame.

Interaction (a x b)	Capsule length (cm)	Seeds number per capsule	1000-seed weight (g)	Seed yield (kg ha^{-1})
4 x 52	3.72 b	74ab	3.38	1267 a
x 56	4.04ab	71ab	3.47	775 bc
x 60	3.88ab	77 a	3.24	855 bc
6 x 52	3.76 b	75ab	3.24	1211 a
x 56	4.09 a	73ab	3.35	924 b
x 60	3.74 b	73ab	3.25	585 c
8 x 52	3.75 b	79 a	3.37	1059ab
x 56	3.89ab	72ab	3.24	919 b
x 60	3.68 b	72ab	3.40	731bc
10 x 52	3.72 b	76ab	3.35	1118ab
x 56	3.79 b	65 b	3.30	695 c
x 60	3.68 b	74ab	3.11	544 c
LSD (5%)	0.29	10.82	ns	213.58

Within each column, means followed by the same letter or letters are not significantly different at $P<0.05$ as determined by Fisher's LSD

4. Aflatoxin contamination

Even though the data were not analyzed statistically, discussion will be done on the trend of this incidence. The results generally revealed aflatoxin B_1 was detected in all the samples. The levels of aflatoxin B_1 ranged from 4.58 to 9.44 ppb with a mean value of 7.58 ppb in sesame seed (Table 7). The maximum allowable limit set by the USFDA is 20 ppb in food for human consumption (Guo *et al*., 2008). Foreign levels are typically within a range of 4 to 15 ppb depending upon the countries. Although the level of aflatoxin B_1 (7.58 ppb) was less than 20 ppb maximum allowable limit, three environmental factors (Table 6) such as amount of rainfall, temperature and relative humidity (RH), affect aflatoxin production in the field (D'Aquino *et al*., 1986; Montani *et al*., 1988; Karunaratne *et al*., 1990 and Ellis *et al*., 1991). Average air and soil temperatures of 25–35°C and relative humidity of above 70% were favorable for aflatoxin contamination. Denizel *et al*. (1976) reported that 82% RH is the minimum humidity required for *A. flavus* spore germination and aflatoxin production in Turkish pistachio nuts. High temperature and moisture are the main factors significantly increase pre-harvest aflatoxin risk. Late-season rainfall delays drying of sesame in the field and favors continued aflatoxin synthesis (Jones *et al*., 1981). Heavy rains during the harvest period may have favored for fungal diseases and continued aflatoxin production. These may be responsible for the detection of aflatoxin B_1 in all the samples. Beuchat *et al*. (2006) revealed that no significant difference in aflatoxin incidence was associated with harvest date treatments. The most appropriate aflatoxin-minimizing technologies are the use of varieties with less risk of contamination, improved postharvest crop processing and storage technologies and separating out of contaminated produce.

Increased temperature and delayed harvest may lead to aflatoxin accumulation before harvest. However, precipitation may influence aflatoxin levels in some years (Wiatrak *et al*., 2005). McMillian *et al*. (1985) also reported a positive correlation of aflatoxin with higher temperature. Higher temperatures increased aflatoxin concentrations in inoculated corn ears (Thompson *et al*., 1980) and aflatoxin accumulation in grain (Payne, 1992). However, these results suggest that increased temperature may lead to aflatoxin accumulation before harvest. Consequently, human beings and animals are exposed to aflatoxin by consuming contaminated food. Although the presence of aflatoxins in sesame seed does not constitutes a serious health hazard to both human beings and animals because of their toxic and carcinogenic property, it is considered unfit for consumption and is one of the most important constraints to international trade.

Table 6 Meteorological data for the experimental area (Suwan Farm) in 2008.

Months	Average temperature (°C)			Relative humidity (%)	Rainfall (mm)
	Min.	Max.	Average		
June	23.3	31.0	27.15	77	50.0
July	23.7	31.3	27.50	72	43.7
August	22.9	30.6	26.75	77	151.8
September	22.4	29.4	25.90	83	363.7
October	22.1	30.2	26.15	83	229.5
November	20.1	28.0	24.05	73	9.4

Table 7 Effects of seeding rates and harvesting dates (days after flowering, DAF) on oil and protein contents and aflatoxin contamination of sesame.

Seeding Rates (kg ha^{-1})	Harvesting Dates (DAF)	Aflatoxin (ppb)	Oil Content (%)	Protein Content (%)
4	52	9.44[1]	42.10[1]	26.00[1]
	56	6.47	38.60	26.60
	60	8.07	33.00	26.20
6	52	7.29	35.80	25.80
	56	9.10	40.70	26.70
	60	4.58	34.20	26.10
8	52	8.63	32.80	25.60
	56	9.05	42.80	26.30
	60	5.78	36.80	26.30
10	52	7.47	41.70	26.90
	56	7.33	34.40	26.80
	60	7.71	36.60	27.00
Mean		7.58	37.46	26.36

[1] no statistical analysis available due to a single observation (Bulk samples)

5. Oil and protein contents

The range of oil and protein contents in the moisture-free basis in sesame ranged from 32.80 to 42.80 % and 25.60 to 27.00 %, respectively (Table 7). Average oil content was 37.46 % and protein content was 26.36 %. Using the seeding rate 4 kg ha^{-1}, the highest oil content was obtained at 52 DAF harvesting date. After that the oil content was reduced by delay harvesting at 56 and 60 DAF. For delay harvest at 56 and 60 DAF, the oil content increased as seeding rate increased up to a certain level (8 kg ha^{-1}) and then the oil content declined. At the second harvest time oil and protein contents reached its maximum level (Table 9). Leach *et al*. (1999) also observed that there was no effect of plant density on seed oil content in rapeseed. The effect of plant density apparently did not show any considerable effect on the oil. Variations in oil accumulation in relation to capsule age revealed that oil formation begins within 5 days after fertilization and maximum accumulation (52% oil) was achieved after 30 days (Saha and Bhargava, 1984). The oil yield was obtained by multiplying the values of oil content by the seed yield (Table 8 and 9). The highest oil yields were obtained from 4 kg ha^{-1} seeding rates and harvest at 52 DAF. The increase in yield of oil per unit land area was due to increasing seed yield more than increasing percent oil in the seed.

For protein content, the lower protein content resulted from early harvest at 52 DAF (Table 9). Seed protein was unaffected by plant densities and delayed harvest. The highest protein content was obtained at 60 DAF harvesting date due to the highest seeding rate. Although 56 DAF harvesting date resulted in higher protein content compared with other harvesting dates but the amount did not change significantly. Kinman and Stark (1954) reported that the chemical composition of seeds was affected not only by genotype but also by agro-climatic conditions. The genotypic-environment interaction is the key factor in the assessment of crop variety performance in terms of quantity and quality of produce. Qiu *et al.* (1991) stated that oil and protein accumulation increased until maturity and had no variation from 36 to 76 days after flowering in soybean.

Low seed quality is associated with high rainfall and temperature during maturity. The literature indicates that the protein concentration increases at higher temperatures. The level of humidity did not affect the protein or oil content of the seed (Woodward and Begg, 1976). Temperature has been found to be an important environmental factor affecting the oil and protein content of oilseed crops. Oil and protein content of the seed are negatively correlated and therefore, react opposite to temperature. High temperatures during ripening reduce oil content while increasing protein content. Conversely, crops growing at cool temperature are characterized by high oil content and low protein content.

Table 8 Seeding rates effect on aflatoxin contamination, oil and protein contents and oil yield.

Treatments	**Aflatoxin (ppb)**	**Oil (%)**	**Protein (%)**	**Oil Yield (kg ha^{-1})**
S1H1	9.44	42.10	26.00	533.41
S1H2	6.47	38.60	26.60	299.15
S1H3	8.07	33.00	26.20	282.15
Mean for S1	**7.99**	**37.90**	**26.27**	**365.99**
S2H1	7.29	35.80	25.80	433.54
S2H2	9.10	40.70	26.70	376.07
S2H3	4.58	34.20	26.10	200.07
Mean for S2	**6.99**	**36.90**	**26.20**	**334.56**
S3H1	8.63	32.80	25.60	347.35
S3H2	9.05	42.80	26.30	393.33
S3H3	5.78	36.80	26.30	269.01
Mean for S3	**7.82**	**37.47**	**26.07**	**338.35**
S4H1	7.47	41.70	26.90	466.21
S4H2	7.33	34.40	26.80	239.08
S4H3	7.71	36.60	27.00	199.10
Mean for S4	**7.50**	**37.57**	**26.90**	**295.17**

S1 = 4 kg ha^{-1} H1 = 52 DAF

S2 = 6 kg ha^{-1} H2 = 56 DAF

S3 = 8 kg ha^{-1} H3 = 60 DAF

S4 = 10 kg ha^{-1}

Table 9 Harvesting dates effect on aflatoxin contamination, oil and protein contents and oil yield.

Treatments	**Aflatoxin (ppb)**	**Oil (%)**	**Protein (%)**	**Oil Yield (kg ha^{-1})**
S1H1	9.44	42.10	26.00	533.41
S2H1	7.29	35.80	25.80	433.54
S3H1	8.63	32.80	25.60	347.35
S4H1	7.47	41.70	26.90	466.21
Mean for H1	**8.21**	**38.10**	**26.07**	**443.39**
S1H2	6.47	38.60	26.60	299.15
S2H2	9.10	40.70	26.70	376.07
S3H2	9.05	42.80	26.30	393.33
S4H2	7.33	34.40	26.80	239.08
Mean for H2	**7.99**	**39.13**	**26.60**	**324.09**
S1H3	8.07	33.00	26.20	282.15
S2H3	4.58	34.20	26.10	200.07
S3H3	5.78	36.80	26.30	269.01
S4H3	7.71	36.60	27.00	199.10
Mean for H3	**6.53**	**35.15**	**26.40**	**238.58**

S1 = 4 kg ha^{-1} H1 = 52 DAF

S2 = 6 kg ha^{-1} H2 = 56 DAF

S3 = 8 kg ha^{-1} H3 = 60 DAF

S4 = 10 kg ha^{-1}

CONCLUSION

Under this study, the results illustrated that, seeding rate and harvesting date treatments showed significant effects on seed yield and most yield components. Among the seeding rates and harvesting dates treatments, the highest seed yield was achieved at 4 kg ha^{-1} seeding rate and harvest date at 52 DAF. For the interaction effects, application of different seeding rates (4, 6, 8 and 10 kg ha^{-1}) with harvest date 52 DAF also observed higher yield than those of other harvest dates. Therefore, it could be suggested that 4 kg ha^{-1} seeding rate and harvesting at 52 DAF was optimum for high sesame yield for drill planting in the rainy season. Using the seeding rate of 10 kg ha^{-1} with harvest at 60 DAF found the lowest seed yield. Therefore, heavy seeding rate and delay harvest may reduce the seed yield of sesame. More yield losses might be due to the indeterminate growth characteristic and seed shattering.

The results revealed that aflatoxin B_1 was presence in all the analyzed samples. Although aflatoxins contamination in sesame seed did not constitutes a serious health hazard to both human beings and animals, because of their toxic and carcinogenic property, it is considered to be unfit for human consumption and trade market and may reduce seed quality for consumption. Prolonged consumption of large quantities of the contaminated grains may lead to aflatoxin related intoxications in livestock and human beings. The aflatoxin contamination did not affect crop productivity but it made produce reduction in quality. Therefore, aflatoxin contamination can be minimized by the use of resistant cultivar, adopting certain cultural practices, proper handling and storage practices.

LITERATURE CITED

Adebisi, M.A. 2004. **Variation, Stability and Correlation Studies in Seed Quality and Yield of Sesame (*Sesamum indicum* L.).** Ph.D Thesis. University of Agriculture, Abeokuta, Ogun state, Nigeria.

_____, M.O. Ajala, D.K. Ojo and A.W. Salau. 2005. Influence of population density and season on seed yield and its components in Nigerian sesame genotypes. **J. Trop. Agric.** 43(1-2): 13-18.

Adeyemo, M.O., A.O. Ojo and D.T. Gungula. 1992. Effects of plant population density on some agronomic traits and seed yield of sesame (*Sesamum indicum* L.) in a Southern Guinea Savannah environment. **Trop. Oilseeds J.** 1(1): 35-42.

Akobundu, I.O. 1987. **Weed and Science in the Tropics: Principles and Practices.** John Wiley and sons, New York, USA.

Alam Sarkar, M.N., M. Salim, N. Islam and M.M. Rahman. 2007. Effect of sowing date and time of harvesting on the yield and yield contributing characters of sesame (*Sesamum indicum* L.) seed. **Int. J. Sustain. Crop Prod.** 2(6): 31-35.

Anonymous. 2008. **World Sesame Situation.** *Available Source:* http://www.sesamegrowers.org/worldstatusofsesame.htm. Retrieved date: August, 2008.

Arzumanova, A.M. 1963. Influence of different cultural conditions on the oil content of till. **Trudy Prikl. Bot. Genet. Selek.** 35: 168-172.

Ashri, A. 1989. Sesame, p. 375–387. *In* G. Robbelen, R.K. Downey and A. Ashri, eds. **Oil Crops of the World.** McGraw-Hill Publishing Company, New York.

Ashri, A. 1994. Genetic resources of sesame: present and future perspectives, p. 25-39. *In* R.K. Arora and K.W. Riley, eds. **Sesame Biodiversity in Asia: Conservation, Evaluation and Improvement.** IPGRI, New Delhi.

_____. 1998. Sesame Breeding, p. 179-228. *In* J. Janick, ed. **Plant Breeding Reviews.** John Wiley and Sons, Inc, New York.

Avila M., J.M. 1999. **Cultivation of Sesame, *Sesamum indicum* L.** National Fund of Agricultural Research, Maracay, Venezuela.

Ayasmy, M. and R. Kulandivelu. 1992. Effect of methods and intervals of irrigations on growth of sesame. **Madras Agric. J.** 79(2): 104-114.

Bahkali, A.H. and M.A. Hussain. 1998. Protein and oil composition of sesame seeds (*Sesamum indicum* L.) grown in the Gizan Area of Saudi Arabia. **Int. J. Food Sci. Nutr.** 49: 409-415.

Bedigian, D. and J.R. Harlan. 1983. Nuba agriculture and ethnobotany with particular reference to sesame and sorghum. **Econ. Bot.** 37: 384-395.

_____, D.S. Seigler and J.R. Harlan. 1985. Sesamin, sesamolin and the origin of sesame. **Biochem. Systemat. Eco.** 13: 133-139.

Bennett, M. 1998. Sesame seed. **A Handbook for Farmers and Investors**. *Available Source:* http://www.ridc.gov.au/pub/handbook/sesame.html. Retrieved date: May, 2009.

_____. and B. Conde. 2003. **Sesame Recommendations for the Northern Territory.** *Available Source*: http://www.primaryindustry.nt.gov.au. Retrieved date: May, 2009.

Beuchat, L.R., D.H. Smith and C.T. Young. 2006. Effect of foliar fungicides on aflatoxin, oil and protein contents and maturing rate of peanut kernels. **J. Sci. Food Agric.** 25(5): 477-482.

Beyer, K., L. Bardina, G. Grishina and H.A. Sampson. 2002. Identification of sesame seed allergens by 2-dimensional proteomics and Edman sequencing: seed storage proteins as common food allergens. **J. Allergy Clinical Immunology** 110: 154-159.

Bisht, I.S., R.K. Mahajan, T.R. Loknathan and R.C. Agrawal. 1998. Diversity in Indian sesame collection and stratification of germplasm accessions in different diversity groups. **Gen. Res. Crop Evol.** 45(4): 325-335.

Bleasdale, J.K.A. 1966. Plant growth and crop yield. **Annals Applied Biol.** 57: 173 – 182.

Bowerman, P. 1984. Comparison of harvesting methods of oilseed rape, p. 157–165. *In* A.A.B., ed. **Agronomy, Physiology, Plant breeding and Crop Protection of Oilseed Rape.** Association of Applied Biologists, British Crop Protection Council, Wellesbourne, Warwick, UK.

Boyacioglu, D., N.S. Hettiarachchy and R.W. Stack. 1992. Effect of three systemic fungicides on deoxynivalenol (vomitoxin) production by *Fusarium graminearum* in wheat. **Can. J. Plant Sci.** 72: 93-101.

Boyle, G.J. and D.J. Oemcke. 1995. Investigation of methods to reduce preharvest seed losses in sesame, p. 169-172. *In* M.R. Bennett and I.M. Wood, eds. **Proc. the First Australian Sesame Workshop.** Northern Territory Department of Primary Industry and Fisheries, Darwin and Katherine, Australia.

Brigelius-Flohe, R., F.J. Kelly, J.T. Salonem, J. Neuzil, J.M. Zingg and A. Azzi. 2002. The European perspective on vitamin E: current knowledge and future research. **Am. J. Clin. Nutr.** 76: 703-716.

Brito, O.J. 1981. Usage of sesame as a source of protein for human consumption. **Dissert. Abstr. Int. B** 41: 105.

Bullock, D., S. Khan and A. Rayburn. 1998. Soybean yield response to narrow rows is largely due to enhanced early growth. **Crop Sci.** 38(4): 1011-1016.

Calil, J. 1965. Sixty Melhorata still Ponca. Co-op. Brazil. 22: 20-24. *In* G. R.bbelen, R.K. Downey and A. Ashri, eds. **World Oilseeds: Chemistry, Technology, and Utilization.** Van Nostrand Reinhold, New York.

Caliskan, S., M. Arslan, H. Arioglu and N. Isler. 2004. Effect of planting method and plant population on growth and yield of Sesame (*Sesamum indicum* L.) in a Mediterranean type of environment. **Asian J. Plant Sci.** 3(5): 610-613.

Cane, J. 1949. Preliminary studies on sesame in Salvador, Central America, *In* **Proc. 1st International Sesame Conference.** Clemson. Agric. Coll., USA.

Carpenter, A.C. and J.E. Board. 1997. Branch yield components controlling soybean yield stability across plant populations. **Crop Sci.** 37: 885-891.

CAST (Council for Agricultural Science and Technology). 1989. Mycotoxins: Economic and Health Risks. **Task Force Report No. 116.** Ames, Iowa.

Chakraborty, P.K., S. Maiti and B.N. Chatteryee. 1984. Growth analysis and agronomic appraisal of sesame (*Sesamum indicum*). **Indian J. Agric. Sci.** 54(4): 291-295.

Chartfield, C. 1934. Sesame seeds have high nutritive value; very rich in calcium, p. 316-317. *In* **USDA Year Book.** U.S. Dept. Agric, USA.

Christensen, C.M. 1965. Fungi in cereal grains and their products, p. 9. *In* G.N. Wogan, ed. **Mycotoxins in Foodstuffs.** M.I.T. Press, Cambridge, Massachusetts.

Christensen, C.M., C.J. Mirocha and R.A. Meronuck. 1977. **Molds, Mycotoxins and Mycotoxicoses.** Agricultural Experiment Station Miscellaneous Report 142. University of Minnesota, St. Paul, MN.

Christmas, E.P. 2002. **Plant Populations and Seeding Rates for Soybeans.** *Available Source:* http://www.ces.purdue.edu/extmedia/AY/AY-217.html. Retrieved date: June, 2008.

Cole, R.J., T.H. Sanders, J.W. Donner and P.D. Blankenship. 1989. Environmental conditions required to induce preharvest aflatoxin contamination of groundnuts: summary of six years research, p. 279-287. *In* D. McDonald and V.K. Mehan, eds. **Aflatoxin Contamination in Groundnut.** ICRISAT, Patancheru, India.

Coulombe, R.A. 1993. Biological action of mycotoxins. **J. Dairy Sci.** 76(3): 880-891.

D'Aquino, M., S. Bejar and E. Bollini. 1986. Bacillus subtiles rec assay for quantification of aflatoxins. **J. Food Prot.** 49 (21): 974-976.

David, B. 1989. AOCS' 4th edition methods. **J. Am. Oil Chem. Soc.** 66(12): 1749.

Davis, N.D. and U.L. Deiner. 1983. Some characteristics of toxigenic and nontoxigenic isolates of *Aspergillus flavus* and *Aspergillus parasiticus*, p. 279. *In* U.L Diener, R.L. Asquith and J.W. Dickens, eds. **Aflatoxin and *Aspergillus flavus* in Corn.** Southern Coop Series Bull, Craftmaster, Opelika, AL.

Day, J. 2000. The effect of plant growth regulator treatments on plant productivity and capsule dehiscence in sesame. **Field Crops Res.** 66: 15-24.

Day, J.S. 2000. Development and maturation of sesame seeds and capsules. **Field Crops Res.** 67: 1-9.

Delgado, M. and D.M. Yermanos. 1975. Yield component of sesame (*Sesamum indicum* L.) under different population densities. **Econ. Bot.** 29(1): 68-78.

Denizel, T., E.J. Rolfe and B. Jarvis. 1976. Moisture equilibrium relative humidity relationships in pistachio nuts with particular regard to control of aflatoxin formation. **J. Sci. Food Agric.** 27: 1027-1034.

Desjardins, A.E., T.M. Hohn and S.P. McCormick. 1993. Trichothecene biosynthesis in *Fusarium* species: chemistry, genetics and significance. **Microbiol. Reviews** 57: 594-604.

Dey, B.B. and H.C. Friedmann. 1951. The oxalate content of gingelly (*Sesamum indicum*) seeds. **Current Sci.** 20: 182.

Diener, U.L. and N.D. Davis. 1968. Effect of environment on aflatoxins production in freshly dug peanuts. **Tropical Sci.** 10: 22-28.

Dowell, F.E. and J.S. Smit. 1995. A note on high moisture content foreign material effects on aflatoxin in peanuts during storage. **Peanut Sci.** 22: 166-168.

Duhoon, S.S. 2004. Exploitation of heterosis for raising productivity in sesame. *In* **Proc. 4th International Crop Science Congress.** Brisbane, Australia.

Eckey, E.W. 1954. **Vegetable Fats and Oils**. American Chemical Society Monograph Series, Reinhold Publishing Co., New York, USA.

Ellis, W.O., J.P. Smith, B.K. Simpson and J.H. Oldham. 1991. Aflatoxins in food: occurrence, biosynthesis, effects on organisms, detection, and methods of control. **Crit. Rev. Food Sci. Nut.** 30: 403-439.

El-Tinay, A.H., A.H. Khattab and M.O. Khidir. 1976. Protein and oil compositions of sesame seed. **J. Am. Oil Chem. Soc.** 53: 648-653.

FAO (Food and Agricultural Organization of the United Nations). 2005. **FAOSTAT Database.** *Available Source:* http://www.apps.fao.org/default.htm. Retrieved date: May, 2009.

Farombi, E.O. 2006. Aflatoxin contamination of foods in developing countries: Implications for hepatocellular carcinoma and chemopreventive strategies. **African J. Biotech. 5**: 1-14.

Gareis, M. and J. Ceynowa. 1994. Influence of the fungicide Matador (tebuconazole/triadimenol) on mycotoxin production by *Fusarium culmorum*. **Z Lebensm Unters Forsch** 198: 244-248.

Geleta, B.M., M.A. Atak, P.S. Baenziger, L.A. Nelso, D.D. Baltenesperger, K.M. Eskridge, M.J. Shipmam and D.R. Shelton. 2002. Seeding rate and genotype effects on agronomic performance and end-use quality of winter wheat. **Crop Sci.** 42: 827-832.

Gerakis, P.A. and C.Z. Tsangarakis. 1971. Responses of sorghum, sesame and groundnut to plant population density in the central Sudan. **Agron. J.** 61: 872-875.

Gharbia-Abou, H.A., A.A.Y. Shehata and F. Shahidi. 2000. Effect of processing on oxidative stability and lipid classes of sesame oil. **Food Res. Int.** 33: 331-340.

Gopalan, C., B.V. Ramasastri and S.C. Balasubramanian. 1982. **Nutritive Value of Indian Foods.** National Institute of Nutrition, Indian Council of Medical Research, Hyderabad.

Guo. B., Z.Y. Chen, R.D. Lee and B.T. Scully. 2008. Drought stress and preharvest aflatoxin contamination in agricultural commodity: Genetics, genomics and proteomics. **J. Integr. Plant Biol.** 50(10): 1281–1291.

Gupta, S., D. Subrahmanyam and V.S. Rathore. 1993. Influence of sowing dates on yield and oil quality in sunflower. **J. Agro. Crop Sci.** 172(2): 137-144.

Hesseltine, C.W. 1983. Conditions leading to contamination by aflatoxins, p. 47-69. *In* **Proc. the International Symposium on Mycotoxins,** National Research Center, Cairo, Egypt.

Imoloame, E.O., N.A. Gworgwor and S.D. Joshua. 2007. Sesame weed infestation, yield and yield components as influenced by sowing method and seed rate in a Sudan Savannah agro-ecology of Nigeria. **African J. Agric. Res.** 2(10): 528-533.

Jackson, C.R. and A.F. Press. 1967. Changes in mycoflora of peanuts. **Oleagineux** 22: 165-168.

Jelinek, C.F., A.E. Pohland and G. Wood. 1989. Worldwide occurrence of mycotoxins in food and feeds. **J. Assoc. Official Anal. Chem.** 72: 223-230.

Jin, U.H., J.W. Lee, Y.S. Chung, J.H. Lee, Y.B. Yi, Y.K. Kim, N.I. Hyung, J.H. Pyee and C.H. Chung. 2001. Characterization and temporal expression of a w-6 fatty acid desaturate cDNA from sesame (*Sesamum indicum* L.) seeds. **Plant Sci.** 161: 935–941.

Johnson, D.L. and R.L. Croissant. 1986. Sesame production. **Bulletin no. 100.** Colorado State University Cooperative Extension.

Johnson, L.A., T.M. Suleiman and E.W. Lusas. 1979. Sesame Protein: A review and prospectus. **J. Am. Oil Chem. Soc.** 56: 463-468.

Johnson, R.H. and W.D. Raymond. 1964. The chemical composition of some tropical food plants: 3. Sesame seed. **Trop. Sci.** 6: 173-179.

Jones, D.B. and C.E.F. Gersdorff. 1927. Proteins of sesame seed, *Sesamum indicum*. **J. Biol. Chem.** 75: 213-225.

Jones, R.K., H.E. Duncan and P.B. Hamilton. 1981. Planting date, harvest date and irrigation effects on infection and aflatoxin production by *Aspergillus flavus* in field corn. **Phytopathology** 71: 810-816.

Joshi, A.B. 1961. **Sesamum.** Indian Central Oilseeds Committee, Hyderabad, India.

Karunaratne, A., E. Wezenberg and L.B. Bullerman. 1990. Inhibition of mold growth and aflatoxin production by *Lactobacillus spp*. **J. Food Prot.** 53(3): 230-236.

Kinman, M.L. and J.A. Martin. 1954. Present status of sesame breeding in the United States. **Agron. J.** 46: 24–27.

Kinman, M.L. and S.M. Stark. 1954. Yield and chemical composition of sesame, *Sesamum indicum* L., as affected by variety and location grown. **J. Am. Oil Chem. Soc.** 31(3): 104-108.

Kobayashi, T. 1991. Cytogenetics of sesame (*Sesamum indicum*), p. 581-592. *In* T. Tsuchiya and P.K. Gupta, eds. **Chromosome Engineering in Plants: Genetics, Breeding, Evolution.** Elsevier Science Publishing Company Inc., Amesterdam, Netherlands.

Kumar, A., T.N. Prasad and U.K. Prasad. 1996. Effect of irrigation and nitrogen on growth yield, oil content, nitrogen uptake, and water- use of summer sesame (*Sesamum indicum*). **Indian J. Agron.** 41: 111-115.

Kutlu, Z., A.S. Cinsoy, M. Yaman, N. Açıkgöz and A. Kıtıkı. 1991. The effect of row distance on yield and yield components in soybean. **J. Aegean Agric. Res. Inst.** 1, ISSN 1300-0225.

Landers, K.E., N.D. Davis and U.L. Diener. 1967. Influence of atmospheric gases on aflatoxin production by *Aspergillus flavus* in peanuts. **Phytopathology** 57: 1068-1090.

Langham, D.R. 2008. **Growth and Development of Sesame.** *Available Source:* http:// www.sesamegrowers.org. Retrieved date: June, 2008.

_____. 2007. Phenology of Sesame, p. 144-182. *In* J. Janick and A. Whipkey, eds. **Trends in New Crops and New Uses**. ASHS Press, Alexandria, VA.

Langham, D.G. and M. Rodriguez. 1949. Improvement of sesame in Venezuela, p. 74–79. *In* **Proc. First Int. Sesame Conf.,** Clemson Agricultural College, Clemson, SC.

Langham, R. and T. Wiemers. 2002. Progress in mechanizing sesame in the US through breeding, p. 157-173. *In* J. Janick and A. Whipkey, eds. **Trends in New Crops and New Uses.** ASHS Press, Alexandria, VA.

Langstraat, A., V.D. Bergh and B.V. Jurgens. 1976. Characteristics and composition of vegetable oil-bearing materials. **J. Am. Oil Chem. Soc.** 53(6): 241-247.

Leach, J.E., H.J. Stevenson, A.J. Rainbow and L.A. Mullen. 1999. Effects of high plant populations on the growth and yield of winter oilseed rape (*Brassica napus*). **J. Agr. Sci.** 132: 173–180.

Lillehoj, E.B. 1983. Effect of environmental and cultural factors on aflatoxin contamination of developing corn kernels, p. 27-34. *In* U.L. Diener, R.L. Asquith and J.W. Dickens, eds. **Aflatoxin and *A. flavus* in Corn.** Southern Coop. Series Bulletin 279, Albama Agricultural Experiment Station, Auburn, Ala.

Lyon, C.K. 1972. Sesame: Current knowledge of composition and use. **J. Am. Oil Chem. Soc.** 49(4): 245-249.

Majumdar, D.K. and S.K. Pal. 1988. Effect of irrigation and nitrogen levels on growth and yield attributes, yields, oil content, and water use of sesame. **Indian Agric.** 32: 147-152.

_____. and S.K. Roy. 1992. Response of summer sesame (*Sesamum indicum*) to irrigation, row spacing and plant population. **Indian J. Agron.** 37: 758-762.

Martin, J.H., W.H. Leonard and D.L. Stamp. 1976. Chapter 39. Miscellaneous industrial crops: sesame, p. 974-977. *In* **Principles of Field Crop Production.** Prentice-Hall, Upper Saddle River, NJ.

Mathew, T. and U.K. Kunju. 1993. Influence of irrigation on growth and yield of sesame. **Field Crop Abst.** 48(5): 3682.

Mazzani, B. 1966. The cultivation of sesame. **Agronomia. Caracas.** 3: 9-18. *In* H. Veenman and B.V. Zonen, eds. **Major Problems of Growing Sesame (*Sesamum indicum* L.) in Nigeria.** Wageningen University, Netherlands.

_____. and M. Cobo. 1956. Effects of different plants densities on some characters of branched varieties of sesame. **Agronomie Trop.** 6: 3-14.

McMillian, W.W., D.M. Wilson and N.W. Widstrom. 1985. Aflatoxin contamination of preharvest corn in Georgia: A six year study of insect damage and visible *Aspergillus flavus.* **J. Environ. Qual.** 14: 200–202.

Menon, E.F. 1967. Effect of varying spacing on yield of sesame. **Indian J. Agron.** 12: 274 – 276.

MOAI (Ministry of Agriculture and Irrigation). 1998. **Myanmar Agriculture in brief.** Myanmar.

MOAI (Ministry of Agriculture and Irrigation). 2009. **Myanmar Agriculture in brief.** Myanmar.

Monahan, F.J., J.I. Gray, A. Asghar, A. Haug, B. Shi and D.J. Bukley. 1993. Effect of dietary lipid and Vitamin E supplementation on free radical production and lipid oxidation in porcine muscle microsomal fractions. **Food Chem.** 46: 1-6.

Mondal, M.R.I., K.P. Biswas, H.M.A. Awal and A.J.M.F.H. Chowdhury. 1995. Effect of maturity stage on siliqua shattering, seed yield and oil content of *Brassica napus.* L. **Bangladesh J. Agric.** 20: 45-49.

Montani, M.L., G. Vaamonde, S.L. Resnik and P. Buera. 1988. Water activity influence on aflatoxin accumulation in corn. **Int. J. Food Microbiol.** 6: 349-353.

Moseley, Y.C., H.B. Manbeck, G.L. Barnes and G.L. Nelson. 1971. Controlled atmosphere for short duration storage of peanuts before drying. **Trans. Am. Soc. Agri. Eng.** 14: 206-210.

Mulkey, J.R., H.J. Drawe and R.E. Elledge. 1987. Planting date effects on plant growth and development in sesame. **Agron. J.** 79(4): 701-703.

Myanmar Sesame. 2005. Department of Agricultural Planning. **Ministry of Agriculture and Irrigation**. Union of Myanmar.

Namiki, M. 1995. The chemistry and physiological functions of sesame. **Food Rev. Int.** 11(2): 281-329.

Narasinga Rao, M.S. 1985. Nutritional aspects of oilseeds, p. 625-634. *In* H.C. Srivastava, S. Bhaskaran, B. Vatsya and K.K.G. Menon, eds. **Oilseeds Production Constraints and Opportunities.** Oxford and IBH, New Delhi.

Nath, R. and K.V. Giri. 1957. Physicochemical studies on indigenous seed proteins, II. Fractionation, isolation and electrophoretic characterization of sesame globulins. **J. Sci. Industr. Res.** 16: 51-58.

Ogunsanwo, B.M., O.O.P. Faboya, O.R. Idowu, O.S. Lawal and S.A. Bankole. 2004. Effect of roasting on the aflatoxin contents of Nigerian peanut seeds. **African J. Biotech.** 3(9): 451-455.

Olowe, V.I.O. and L.D. Busari. 1994. Appropriate plant population and spacing for sesame (*Sesamum indicum* L.) in the Southern Guinea Savannah of Nigeria. **Trop. Oilseeds J.** 2: 18-27.

Onilude, A.A., O.E. Fagade, M.M. Bello and I.F. Fadahunsi. 2005**.** Inhibition of aflatoxin-producing aspergilli by lactic acid bacteria isolates from indigenously fermented cereal gruels. **African J. Biotech.** 4(12): 1404-1408.

Payne, G.A. 1992. Aflatoxin in maize. **Crit. Rev. Plant Sci.** 10: 423–440.

Prakash, V. 1986. Effect of sodium chloride on the extractability of proteins from sesame seed (*Sesamum indicum* L.). **J. Agri. Food Chem.** 34: 256–259.

_____. and P.K. Nandi. 1978. Isolation and characterization of α-globulin of sesame seed. **J. Agri. Food Chem.** 26: 320–324.

Qiu, L.J., J.L. Wang and Q.X. Meng. 1991. Accumulating pattern of protein and fat during developing seed in three soybean types. **Soybean Genetics Newsletter** 18: 98-103.

Rachaputi, N.C., G.C. Wright, S. Krosch and J. Tatnell. 2001. Management practices to reduce aflatoxin contamination in peanut, *In* **Proc. of the 10th Australian Agronomy Conference,** Australian Society of Agronomy, Australia.

Rahman, M.M., M.G. MauIa, S. Begum and M.A. Hossain. 1994. Maximization of yield of sesame through management practices. **Central Annual Res.** p. 53-56.

Rajendran, S. and V. Prakash. 1988. Isolation and characterization of β-globulin low molecular weight protein fraction from sesame seed (*Sesamum indicum* L.). **J. Agri. Food Chem.** 36: 269–275.

Ramachandra, B.S., M.C.S. Sastry and L.S. Subba Rao. 1970. Process development studies on the wet dehulling and processing of sesame seed to obtain edible protein concentrates. **J. Food Sci.Technol.** 7: 127-131.

Rao, P.V. and P.S. Rao. 1981. Chemical composition and fatty acid profiles of high yielding varieties of oilseeds. **Indian J. Agric. Sci.** 51: 703-707.

Reddy, S.V., D. Kiranmayi, M. Uma Reddy, K. Thirumala Devi and D.V.R. Reddy. 2001. Aflatoxins B_1 in different grades of chillies (*Capsicum annuum* L.) in India as determined by indirect competitive ELISA. **Food Additives Contaminants** 18: 553-558.

Rivas, N.R., J.E. Dench and J.C. Caygill. 1981. Nitrogen extractability of sesame (*Sesamum indicum* L.) seed and the preparation of two protein isolates. **J. Sci. Food Agric.** 32: 565-571.

Russell, T.E., T.F. Watson and G.F. Ryan. 1976. Field accumulation of aflatoxin in cottonseed as influenced by irrigation termination dates and pink bollworm infestation. **Appl. Environ. Microbiol.** 31: 711-713.

Saha, S.N. and S.C. Bhargava. 1984. An evaluation of the oil concentration in sesame seeds in relation to developmental stage, node position and capsule age. **Exp. Agric.** 20: 129-134.

Salunkhe, D.K., J.K. Chavan, R.N. Adsule and S.S. Kadam. 1991. Sesame, p. 371-402. *In* G. R.bbelen, R.K. Downey and A. Ashri, eds. **World Oilseeds: Chemistry, Technology, and Utilization.** Van Nostrand Reinhold, New York.

Sapin, V., G. Mills, D. Schmidt and P. O'Shanesy. 2000. **Growing Sesame in South Burnett.** *Available* Source: http:// www.dpi.qld.gov.au/fieldcrops/2888.html. Retrieved date: August, 2008.

Sawaya, W.N., M. Ayaz, J.K. Khalil and A.F. Al-Shaltat. 1985. Chemical composition and nutritional quality of tahini (sesame butter). **Food Chem.** 18: 35-45.

Seegeler, C.J.P. 1983. **Oil Plants in Ethiopia: Their Taxonomy and Agricultural Significance.** Center for Agricultural Publishing and Documentation, Wageningen.

_____. 1989. *Sesamum orientale* L. (Pedaliaceae): sesame's correct name. **Taxon.** 38: 656–659.

Singh, H., M.L. Gupta and K.A. Raon. 1960. Effect of NPK on yield and oil content of sesame. **Indian J. Agron.** 4: 176-181.

Smith, K.J. 1971. Nutritional framework of oilseed proteins. **J. Am. Oil Chem. Soc.** 48: 625-628.

Squire, R.A. 1981. Ranking animal carcinogens: a proposed regulatory approach. **Science** 214: 877–880.

Stoloff, L. and F.B. Lillehoj. 1981. Effect of genotype (open-pollinated vs. hybrid) and environment on preharvest aflatoxin contamination of maize grown in Southeastern United States. **J. Am. Oil Chem. Soc.** 58(12): 76-80.

Suddhiyam, P. and S. Maneekhao. 2005. Sesame, p. 105-112. *In* **A Guide Book for Field Crops Production in Thailand.** Department of Agriculture, Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

Taha, F.S., M. Fahmy and M.A. Sadek. 1987. Low-phytate protein concentrates and isolates from sesame seed. **J. Agric. Food Chem.** 35: 1289-1292.

Tai, S.S.K., T.T.T. Lee, C.C.Y. Tsai, T.J. Yiu and J.T.C. Tzen. 2001. Expression pattern and deposition of three storage proteins, 11S globulin, 2S albumin, and 7S globulin in maturing sesame seeds. **Plant Physio. Biochem.** 39: 981–992.

Takada, N. and T. Uno. 2001. Japanese market and Thai black sesame seeds, p. 15-30. *In* **Proc. 2nd National Conference on Sesame, Sunflower, Castor and Safflower,** Bangkok, Thailand.

Thompson, D.L., E.B. Lillehoj, K.J. Leonard, W.F. Kwolek and M.S. Zuber. 1980. Aflatoxin concentration in corn as influenced by kernel development stage and post inoculation temperature in controlled environments. **Crop Sci.** 20: 609–612.

Trail, F., N. Mahanti and J. Linz. 1995. Molecular biology of aflatoxin biosynthesis. **Microbiology** 141: 755-765.

Uzun, B. and M.I. Cagirgan. 2006. Comparison of determinate and indeterminate lines of sesame for agronomic traits. **Field Crops Res.** 96: 13-18.

_____, S. Ulger and M.I. Cagirgan. 2002. Comparison of determinate and indeterminate types of sesame for oil content and fatty acid composition. **Tr. J. Agric. For.** 26: 269-274.

Vasanthi, S. and R.V. Bhat. 1998. Mycotoxins in foods occurrence, health and economic significance and food control measures. **Indian J. Med. Res.** 108: 212-222.

Vles, R.O. and J.J. Gottenbos. 1989. Nutritional characteristics and food uses of vegetable oils, p. 36–86. *In* G. Robblen, R.K. Downey and A. Ashri, eds. **Oil Crops of the World**. McGraw Hill, New York, USA.

Waliyar, F., A. Ba, B. N'tare and A. Traor. 2000. **Combating Aflatoxin Contamination of Groundnut.** *Available Source:* http://www.icrisat.org/aflatoxin/com_afla_con_grn.asp. Retrieved date: June, 2008.

Walton, G. 2008. **Sesame Oil Benefits.** *Available Source:* http://www.newrinkles.com/index.php/health/sesame-oil-benefits. Retrieved date: August, 2009.

Weiss, E.A. 1971. **Castor, Sesame and Safflower.** Leonard Hill Books, London.

Weiss, E.A. 1983. **Oilseed crops.** Longman, London.

Weiss, E.A. 2000. Sesame, p. 131-164. *In* E.A. Weiss, ed. **Oilseed Crops.** 2nd ed. Blackwell Science Pty Ltd, Carlton, Victoria, Australia.

Wiatrak, P.J., D.L. Wright, J.J. Marois and D. Wilson. 2005. Influence of planting date on aflatoxin accumulation in Bt, non-Bt, and tropical non-Bt Hybrids. **Agron J.** 97: 440–445.

Wicklow, D.T. 1983. Taxonomic features and ecological significance of sclerotia, p. 279. *In* U.L. Deiner, R.L. Asquith and J.W. Dickens, eds. **Aflatoxin and *Aspergillus flavus* in Corn.** Southern Coop. Serv. Bull.. Craftmaster, Opelika, AL.

Williams, J.H., T.D. Phillips, P.E. Jolly, J.K. Stiles, C.M. Jolly and D. Aggarwal. 2004. Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences and interventions. **Am. J. Clin. Nutr.** 80: 1106-1122.

Wilson, D.A. and E. Jay. 1976. Effect of controlled atmosphere storage on aflatoxin production in high moisture peanuts (groundnuts). **J. Stored Prod. Res.** 12: 97-100.

Wolff, N., U. Cogan, A. Admon, I. Dalal, Y. Katz and N. Hodos. 2003. Allergy to sesame in humans is associated primarily with IgE antibody to a 14 kDa 2S albumin precursor. **Food Chemical Toxicology** 41: 1165-1174.

Woodward, R.G. and J.E. Begg. 1976. The effect of atmospheric humidity on the yield and quality of soya bean. **Australian J. Agri. Res.** 27(4): 501-508.

Wyatt, R.D. 1991. Poultry, p. 553-606. *In* J.E. Smith and R.S. Henderson, eds. **Mycotoxins in Animal Foods.** CRC Press, Boca Raton, Florida.

Xue, H.Q., T.G. Isleib, H.T. Stalker, G.A. Payne and G. Obrian. 2004. Evaluation of *Arachis* species and interspecific tetraploid lines for resistance to aflatoxin production by *Aspergillus flavus*. **Peanut Sci.** 31: 134-141.

Yen, G.S., S.L. Shyu and J.S Lin. 1986. Studies on protein and oil composition of sesame seeds. **J. Agric. Forest** 35: 177-181.

Yermanos, D.M. 1978. Oil analysis report on the world sesame collection. **World Farming**. 14: 5-11.

Yermanos, D.M., R.T. Edwards and S.C. Hemstreet. 1964. Sesame an oilseed crop with potential in California. **Calif. Agric.** 7: 2-4.

Yermanos, D.M., S. Hemstreet, W. Saleeb and C.K. Huszar. 1972. Oil content and composition of the seed in the world collection of sesame introductions. **J. Am. Oil Chem. Soc.** 49(1): 20-23.

Yilmaz, N. 2003. The effect of different seed rates on yield and yield components of soybean (*Glycine max* L. Merill). **Pak. J. Biol. Sci.** 6(4): 373-376.

Yoshida, H., M. Tanaka, Y. Tomiyama and Y. Mizushina. 2007. Regional distribution in the fatty acids of triacylglycerols and phospholipids of sesame seeds (*Sesamum indicum*). **J. Food Lipids.** 14: 189–201.

APPENDICES

Appendix Table 1 Annual rainfall (mm) at the National Corn and Sorghum Research Center for the year 2008.

Date	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	T	1.6	2.7	T	8.5	21.8	0.0	0.0
2	0.0	10.7	0.0	0.0	0.4	0.9	T	T	0.4	8.4	T	0.0
3	0.0	6.8	0.0	19.3	3.8	5.9	0.0	0.3	T	3.4	0.0	0.0
4	0.0	T	0.0	0.2	0.0	5.1	0.0	0.0	0.0	0.0	T	0.0
5	0.0	0.4	0.0	1.9	0.0	13.1	0.5	7.0	0.0	0.0	8.1	0.0
6	0.0	0.0	0.0	0.5	1.4	0.0	0.7	T	2.3	1.9	0.0	0.0
7	0.0	0.0	0.0	14.9	0.0	0.0	13.6	1.0	19.9	62.4	T	0.0
8	0.0	0.0	0.0	0.0	0.0	T	4.0	0.9	0.0	0.7	0.2	0.0
9	0.0	0.0	0.0	0.0	0.0	0.9	5.8	0.7	6.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	29.2	0.0	0.0	7.4	42.1	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	8.7	T	0.0	12.6	145.9	0.0	0.0	0.0
12	0.0	0.0	4.8	0.0	81.2	1.1	0.0	6.1	8.4	0.0	0.0	0.0
13	0.0	0.0	5.0	1.5	33.6	4.1	0.0	4.8	6.8	0.0	0.0	0.0
14	0.0	0.0	1.3	0.0	10.9	0.3	0.0	6.1	0.0	0.0	0.0	0.0
15	0.0	0.0	3.3	T	0.0	T	T	0.0	43.7	0.0	1.0	0.0
16	0.0	0.0	0.0	0.0	1.0	2.2	0.0	0.0	20.7	0.0	0.0	0.0
17	0.0	0.0	1.3	0.0	0.0	0.1	0.0	0.0	22.0	2.3	0.0	0.0
18	0.0	0.0	0.0	0.0	4.0	T	3.6	7.9	T	1.4	0.1	0.0
19	0.0	0.0	4.6	2.2	28.4	4.7	3.3	15.3	0.0	T	0.0	0.0
20	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	16.1	0.0	0.0	0.0
21	0.0	0.0	T	3.1	0.0	0.0	0.2	0.4	0.0	0.4	0.0	0.0
22	0.0	0.0	0.0	35.4	0.0	0.0	0.0	0.0	0.0	20.6	0.0	0.0
23	0.0	0.0	0.0	16.8	0.0	0.0	T	0.0	0.0	7.2	0.0	0.0
24	0.1	0.0	26.7	12.0	0.0	0.0	0.0	0.0	5.0	4.2	T	0.0
25	0.0	0.0	23.7	0.0	0.0	0.0	4.4	0.0	T	17.2	0.0	T
26	0.0	T	3.7	0.0	0.0	10.0	T	0.0	T	T	0.0	0.0
27	T	0.0	0.0	16.0	0.0	0.0	0.2	9.1	0.0	0.2	0.0	0.0
28	0.0	0.0	0.0	35.7	38.2	0.0	0.0	58.1	14.2	1.5	0.0	0.0
29	0.0	0.0	0.0	10.3	1.2	0.0	0.0	14.1	1.5	0.4	0.0	0.0
30	0.0		0.0	6.3	6.3	T	4.7	T	0.2	58.1	0.0	0.0
31	T		5.9		0.0		0.0	0.0		17.4		0.0
Total	0.1	17.9	80.3	177.0	248.3	50.0	43.7	151.8	363.7	229.5	9.4	0.0
Average	0.0	0.6	2.6	5.9	8.0	1.7	1.4	4.9	12.1	7.4	0.31	0.0
Rainy da	1	3	10	16	14	13	12	16	17	18	4	0

Source: Meteorology station, Corn and Sorghum Research Center, Pak Chong, Nakhon Ratchasima Province, Thailand.

Appendix Table 2 Maximum temperature (˚C) at the National Corn and Sorghum Research Center for the year 2008.

Date	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	27.5	34.4	30.1	34.0	29.2	31.9	32.0	30.3	30.5	27.9	30.5	25.2
2	23.8	31.4	31.7	33.8	30.8	31.2	31.8	29.0	31.0	31.0	30.0	26.1
3	26.0	23.4	30.5	31.4	31.4	31.1	31.5	32.0	32.1	28.2	31.7	29.6
4	28.5	23.6	29.6	32.1	30.4	30.6	31.5	31.0	31.9	29.9	29.1	29.0
5	29.0	23.7	30.8	33.5	31.8	31.0	31.2	31.0	32.0	31.7	29.5	28.0
6	29.6	32.2	31.4	31.8	31.5	31.4	31.5	28.2	32.0	30.9	30.0	25.7
7	30.4	32.6	32.9	30.5	31.0	31.4	30.6	29.2	29.2	30.0	31.1	26.7
8	31.7	32.8	31.7	32.6	31.1	31.2	30.0	28.0	30.6	27.4	30.2	27.0
9	33.5	33.0	32.5	34.0	32.5	29.9	31.1	30.9	30.6	30.5	28.4	26.4
10	32.0	32.0	33.7	34.4	33.6	32.0	31.1	31.1	30.5	31.7	25.9	26.9
11	32.4	31.8	34.3	35.4	30.8	32.5	30.4	31.0	24.2	30.5	26.1	26.4
12	33.3	30.9	34.2	35.5	28.9	30.7	31.5	29.6	27.6	31.4	25.0	27.5
13	34.0	29.3	33.8	35.3	28.2	29.6	32.0	29.0	29.0	31.8	26.2	30.0
14	32.1	30.0	33.0	33.2	30.5	30.0	32.6	30.2	29.7	31.1	26.2	27.6
15	30.7	28.0	32.9	34.0	30.5	30.7	32.7	30.5	29.7	31.5	28.8	27.0
16	31.1	31.7	33.1	35.0	31.5	30.7	31.9	31.0	26.2	31.4	27.6	27.6
17	29.4	30.4	35.1	34.5	30.9	30.7	32.1	30.9	25.1	27.3	30.0	26.9
18	30.0	30.6	35.5	34.8	30.5	29.1	31.9	31.1	27.4	26.7	27.6	25.7
19	32.0	29.4	35.7	34.3	30.7	27.8	32.8	28.7	29.0	30.5	27.6	26.0
20	33.0	28.8	34.7	33.7	30.8	30.0	30.0	30.0	28.1	31.5	27.3	28.2
21	34.0	28.1	34.8	34.4	31.2	31.4	32.0	30.5	28.2	31.8	26.5	27.9
22	32.8	31.1	36.0	34.6	31.5	30.8	31.5	31.0	29.8	32.2	26.6	28.5
23	30.8	31.8	34.7	30.5	31.4	32.0	31.4	32.8	30.7	32.3	29.9	27.5
24	29.4	32.8	33.5	30.4	31.6	32.2	29.0	31.7	30.1	29.6	28.5	27.6
25	26.3	33.0	31.5	30.5	31.5	32.0	31.2	32.5	29.3	29.5	26.0	27.8
26	29.3	32.3	32.3	30.7	32.4	31.7	31.7	33.0	29.0	28.7	28.7	27.6
27	31.7	27.8	35.1	30.5	32.2	31.2	30.1	31.5	30.5	30.0	27.7	22.1
28	33.5	28.0	34.0	31.0	31.4	31.2	30.6	30.0	30.6	29.7	25.9	27.6
29	33.0	31.4	34.6	30.5	30.4	32.0	31.2	30.9	28.5	29.7	25.7	28.0
30	31.6	-	35.8	31.5	30.9	33.0	31.5	31.2	30.2	29.1	25.0	30.0
31	32.7	-	34.1	-	30.8	-	31.0	32.2	-	29.4	-	29.2
Average	30.8	30.2	33.3	32.9	31.0	31.0	31.3	30.6	29.4	30.2	28.0	27.3

Source: Meteorology station, Corn and Sorghum Research Center, Pak Chong, Nakhon Ratchasima Province, Thailand.

Appendix Table 3 Minimum temperature (˚C) at the National Corn and Sorghum Research Center for the year 2008.

Date	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	15.6	20.8	20.0	22.0	22.7	23.5	24.2	23.9	22.5	23.0	22.6	16.5
2	13.0	20.5	19.5	22.5	22.7	22.8	23.7	22.7	21.7	21.5	20.9	16.0
3	14.9	18.8	18.8	2.3	23.3	22.4	22.9	22.4	22.6	22.0	20.0	15.0
4	14.8	17.4	18.0	21.5	24.9	22.0	23.5	22.5	22.5	21.6	22.4	16.0
5	17.4	19.9	17.0	21.5	23.9	23.0	22.2	3.8	22.3	21.4	22.8	17.3
6	18.2	19.5	17.5	21.5	23.4	22.5	22.8	23.2	21.5	22.2	21.7	19.0
7	15.9	19.7	21.0	22.5	23.2	23.0	23.0	23.4	22.7	21.6	21.5	18.4
8	16.5	19.5	19.6	22.3	23.2	23.0	24.2	22.7	22.5	21.6	21.5	18.0
9	16.0	19.7	20.5	22.2	25.1	22.9	24.2	23.9	22.5	21.8	22.5	16.0
10	17.3	18.0	20.0	22.5	23.0	23.2	24.0	24.5	21.8	22.0	19.8	13.9
11	15.6	18.9	20.0	23.0	22.2	23.0	23.4	23.3	22.1	22.9	17.9	13.2
12	15.0	19.9	22.5	22.0	22.1	23.0	23.8	23.3	22.4	22.7	17.0	14.9
13	15.5	17.8	21.7	23.0	21.9	22.5	24.3	22.6	22.3	21.5	16.6	14.9
14	19.3	19.0	22.4	23.2	20.8	24.3	24.5	22.1	22.3	22.1	16.4	16.5
15	20.5	16.9	23.1	23.1	22.0	26.0	25.6	22.1	21.5	22.0	18.7	18.9
16	18.5	17.3	21.7	22.9	22.2	25.3	25.0	23.3	20.8	22.0	22.2	17.4
17	17.5	19.0	21.9	24.2	24.7	23.6	25.0	23.0	21.6	22.8	22.7	19.0
18	17.5	20.6	21.9	23.5	25.0	23.0	23.9	23.0	22.2	22.5	22.1	15.4
19	18.5	17.4	20.4	23.7	23.4	22.6	24.0	23.5	22.8	22.7	20.3	16.0
20	17.2	16.4	21.7	23.5	22.9	22.3	22.6	23.0	23.0	22.7	20.0	14.4
21	16.0	15.6	22.0	23.5	23.4	21.5	23.0	22.3	22.5	22.7	19.9	14.1
22	17.3	16.8	22.4	23.4	24.0	23.0	24.0	22.4	23.0	21.3	19.5	15.6
23	18.0	18.8	22.4	21.3	22.7	25.3	23.7	23.5	21.4	21.5	20.6	16.7
24	19.0	19.4	22.0	22.2	25.1	23.0	24.6	23.0	23.0	22.3	21.4	18.0
25	19.0	19.9	22.0	21.9	24.6	23.5	24.5	22.8	23.2	22.9	21.6	17.2
26	19.1	22.5	22.2	22.5	24.0	24.3	22.4	22.0	23.8	22.5	21.0	20.0
27	22.3	22.3	22.7	22.7	24.1	22.5	22.2	23.0	22.9	20.5	19.6	20.0
28	20.1	17.0	22.5	22.5	23.2	24.0	24.2	22.0	22.2	21.9	17.5	19.6
29	20.0	18.0	21.5	22.8	23.4	23.7	24.1	22.3	22.0	23.4	16.9	19.8
30	20.9	-	22.5	22.5	23.0	24.3	24.0	22.3	23.5	23.1	16.0	19.4
31	20.9	-	24.5	-	22.0	-	22.0	22.1	-	21.5	-	20.5
Mean	17.7	18.9	21.2	22.6	23.3	23.3	23.7	22.9	22.4	22.1	20.1	17.0

Source: Meteorology station, Corn and Sorghum Research Center, Pak Chong, Nakhon Ratchasima Province, Thailand.

Appendix Table 4 Relative humidity (%) at the National Corn and Sorghum Research Center for the year 2008.

Date	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	53	72	47	70	83	76	77	73	86	91	86	56
2	58	76	43	72	78	77	75	75	86	88	86	56
3	55	86	30	82	78	81	74	68	84	92	83	60
4	58	81	37	84	74	88	70	74	81	85	86	69
5	55	81	41	76	74	76	75	71	83	79	84	68
6	62	70	48	83	80	82	72	81	85	88	81	63
7	59	70	47	81	75	83	78	73	92	89	83	67
8	56	65	59	75	69	83	76	72	85	91	82	67
9	51	60	59	66	66	87	72	71	84	82	72	66
10	63	58	58	66	79	83	73	74	87	82	65	62
11	66	65	55	60	90	75	75	79	97	81	62	67
12	61	70	67	63	91	81	74	79	88	74	69	72
13	57	53	78	69	91	78	73	82	83	73	69	59
14	62	53	80	72	89	76	73	79	78	73	66	65
15	57	55	77	74	85	74	66	74	81	76	68	63
16	52	54	69	71	76	77	69	72	94	77	80	63
17	54	55	72	72	70	77	67	72	92	80	75	64
18	56	55	63	74	74	78	72	74	87	89	79	61
19	55	57	60	80	76	80	75	86	81	81	76	58
20	50	55	67	78	78	77	81	83	78	81	67	59
21	53	50	70	78	74	75	76	79	80	82	75	66
22	50	47	64	80	75	70	74	77	70	78	78	65
23	51	45	66	86	73	68	71	72	70	81	74	71
24	62	53	70	81	71	68	70	74	76	83	74	65
25	73	60	84	84	68	69	64	80	76	87	69	65
26	67	71	82	81	73	72	66	79	75	83	65	67
27	63	68	72	84	71	73	70	79	82	82	60	81
28	62	61	69	88	73	74	66	87	79	83	53	75
29	65	53	67	91	76	72	65	87	86	80	60	69
30	75	-	65	80	80	70	69	82	86	85	56	65
31	69	-	65	-	81	-	71	79	-	89	-	*
Total	1830	1799	1931	2301	2391	2300	2229	2387	2492	2565	2183	*
Mean	59	62	62	77	77	77	72	77	83	83	73	*

Source: Meteorology station, Corn and Sorghum Research Center, Pak Chong, Nakhon Ratchasima Province, Thailand.

Appendix Table 5 World regional sesame production and trade (2005).

Region	Area harvested (million ha)	Production (tons)	Imports (tons)	Export (tons)
Asia	4.48	2547	6901	342
Africa	2.80	953	60	422
South America	0.14	79	4	54
Central America	0.13	81	32	37
North America	0.00	0	54	3
Europe	0.40	2	146	25
Oceania	0.00	0	8	0
World	**7.55**	**3662**	**996**	**884**

Source: FAO, (2005)

Appendix Table 6 Oilseed Crops Growing Area (million hectares) in Myanmar.

Oilseed crops	1998 99/	1999 20/	2000 01/	2001 02/	2002 03/	2003 04/	/2004 05	2005 06/	2006 07/	2007 /2008
Groundnut	0.497	0.560	0.584	0.562	0.574	0.647	0.676	0.722	0.747	0.806
Sesame	1.185	1.341	1.407	1.367	1.400	1.448	1.478	1.323	1.426	1.490
Sunflower	0.119	0.339	0.482	0.512	0.492	0.455	0.505	0.510	0.681	0.825
Mustard	0.030	0.040	0.051	0.055	0.059	0.064	0.067	0.066	0.074	0.091
Niger	0.056	0.081	0.100	0.100	0.059	0.103	0.110	0.127	0.120	0.145
Total	1.886	2.361	2.614	2.586	2.585	2.717	2.837	2.748	3.047	3.357

Source: Myanmar Agriculture in Brief, (2009)

Appendix Table 7 Sown hectares, harvested hectares and production of sesame in different seasons of Myanmar (2006/07).

Seasons	**Sown hectares ('000)**	**% of Total area**	**Harvest hectares ('000)**	**% of Sown Area**	**Yield (kg/ha)**	**Production ('000 ton)**	**% of total Production**
Pre-monsoon	1,426	50%	1,426	100%	523.43	29,169	53%
Monsoon	1,105	39%	1,082	98%	451.64	18,104	33%
Cool Season	314	11%	272	87%	686.05	7,459	14%
Total	**2,846**	**100%**	**2,780**			**54,732**	**100%**

Source: MAS

Appendix Table 8 Physical and chemical characteristics of sesame seed oil.

Physical Characteristics of Sesame Seed Oil	
Specific Rotation	2.28
Specific Gravity	0.89
Refractive Index	1.5
Viscosity	21 - 22
pH	5.03 – 5.6
Chemical Characteristics of Sesame Seed Oil	
Iodine Value	114.85 g/100g
Sponification Value	186 – 189 mg/g
Peroxide Value	6.5 – 6.8 meq H_2O_2/Kg
Acid Value	4.92 – 6.12 mg/g

Source: El-Khier *et al.* (2008)

Appendix Table 9 Fatty acids found in sesame oil.

Fatty Acid		Range
Palmitic	C16:0	7.0-12.0%
Palmitoleic	C16:1	Trace-0.5%
Stearic	C18:0	3.5-6.0%
Oleic	C18:1	35.0-50.0%
Linoleic	C18:2	35.0-50.0%
Linolenic	C18:3	Trace-1.0%
Eicosenoic	C20:1	Trace-1.0%

Source: (http://www.essentialoils.co.za/sesame-oil-analysis.htm)

Appendix Table 10 Sesame variety KU-18 characteristics.

50% Flowering	32 days
Flowering Period	70 days
Harvesting in the rainy season	90 days
Harvest in the late rainy season	85 days
Plant Height	126-129 cm
Yield	148 kg rai^{-1} (925 kg ha^{-1})
1000-Grain Weight	3 g
Seed Color and Seed Coat	Black, thick , One layer, single husk
Plant Canopy	Single stem
Pod Character	2 carples, bicarpellate, dark green
Pod Arrangement	Opposite, two pods per one node
Height to 1^{st} pod	Approximately 3 or 4 nodes
Oil Content	48.2 (Soxhlet Method)
Sesamin	4038.91 mg kg^{-1}
Sesamolin	4635.66 mg kg^{-1}
Growth Habit	Indeterminate

Appendix Table 11 Details of how each traits was measured and the units of each measurement are given.

Traits	How Measured	Character Unit
Days to emergence	Over 50% of seedlings emergence	7-14 days
Plant Population at Emergence	Total number of plants at emergence	number
Plant Population at Harvest	Total number of plants at harvest	number
Days to first flowering	Number of days 50% plants had at least one flower	25-30 days
Days to 50% flowering	Number of days all plants had at least 50% flower	30-36 days
Flowering Period	Number of days from first flower to terminal flower	30-85 days
Plant Height at Flowering	Length of the main stem at flowering	cm
Plant Height at Harvest	Length of the main stem at harvest	cm
Plant Height to First Capsule	Length of the main stem from soil to first capsule	cm
Number of Nodes per Plant	Total nodes number on plant	number
Number of Capsules per Plant	Total capsules number on plant	number
Capsule Length	Length of capsule	cm
Number of Seeds per Capsule	Total number of seeds were counted in the capsule	number
1000-Seed Weight	Weight of 1000 seeds	g/1000 seeds
Seed Yield	Weight of total harvested seeds	kg ha^{-1}

Appendix Table 12 Some mycotoxins, fungi that produce mycotoxin and symptoms in animals consuming feed contaminated with mycotoxin.

Mycotoxins	**Fungi associated**	**Symptoms/ toxicology**
Aflatoxin	*Aspergillus flavus, A. parasiticus*	Liver necrosis, liver tumors, reduced growth, depressed immune response, carcinogen
Fumonisin	*Fusarium moniliforme, F.proliferatum*	Equine leukoencephalomalacia, porcine pulmonary edema
Deoxynivalenol (DON)	*F. graminearum*	feed refusal, reduced weight gain, diarrhea, vomiting
Trichothecenes	*F. graminearum, F. culmorum, F. poae*	alimentary toxic aleukia, necrosis, hemorrhages, oral lesion in broiler chickens
Ochratoxins	*Penicillium verrucosum, Aspergillus ochraceus*	porcine nephropathy; various symptoms in poultry
Citrinin	*Penicillium sp., Aspergillus sp.*	kidney damage
Cyclopiazonic acid	*Penicillium sp., Aspergillus sp.*	neurotoxin
Sterigmatocystin	*Aspergillus sp.*, and others	carcinogen, mutagen

Appendix Table 13 Chemical and physical properties of aflatoxins.

Aflatoxin	**Molecular formula**	**Molecular weight**	**Melting point**
B_1	$C_{17}H_{12}O_6$	312	268-269
B2	$C_{17}H_{14}O_6$	314	286-289
G1	$C_{17}H_{12}O_7$	328	244-246
G2	$C_{17}H_{14}O_7$	330	237-240
M1	$C_{17}H_{12}O_7$	328	299
M2	$C_{17}H_{14}O_7$	330	293
B2A	$C_{17}H_{14}O_7$	330	240
G2A	$C_{17}H_{14}O_8$	346	190

CURRICULUM VITAE

NAME : Mrs Mya Thandar

BIRTH DATE : August 29, 1975

BIRTH PLACE : Yangon, Myanmar

EDUCATION	: **YEAR**	**INSTITUTE**	**DEGREE/DIPLOMA**
	2000	Yezin Agri. Univ.	B.Agr.Sc.

POSITION/TITLE : Assistant Supervisor

WORK PLACE : Myanmar Agriculture Service, Bago (West)

SCHOLARSHIP/ AWARDS : OFID Fund, Myanmar Government Scholarship 2007- 2009