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DEPARTEMENT OF HORTICULTURE

EFFECT OF ISOLATION DISTANCES ON VARIETAL SEED PURITY FOR OPEN POLLINATED VARIETIES OF PEARL MILLET [*Pennisetum glaucum (L.) R. Br.*] AT FARMERS' LEVEL IN NORTHERN GHANA.

BY

LIMAN SOULEY ABDOULKARIM

(B. AGRIC)

AUGUST 2015

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A Thesis Submitted to the Department of Horticulture, Kwame Nkrumah University of Science and Technology in Partial Fulfilment of the Requirement for the Degree of

MASTER OF PHILOSOPHY (SEED SCIENCE AND TECHNOLOGY)

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Declaration

I, LIMAN SOULEY Abdoulkarim, hereby declare that this submission is my own work towards the Master of Philosophy (Seed Science and Technology) and that, to the best of my knowledge, it contains no material previously published by another person, nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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Abstract

Pearl millet seed supply in West Africa is dominated by the informal system in which small scale farmers produce and supply local seeds of landraces or open pollinated varieties mostly without any quality control during production. Standards for quality control are mostly designed for the formal and commercially oriented system which fails to supply adequate quantity of seeds. To increase agricultural productivity through the use quality planting materials more attention is required on small seed producers to ensure that seed of acceptable quality are produced and used by large scale millet producers.

This study aimed at assessing the level of varietal seed purity at farmer‟s level. Two open pollinated varieties of Pearl millet were used, one variety as pollen source characterized by yellow coloured seeds and the other seed parent with grey coloured seeds. After cross pollination, it was expected to produce hybrid of yellow coloured seeds on the seed parents due to xenia effect. The results showed significant differences ($p<0.001$) in varietal seed purity with regard to the interaction between distance and direction of seed parents from the pollen parents. Closer pollen parents (from 0.4 to 30 m) showed higher significant differences in varietal seed purity compared to distant seed parents (from 40 to 60 m). Seed parents located to the direction of wind from pollen parents produced seeds with significantly lower seed quality compared to those located in the opposite direction. Varietal purity was positively and strongly correlated ($p<0.01$) with distances from pollen parents.

Wind speed and direction showed significant direct effect on varietal seed purity while other climatic parameters such as temperatures, relative humidity and rainfall may have

some indirect effects. Although it was possible to produce pure seed on some points of the experimental field at 60 m to the South East and to the West, 45 m and above to the South East, 50 m and above to the South, 55 m and above to the South West and North West, it is very challenging for farmers to produce seeds that meet standards. However, some measures can be taken by farmers in order to produce seed with an acceptable level of seed purity. These measures include: plotting the seed field by considering the prevailing wind direction in the area, planting at least 3 weeks after the source pollen is planted, choosing seed parents that are „"taller"" than the pollen parents, adopt a communal seed grower system where a cluster of farmers grow the same variety. These could not prevent cross-contamination from neighbouring farms with different varieties but rather can minimize the flow of pollen grains in the seed production filed.

Dedication

I dedicate this work to my parents (Mr and Mrs LIMAN SOULEY) for their inestimable support throughout my life and to my family (my beloved wife Djamila, my daughters Saadiya and Ihsane and my son Amar) who endured my long absence during this programme.

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Abreviations, Acronyms and Symbols

#	number
%	percentage
<	less than
°C	degree celcius
am	ante meridium (between midnight and midday)
ANOVA	analysis of variance
cm	centimeter
DAP	day after planting
E	East
ECOWAS	Economic Commission of West African States
et al.	et alia (and other people)
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	FAO statistics
FORIG	Forestry Research Institute of Ghana
g	gramme
G4	Conventional name of foundation seed in West Africa
GE	Genetically Engineered
GMO	Genetically Modified Organisms
Hz	Hertz
i.e	that is

IBSH	Improved Bongo Short Head
ICRISAT	International Crop Research Institute for the Semi Arid Tropics
INSAH	Institut du Sahel
ISTA	International Seed Testing Association
ITY	Improved Tongo Yellow
lsd	least significant difference
m	meter
m^2	square meter
mm	millimeter
N	North
NE	North East
NPK	Nitrogen Phosphorous and Potassium
NW	North West
OECD	Organisation for Economic and Cooperation Development
OPV	Open Pollinated Variety
P	probability
pm	post meridiem (after 12 O"clock noon)
R1	Conventional name of first generation of certified seed in West Africa
R2	Conventional name of second generation of certified seed in West Africa
RF	Rainfall
RH	Relative Humidity
S	South
SARI	Savanna Agricultural Research Institute
SE	South East
SRID	Statistical Research and Information Directorate
SW	South West

VP/NSB Varietal Purity on Number of Seed Basis

VP/WSB Varietal Purity on Weight of Seed Basis

W West.

CHAPTER ONE

1.0 INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is traditionally a dry land crop, cultivated mostly in marginal environments of the arid and semi-arid regions, characterized by low rainfall, sandy soils with low fertility where other cereals such as sorghum and maize fail to produce assured yields (Manga and Kumar, 2011). The crop is believed to have originated from West Africa where the greatest numbers of both wild and cultivated forms of this species occur (Khairwal *et al.*, 2007 and Subi and Idris 2013). The term millet is broadly applied to over 140 species belonging to the Genus *Pennisetum* (Subi and Idris, 2013).

The crop is predominantly cultivated in Africa (about 14 million hectares) and Asia (12 million hectares on the average) and is ranked as the fifth most important cereal crop, and the most important millet (Khairwal *et al.,* 2007, *Raï et al.,* 2009 and Mathur *et al.,* 2012). Area under production and production figures of pearl millet in most statistical data are presented combined with those of other millet crops such as finger millet, foxtail millet, among others. Even though, separate data are not available for pearl millet, the crop accounts for about 50% of the total area under all millets worldwide (Mathur *et al.*, 2012).

In Africa, Pearl millet is grown in West Africa mostly in countries such as Nigeria, Niger, Senegal, Mali and Burkina Faso. In Ghana, millet is predominantly grown in northern part of the country and according to the Ministry of Food and Agriculture,

177,000 ha were cultivated with millet and the production was estimated to be 219,000 metric tons in 2010 (SRID, 2011). Pearl millet is mostly grown in the Upper East and West regions with the harshest environmental conditions in the country.

Pearl millet is the staple food grain and source of feed, fodder, fuel and construction material in the hottest, driest, semi-arid and arid regions where rainfed agriculture is practiced (Khairwal, *et al.*, 2007). It is a principal source of energy, protein, vitamins and minerals for millions of poorest people in the regions where it is cultivated (Khairwal *et al.*, 2007). Pearl millet grain compares favourably with maize and sorghum as high-energy and high-protein ingredient in feed for poultry, pigs, cattle and sheep and its grain is also gaining importance as a cheap source of starch for making fine quality breweries (Khairwal *et al.*, 2007).

Despite its economic importance, its nutritional values and its adaptation to a wide range of environmental conditions, in West Africa the production of Pearl millet has many constraints such as the poor adoption of improved varieties of quality planting materials, pest and disease pressure such as downy mildew (Ndjeunga and Nelson 2003 and Kwairwal *et al.*, 2007). In Niger, for instance, where pearl millet covers more than 65% of the total cultivated area (Mariac *et al*. 2006) the average yield from 2004 to 2013 was less than 500 kg/ha according to Food and Agricultural Organisation of the United Nations (FAOSTAT, 2014). The average yield worldwide for Pearl millet was around 900 kg/ha for the same period. Some countries such as Ghana are experiencing a significant reduction in area under millet production. It dropped from 200,000 ha in 2006 to 160,000 ha in 2013 (FAOSTAT, 2014) due to a gradual displacement of millet with maize as an alternative cereal crop with high productivity.

Poor adoption of improved varieties of Pearl millet is mainly associated with seed supply and demand constraints (Ndjeunga and Nelson, 2003). In West Africa, breeding programmes concentrated on the development of open pollinated varieties (Izge and Song 2013). As such, landrace and improved varieties are generally used by farmers (Tuinstra, 2007) and hybrid breeding is still in its infant stage and the first hybrid variety was released only in 2005 (Haussmann and Angarawai 2007). In addition, Pearl millet seed production and distribution in most West African countries is still dominated by the informal system with low improved variety adoption and low or no quality maintenance (Ndjeunga *et al.*, 2000). Izge and Song (2013), stated that limited seed production and distribution has in addition to research progress been a major bottleneck and has slowed the spread of improved cultivars of millet in the region.

Also, the production system led by government agencies in developing countries was not able to assure a regular flow of certified seeds to many farmers (Almekinders and Louwaars, 2002). The farmers‟ systems of seed supply formed by far the most important source of seed in most farming systems of the world (Almekinders, and Louwaars, 2002). In addition, according to Soniia (2004), a major reason for the low adoption of modern varieties of seed among small-scale farmers in developing countries is the inability of formal, centralized seed production systems to meet their complex and diverse seed requirements.

While the formal seed system has the advantages of providing a relatively regular flow of new improved varieties and guaranteed quality, the informal seed supply on the other hand guarantees availability of seed in the farmer‟s proximity. It is also the most accessible source of seeds to farmers. Despite all its merits, less attention is paid to famers‟ seed

production and seed exchange at policy level and in technical assistance projects (Almekinders and Louwaars, 2002)

Pearl millet being a very cross pollinated crop requires a considerable isolation distance in order to maintain genetic/varietal purity during seed production. The West African harmonized Seed Law, for instance, recommends an isolation distance of 300 m from any millet pollen source when producing certified seed (INSAH, 2012). At farmers‟ level, those standards are very difficult to follow due to the prevailing farming systems in millet growing areas (intensive production of millet in relatively small plots all round) and also because of the additional cost of production that may result in arranging for such isolation distance. This may definitely have repercussions on the unit price of seeds produced reducing henceforth the commercial value of the crop.

For this reason, Ndjeunga *et al*., (2000) and Minot *et al*, (2007) suggested that crops of low commercial value such as pearl millet are more suitable for informal seed systems; to increase seed uptake, one should focus on improvement of the informal sector.

Generally, strengthening of the farmer‟s seed system will increase seed security– which in turn enables farmers to continue to grow and maintain *in situ* the genetic diversity of their preference and choice. Strengthening farmer seed system will thereby contribute simultaneously to the sustainability of farmers‟ livelihood and in situ maintenance of crop genetic diversity (Almekinders and Louwaars, 2002).

The aim of this study was to assess the level of seed purity at different distances from the pollen source at farmers‟ level in northern Ghana with the following specific objectives:

1. To determine the degree of varietal purity of OPV millet at specific distances from pollen source in farmers‟ fields.
2. To establish the relationships between the varietal purity, the distances from pollen source and plant parameters affecting pollination.
3. To recommend measures for getting an acceptable level of seed purity at farmers‟ level.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BOTANICAL CLASSIFICATION

Pearl millet is an allogamous, annual, diploid cereal, belonging to the *Poaceae* family, subfamily *Panicoideae,* tribe *Paniceae*, subtribe *Panicinae*, section *Penicillaria* and genus *Pennisetum*. About 140 species constitute the genus *Pennisetum* (Mathur *et al.*, 2011).

Pearl millet was previously named *Pennisetum. typhoideum* L.C. Rich and later *Pennisetum. americanum* (L.) Leeke. In 1977, four cultivated forms of Pearl millet have been identified by Brunken in his systematic study of Pennisetum. There are Pennisetum *typhoides* found mainly in India and also in Africa, Pennisetum *nigritarum* dominant in eastern Sahel, Pennisetum *globosum* prevailing in the western Sahel and Pennisetum*leonis* cultivated mostly in West African coast.

2.2 ORIGIN AND GENETIC DIVERSITY

2.2.1 Origin and Domestication

Pearl millet originated in tropical Western Africa some 4000 years ago. It is a member of the grass family and was originally a wild plant in Africa where the largest members of both wild and cultivated forms prevail (Manga *et al.*, 1999).The plant was believed to be domesticated as a food crop some 4 000 to 5 000 years ago along the southern margins of the central highlands of the Sahara and then became widely distributed across the semiarid tropics of Africa and Asia (Department of Agriculture, Forestry and Fisheries, South Africa, 2011).

2.2.2 Pearl millet populations

Probably because of its evolution under a wide range of agro-climatic conditions, Pearl millet inherits varying morphological traits such as yield components, adaptation and other quality traits which denotes its genetic variability (Khairwal *et al*., 2007).

The important wild relatives of cultivated pearl millet include the progenitor, *Pennisetum glaucum* subsp. *monodii* Maire, *P. purpureum* K. Schumach, *P. pedicellatum* Trin., *P. orientale* Rich, *P. mezianum* Leeke, and *P. squamulatum* Fresen (Mathur *et al.*, 2012).

Numerous populations of pearl millet are scattered throughout Sahelian Africa zone, from Mauritania to Sudan, which is believed to be its centre of diversity (Marchais, 1994). According to Tostain (1992) their morphological structures differ according to the presence or absence of cultivated millets in their environment. For instance, in the agricultural zone, spontaneous millet populations show a very diverse continuous array or morphotypes including many types intermediate between the wild and cultivated millets.

2. 2.3 Racial classification of Pearl millet

Brunken (1977) scored the world collection for a number of floral and grain characters and identified grain shape as the most consistent trait, which follows geographic pattern. Four basic grain shapes were found in the world collection and were used for racial classification, although not all pearl millet accessions fit neatly into one of these four basic races.

Race typhoides: It is characterized by inflorescences that are mostly cylindrical in shape and caryopses that are obtuse and terete in cross section. It occurs in entire Africa and is the most variable among the four races and in addition is also most widely distributed. Also, it is the only basic race found outside Africa and the predominant race grown in India (Brunken *et al.,* 1976).

Race nigritarum: This race is generally found in Africa in area stretching from western Sudan to northern Nigeria. The inflorescences of this race are candle-like and the caryopsis is angular in cross-section with three and six facets per grain which apex is usually truncate and often tinged purple. The mature grain is generally longer and protrudes beyond the floral bracts (Brunken *et al.,* 1976).

Race globosum: According to Bono (1973), it is the most common race in West Africa in areas like the central Nigeria, Niger, Ghana, Togo and Benin. The inflorescences are candle shaped and often exceed 1 m in length and the caryopsis is spherical with each of its dimensions being approximately equal. Depth of the grain always exceeds 2.4 mm and is otherwise terete and obtuse.

Race leonis: Grown specifically in Sierra Leone but also in Mauritania and Senegal, the race is characterized by candle-like inflorescence and an acute, oblanceolate, terete caryopsis. The most distinct character of the leonis grain is its acute apex, which is terminated by the remnants of the stylar base. At maturity, approximately one-third of the grain protrudes beyond the floral bracts (Brunken *et al.,* 1976).

2.3 ECONOMIC IMPORTANCE AND NUTRITIONAL VALUE

Pearl millet is the fifth most important cereal crop in the world after rice, wheat, maize, and sorghum. It is a widely grown rainfed cereal crop in the arid and semi-arid regions of Africa and Southern Asia, and can be grown in areas where rainfall is not sufficient for the cultivation of maize and sorghum (Khairwal *et al.*, 2007; Mathur *et al.*, 2012,).It is probably the world‟s hardiest crop and has great potential because of its suitability to the extreme limits of agriculture (Department of Agriculture Forestry and Fisheries South Africa, 2011). Its ability to tolerate drought, extremes temperatures, soil toxicity more than other cereals like maize, wheat and rice is mostly due to its evolution under the pressures of drought and high (Khairwal *et al.*, 2007).

The exact area under cultivation and the production per unit area is not known at global level as most of the information available is combined with other millets like finger millet, foxtail millet, etc. However, pearl millet accounts for almost half of global millet production, with 60% of the cultivation areas in Africa, followed by 35% in Asian countries. European countries represent 4% of millet cultivation and North America only 1%, mainly for forage. Areas planted with pearl millet are estimated at 15 million hectares annually in Africa and 14 million hectares in Asia (Mathur *et al.*, 2012)

Pearl millet is an important food and forage crop in Africa and Asia, and forage crop in the Americas (Department of Agriculture Forestry and Fisheries South Africa, 2011). Of the 30 million tons of millet produced in the world, about 90% is utilised in developing countries, and only a tiny volume is used in the developed countries (Izge and Song, 2013). Currently, millet is a staple for more than 500 million people (Mathur *et al.*, 2012).

Pearl millet is also nutritionally superior compared other cereals such maize and rice. The protein content of pearl millet is higher than maize and it has a relatively high vitamin A content. According to some studies, compared to maize, pearl millet is 8–60% higher in protein content, and 40% richer in essential amino acids such as methionine and lysine (Khairwal *et al.*, 2007).

It can generally have up to 13% protein, but large variation among genotypes and a range of 6 to 21% has been observed. Its grain contains more calories than wheat, probably because of its higher oil content and half of those oils are polyunsaturated fatty acids. It is also rich in other elements namely calcium, potassium, magnesium, iron, zinc, manganese, riboflavin, thiamine, niacin. In addition Pearl millet grain is free from gluten which make it the only grain that retains its alkaline properties after cooking which is ideal for people with gluten allergies (Khairwal *et al.*, 2007).

Pearl millet is also used in making a popular fried cake named *"masa" or ''wayna''.* Its flour is also used in preparing *"tuwo"* a thick binding paste, also referred to as *"toh"* in northern Africa. It is often ground into flour, rolled into large balls, parboiled, liquefied into a watery paste using fermented milk and then consumed as a beverage. This beverage known as *"fura"* in Hausa or *"tukura"* in Marghi language is a popular drink and regularly consumed in northern Nigeria and southern Niger (Izge. and Song, 2013).

Pearl millet is an excellent forage crop because of its low hydrocyanic content. The green fodder is also rich in protein, calcium, phosphorus and other minerals. It is more digestible when fed green to animals rather than chaffed straw (Chopra, 2001). The glumes and pericarp know as*"dusa"* in Hausa are also used in preparing feeds for livestock (Izge. and

Song, 2013). It also seems to be an excellent feed for other birds and swine. Being gluten-free, marketing opportunities for this grain also exists in the healthfood outlets (Izge and Song, 2013).

The crop residue or millet stover is an important source of fodder (particularly in low rainfall regions) accounting for 40-50% of the dry matter intake and is often the only source of feed in dry months (Manga and Kumar, 2011).

2.4 DESCRIPTION OF PEARL MILLET PLANT

Pearl millet is a member of the grass family and it was originally a wild plant in Africa (Khairwal *et al.* 2007). A mature Pearl millet plant may grow from 50 cm to up to 4m tall depending on the genotype, and may tiller profusely under favourable environmental conditions (Departement of Agriculture Forestey and Fisheries, 2011).

Stems are pithy, tiller freely and produce an inflorescence with a dense spike-like panicle which is 35.56 cm long or more and 2.54 cm or less in diameter depending on the genotype. The plant has long-pointed leaves that are slender with smooth or hairy surfaces and finely serrated margin. The colour of the leaves may vary from light yellowish green to deep purple. Pearl millet usually flowers from 40 to 55 days or even more and the flowering structure (inflorescence) in pearl millet is called a panicle, head or ear. The mature panicle colour varies with genotype. The seed begins developing after fertilisation and matures 25 to 30 days later. The seeds colour is variable and can be nearly white, yellow, brown, grey, slate blue or purple in colour. The size of the seed is about one-third that of sorghum and the weight about 8 mg on average (Departement of Agriculture Forestey and Fisheries, 2011).

The growth and development of pearl millet can be divided into three major phases:

Growth phase 1: During this phase there is seedling establishment with root, leaf and tiller development. Panicle initiation also begins in this phase (Maiti and Bidinger, 1981).

Growth phase 2: Elongation of all the leaves, emergence of all tillers, floral initiation in tillers, and stem elongation take place during this phase. The elongation of the panicle and formation of floral parts are found in this phase. It ends with the emergence of stigmas on the panicle (Maiti and Bidinger, 1981)..

Growth phase 3: This phase begins with the fertilization of florets and continues up to maturity of the plant. The dry matter accumulation is mainly in grain formation and partly in the enlargement of stem and leaves of the tillers. The end of this phase is physiological maturity, indicated by the development of dark layer at the bottom of the grain (Maiti and Bidinger, 1981).

2.5 INFLORESCENCE, SEED DEVELOPMENT AND MATURITY

The flower structure (inflorescence) in pearl millet is a compound terminal spike, also called panicle or ear head. Each spike consists of 800–3000 spikelets, depending on the size of the spike, and each spikelet consists of two florets. Those which are hermaphrodite (bisexual) contain both male organs (stamens) and female organs (pistils). There are florets which only have stamens. Stamens have anthers and pistils have stigmas. Stigmas emerge first and anthers 3–4 days later (Khairwal *et al.*., 2007;

Haussmann and Angarawai, 2007).

This flowering behaviour called protogyny makes pearl millet a highly cross pollinated crop. It makes both selfing and crossing easy in this crop because selfing just requires covering the spike with a paper bag when it is emerging from the boot (Khairwal *et al.*, 2007.

The pearl millet seed is a caryopsis. The grain matures in 25 to 30 days after fertilization. The shape of the grain can be obovate, lanceolate, elliptical, hexagonal or globular. The 1000 seeds weight can vary from 2.5 to 20 g, but most of the improved varieties can have between 7 to12 g of 1000 seed weight (Khairwal *et al.*, 2007).

The total dry weight of the plant reaches maximum at physiological maturity and nutrients uptake mostly ceases at this stage. Like in sorghum, physiological maturity can be determined by the development of a small dark layer at the bottom of the grain and this occurs about 30 days after flowering. After harvest, the seeds should be properly dried as the seed moisture at this stage can be up to 20% (Khairwal *et al*., 2007).

2.6 POLLINATION AND THE CONCEPT OF POLLEN MEDIATED GENE FLOW

Pollination can be defined as the transfer of pollen grains from an anther of a flower to a stigma of the same or another flower followed by fertilization of the ovule (FAO, 2010). Basically there are two types of pollination depending on the source of pollen: Self Pollination or autogamy and Cross Pollination or allogamy.

Cross-pollinating species are those in which pollination occurs by exchange of genetic material in the form of pollen from one plant to another as opposed to self-pollinating species where the exchange is within the same plant.

According to Rai *et al.*, (2009), pearl millet is mainly cross pollinated and protogynous and affected mostly by wind with an outcrossing rate of more than 85%. The protogynous flowering and wind-borne pollination favour cross-pollination, making open pollinated varieties (OPVs) as the natural cultivar state of this crop.

Understanding the pollination process and the factors affecting it has been useful in plant breeding especially in variety development and maintenance. Its importance has been extended to quality seed production mostly in ensuring seed genetic purity (Deynze *et al.*, 2011). The concept often used to capture this process is known as „"Gene flow"".

With the development of plant Genetically Modified Organisms (GMO) and the interest in genetic diversity preservation, „"gene flow"" has regained much more interest. As stated in the report of a conference on "**The Science of Gene Flow in Agriculture and Its Role in Co-existence"** held at the United State Department of Agriculture in Washington, DC on September 7-8th, 2011 „", until recently, gene flow has primarily been a concern for the seed industry, which has developed certification programs and quality standards to assure buyers of the genetic purity of its products. Currently, controversial aspects of gene flow in agriculture largely derive from concerns about the possibility of genes from Genetically Engineered (GE) crops moving to related wild relatives or to conventional or organic crops"".

On a scientific basis, gene flow can be defined as the transfer and introgression of genetic material (genes in living plant materials) from one plant to another (Deynze *et al.*, 2011). Furthermore, Gustafson *et al*,. (2005) defined pollen-mediated gene flow as the transfer and incorporation of genetic information between distinct plant populations when cross-pollination occurs. The term "pollen-mediated gene flow" is often used synonymously with "outcrossing" or "cross-pollination."

Negative consequences of gene flow in agriculture are largely associated with the unintended presence of certain genes or traits in products that require high genetic purity,

such as in seed production or markets that restrict the presence of GE traits. Also, negative consequences in the environment could be associated with transfer of specific traits to related wild relatives, thereby altering their fitness or success relative to other plants (Deynze *et al.,* 2011).

Besides those negative consequences, gene flow can enhance the genetic diversity of plant populations and may therefore increase the population‟s ability to respond to changing stress in the environment (Gustafson *et al.,* 2005).

Pollen mediated gene flow in Pearl millet has been used by research to study the introgression between the spontaneous and cultivated species. Renno *et al..,* (2007) in an experimental study of gene flow between wild and cultivated Pennisetum glaucum come out with the following results: The percentage of hybrids formed as a result of gene flow from the wild to the cultivated and the shibra each day ranged between 35 and 66% for the cultivated and between 24 and 79% for shibra with an average not significantly different between the cultivated (50%) and the shibra (42%).

Inversely, the percentage hybrids formed as a result of gene flow from the cultivated sample and the shibra to the wild sample each day during the flowering of the cultivated millet varied between 0.5 and 29% with an average of 11%.

Similarly analyses of introgressions between cultivated and wild accessions showed modest but statistically supported evidence of introgressions (Mariac *et al.,* 2006).

It is there obvious that there is a massive exchange of pollen within Pearl millet which greatly account for its high level of cross pollination.

2.7 XENIA EFFECTS

Xenia is referred to as the direct effect of cross fertilisation on the grain traits of the female component in the year of crossing (Bozinovic *et al.,* 2012). Such immediate or direct effects are termed "xenia" and have been described in many species since 1881 by Focke. It was further discovered that the "xenia," covers all direct pollen effects in seeds and fruits, whether discerned in embryo, endosperm, or maternal tissues, in the period from fertilization to germination (Denney, 1992).

Subsequent studies showed that there are many direct effects of male pollen grains on female seeds and fruits and many classifications were suggested. Based on several research work conducted by many scientists from 1881 to 1988, Denny (1992) xenia effects were put into two main groups as: quantitative xenia effect and qualitative xenia effects. The quantitative trait affected by xenia is the grain size while the qualitative traits are the grain colour, shape, sugar content, chemical composition and time of maturity. Crops are hence grouped on the basis of their response to the different xenia effect.

Furthermore, distinctions in types of xenia based on the various discernible characteristics has been proposed by Denny (1992) as xenochromes (color effects), xenoplasms (shape effects), xenodoches (size effects),xenochems (chemical effects), and xenochrons (timing effects).

Many research works have been conducted assessing the xenia effects on all those traits especially on maize crops. Recently, the combined effects of Xenia and Cytoplasmic Male Sterility (CMS) have become a major area of studies in breeding. It is referred to as Plus-

hybrid and it is used in attempting to increase cultivars yield and quality of the grains (Bozinovic *et al.,* 2012).

The occurrence of xenia in Pearl millet was first discovered by Patel in 1939 in India following the discovery of yellow coloured seed from African variety in Indian bluish green seeded variety resulting from a cross pollination of the two varieties.

2.8 SEED PRODUCTION SYSTEMS AND SEED QUALITY

Seed system can be defined as a set of interconnected actors or group of actors, performing interrelated activities, involved in the variety development, production, quality maintenance and distribution of seeds to farmers within an area (Louwaars *et al.*,2009). In developing agriculture, two major seed production and delivery systems govern basically the seed sector: the formal seed system and the informal or traditional seed system.

The formal seed systems generally consist of public sector research institutions, public and private sectors‟ agencies producing and marketing seeds and organizations responsible for seed certification and quality control. The informal or traditional seed system consists of large number of farmers who produce both traditional and modern varieties, market their own produce, and take care of their own research need (Sentimela *et al.*, 2004).

While the formal seed systems focus on providing quality seed of improved varieties through breeding and command the control over all components of the system and certification, the informal seed systems have the advantages of making seed available and accessible to farmers.

There is now a growing awareness that the formal system (the legally prescribed adherence to defined quality standards) may not be able to solve the problem of availability of quality seed (Amstel *et al.*, 1995).

This brought about the new approach of integrating the two systems in order to face the double challenge of quality issues and the availability of seeds to farmers. This new approach is termed „"integrated seed system"", „"community based seed system"" or „"on farm seed production"" depending on literature (Sentimela *et al.*, 2004).

The development of such integrated seed systems requires adaptation of technology, a flexible seed legislation and regulation, wise enforcement, and institutional capacity. Farmers should be recognized as essential and active partners in seed system development (Amstel *et al.*, 1995).

Seed quality is a major issue in all seed production and delivery systems. Every seed programme seeks to produce and supply seed of highest quality in order to increase productivity, resist or tolerate pest and diseases pressure and meet the market demand of quality produce (Gastel *et al.*, 2002).

However, according to Minot *et al.*, (2007) seed quality is a function of five main factors. These factors are the genetic content of the seed, the physical purity, the „"purity"" of the variety, the vigour and the seed health.

Varietal purity refers to the percentage of the pure seed that will produce plants that exhibit the characteristics of that specific crop variety.

The crop produced by a mixture of genetic lines or varieties will mature at different times, and will generally have a lower yield potential when grown under the most favourable

conditions. On the other hand, farmers often choose varietal mixtures that may be more resistant to disease, pests, and abiotic stress. This may be one reason why farmers in risk-prone environment are less likely to rely entirely on certified (Minot *et al.*, 2007).

Even though the formal seed system puts more emphasis on the management of the varietal purity through systematic quality control and restricting regulations, this issue is also important in the informal sector. Sound seed policy taking into consideration these aspects are now designed in most developing countries to take the advantages of both systems (Amstel *et al.*, 1995).

2.9 QUALITY CONTROL, REGULATIONS AND SEED POLICY

Quality control refers to the set of activities conducted along the seed system‟s value chain to ensure that seed of highest possible quality are produced, processed and marketed. Under the authority of a National Seed Law, seed quality is regulated and must meet established minimum standards (Gastel *et al.*, 2002).

During seed production, the most restricting standards depending on the crop are: minimum isolation distance, maximum off-type and minimum varietal purity. Other important standards such as minimum seed analytical purity, minimum germination potential, maximum moisture content are of most concern during laboratory analysis. These standards also vary from country to country and are function of the generation of seed to be produced.

The minimum isolation distance required to produce certified seed of Pearl millet which is the last generation of seed that can be produced in the seed chain ranges from 200 to 400 m depending on the country. While Muliokela (1995), Sentimela *et al.*, (2004) recommend a range of 300 to 400 m of isolation distance, the Economic Community for

West African States (ECOWAS) technical guideline for the harmonized seed law impose a distance of 300 m (INSAH, 2012). The Southern Africa Development Countries field standards fixed the minimum isolation distance for Pearl Millet to be 200 m (Mujaju, 2010).

Similarly, the stipulated isolation distance for the same generation of seed both for hybrids and OPV in India is 200 (Khairwal *et al.*, 2007). In Ghana, 200 m is recommended for OPV certified seeds and 400 m for hybrid certified seeds. These standards obviously take small holder farmers out of the system.

During field inspection, the maximum off- types tolerated is 0.5 for each 1000 sampled plants for certified seeds according the harmonized seed regulation of South African Countries while in West Africa the maximum number of off-types is 0.6 for 100 sampled plants.

For varietal purity which is the result of proper application of the above standards (minimum isolation distance and maximum tolerated off types), 98 to 99% of purity is required for seed certification.

2.10 ALTERNATIVE SEED REGULATORY SYSTEMS

As discussed earlier, standards for seed quality control are mostly designed for the formal seed system which is supposed to provide quality seeds for commercialisation and exchange. But the informal system still play a major role in the seed delivery chain in most developing country. The seed quality control agencies do not have enough human resources to ascertain the quality of seed all over. There is a need to pay more attention to what small scale seed farmers produce in terms of quality as such quality control should be reviewed in term to whom should it be conducted by whom it should be conducted.

Roberts *et al.*, (1997) extensively stated that the seed quality standards should be appropriate to the farming conditions and seed production capability of the country in question. The level at which the standards are set should be decided through open debate among seed producers and farmers and should reflects changes in market demand and production conditions. It is also reasonable to expect that the standards for local seed production projects might be different from those used in large commercial operations, even though a single authority body might control both.

Other approaches are suggested and tested in some countries. Concepts like quality declared seed system and truth to labelling arose for that matter.

The Quality Declared Seed system was developed by the FAO and allows the producer to declare the seed quality, based on tests that the company has arranged to be conducted (Gastel *et al.*, 2002). The purpose of this system is to have a realistic quality assurance process and standards for seeds in countries that are at the initial stages of seed industry development (Osborn and Napolitano, 2010).

It gives room to Internal Quality Control and is mostly developed in countries where the official control system is weak or mostly in case of emergency.

Since it makes use of internal quality control mechanism, the system may not be very effective in developing countries where the bulk of seed operators do not have minimum personnel and equipment to conduct some of the required quality tests.

However, it is much cheaper than the Comprehensive Regulatory approach and thus requires less government resources. On the other hand, it is still expected to provide sufficient guarantee for farmers to receive quality seed (Gastel *et al*., 2002).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 STUDY AREA

The experiment was conducted in Binduri district in the Upper East Region of Ghana. Upper East is located in the north-eastern corner of the country between longitude 0° and 1° West and latitudes 10° 30”N and 11°N. The land is relatively flat with a few hills to the East and southeast. The total land area is about 8,842 sq km, and the region‟s soil is “upland soil” mainly developed from granite rocks. It is shallow and low in fertility, weak with low organic matter content and predominantly coarse textured. The climate is characterized by one rainy season from May/June to September/October. The mean annual rainfall during this period is between 800 mm and 1.100 mm. The rainfall is erratic spatially and in duration. Temperatures during this period can be as low as 14 degrees centigrade at night, but can be more than 35 degrees centigrade during the daytime. Humidity is, however, very low making the daytime high temperature less uncomfortable.

The experimental area was under Manga (Bawku) sub-station of the Savanna Agricultural Research Institute (SARI). The field lies between the latitude 10°56‟57.8”” North and the longitude 00°18‟54.2”” East.

3.2 MATERIALS

Two open pollinated varieties developed from the local land races were used in the experiement: the Improved Bongo Short Head (IBSH) and the Improved Tongo Yellow (ITY). The two cultivars are Early Maturing Varieties (EMV) and are yet to be released by the Savanna Agricultural Research Institute (SARI).

The main features of the Improved Bongo Short Head are: very short globose panicle (head) and dark grey hexagonal grain colour. The Tongo Yellow is characterized by a short cylindrical panicle and most importantly with its hexagonal yellowish grain colour. The table 3.1 shows the main features of the two varieties as described by Afribeh (2005).

Table 3. 1: Main characteristics of the two varieties

Population	**Major features**	**Area of cultivation**
Bongo Short Head	Very short and plump balllike ear heads Dark grey grain colour	Bongo township and the surrounding areas (Bongo district)
Tongo Yellow	Short head with yellow grains	Tongo, Zebilla, Tilli and some areas in Kassena Nankwa and Builg districts.

The two varieties have almost the same cycle and this ensure pollen shedding synchrony when planted at the same time.

In this experiment the ITY was used as „‟pollen donor‟‟‟ or synonymously pollinator or pollen parent. The IBSH was used as „‟pollen receiver‟‟‟ which was the same as seed parent.

3.3 EXPERIMENT LAYOUT AND CROP MANAGEMENT

3.3.1 Layout

The experiment was set up in such that the „"pollen donor „" variety was surrounded by the „pollen receiver"" at specific distances along each of the eight geographical positions (North, North-East, East, South-East, South, South-West, West and North-West).

- A circular area of around 95 m² (radius 5.5 m) was planted with the ITY at the center of each plot at 0.4 m inter and intra row spacing. The expected plant population of the ITY from that area represent around 0.7% of the total population if the total area had to be planted with Pearl millet at the same spacing. This was higher than the tolerated level of off-types in a normal certified seed production (0.6%) according to the West African Seed Regulation.

  The ITY population was expected to produce and supply enough pollen grains for the field to be rejected in case of field inspection.

- Then five hills of a „"pollen receiver"" that is the IBSH were sown at regular intervals (0.4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 m distance from the point source at 45 degree intervals all around the pollen point source [that is, due north (N) of the point source (360 degrees or 0 degrees), then northwest (315 degrees), west (270 degrees), southwest (225 degrees), south (180 degrees), southeast (135 degrees), east (90 degrees) and northeast (45 degrees)].

- The plot was replicated 3 times (i.e. on 3 different plots) and care taken to isolate plots from each other (by at least 300 m). The land was fairly flat and sources of obstruction were avoided during the layout.

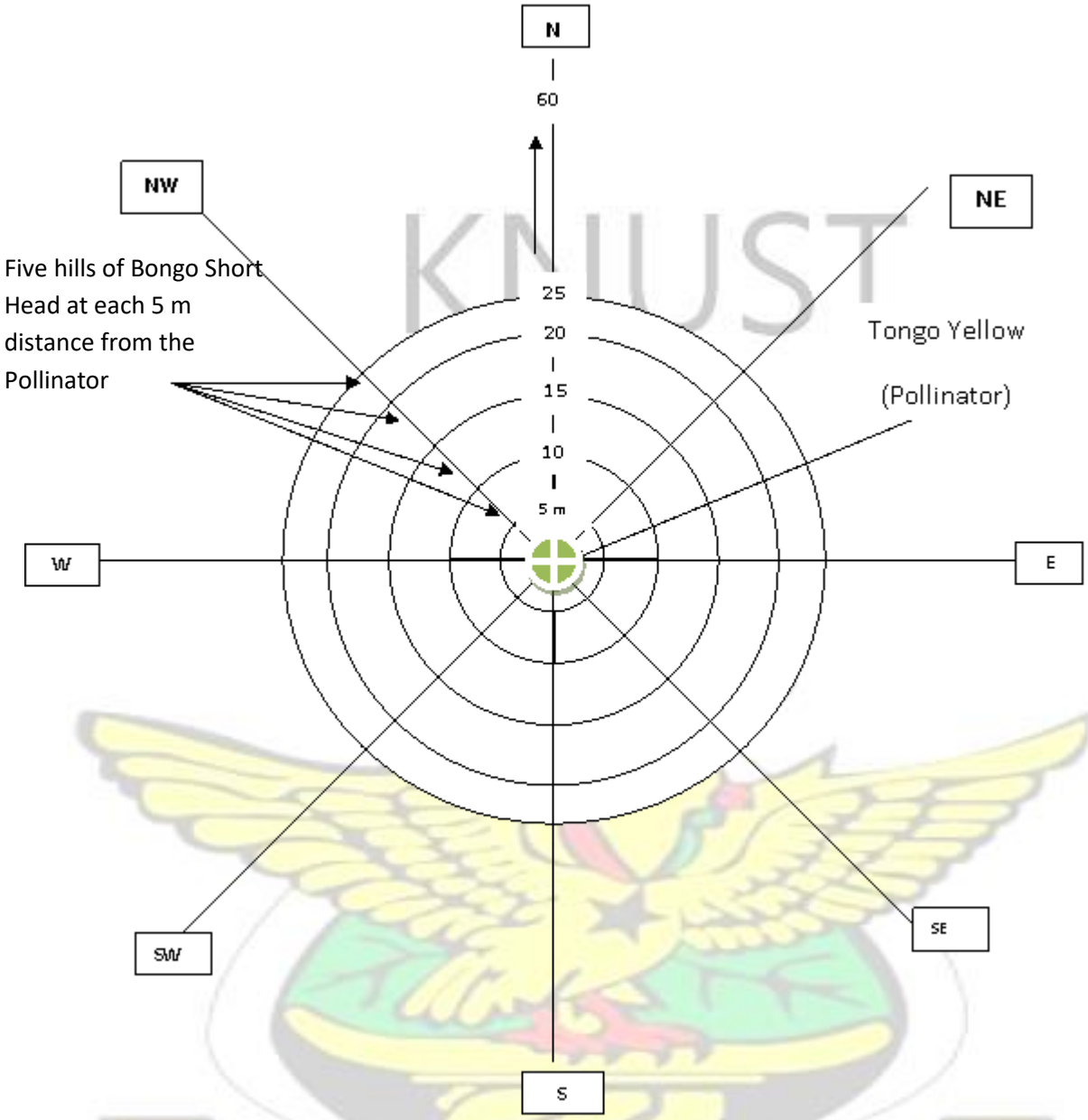

Figure 3.1: Experimental layout

3.3.2 Crop Management

From layout to harvest the following good agricultural practices were applied: land preparation (land clearing, ploughing and harrowing, pre-emergence herbicide application), planting on june 27th 2014 (at 40cmx40cm spacing), basal application of compound fertilizer (NPK 15-15-15; micro-dosing, 3 g/hill), thinning 2 weeks after

planting (2 plants per hill), replanting and transplanting 3 weeks after planting, weeding (2 times), side dressing of Nitrogen fertilizer (Ammonium Sulphate, 3g/hill), insects and disease control and bagging of fertilized panicles of the pollen receiver, etc.

3.4 DATA COLLECTION

Two types of data were collected: crop parameters and climatic data:

3.4.1 Crop's Field Data

The field data are mostly agronomic parameters that can affect cross pollination:

- Dates of first panicle flowering: For the pollen parents it is the day at which pollen was shed on the first panicle while for seed parent is the day at which the stigma became receptive on the first panicle for each experimental unit. Observations were done in the morning from around 8:00 am to about 11:00 am.
- Dates of 50% panicles flowering: For the pollen parents it was the day at which 50% of panicles from the main plants shed pollen grain. For seed parent it was the day at which 50% of panicles from the main plants of the experimental unit had receptive stigma (Bidinger *et al.*, 1999).

  No specific method or technique was used to measure the volume and flux of pollen grains produced by pollen parents and to assess the receptivity of seed parents. The follow up of the trend of the period of flowering for both pollinators and pollen receivers by recording the above variables.
- Average plant height at the flag leaf: it is the height of the millet plant (for both pollinators and pollen receivers) measured from the level of the soil to the point of attachment of the flag leaf. A sample of plants from 40 hills was randomly collected in each plot of the pollinators. For each of the experimental unit bearing

pollen receivers all the main plants were measured (number ranging from 2 to 10 plants). The measurement was done using a graduated wooden ruler shortly before harvest and the averages were obtained by adding the records for each plot and dividing by its respective number of plants measured.

- Average full plant height or natural height: It is the height from the level of the soil to the edge of the panicle. The measurement was done on the same plants which plant height at flag leaf was measured and under the same conditions.
- Number of panicles from the main plants: It is the number of panicles from the main plants of the seed parents harvested. Well filled panicles, free from any visible disease impact were selected as it is done under a normal seed production system.
- Number of panicles from tillers: It was the number of panicles from the tillers of seed parents selected like above.
- Total number of panicles: was the sum of number of panicles harvested on the main plants and those harvested on the tillers.

3.4.2 Climatologic data

Meteorological data from 1st June to 30th September 2014 for Binduri District meteorological station were obtained from the regional office in Bolgatanga. The data included the following:

- Daily rainfall: represents the quantity of rainfall within 24 hours of the day recorded in mm.

- Daily maximum and minimum temperature: the highest and lowest records of temperature respectively, expressed in degree Celsius (°C) for a day.
- Daily wind speed: the average wind velocity within a day and express in knot.
- Daily wind direction: the geographical direction from where the wind originated.
- Relative humidity: the atmospheric humidity expressed in percentage recorded at specific periods of the day (at 6:00 am, 9:00 am, 12:00 pm and 3:00 pm).

3.5 POST HARVEST OPERATIONS

3.5.1 Drying, Threshing and Cleaning

Harvested and sorted heads of Pearl millet of each of the experimental unit were dried, threshed and cleaned thoroughly from inert materials. Because of the relatively small amount of the produce and to reduce grain wastage, both operations were performed using hands. The two operations were performed on the Manga Research Sub-Station"s drying and threshing plateform.

3.5.2 Sampling and Sorting

Out of the threshed and cleaned millet seeds and mixed thoroughly, working samples weighing 15g each, as recommended by ISTA for any Pearl millet sample, were taken and submitted for laboratory analysis.

The sampled seeds were then sorted based on the colour of the grain. Yellow grains were separated from those which were grey.

The general laboratory of the Manga Research Sub Station was used to perform the sampling and the preliminary sorting of the seeds.

3.6 SEED WHEIGHING/COUNTING AND DATA COMPUTATION

3.6.1 Seed Weighing and Counting

All separated samples were sent to the Laboratory of the Department of Horticulture of the Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi. Sensitive scale was used to weigh and record the separated sample portions.

The same samples were then transferred to the Seed Laboratory of the National Tree Seed Centre located at the Forestry Research Institute of Ghana (FORIG) for grain counting. Wagtech International Electronic Grain Counter was used to count the subsamples. Prior to counting, the grain counter was calibrated to suit the small size of the Pearl millet seeds. The following characteristics were set: minimum grain size = 1 mm (diameter), frequency of the counter = 10 Hz.

Also, after calibration, the precisions of seed counter was measured both for the grey and yellow seeds. Ten samples of 1000 hand counted seeds for each of the two groups of seeds were counted using the calibrated grain counter. After recording and calculating the counted seeds, the following precisions were obtained: 97.12% for the grey seeds and 97.33% for the yellow seeds.

3.6.2 Computing

Data recorded after weighing samples and seed counted were used to compute the varietal purity of each of the treatment combination. According to the Regulation C/REG.4/05/2008 on the harmonization of rules governing quality control, certification and marketing of plant seeds and seedlings in the ECOWAS region, varietal or genetic purity means the proportion of plants in the field that meet the standards of the variety.

In the laboratory, it means the proportion of a given variety in a seed batch or lot.

Seed varietal purity on weight basis (VP/WSB) and seed varietal purity on number of seeds basis (VP/NSB) were henceforth both calculated.

While seed varietal purity on weight basis is important to measure the actual weight of pure seeds produced and marketed by seed growers (laboratory calculated), the seed varietal purity on number of seed basis will help to predict the percentage of pure plants on the field (proportion of plants in the field meeting the standards) or inversely to assess the level of off-types on a plot planted with those seeds.

The following formulas were used:

$$\text{VP/WB} = \frac{\text{Weight of grey seeds}}{\text{Weight of yellow seeds} + \text{Weight of grey seeds}} X\ 100$$

$$\text{VP/NSB} = \frac{\text{Number of grey seeds}}{\text{Number of yellow seeds} + \text{Number of grey seeds}} X\ 100$$

3.7 DATA ANALYSIS

Gen Stat 9th Edition was the statistical package used in analyzing data and lsd at 5% used to separate means where significances were observed:

- Analysis of Variance (ANOVA) was used to check for the differences in seed varietal purity between treatment means and treatment means combinations. It was also used to assess the variation of some crop parameters of parent seeds.
- Regression and Correlation analysis was used to determine the type and degree of relationships between the parameters and seed varietal purity.

a.

b.

Plate 3.1: Pollen parent panicle shading pollen grains (a.) and Receptive stigma on seed parent panicle (b.)

a.

b.

CHAPTER FOUR

4.0 RESULTS

4.1 EFFECTS OF DISTANCEANDDIRECTIONON VARIETALPURITY

The interaction between direction and the distance showed that varietal purity can be as low as 40.86% on weight of seed basis, 42.65% on number of seed basis at 0.4 m East (Table 4.1 and Table 4.2) . However, on the weight of seed basis, varietal seed purity of 100% was observed at 45m South-East, 60m South-East, 30m South, 50m South upward, 55m and 60m to the South-West, 60m West, 40m, 55m and 60m North-West (Table 4.1). On the number of seed basis, 100% pure seeds was observed at 45m SouthWest, 60m South-West, 30m, 50m, 55m and 60m South, 55m and 60m South-West, 60m West, 55m and 60m North-West (Table 4.2).

None of the direction attained the minimum required level of varietal purity on weight of seed basis and on number of seed basis. As for the distance, minimum seed purity level of the second generation of certified seed was obtained at 45m on the seed weight basis and at 40m on the number of seed basis (Table 4.1 and Table 4.2).

Table 4. 1: Varietal purity on weight of seed basis per distance and direction

		Distance (m)													
		0.4	5	10	15	20	25	30	35	40	45	50	55	60	Mean
Direction	N	56.48	81.44	80.91	87.94	88.03	93.39	97.34	96.51	98.87	99.28	98.34	99.09	99.41	90.54
	NE	64.60	74.04	80.91	87.19	97.13	97.04	97.53	97.89	98.21	98.68	99.20	99.38	99.87	91.75
	E	40.86	77.99	88.98	86.85	86.51	91.36	95.99	95.00	96.58	97.63	98.67	98.74	99.02	88.72
	SE	69.87	89.91	92.60	94.24	94.38	97.47	99.47	99.66	99.69	100.0	99.78	99.41	100.0	95.16
	S	75.03	91.25	94.54	96.30	96.05	97.46	100.0	99.40	99.98	99.61	100.0	100.0	100.0	96.13
	SW	65.29	82.49	95.14	94.15	95.40	99.12	99.02	99.06	98.35	99.89	99.83	100.0	100.0	94.44
	W	87.36	93.26	96.13	97.76	96.98	96.12	96.29	98.60	99.43	99.63	98.00	99.75	100.0	96.87
	NW	74.34	82.16	90.78	91.87	93.05	98.01	97.49	98.83	100.0	98.33	99.01	100.00	100.0	94.16
	Mean	66.73	84.07	90.03	92.04	93.44	96.25	97.91	98.12	98.90	99.19	99.10	99.55	99.80	**93.47**
		LSD: Distance = 2.87, Direction = 2.25, Distance x Direction = 8.12, CV = 1.2													

Table 4. 2: Varietal purity on number of seeds basis per distance and direction

		Distance (m)													
		0.4	5	10	15	20	25	30	35	40	45	50	55	60	Mean
Direction	N	57.39	83.12	82.13	89.07	88.99	93.76	97.99	96.83	98.63	99.25	98.80	99.34	99.45	91.14
	NE	67.31	74.98	82.77	87.68	97.19	97.24	98.09	98.18	98.26	98.91	99.17	99.44	99.93	92.24
	E	42.65	80.24	89.58	88.54	87.62	93.06	96.59	95.65	96.95	98.05	98.90	98.70	99.06	89.66
	SE	70.98	90.56	93.57	95.20	94.67	97.58	99.74	99.85	99.88	100.0	99.96	99.41	100.0	95.54
	S	76.39	92.14	94.97	96.73	95.87	97.53	100.0	99.68	99.99	99.85	100.0	100.0	100.0	96.40
	SW	67.60	83.65	96.11	95.16	95.15	99.55	99.25	99.62	99.16	99.99	99.85	100.0	100.0	95.01
	W	88.69	94.09	96.73	98.18	97.13	97.04	96.85	99.05	99.49	99.65	99.82	99.76	100.0	97.42
	NW	75.95	83.39	91.56	92.77	93.96	98.74	97.96	99.35	100.0	98.96	99.26	100.00	100.0	94.77
	Mean	68.37	85.27	90.93	92.92	93.82	96.81	98.32	98.53	99.05	99.40	99.47	99.58	99.81	**94.02**
		LSD: Distance = 2.71, Direction = 2.12, Distance x Direction = 7.67, CV = 1.2													

4.2 CROP PARAMETERS AFFECTING SEED PURITY AND THEIR VARIATION

4.2.1 Flowering Trends of the Pollinators and Pollen Receivers

Compared to seed parents (IBSH), the pollen parents (ITY) had lengthy flowering periods. The period from first panicle flowering to 50% panicles flowering lasted 9 days in pollen parents against 5 days in seed parents. Also, pollen parents experienced 36 days of second flowering phase (from 50% panicles flowering to harvest) while the seed parents second flowering phase lasted only for 31 days (Table 4.3).

Both varieties continued to flower till harvest through their secondary tillers that emerged continuously.

Table 4. 3: Average flowering phases length of the two varieties (number of days).

Flowering Phase	**Improved Tongo Yellow**	**Improved Bongo Short Head**
Panicle flowering to 50% flowers	9	5
50% flowering to harvest	36	31
Total	**45**	**36**

4.2.2 Variation in Flowering Dates of the Seed Parents

There were significant differences ($p<0.001$) in number of days to first panicle flowering and days to 50% panicles flowering for both direction and distance but no significant difference were observed for their interaction.

Table 4.4 shows for day to first panicle flowering, the least number of days was observed to the West (57.36 days) while the significantly highest number of days was observed to the South (61.70 days). Regarding distances, seed parents at 0.4 m initiated flower earlier (55.67 days) while late first flower appearance was observed at 55 m from the pollen source (61.50 days).

Similarly, number of days to 50% panicles flowering was lower to the west (62.59 days) but higher to the South (66.40 days). Also, the lowest number of days to 50% panicles flowering was observed at 0.4 m (61.21 days) while the longest time for 50% panicles to flower was observed at 55m (Table 4.4).

Table 4. 4: Differences in average flowering dates of the seed parent (in number of days after planting).

Treatment	**First Flowering (DAP)**	**50% flowering (DAP)**

Direction		
N	58.05	62.77
NE	59.91	64.26
E	58.36	63.29
SE	60.5	64.79
S	**61.70**	**66.40**
SW	59.21	64.60
W	**57.36**	**62.59**
NW	58.71	64.06
Lsd (5%)	**1.57**	**1.41**
Distance (m)		
0.4	**55.67**	**61.21**
5	58.33	63.25
10	58.29	63.37
15	58.29	63.46
20	57.61	63.16
25	60.08	64.39
30	59.46	64.21
35	59.96	64.62
40	60.71	65.21
45	60.08	64.89
50	60.46	65.08
55	**61.50**	**65.84**
60	59.57	64.54
Lsd (5%)	**2.00**	**1.80**
Grand mean	**59.23**	**64.10**
CV%	**2.5**	**2.3**

4.2.3 Average Plant Height for Pollinators and Pollen Receivers.

On the average, the pollinators were „"taller"" than the pollen receivers both at flag leaf and in full length. The difference between the natural length and the length at flag leaf representing the panicle and the peduncle length was also taller for pollinators than for the pollen receivers as shown in table 4.5 below.

Table 4. 5: Mean plant heights for pollinators and pollen receivers

	Mean plant height (PH), (cm)		Difference
Plot	**Full PH**	**PH at Flag Leaf**	
ITY	167	137	**30**
IBSH	144	121	**23**
Difference	**23**	**16**	

4.2.4 Variation in Plant Height of the Seed Parents

There were no significant differences in plant height (full plant height and plant height at flag leaf) with regard to direction and distance and their interaction (Appendix A5 and A6).

For direction, the full plant height ranged from 132.1 cm to 143.3 cm and the plant height at flag leaf ranged from 116.5 cm to 127.3 cm. For distance, the full plant height ranged from 128.9 cm to 142.3 cm while the plant height at flag leaf is between 111.9 cm and 133.4cm.

4.2.5 Variation in Number of Panicles of the Seed Parents

There were significant differences ($p<0.001$) among distances and directions for both total number of panicles harvested and the number of panicles on the main plants (Appendix 7 and 8). Significant difference ($p<0.05$) was observed among directions for the number of panicles on tillers (Appendix 9). As shown in Table 4.6, the highest number of panicles was observed to the East for both total number of panicles, panicles on main plants and panicles on tillers. The lowest number of total panicles, panicles on main plants and panicles on tillers was harvested to the directions of North-East, South and North-East respectively (Table 4.6).

Table 4. 6: Differences in number of panicles (transformed data)

Treatment	Total n° of panicles	Panicles on main plant	Panicles on tillers
Direction			
N	2.80	2.12	1.94
NE	**2.55**	1.87	**1.81**
E	**3.15**	**2.31**	**2.24**
SE	2.68	1.87	1.99
S	2.68	**1.77**	2.08
SW	2.74	1.92	2.04
W	2.96	2.06	2.22
NW	2.72	1.94	1.99
Lsd (5%)	**0.26**	**0.19**	**0.24**
Distance (m)			
0.4	3.16	2.30	
5	**3.17**	2.30	
10	3.15	**2.31**	
15	2.92	2.18	
20	2.81	2.02	
25	2.85	2.03	
30	2.70	1.94	
35	2.69	1.96	
40	2.60	1.79	
45	2.59	1.80	
50	2.65	1.81	
55	2.55	1.71	
60	**2.38**	**1.61**	
Lsd (5%)	**0.34**	**0.25**	
Grand mean	**2.79**	**1.94**	
CV%	**4.1**	**8.3**	**3.8**

4.3 RELATIONSHIPS BETWEEN PLANT PARAMETERS AND VARIETAL PURITY

4.3.1 Correlations between Varietal Purity and Crop Parameters of Seed Parents

According to results in Table 4.7, varietal purity correlated positively with flowering dates (both first flowering and 50% flowering) but correlated negatively with plant height (total plant height and plant height at flag leaf) and the number of panicles (total number of panicles, number of panicles on the main plants, number of panicles on tillers).

From the same table 4.7, significant correlations were observed between varietal purities (both on weight basis and number of seed basis) and distance.

Only varietal purity and distance strongly correlated. First flowering, 50% flowering, total number of panicles, panicles on the main plants weakly correlated with varietal purity.

Table 4. 7: Correlation matrix between varietal purity and field parameters

Distance	1.000									
FPF_DAP*	0.293	1.000								
%50_PF_DAP	0.268	0.902	1.000							
FPH	-0.141	-0.041	-0.021	1.000						
PH_FL	-0.151	-0.041	-0.027	0.978	1.000					
NPH	-0.348	-0.221**	-0.207**	0.110	0.123	1.000				
PMP	-0.410	-0.260**	-0.270**	0.090	0.104	0.839	1.000			
PT	-0.160	-0.127	-0.089	0.093	0.102	0.828	0.409	1.000		
VP_WB	0.653**	0.263**	0.246**	-0.176	-0.181	-0.214**	-0.318**	-0.042	1.000	
VP_NSB	0.643**	0.255**	0.238**	-0.178	-0.182	-0.206**	-0.309**	-0.038	0.998**	1.000
	Distance	FPF_DAP	50%_PF_DAP	FPH	PH_FL	NPH	PMP	PT	VP_WB	VP_NSB

** significant at 0.01probability level

* FPF=First Panicle Flowering, 50%PF=50% panicle flowering; FPH=Full plant height, PH_FL= Plant height at flag leaf, NPH=Number of Panicles harvested, PMP=Panicles on main plants, PT=Panicles on Tillers, WB = Weight Basis, NSB = Number of seed basis.

4.3.2 Regression equations between Distance and Varietal Purity per Direction.

The correlation matrix (table 4.7) showed strong correlation between distance and varietal purities. Table 4.8 shows that variety purity varied much more strongly with distance to the East (R^2=0.693) and less to the West (R^2 = 0.507).

Table 4. 8: Regression equations

Direction	**Equation**	**Regression coefficient (R^2)**	**Probabity (p)**
North	y=0.005x +0.725	0.527	P=0.005
North-East	y=0.005x +0.762	0.666	P<0.001
East	y=0.004x +0.784	0.693	P<0.001
South-East	y=0.003x +0.852	0.687	P<0.001
South	y=0.002x +0.891	0.521	P=0.005
South-West	y=0.003x +0.865	0.529	P=0.005
West	y=0.003x +0.846	0.507	P=0.006
North-West	y=0.001x +0.934	0.659	P<0.001

y is the varietal purity (in percentage) and x the distance (m).

4.4 VARYNING CLIMATOLOGICAL PARAMETERS DURING THE CROPPING SEASON

4.4.1 Wind Speed and Direction (in Knot) on Pollen Parents

From Table 4.9, wind blew in 2 directions during the flowering periods of the pollinators: from South-West and from North West. However, the South-West wind was the most prevailing (42 days) compared to the north-west one (3 days).

The average wind speed during the first period of flowering was 5.67 knots and dropped to 5.14 knots during the second phase of flowering. The maximum wind speed was 7 knots during the two phases but minimum wind speed was 5 knots and 4 knots during the first and second phase, respectively (Table 4.9).

Table 4. 9: Average wind speed during the crop growth and development of Tongo Yellow

Flowering period	**Direction (in # of Days)**		**Speed (Knot)**		
	SW**	NW	Average	Max	Min
Panicle flowering to 50% flowers	8	1	5.67	7.00	5.00
50% flowering to harvest	34	2	5.14	7.00	4.00
Total/Average	42	3	5.24	7.00	4.00

** SW = wind originating from South West; W = from West; NW = from North West.

4.4.2 Temperatures (in °C)

Table 4.10 showed that the average maximum temperatures recorded on the pollinators were 31.3°C and 32.1°C for the first period of flowering and the second period of flowering respectively. The pollen receivers were subjected to maximum temperatures of 32.2°C and 32.1°C during the first and second flowering period.

The average minimum temperatures on the pollinators were 15.0°C during the first flowering period and 20.2°C during the second period. On pollen receivers, average

temperatures recorded were 15.6°C during the first period and 20.9°C during the second period (Table 4.10).

Table 4. 10: Average temperatures (max and min) during the phases of growth and development of the crop (in °C)

	Improved Tongo Yellow		Improved Bongo Short Head	
Period	**Mean Max**	**Mean Min**	**Mean Max**	**Mean Min**
Vegetative growth	33.6	16.4	33.3	16.2
Panicle flowering to 50% flowers	31.3	15.0	32.2	15.6
50% flowering to harvest	32.1	20.2	32.1	20.9
Average	**32.0**	**19.2**	**32.1**	**20.2**

4.4.3 Relative Humidity (%)

Average relative humidity recorded on the pollinators during the flowering periods ranged from 73.02% in the morning (06:00 am) to 45.13 in the afternoon (3:00 pm) while the recorded relative humidity on pollen receiver ranged from 78.66% in the morning to 49.47% in the afternoon (Table 4.11).

Also, lower relative humidity percentages were recorded during the first phase of flowering compared to the second phase for both pollinators and pollen receivers from morning to afternoon (Table 4.11).

Table 4. 11: Mean relative humidity during the phases of growth and development of the crop (in %)

	Average RH on ITY				Average RH on IBSH			
Phase	***RH6**	**RH9**	**RH12**	**RH15**	**RH6**	**RH9**	**RH12**	**RH15**
Vegetative growth	52.02	39.49	31.39	28.35	51.78	39.55	31.53	28.27
Panicle flowering to 50% flowers	50.44	39.89	32.33	27.78	51.20	40.20	32.00	27.00
50% flowering to harvest	78.67	66.28	57.17	49.47	83.10	70.48	61.23	53.10
Average	**73.02**	**61.00**	**52.20**	**45.13**	**78.66**	**66.27**	**57.16**	**49.47**

*RH6 = Relative Humidity at 6 O"clock am; RH9 = Relative humidity at 9 O"clock am; RH12 = Relative Humidity at 12 noon; RH15 = Relative humidity at 3 O"clock pm.

4.4.4 Rainfall (in mm and number of days)

During their vegetative growth, pollinators received 147.9 mm in 11 days of rain while a rainfall of 183 mm in 13 days was recorded for pollen receivers (Table 4.12).

During the first flowering period only 35.1 mm in 2 days and 19.4 mm in 1 day were recorded for the pollinators and pollen receivers, respectively. The second period of flowering however experienced rainfall of 245.6 mm in 13 days for the pollinators and 226.2 mm in 12 days for the pollen receivers (Table 4.12).

Table 4. 12: Average rainfall (mm) and number of days of rain per phase and per plot.

	RF on ITY	**RF on IBSH**

	Rainfall (mm)	# days of Rain	Rainfall (mm)	# days of Rain
Veg. growth	147.9	11	183	13
Panicle flowering to 50% flowers	35.1	2	19.4	1
50% flowering to harvest	245.6	13	226.2	12
Total	**280.7**	**15**	**245.6**	**13**

CHAPTER FIVE

5. DISCUSSIONS

5.1 VARIETAL PURITY AFFECTED BY DISTANCES AND DIRECTIONS

The study revealed that varietal purity in pearl millet seed production was closely related to the distance from the pollen sources irrespective of where the seed field was located. The closer the seed field is to the source of pollen pollution the lower the seed varietal purity and vice versa. There was a steady and significant reduction in varietal purity within distances ranging from 0 to 30 m but above this distance, the variations from one distance to another were not significant.

In a similar study conducted on maize by Bannert and Stamp (2007) in some of their research fields, spatial gradients of varying crosspollination were found and these gradients were characterized by a higher rate of cross-pollination (that is low purity) in the border row, exposed to the nearest yellow grain pollen donor field, with a rapid decrease in direction inside the field. In another study on gene flow from transgenic to

non-transgenic maize, Goggi *et al.*, (2006) also discovered that the out-crossing decreased rapidly beyond certain distances from the pollen source.

Regarding direction, 3 directions which are North, East and the North-East recorded lower average varietal seed purities while directions that were opposite to them, that is, South, West and South-West recorded the highest average varietal seed purities. Significant differences were observed when comparing each opposite directions that is
North against South, North-East against South-West, and East against West. This suggests that cross pollination which is due to the movement of pollen grains from pollen source was much more important Northward, Eastward and in between than toward the opposite directions. However, the difference in varietal purity between South East and North West was not significant showing that the pollen grains movement from the pollen sources was almost at the same rate toward these two opposite directions. This confirmed the results obtained by Bannert and Stamp (2007) who noticed that fields with clear gradients are exposed to the main wind direction with regard to the nearest yellow grain pollen donor field.

The results showed that none of the distances (from 0.4 to 60 m) was satisfactory for the production of pure breeder (G1, G2, G3) and foundation (G4) seed with regard to the
West African Seed Regulations requiring a varietal purity of 99.9% (INSAH 2012). However, the average varietal purity met the required standard for first generation of certified seed (99.7%) and second generation of certified seed (99.0%) at distances of 60 m and 40 m from the pollen source respectively. These are lower than the minimum isolation distances required for the production of such category of seed. Also, with regard

to the direction, none of the average varietal purity satisfied the minimum purity requirement mentioned above according to West Africa seed regulation (INSAH, 2012).

The grand mean of varietal purity recorded was 94.02% on number of seed basis and 93.47% on seed weight basis. That is to say, if a farmer randomly harvested seeds around a source of pollen contamination within a radius of 60 m, he may likely get a seed lot which varietal purity is close to the above values. These values are far below the minimum standards (99.0% and above) meaning that the minimum isolation distance for Pearl millet seed production should be above 60 m confirming almost all the standards (INSAH 2012, Mujaju 2010, Muliokela 1995).

Variations were however observed from one spot of the field to another. On one hand, the varietal purity was as low as 42.65% and 40.86% on number of seed basis and seed weight basis respectively showing a level of out-crossing of around 59%. On the other hand from the same results, pure seeds (100% varietal purity) were recorded in some spots of the field. The percentage of adventitious grain observed in a nontransgenic grain production field of maize was as high as 47% adjacent to the transgenic pollen source (Goggi *et al.*, 2006)

Also, high out-crossing rate in Pearl millet was reported by many authors and this can range from 70 to 80% (Muliokela 1995 and Rai *et al*., 1999).

Several factors can be accountable for the large variation (from highly cross-pollinated to pure seeds) among which are factors related to the characteristics of the varieties involved (both seed parents and pollen), such plant heights and flowering date and others linked to

the prevailing environmental conditions such as wind speed and wind direction, relative humidity and rainfall.

5.2 EFFECTS OF CROP PARAMETERS ON VARIETAL PURITY

Afribeh (2005) in a study on components of variation, combining ability and heterosis in Ghananian pearl millets, reported that there are significant genetic variations in the populations of the varieties studied among which are the Bongo Short Head (seed parent) and the Tongo Yellow (pollen parent). The variation was related to some characteristics such as days to blooming, plant height, earhead length and number of effective tillers per plant in BSH. Also statistical data from the same study showed significant difference among the two varieties in terms of the characteristics mentioned above.

5.2.1 Flowering dates

Results show that the flowering duration from first flowering to harvest period higher for the pollen parents (Tongo yellow) than for seed parents (Bongo short head) because the pollen parents started flowering earlier than the seed parents. This is in line with the results obtained by Afribeh (2005).

The difference in flowering trend of the pollinators and the pollen receivers may have caused pollination synchrony between the two varieties because the receptivity of the seed parents may have coincided with the period of high pollen shedding of the pollinators. This was supported by Tejagouda *et al*., (2014) who stated that the smaller differences in days to 50 per cent flowering noticed between the female and male parents has also caused better synchronization of flowering due to more availability of viable pollens at peak flowering period.

Flowering synchrony is one of the traits used in Pearl millet breeding to favour hybrid seed production (Hash, 2007). This is so because synchronous flowering is assumed to be a prerequisite for high rates of cross-pollination (Halsey *et al.*, 2005; Goggi *et al.*, 2006)

Results on table 4.3 showed significant differences in flowering within the seed parents with regard to distance and direction. Variation in flowering dates is peculiar to BSH populations (Afribeh, 2005). However individual plants of the field can flower much earlier or later resulting in extended flower overlapping because of varying soils, fast sowing (deposit of seeds in different depths) and spatially variable phytopathogenic pressure may influence the plant development and decrease flowering uniformity of field (Bannert and Stamp, 2007).

Results also showed significant positive correlation between varietal purity and the number of days to first panicle flowering in one hand and varietal purity and days to 50% panicles flowering. This is showing that treatments that flowered late scored higher varietal purity because they may have escaped from the period of highest production and shedding of pollen grains by the pollinators. Similarly, Bennart *et al.*, (2007), showed that differences in the synchrony of donor and receptor flowering of even a few days (5– 7 days) decreased cross-pollination.

In general, flowering trend also showed that the two varieties have very long period of pollen shedding and stigma receptivity. This is peculiar to Pearl millet because of its ability to produce tillers that can flower throughout the development of the plant making isolation in time very difficult during seed production (Kelly, 1988)

5.2.2 Plant Height

The results showed that on the average, pollen parents are taller than the seed parents both at flag leaf and in full. This contrast the results obtained by Afribeh (2005) that showed Bongo Short Head to be „"taller"". However, the average full plant height (167 cm) of Tongo yellow from this study was in between that obtained by Afribeh (2005) which is 157.1 m in the average for the check plants and that pointed out by Asungre (2014) that is 175.8 m. This confirmed the variability with regard to this trait for the two varieties (Afribeh, 2005).

Also, pollinator"s panicle together with the peduncle (girth) was longer than that of the pollen receiver on the average. In describing the two varieties, Afribeh (2005) showed that the pollen receiver (BSH) has a very short ear or panicle while the pollinator (TY) was described as hort.

The difference in height may have favoured the transfer of pollen grains from the pollinators to the shorter pollen catcher. This indeed is a very favourable condition for crossing varieties in hybrid production as stated by Hash (2007), „"for breeding performance in seed production, shorter height of the seed parent may increase effective pollination as pollen is unlikely to „"fall"" up"". Similarly, Gowda *et al.*, (2006) in describing the way all the high-yielding hybrids have been developed and released in India pointed out that the height of R-line (Pollen donor) should not be less than that of an A-line (Pollen receiver).

The results showed no significant differences in plant height (both at flag leaf and in full) with regard to distance and direction.

5.2.3 Number of Panicles on Seed Parents.

In assessing seed purity during field inspection in a cereal field with high tillering potential, it is important to consider the number of ears or panicles in sampling the population (OECD, 2001).

On seed parents, significant variation was observed in the total number of panicles and in the number of panicles on the main plants with regard to distance and direction. This may be due to higher variation in the number of surviving plants among treatments although the number of effective tillers (productive panicles on main plants and tillers) was one of the varying traits in Bongo Short Head populations according to Afribeh (2005).

Significant variation was noted on the number of panicles on the tillers among directions. This may be due to varying soil fertility gradient creating a difference in number of tillers between rich and poor soils. Relatively reduced number of productive tillers may be one of the varietal inheritable characteristics since Afribeh"s (2005) study recorded a mean number of effective tillers to be 1.4 and 1.5 for the progeny and the check respectively.

5.3 INFLUENCE OF CLIMATOLOGICAL PARAMETERS ON VARIETAL PURITY

5.3.1 Influence of Wind Parameters (Direction and Speed)

Wind is the major cross-pollinating agent in pearl millet according to Manga *et al.,* (1999). During the two flowering phases, wind mostly originated from South West. The shaded pollens from the pollinators were then directed toward North East and the surroundings.

This must have explained why the varietal purity was lower to the North, North-East and East but higher at their opposite counterparts directions (that is South, South-West and West). Bannert and Stamp (2007), Hsu *et al.*, (2011) got similar results and found cross-pollination gradients only in fields that were exposed to the main wind direction

Wind originating from North-West did not show any significant impact on varietal purity since no significant difference was noted in term of seed purity between the direction from where the wind originated and that toward which the wind is directed. The number of days wind blew from this direction is relatively few compared to that of the South-West direction.

Records on wind speed showed that the velocity of the wind was higher during the first phase of flowering (that is from the first panicle flowering to 50% panicle flowering). It was during this period that there was an increase in pollen production by the pollinators and maximum cross pollination must have occurred during that period. The slightly reduced speed of the wind during the second phase together with reducing pollen producing trend accounted for reduced synchrony as discussed earlier. It can explain indeed the reduced rate of cross pollination on late panicles confirming the positive significant correlation between varietal purity and flowering dates and the negative and significant correlation between varietal purity and number of panicles.

5.3.2 Influence of Temperatures and Relative Humidity

Generally, large variability for heat tolerance, both at the seedling and reproductive stages, has been demonstrated in pearl millet (Gowda *et al.*, 2006). However, germination, leaf and spikelet initiation, tillering, and grain filling have been shown to have pronounced

differences in their responses to optimum and maximum temperatures (Spencer and Sivakumar, 1987).

Although known as a hardy crop that can be grown in areas which are very hot and dry (Khairwal *et al.*, 2007), Pearl millet pollination can indirectly be affected by varying humidity and temperature during anthesis. According to Manga *et al*., (1999), an increase in humidity and a decrease in temperature have been noted to reduce anther emergence while the reverse enhances its emergence.

However, Coaldrake and Pearson (1985) discovered that temperature prior to panicle initiation determined the number of leaves initiated on the main stem which in turn influenced the duration of the phase from panicle initiation to anthesis. They further found out that high temperature (30°C) induced panicle differentiation earlier than lower temperatures (21°c).

Meteorological data during of this study showed that from the first phase of flowering to the second phase, there was an increase of both average temperature and average relative humidity.

In all the stages of Pearl millet development temperatures were high and the maximum averages exceeded 30°C. Morning (from 6:00 to 9:00 am) relative humidity was particularly high and even increased during the second phase of flowering. This is the period during which pollination mostly occur in pearl millet and that is why artificial dusting of pollen for hybrid production is mostly undertaken at that time (Rattunde *et al.*, 2007).

According to Hasley et al., (2005), the influence of humidity on random and episodic PMGF may perhaps be understood on a population basis, where the proportion of viable pollen grains in a population available for dispersal is reduced more quickly under arid than under more humid conditions.

From the above, it can be concluded that temperature and moisture recorded at the experimental site were favorable for anthesis and pollination mostly during the first flowering phare where temperature and humidity were not too high. Cross pollination indeed occurred mostly during this phase.

5.3.3 Influence of Rainfall

According to the South African Department of Forestery and Fisheries (2011), Pearl millet requires an evenly distributed rainfall during the growing season despite its drought resistance. Also, too much rain at flowering can also cause a crop failure.

Water is an essential input to ensure good seed yield. The most critical stages to irrigate pearl millet seed crop are tillering, flowering and seed development. Moisture stress at any of these stages reduces seed yield considerably (Khairwal et al., 2007).

Rainfall data during the long vegetative growth stage (more than 50 days) showed that it rained only for 11 days with a total of 147.9 mm. The data showed an intermittent drought period of 1 week during this vegetative growth phase. This must have impacted the overall growth of the crop. These periods of drought delayed the re-sowing date which was undertaken 3 weeks after first planting.

But during the development stage (the two flowering periods), enough and well distributed rainfall was registered which surely helped in crop recovery. This is one of the most critical stages requiring rainfall.

5.4 MEASURES TO OBTAIN ACCEPTABLE LEVEL OF SEED PURITY AT FARMERS' LEVEL

From the above results, a minimum distance of 40 m is required to produce an acceptable level of seed purity by farmers. This is far below the 300 m isolation distance recommended by the West Seed regulation (INSAH, 2012).

Other measures should be added by farmers to minimize the level of cross pollination from pollen sources. This can enable farmers to produce and harvest seeds with an acceptable level of purity and supply the local seed system which is in need of improved planting materials. Those seeds cannot be used in the formal system as it can hardly meet the minimum required.

The combination of the following measures can be considered:

- If the source of cross pollination is known and seasonal wind movement also known or predictable, the seed production plot should be installed before the source of pollen pollution when moving toward wind direction;
- Plant the seed parents at least 3 weeks after the source of pollen is planted to avoid the period of highest pollinators pollen shedding so as to minimize (not to eliminate) cross pollination;
- Use seed parents that are „"taller"" than the pollen parents. If possible plant another species (such as tall sorghum) which is „"taller"" than both the pollen parents and the

seed parents within the 40 m. This species is to be used as wind break and can prevent the free flow of pollen grains.

- Harvest panicles that are at least 40 m away from the pollen source to avoid the area where significant pollution by donors pollen grains occurs;
- Bulk the seeds obtained from all the panicles because selecting panicles can lead to the choice of those that are highly hybridized resulting in low level of seed purity;
- Encourage neighbouring farmers to grow same variety by supplying seed and fertilizer as incentive.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Varietal seed purity in the field was greatly affected by the distance of the pollen receiver from the pollen source and its direction. Very low varietal seed purity and a higher variation were observed on seed parents that were closer to pollen source. Variation in varietal seed purity was highly important among directions that were opposite.

Mean varietal purity in a relatively small seed field (farmers) was below the standard (minimum required by the ECOWAS seed regulation) even though high varietal purity can be recorded in some parts of the field.

Flowering synchrony was observed between the two varieties ensuring high level of cross pollination. An extended flowering period was also observed making isolation by time difficult. Pollen parents were „"taller"" than seed parents ensuring good dispersal of pollen on the receptive stigma of the receivers.

Varietal seed purity strongly correlated with distance and this relationship is stronger to East and Weaker to the West.

Among the climatologic parameters, wind direction directly affected the spatial distribution of seed purity. Other parameters such as temperatures, relative humidity and rainfall affected indirectly seed varietal purity.

To produce seeds of acceptable level of varietal purity, additional measures can also be adopted by farmers during seed production field layout, when choosing the seed parents and also after harvest.

6.2 RECOMMENDATIONS

1. This study should be repeated under different environments and on larger fields, for more than one cropping season using more elaborate analytical tools in order to:

- understand and evaluate the effect of varying climatologic parameters on varietal purity;
- develop a model or parametric equation (if it doesn"t exist) that include all factors that can affect seed purity which can help in predicting the minimum isolation distance for Pearl millet seed production.

2. The two planting materials could be used as a basis of a breeding programme (hybrid development) because of the following:

- the flowering synchrony observed between the two variety;
- the favourable plant height differences between the two varieties
- the relative gain in weight (compared to the seed parents) on hybrid seed as a result of differences in varietal purity on seed weight basis and number of seed basis.

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Appendix

Appendix A: ANOVA tables for different parameters for seed parents Appendix A1: ANOVA table for varietal purity on weight of seed basis

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Rep	2	0.024363	0.012181	4.78	
Direction	7	0.222413	0.031773	12.47	<.001
Distance	12	2.489865	0.207489	81.46	<.001
Direction x Distance	84	0.453057	0.005394	2.12	<.001

Residual	193 (13)	0.491580	0.002547	
Total	298 (13)	3.639284		

Appendix A2: ANOVA table for varietal purity on number of seed basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.025805	0.012903	5.68	
Direction	7	0.201131	0.028733	12.65	<.001
Distance	12	2.256825	0.188069	82.79	<.001
Direction x Distance	84	0.439382	0.005231	2.30	<.001
Residual	193	0.438433	0.002272		
Total	298	3.327321			

Appendix A3: ANOVA table for date to first panicle flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	464.66	232.33	18.68	
Direction	7	555.93	79.42	6.39	<.001
Distance	12	693.89	57.82	4.65	<.001
Direction x Distance	84	967.83	11.52	0.93	0.651
Residual	194	2412.81	12.44		
Total	299	4843.93			

Appendix A4: ANOVA table for date to 50% panicles flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Rep	2	434.83	217.42	21.65	
Direction	7	418.51	59.79	5.95	<.001
Distance	12	415.11	34.59	3.45	<.001
Direction x Distance	84	755.08	8.99	0.90	0.715
Residual	194	1947.79	10.04		
Total	299	3775.79			

Appendix A

5: ANOVA table for full plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	308.3	154.1	0.30	
Direction	7	3612.8	516.1	1.00	0.436
Distance	12	11068.3	922.4	1.78	0.054
Direction x Distance	84	35511.5	422.8	0.82	0.856
Residual	193	100089.4	518.6		
Total	298	144500.7			

Appendix A6: ANOVA table for plant height at flag leaf

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	287.8	143.9	0.30	
Direction	7	3162.8	451.8	0.95	0.469
Distance	12	10161.1	846.8	1.78	0.054
Direction x Distance	84	34636.5	412.3	0.87	0.769
Residual	193	91756.3	475.4		
Total	298	134614.4			

7: ANOVA table for total number of panicles harvested (transformed

Appendix A

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	5.5648	2.7824	14.40	
Direction	7	8.2123	1.1732	6.07	<.001
Distance	12	16.0113	1.3343	6.91	<.001
Direction x Distance	84	20.9366	0.2492	1.29	0.077
Residual	193	37.2796	0.1932		
Total	298	84.8845			

Appendix A

data)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	2.6525	1.3263	3.66	
Direction	7	9.6291	1.3756	3.80	<.001
Distance	12	18.4779	1.5398	4.25	<.001
Direction x Distance	84	33.7572	0.4019	1.11	0.277
Residual	193	69.8711	0.3620		
Total	298	131.1468			

Appendix A8: ANOVA table for number of panicles on main plants (transformed data)

Appendix A

9: ANOVA table for number of panicles on tillers (transformed data)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	1.2228	0.6114	2.05	
Direction	7	5.5025	0.7861	2.63	0.013
Distance	12	3.7093	0.3091	1.04	0.418
Direction x Distance	84	24.5843	0.2927	0.98	0.533
Residual	193	57.6216	0.2986		
Total	298	91.2117			

Appendix B: Climatological data of Binduri Station – form June to September 2014

Appendix B1: Climatological data of Binduri Station – Month of June 2014

Day	Rainfall	Max temp	Min temp	WinDir	WinSpe	RH6	RH9	RH12	RH15
1	0.00	36.00	18.00	w	5	54	37	31	27
2	2.60	36.00	18.00	sw	6	57	43	33	28
3	0.00	37.00	17.00	w	5	51	37	27	26
4	0.00	36.00	18.00	sw	5	54	39	28	28
5	4.30	34.00	17.00	sw	7	53	44	28	27
6	24.20	35.00	16.00	sw	7	52	41	32	32
7	0.00	36.00	17.00	sw	5	49	39	30	27
8	0.00	35.00	18.00	sw	5	51	40	32	28
9	20.00	37.00	17.00	sw	6	47	37	33	25
10	0.00	37.00	17.00	sw	6	51	37	27	24
11	0.00	36.00	18.00	sw	6	54	39	28	28
12	38.90	35.00	18.00	sw	5	51	40	29	28
13	0.00	36.00	16.00	sw	5	52	38	26	23
14	0.00	37.00	18.00	sw	5	58	43	32	28
15	0.00	36.00	19.00	sw	6	58	42	31	30
16	0.00	36.00	17.00	sw	6	51	37	26	26
17	0.00	36.00	17.00	sw	4	49	39	28	24
18	0.00	37.00	17.00	sw	5	53	40	29	26
19	0.00	36.00	19.00	sw	5	58	42	31	30
20	0.00	37.00	18.00	w	5	54	39	32	28
21	0.00	36.00	18.00	sw	5	54	40	32	28
22	12.30	35.00	17.00	sw	7	53	42	31	27
23	10.00	35.00	18.00	sw	7	51	40	33	28
24	0.00	34.00	17.00	sw	7	49	39	31	27
25	0.00	36.00	16.00	sw	6	49	36	29	28
26	0.00	36.00	17.00	sw	6	53	37	27	26
27	0.00	35.00	16.00	sw	6	52	36	23	22
28	30.00	35.00	18.00	sw	7	57	40	32	28
29	0.00	36.00	17.00	sw	6	52	39	28	27

Appendix – Month of

30	0.00	37.00	18.00	sw	5	57	40	29	28

B2: Climatological data of Binduri Station July 2014

Day	Rainfall	Max temp	Min temp	WinDir	WinSpe	RH6	RH9	RH12	RH15
1	2.40	35.00	17.00	sw	7	53	37	27	26
2	0.00	34.00	17.00	sw	6	49	36	26	25
3	0.00	34.00	16.00	sw	7	52	41	29	28
4	0.00	35.00	17.00	sw	6	52	39	29	25
5	0.00	34.00	17.00	sw	6	53	40	30	29
6	0.00	34.00	16.00	sw	6	55	41	32	28
7	21.00	33.00	15.00	sw	7	57	46	35	26
8	0.00	34.00	17.00	sw	7	53	42	35	30
9	0.00	35.00	16.00	sw	7	52	36	29	28
10	0.00	35.00	17.00	sw	6	49	35	28	27
11	0.00	35.00	17.00	sw	5	51	37	27	26
12	0.00	35.00	18.00	sw	6	54	39	32	31
13	0.00	35.00	17.00	sw	6	49	39	31	27
14	0.00	35.00	18.00	sw	7	51	40	33	28
15	0.00	35.00	17.00	sw	7	53	40	29	28
16	0.00	34.00	16.00	sw	6	52	36	26	25
17	0.00	34.00	16.00	sw	7	54	38	30	26
18	10.60	33.00	16.00	sw	7	52	39	32	28
19	7.00	34.00	17.00	sw	7	53	42	35	30
20	0.00	35.00	17.00	nw	5	55	44	31	27
21	0.00	34.00	18.00	sw	5	54	40	33	32
22	0.00	33.00	17.00	sw	7	49	39	32	28
23	24.50	34.00	18.00	sw	7	54	40	34	33
24	0.00	34.00	16.00	sw	7	48	38	30	26
25	0.00	34.00	17.00	nw	6	51	40	30	29
26	0.00	33.00	16.00	nw	5	48	36	30	26
27	0.00	34.00	16.00	sw	5	52	36	29	28
28	0.00	33.00	18.00	sw	6	54	40	34	33
29	0.00	33.00	17.00	nw	7	53	42	37	36

Appendix – Month of

30	14.00	32.00	16.00	nw	7	52	39	30	29
31	0.00	33.00	16.00	sw	7	54	42	35	29

B3: Climatological data of Binduri Station August 2014

Day	Rainfall	Max temp	Min temp	WinDir	WinSpe	RH6	RH9	RH12	RH15
1	0.00	32.00	16.00	sw	5	52	41	30	29
2	3.40	32.00	15.00	sw	6	50	39	32	26
3	0.00	33.00	16.00	sw	5	54	42	35	30
4	0.00	32.00	16.00	sw	5	52	38	32	26
5	0.00	32.00	16.00	sw	4	52	44	37	32
6	0.00	33.00	15.00	sw	5	47	36	31	26
7	0.00	33.00	15.00	sw	4	48	35	28	24
8	0.00	33.00	16.00	sw	5	52	39	30	26
9	10.00	32.00	15.00	sw	6	50	41	35	31
10	0.00	33.00	15.00	sw	4	48	39	32	27
11	0.00	32.00	16.00	sw	6	52	38	31	26
12	0.00	33.00	16.00	sw	4	52	44	39	34
13	11.20	32.00	15.00	sw	4	50	39	32	26
14	0.00	31.00	15.00	sw	5	54	44	36	30
15	0.00	31.00	16.00	sw	6	52	42	37	30
16	13.80	31.00	16.00	sw	7	52	39	32	41
17	0.00	32.00	15.00	sw	5	50	42	35	31
18	0.00	31.00	15.00	sw	7	50	38	31	25
19	19.80	31.00	15.00	sw	5	53	41	33	28
20	0.00	32.00	15.00	nw	5	50	42	32	27
21	0.00	31.00	15.00	sw	6	50	39	31	30
22	15.30	31.00	15.00	sw	7	50	41	35	30
23	0.00	32.00	15.00	sw	5	53	41	33	27
24	0.00	31.00	15.00	sw	5	50	39	32	27
25	0.00	31.00	15.00	sw	6	48	36	29	25
26	19.40	32.00	15.00	sw	7	53	45	36	28

Appendix – Month of

27	0.00	31.00	15.00	sw	6	47	38	31	25
28	0.00	33.00	16.00	sw	4	52	39	32	27
29	0.00	32.00	16.00	sw	5	52	41	30	29
30	0.00	33.00	16.00	nw	5	52	38	31	26
31	0.00	32.00	16.00	nw	6	52	39	30	29

B4: Climatological data of Binduri Station September 2014

Day	Rainfall	Max temp	Min temp	WinDir	WinSpe	RH6	RH9	RH12	RH15
1	39.50	30.00	21.00	sw	5	83	73	56	49
2	0.00	31.00	18.50	sw	5	86	68	56	49
3	0.00	31.00	20.00	sw	4	79	66	57	50
4	0.00	30.00	21.00	sw	5	79	66	58	56
5	22.20	31.00	20.00	sw	7	82	75	72	60
6	0.00	31.50	21.00	sw	5	83	73	64	56
7	20.00	31.00	20.00	sw	7	91	91	91	76
8	0.00	32.00	21.00	sw	4	91	73	62	60
9	3.90	31.00	20.50	sw	5	87	76	64	56
10	16.50	32.00	21.00	sw	6	91	80	80	68
11	0.00	32.00	21.00	sw	5	83	70	59	54
12	0.00	33.00	21.00	sw	5	79	66	58	49
13	0.00	34.00	22.00	sw	4	83	70	59	52
14	0.00	33.00	22.00	sw	5	83	67	57	50
15	29.10	33.00	21.00	sw	5	87	83	64	54
16	19.00	33.00	21.50	sw	5	83	66	58	49
17	0.00	32.00	22.00	sw	5	83	67	59	52
18	0.00	32.00	21.00	sw	5	79	64	56	49
19	0.00	32.50	21.50	sw	4	79	60	51	45
20	9.80	32.00	22.00	sw	4	91	76	68	55
21	13.20	31.00	21.00	sw	6	79	70	61	56

Appendix **– Month of**

22	0.00	31.00	22.00	sw	5	83	73	64	57
23	12.50	32.00	21.00	sw	5	83	69	61	51
24	0.00	34.00	21.50	sw	5	87	70	59	52
25	0.00	34.00	22.00	sw	4	83	64	54	47
26	0.00	33.00	21.50	sw	5	83	70	62	50
27	11.50	34.00	21.00	sw	5	87	83	76	59
28	0.00	33.00	21.00	sw	5	79	64	54	47
29	29.00	32.00	21.00	sw	6	91	77	64	55
30	0.00	32.00	22.00	sw	6	87	76	64	54