BREEDING INVESTIGATIONS OF FINGER MILLET CHARACTERISTICS INCLUDING BLAST DISEASE AND *STRIGA* RESISTANCE IN WESTERN KENYA

BY

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DECLARATION

I **CHRISPUS O.A. ODUORI** declare that:

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Chrispus O.A. Oduori (Candidate)

As the candidate's supervisor I agree to the submission of this thesis

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THESIS ABSTRACT

Finger millet (*Eleusine coracana* (L.) Gaertn. ssp. *coracana*) is an important food, food security and cash crop in eastern and southern Africa where small-scale farmers grow it in low input farming systems. The crop has food security, nutritional, cultural, medicinal, and economic value with high industrial potential. Little research and hardly any breeding have been done on the crop leading to low yields and low production. A project was therefore implemented in western Kenya during 2004-2007 seasons to investigate the possible breeding contributions to enhance productivity and production of the crop. The research comprised a social survey, germplasm evaluation, appraisal of ethrel as a chemical hybridising agent (CHA), genetic analysis of yield, and resistance to blast and *Striga*, and breeding progress in developing new finger millet varieties.

A participatory rural appraisal (PRA) was conducted in three districts during 2006 to position finger millet (FM) in the farming systems, production constraints, and variety diversity and farmer preferences. The PRA established the high rating the peasant farmers gave to finger millet among crop enterprises, using it for food, cash, brewing, ceremonies and medicinal purposes. Farmers cultivated many varieties ranging from five to nine in a district, but each district had its own popular variety. Farmers used the following criteria to select new cultivars: high yield potential; early maturity; resistance to blast disease, *Striga*, birds, drought, and lodging; large head size, dark grain colour, and good taste. This probably indicated the willingness of farmers to adopt new varieties. Farmers identified constraints to production as blast disease, *Striga,* wild FM, birds, rats, termites, lack of market, labour shortage, and low yield. The farmers' variety selection criteria and production constraints underscored the need to improve finger millet varieties.

Evaluation of 310 accessions for trait variability and association conducted during 2005 long rain (LR) season at two sites revealed wide variation among the accessions for yield and secondary traits. The best accessions grain yield was above the yield potential of 5,000-6,000kg ha^{-1} reported in other environments. Accessions KNE 072 (7,833kg ha^{-1}), GBK 028463 (7,085kg ha^{-1}), GBK 029661 (6,666kg ha^{-1}) and FMBT ACC#42 (6,566kg ha^{-1}) were outstanding. The data showed the opportunity to select for yield directly because of its wide variability but indirect selection could also be used to exploit seedling vigour as shown by its high correlation to yield and direct and indirect positive effects on yield through plant height and single plant yield in path analysis. The wide genetic variability among the genotypes for several traits indicated high potential to breed new and better finger millet varieties.

Ethrel (2-chloro-ethyl-phosphonic acid) was studied for its efficacy as a chemical hybridising agent on FM both under greenhouse and field conditions. The greenhouse study led to an 8x8 diallel crossing of six western Kenya elite plus two exotic varieties at 1,500 and 2,000ppm concentrations at success rates of 0.19-8.63%. Application of 1,500ppm-2,000ppm ethrel at DS 45 in the field resulted in emasculation of 15-38% without causing female infertility and adverse effects on yield and maturity period. However, ethrel significantly reduced plant height and ear exertion by 25 and 50%, respectively. There were no significant interactions between factors. Ethrel could, therefore, enable hybridisation for breeding purposes.

Studies of genetic control of yield and important secondary traits of the six western Kenya elite varieties using F_5 lines showed additive gene effects influenced yield, finger branching, neck and head blast, days to 50% flowering, ear shape, and days to physiological maturity, underscoring potential to generate superior varieties. Overdominance gene effects influenced plant height, lodging, and plant stand establishment. Dominant genes conferred resistance to neck and head blast, lodging, higher plant stand establishment and fist ear shape. Recessive genes conferred early maturity and open ear shape. There was no evidence for significant genetic variation for resistance to shootfly, foliar blast and *Striga*. Parent lines OK, GE, and U-15 showed high additive effects for yield and crosses OKxGE, P-224xOK, and U-15xGE produced high yielding progeny.

Evaluation for breeding progress done on selected F_5 lines against the eight parents, showed all traits responded to selection with mean yield gain of 5.84%. On average progeny lines had experimental, parental, and non parental checks means relative grain yield (RGY) superiority of up to 154.95%, 170.76% and 173.48%, respectively. The best three lines: OKxGEF4BSB13R10(R31), OKxGEF_4SB13R10(R27) and GBK033439 had resistance to blast and lodging (except GBK033439) and high yield >2,250kg ha^{-1}. The results indicated potential breeding progress on selection from segregating populations.

Overall, it is shown that breeding can make a significant contribution to enhancing finger millet productivity. This can be achieved through direct selection from available germplasm and creating new genetic variation by hybridisation of elite lines. Hybridisation will also facilitate genetic studies of finger millet traits with a possible positive impact on finger millet variety improvement and food security in sub-Saharan Africa.

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Last but not least, I thank the Almighty God for enabling everything!

DEDICATION

This work is dedicated to my dear parents Mama Sarah Akochi Adeti and Baba John Machio Adeti Ombutu of Bukhwamba Village, Samia, Busia District, Kenya. I pay great tribute to my father for the sacrifices he made in committing his meagre wages to see us, his children, through school and enabling pursuit of such levels of higher learning possible for us.

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INTRODUCTION TO THESIS

Background information

Finger millet (*Eleusine coracana* (L.) Gaertn. ssp. *coracana*) (Hilu et al., 1979) is a small grain crop, which is indigenous to East Africa, especially Uganda and Ethiopian highlands (Haore et al., 2007). Figure 1 represents photographs of finger millet crop of two varieties on farmer's fields. The crop is cultivated in diverse eco-geographical areas worldwide and displays high genetic variability (Hilu and de Wet, 1976), indicating that it can be improved through breeding. According to Holt (2000) the crop has wide adaptability, probably due to its C_4 photosynthetic nature. The annual worldwide production of finger millet is about 4.5 million tons, equally divided between India and Africa (M.S. Swaminathan Research Foundation India, 2003), grown on approximately 3.8 million hectares (Anon., 2004). This suggests that the global average yield is about 1.1tons ha^{-1}. In Africa smallholder farmers grow finger millet with area allocated to the crop varying from country to country. In eastern Africa, finger millet is produced in Uganda, Kenya, Tanzania, Rwanda and Burundi (Obilana et al., 2002). Kenya and Uganda are among the leading producers of fingermillet in Africa and worldwide. In Uganda, the crop is devoted to about 600,000ha, while in Kenya it is grown on about 65,000ha (Takan et al., 2002; FAOSTAT, 2008). In Kenya, it is mainly grown in Western, Nyanza, and Rift Valley Provinces. Figure 1 is a photograph of two farmer's fields of finger millet in western Kenya. There is huge potential to improve production of finger millet in Kenya given its importance.

Figure. 1. Large plots of different finger millet varieties on farmers's fields in western Kenya

Importance of finger millet

Finger millet is the most important small millet and one of the most important millets (Riley et al., 1989), for subsistence and food security, and especially for its nutritive and cultural values. It is also important for livestock feed and it has industrial potential. As a subsistence

and food security crop, finger millet is highly valued as a reserve food in times of famine, due to its good storability property that is a result of its small grain size (Duke, 1978). This makes finger millet fit well in farmers' risk avoidance strategies in drought-prone regions of eastern Africa and south Asia (Holt, 2000). As a feed, finger millet straw is used as fodder that contains up to 61% total digestible nutrients, better than pearl millet, wheat, or sorghum (NRC[1], 1996). The straw may be used for thatching and weaving e.g. baskets (Takan et al., 2002). According to the NRC (1996) the food uses of the crop include: porridge; bread and other products of special flavour and aroma made from flour; popped products (mainly in India); malt – malt from finger millet is nutritious and easily digested; beverages - finger millet in Africa is used to make alcohol because its amylase enzymes readily convert starch to sugar, which is subsequently converted to alcohol. In many communities, finger millet has cultural value and it is used in weddings, bride price payment, and funeral ceremonies (Takan et al., 2002).

As food, the grain has good taste and is a dietary source of methionine (an amino acid lacking in diets of many poor people's carbohydrate staples) and calcium, iron, phosphorus, and manganese minerals (NRC, 1996). According to NRC (1996), the grain's protein content (7.4%) is comparable to that of rice (7.5%), but the main protein fraction (eleusinin) has high biological value, with good amounts of tryptophan, cystine, methionine, and total aromatic amino acids, which are crucial to human health and growth and are deficient in most cereals. In addition to better protein profile, it is richer in minerals such as calcium, iron, manganese, and copper than maize (NRC, 1996). The high nutritive value makes the crop especially important in the diets of children, convalescing patients, and pregnant and breast-feeding women. The high nutritive value gives finger millet some medicinal value, making it an important cereal for community-based health care programmes and children feeding schemes in rural institutions in developing countries. For example, it is used in management of measles, anaemia, and diabetes (NRC, 1996). According to Haore et al. (2007), it is also used in traditional medicine as an internal remedy for leprosy or liver disease. According to reports by Kumari and Sumathi (2002) finger millet based diets had significantly lower plasma glucose levels than rice and wheat, probably due to either the higher fiber content of finger millet or the presence of anti-nutritional factors in the whole finger millet flour, which are known to reduce starch digestibility and absorption. Importantly, the lower plasma glucose level diets are important in the management of diabetes. Amruthmahal et al. (2003) finding of finger millet having the highest total rapidly digestible starch (RDS), and slowly digestible starch (SDS), among rice, wheat, and sorghum grain added to explanation on why it is used for diabetes management.

[1] National Research Council, USA.

The high nutritive value also gives finger millet industrial potential in the manufacture of baby and sick person's food formulations and breakfast cereals. In the brewing industry, it has a place because of its good malting qualities, which are second only to barley (NRC, 1996). In tropical sub-Saharan Africa, finger millet might have a comparative advantage over barley, a temperate crop that can only be grown in highland areas in the region. According to Durham (2005), the grain's richness in calcium, iron, methionine, and tryptophan and the fact that it can be popped like popcorn, may soon give it a niche in the USA. Production and trade in finger millet can enhance household income. According to Takan et al. (2002), this enhances the status of women in the household and community, as women and young children mostly cultivate the crop.

Mgonja (2005) summed up the importance of finger millet in four points: (a) contains 3-5 times more iron and calcium than any other cereal, (b) can be safely stored for decades under normal farm household conditions without damage, (c) fetches double the price of maize or sorghum in East Africa, (d) has shown excellent potential in field trials in Europe, as a forage crop. The demand of finger millet is high in Kenya and it fetches prices over twice that of sorghum and maize in local markets (Obilana et al., 2002). Therefore, there is potential to improve the status of the crop from subsistence to commercial, which will give impetus for breeding and production.

Current finger millet production levels

Poor research attention has been paid to improvement of finger millet, especially in Africa, which is evident from the scarcity of literature on the crop, and poor productivity. The reasons given for poor research attention on the crop include lack of international research and political support in sub-Saharan Africa and Asia. Lenne et al. (2007) and M.S. Swaminathan (n.d.) contended that major donors to agricultural research have neglected the crop. This is possibly because it has been regarded for a long time as a subsistence crop, but there is tremendous potential to upgrade finger millet to commercial and industrial status. This will then attract donorship and international research attention. Due to the little research effort on this crop the yield of finger millet on farmers' fields in Kenya is low, ranging between 500 and 750kg ha^{-1} (Mitaru et al., 1993 and Takan et al., 2002). Slightly higher yields, ranging between 680 and 1,000kg ha^{-1} have been reported in neighbouring Uganda and in India (NRC, 1996 and Tenywa et al., 1999) under rainfed conditions. The higher yields in Uganda partly explain the higher production in Uganda than Kenya (see Figure 2). Although the crop is not produced under irrigation in sub-Saharan Africa, in India the average yield of 2,000kg ha^{-1} under irrigation has been reported (NRC, 1996). However, this is still below the

yield potential of the crop, which is 6,000kg ha^{-1} under irrigation condions (NRC, 1996), and 5,000kg ha^{-1} under rainfed conditions (Duke, 1978). In individual countries yield potential of finger millet has been estimated at 4,265kg ha^{-1} in Uganda (Odelle, 1993), 6,060kg ha^{-1} in Zimbabwe (Mushonga et al., 1993), 3,700kg ha^{-1} in Ethiopia (Mulatu and Kebede, 1993), and 4,789kg ha^{-1} in India (Bondale, 1993). In the light of these statistics there is room to improve productivity of the crop in Kenya through investment in breeding new high yielding varieties that meet farmers' requirements. The CGIAR (2001) and NRC (1996) concur that with research, finger millet grain yields can be competitive with those of rice and other "green revolution" cereals. Oduori (2000) reported that farmers planting improved varieties and adopting improved management practices could improve yields of finger millet in Kenya.

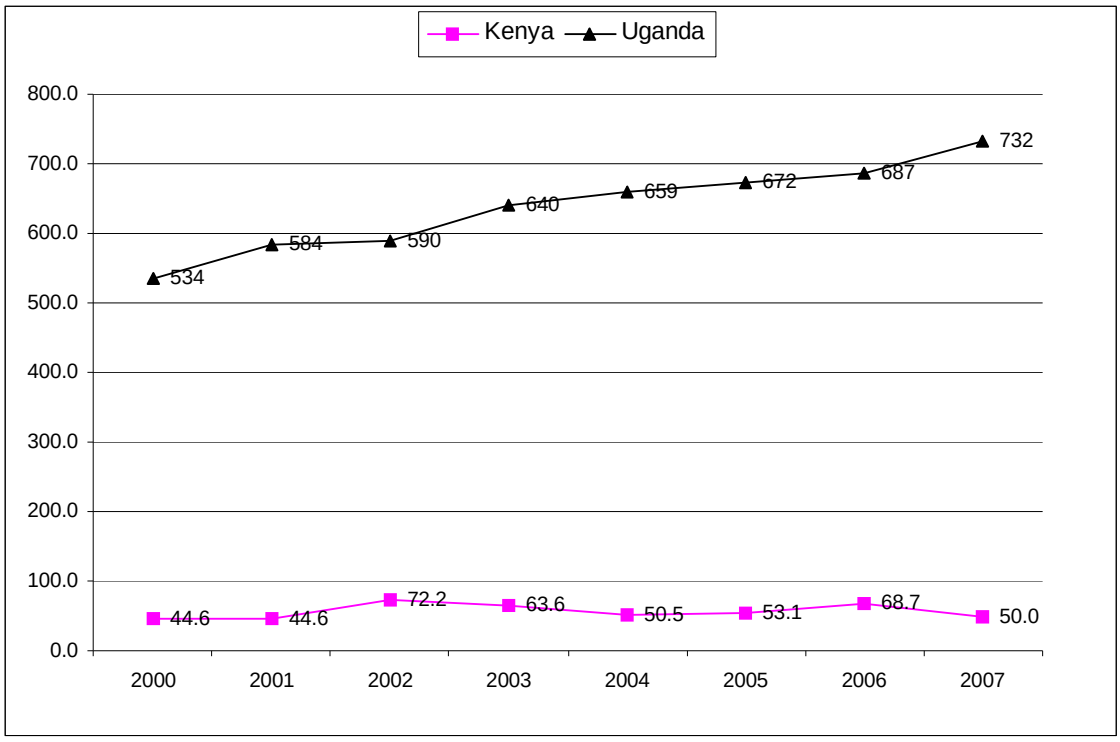

Figure 2. Kenya and Uganda finger millet eight year annual production, '000 tons (DataSource: FAOSTAT (2008)

Production constraints

Very little effort has been made to understand finger millet production system and constraints that limit productivity among the small-scale farmers in sub-Saharan Africa. Audi et al. (2003) identified *Striga*, blast disease, low soil fertility, and low yielding varieties among finger millet production constraints in western Kenya. According to the National Research Council (1996), blast disease, *Striga* weed, lodging, poor soils and drought are some of the constraints that need immediate research attention. It is generally agreed that

finger millet blast disease caused by the fungus *Pyricularia grisea* (a close relative of rice blast) is the most serious disease of finger millet (Department of Agriculture, Sri Lanka n.d; NRC, 1996; CGIAR, 2005). Figure 3 below shows blast and *Striga* damage to finger millet. The NRC (1996) adds that the poor attitude to the crop is also a major constraint to finger millet production. These constraints together have resulted in farmers attaining only about 15% of the 5,000kg ha^{-1} or above reported by Duke (1978) and the NRC (1996).

Figure 3. The effect of blast disease (left) and *Striga* (right) on finger millet in western Kenya.

The research reported

From the foregoing, finger millet is an important food and cash crop in East Africa with high potential to play a significant role in improving the living standards among the rural poor. The problem is that the productivity of the crop is low due to constraints that can be resolved through research, yet it has hardly received any research attention. The productivity is low because of several factors affecting its value chain, among them poor production technologies and lack of appropriate policies to exploit its commercial value. Among the poor technologies is the problem of farmers growing landraces with low yield genetic potential, yet genetic diversity to improve variety productivity exists. It is with a view to alleviate the problem of low genetic potential varieties that this finger millet breeding programme was formulated in 2003 and implemented from 2004 to 2007. This programme was designed to lead to a need-oriented breeding research that addresses diverse socio-economic conditions, production environments, and management practices that will enhance the adaptability and adoptability of the resultant varieties. A participatory rural appraisal (PRA) formed part of the research. After identification of farmers' constraints and needs, a breeding agenda needs to be based on good knowledge of existing germplasm and methodologies available and suitable to efficiently extract close to farmers' ideal crop varieties from the available genetic base. To this end, a literature review was carried out to

identify researchable gaps that exist in finger millet breeding, an area that previously hardly received research attention. Hybridization has been a challenge in finger millet breeding for a long time due to the small florets compact arrangement on the inflorescence (Riley et al., 1989). In this direction, an investigation of possibilities of using ethrel as a chemical hybridizing agent (CHA) on finger millet was undertaken. Subsequently an evaluation of germplasm and diallel crossing of six western Kenya elite finger millet varieties followed. After crossing, segregating populations were advanced to F_5 and an investigation of the genetics of the six varieties and determination of breeding progress for yield and resistance to blast disease, *Striga* and lodging resistance were undertaken.

Research objectives

The major objective of the study was to improve finger millet varieties for agronomic traits and contribute to increased production in western Kenya. This was achieved through the following specific objectives:

1. To identify the place of finger millet in the farming systems, production constraints, variety diversity and farmer preferences;
2. To determine the genotypic variability for yield and some agronomic traits, and the correlations among the traits;
3. To determine the feasibility of using chemical hybridizing agents to cross finger millet varieties;
4. To study the inheritance of yield, blast and *Striga* resistance, and other secondary traits in fingermillet;
5. To identify elite x elite crosses with potential for use as source germplasm in developing new finger millet pure line varieties;
6. To determine the level of breeding progress achievable in improvement of finger millet.

Research hypotheses

1. Finger millet is an important crop in western Kenya and the farmers know the diversity of varieties and recognise the key attributes and production constraints that can be used to improve the crop through breeding;
2. There is large genotypic variability among finger millet germplasm at KARI-Kakamega that can be exploited to develop new high yielding varieties with farmer desired traits and resistance to *Striga* and blast;

3. Chemical hybridising agents can be effectively used to make crosses in a finger millet breeding programme;
4. Finger millet varieties in western Kenya are genetically diverse and their desirable traits are controlled by different modes of gene action, which if understood could be better integrated to facilitate improvement of the varieties;
5. Segregating populations from crosses of elite varieties and blast and *Striga* resistance selections have wide trait variability and large mean frequency of the desired alleles to elicit breeding progress in finger millet;

Structure of thesis

The results of this work are herein presented in seven chapters outlined below, following the format and style of Agronomy Journal. The thesis is presented in the listed chapter sequence, each chapter taking the form of a complete journal article:

Chapter	Title
1	Review of the literature
2	Participatory rural appraisal for farmers' finger millet variety preferences, uses and production constraints in western Kenya
3	Finger millet genoptypic variability and path analysis of yield components
4	Finger millet hybridisation using ethrel chemical hybridising agent
5	Studies of genetic components of agronomic traits and blast disease and *Striga* resistance in six elite finger millet varieties of western Kenya
6	Progress in breeding finger millet for yield and secondary traits
7	Overview

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CHAPTER 1

Literature Review

INTRODUCTION

This chapter reviews literature on finger millet to date covering: finger millet as a crop, blast disease, *Striga*, and progress in breeding finger millet. As reported by Fakrudin et al. (2004) and Bedis et al. (2006), little research has been done on finger millet. This has lead to many instances of internet literature citation and drawing of parallels with research done on other self-pollinated cereal crops, especially wheat, barley, and rice in this report.

FINGER MILLET AS A CROP

Finger millet botany

A good understanding of crop botany is pertinent to successful breeding of any crop as it outlines basic genetics, physiology and ecology that determine crop deployment and adaptation. Weakley (1996) gives the botanical description and classification of finger millet. Finger millet belongs to the Chloridoideae subfamily (Philips, 1972; Clayton and Renvoze, 1986) that includes the only other crop, tef (Hilu, 1988; Bennetzen et al., 2003). It is the only crop species in the genus *Eleusine* that comprises nine species, eight of which are predominantly wild African grasses (Werth et al., 1994). Finger millet is an annual growing 40-130cm tall and matures in 2½ - 6 months (Watson and Dallwitz, 1992). Its panicle consists of finger like bisexual spikes with bisexual spikelets and hermaphrodite florets that are exposed non-opening self pollinating (cleistogamous) or opening after pollination (chasmogamous) (Chase, 1918; Watson and Dallwitz, 1992; NRC[2], 1996; Duke, 1983). Finger millet is 97-99% self-pollinating (Hilu and de Wet, 1980; CAB, 2005). The floral architecture and high self pollination make finger millet difficult to hybridize.

Crop requirements

The NRC (1996) and Haore et al. (2007) outlined the finger millet growth requirements. It is a short to medium day length plant with optimal photoperiod of 12-hours and grows well under moderate rainfall (500-1,000mm with optimum of 900mm), well distributed during the growing season without prolonged droughts, but with good distribution, it can tolerate rainfall as low as 130mm. Finger millet does not tolerate flooding. It grows best where average maximum temperatures exceed 27℃ and average minimum do not fall below 18℃, but can

[2] National Research Council, USA.

grow in temperatures up to 35℃. Dry weather is required for drying the grain at harvest as the crop is harvested at physiological maturity to avoid shattering on drying in the fields. Most of the world's finger millet is grown at intermediate elevations between 500 and 2,400 meters above sea level (masl), but it can grow from sea-level to over 2,400masl. In Africa the crop is usually grown at between 1,000 and 2,000masl and in Nepal up to 2,400masl (NRC, 1996). In East Africa, it is grown mostly at 900masl. Finger millet can grow on a variety of soils, but does well on well-drained silt loam soils - reddish brown earth, calcic red yellow latasols and sandy regosols. The crop requires a well-prepared seedbed because of its small seed size, and inability to stand weed competition. It is mostly hand weeded to remove *Eleusine indica* and *E. africana* which are hard to distinguish from finger millet at vegetative stages. Finger millet seedlings are slow growing and require a weed free environment for 45 days to develop vigorous plants. Planting in rows facilitates weeding. It is sown early in the season to spread the labour over various crops in East Africa. These growth conditions describe typical tropical environments and hence the crop is expected to perform well in East Africa where, unfortunately, yields are dismally low. Finger millet has potential to play a greater agricultural role in both drier savanna areas with moderate rainfall, though it is not as drought tolerant as pearl millet or sorghum, and highland areas with adapted cultivars (NRC, 1996).

The origin and distribution of finger millet

Finger millet is thought to have originated from Uganda or neighbouring Ethiopian highlands where wide diversity of the genus *Eleusine* exists (Hilu, et al., 1979; Werth et al., 1994). *Eleusine* species occupy diverse habitats, ranging from open, dry places to under-covers of forests from sea level to highlands and finger millet is grown extensively in the semi-arid regions of Africa and India (Werth et al., 1994). Cytogenetical, morphological, flavonoid chemistry, and chloroplast and ribosomal DNA evidence indicates that finger millet evolved directly from the wild tetraploid *E. coracana* subsp. *africana*, an annual weed common in Africa (Hiremath and Chennaveeraiah, 1982; Hilu and Johnson, 1991; Baired et al., 2001). Finger millet and its wild progenitor *E. Africana* are allotetraploids derived from hybridization between diploid *E. indica* and an unknown diploid (Hiremath and Salimath, 1992; Werth et al., 1994; Bennett and Leitch, 1995; Dida et al., 2006). It has x = 9 and 4x= 36 chromosmes (Bennett and Leitch, 1995) with genome composition AABB (Dida et al., 2006).

Finger millet was introduced to South Asia from its center of origin by sea probably in the third millennium B.C., especially India where it has gained importance and is called “ragi” (Hilu, et al., 1979; Bennetzen et al., 2003). The crop is cultivated in diverse eco-geographical areas where *Eleusine* displays high variability in vegetative, floral and seed

morphology (Hilu and de Wet, 1976). Hilu and de Wet (1976) identified three eco-geographical races: (i) African highland race cultivated in East African highlands, (ii) lowland race grown in the lowlands of Africa and South India, and (iii) Indian race with its centre of distribution in Northeast India. The African highland race is the most primitive and is the precursor of the lowland race (Hilu and de Wet, 1976), which was subsequently introduced to southern India that developed into a secondary center of diversity, resulting in the Indian race. Hilu and de Wet (1976) believe natural selection was significant in finger millet evolution, with artificial selection restricted within the limits of adaptation of the races to their environments. Archaeological evidence indicates finger millet was a staple crop of the southern Africa region before maize introduction, and today it is found in eastern and southern Africa and is the principal cereal grain in Uganda (especially in northern and western regions), and also found in Zambia and Mozambique (NRC, 1996).

Finger millet production is increasing in Asia and India's yields have increased 50% since 1955 and Nepal's land under the crop is expanding at 8% per year (NRC, 1996). The growth requirements and the location of center of origin and diversity in East Africa paint a promising future for the improvement of the crop, as the genetic variation needed for breeding should be readily available and growth conditions are what the crop is adapted to, hence yield and production should expand in this region as well.

FINGER MILLET BLAST DISEASE

Finger millet blast caused by the fungus *Pyricularia grisea* Sacc. is the major finger millet disease and highest priority production constraint in East Africa where most landraces are susceptible (Anon., 2008). It was found to be the most important and widespread disease of finger millet in farmers' fields in Busia, Teso and Kisii districts of Kenya (Obilana, 2002; Takan et al., 2002). The disease affects finger millet at all stages of growth and causes yield losses of 10% to 80% in Kenya and Uganda (Holt 2000; Obilana, 2002; Takan et al., 2002; Takan et al., 2004). Blast is also reported to cause finger millet grain quality decline, increasing protein and decreasing starch and ash contents in the seed (Pall, 1994). Its infection results in an imbalance of total carbohydrates and causes increase in beta-glucosidase in the neck infected tissue of the plant (Pall, 1994). Although first recorded in Uganda in 1933, there is still limited knowledge on its control and farmers identified it in 1997 as one of the major constraints to production (Takan et al., 2002). Despite speculation on its ecological nitches, it is only recently that some light was shed on the pathogen diversity and characteristics in East Africa (Sreenivasaprasad et al., 2005). The symptoms of finger millet blast disease include diamond shaped, greyish white lesions bordered by a brown margin that develop on leaves and black lesions on the inflorescence (Department of Agriculture, Sri

Lanka n.d; Holt, 2000). Seedlings may die under epidemic conditions, and empty fingers and broken pedicels may result in mature plants. Using amplified fragment length polymorphism (AFLP) analysis, Takan et al. (2004) compared isolates causing leaf, neck and head blast and found them genetically similar, suggesting that the same strains probably cause the different symptoms under suitable conditions.

Finger millet blast pathogen distribution

Takan et al. (2004) found no distinct genetic and pathogenic difference between blast pathogen isolates from weed hosts and finger millet, indicating the potential of weeds to provide inoculum for blast on finger millet. Uddin (2000) found the pathogen on ryegrass in the United States not to be genetically as diverse as it appears globally, prompting them to speculate the likelihood of the U.S. populations they studied to have descended from a common ancestor. On the contrary, Roumen et al. (1997) found genetic variability of rice blast pathogen in Europe larger than expected and found virulence for several of the known resistance genes despite absence of these genes in rice cultivars grown in Europe. The virulence pattern of the isolates closely corresponded with their lineage classification. According to Roumen et al. (1997), recent studies around the world show that blast pathogen populations are made up of a number of clonal lineages, each of which is virulent to a limited range of resistance genes. The limited variation in P. grisea could be due to its predominant asexual reproduction as Uddin (2000) reported sexual reproduction to be rare. This would imply that identification of resistance genes for virulent pathogen genes would fairly control blast in East Africa, as there would not be pathogen race diversity in a region to easily break deployed resistances. This gives hope of the usefulness of vertical resistance.

All farmers varieties in western Kenya show varying degrees of susceptibility to finger millet blast disease with neck and head blast (NHB) being more frequent than foliar blast. Obilana (2002) and Takan et al. (2002) found this to be the case in Busia, Teso and Kisii districts in western Kenya with compact headed landraces showing less blast incidence relative to the open headed ones. The incidence and severity was higher in Kisii during long rain season (February-July) than in short rain (August-December) and Kisii had higher blast incidences than Busia and Teso. This is probably due to continuous planting in Kisii (two seasons in a year) and the higher humidity as Kisii has more rainfall than Busia and Teso and long rain season has more rain than the short rain season. Blast susceptible grass weeds (*Eleusine indica*, *Dactyloctenium* spp., *Cyperus* spp.) were frequent in finger millet fields across the districts, but *Eleusine indica* frequency was higher in Busia and Teso than in Kisii and Gucha districts (Obilana et al., 2002). This would imply wild grasses play an insignificant role in blast incidence.

Finger millet blast disease epidemiology

Air and seed spread blast disease pathogen with seed transmission being significant through seed movement (Kato et al., 2000 and Takan et al., 2004) and according to Pall (1988) one infected seed could cause an epidemic of finger millet blast. According to Uddin (2000) *P. grisea* sexual stage is rare and only the asexual stage has been found in the USA, but high isolates fertility was reported in laboratory crosses (Yaegashi and Nishihara, 1976). In each infection cycle, reproduction occurs through production of millions of conidia (spores) within a short period (1 or 2 days) when conditions are conducive (Uddin, 2000; Ruiz, 2003). The conidia of the fungus are produced and released during periods of high relative humidity (> 89 % RH), and optimal temperature of 25-28℃ and ge rminate within a few hours (Ruiz, 2003). *Pyricularia grisea* plant infection involves development of a specialized dome-shaped cell, the appressorium at temperatures of 16-25℃, which generates high turgor pressure and physical force, allowing the fungus to break the host cuticle and invade plant tissue within 10h (Talbot, 2003). In the field the first lesions appear 96h after infection and several consecutive infection cycles may follow during a single season, resulting in extensive disease damage in fields (Talbot, 2003). The fungus appears to overwinter as mycelia in the infected living leaves or dead plant debris in the soil (Uddin, 2000). The disease develops in ryegrass during periods of warm days with high humidity and prolonged leaf wetness in late summer (mid-August to early October) (Uddin, 2000). High temperature, high relative humidity and leaf wetness are critical environmental factors that influence disease development (Uddin, 2000; Ruiz, 2003). Reports that the disease spreads by seed Kato et al., 2000 and Takan et al., 2004) means that seed selection and hygiene are factors in the control of the disease.

Blast disease control methods

Sri Lanka Department of Agriculture (n.d.) recommends control of blast disease on finger millet by avoiding both high plant populations and heavy nitrogen (N) fertilizer application and applying chemicals, especially systemic fungicides like azoxystrobin, thiophanate-methyl, trifloxystrobin and triadimefon, and contact Chlorothalonil. Rao and Chennamma (1983) found carbendazim applied at flowering and at milk stage to effectively control blast on finger millet field trials. Use of resistant varieties is the traditional disease-management strategy for many plant diseases. The development of finger millet transgenic plants with single gene resistance to foliar blast reported by Latha et al. (2005) promises to contribute to application of host plant resistance in control of finger millet blast disease.

Blast disease resistance

Blast disease resistance has been found in finger millet and correlated to some chemical and variety characteristics. Mantur and Madhukeshwara (2001); Narayanan et al. (2002); Jain and Yadava (2003); Sreenivasaprasad et al. (2005) reported it in finger millet. Jain and Yadava (2003) found seeds of moderately resistant genotypes with higher total phenol content and susceptible with higher total sugars and reducing sugars resulting in positive significant correlations between foliar and NHB with total and reducing sugars content and significantly lower correlations with total phenols. Path coefficient analysis revealed total phenols at dough stage and total sugars, reducing sugars in dry seed, and 35-day-old seedlings determined blast resistance in finger millet (Jain and Yadava, 2003). Results from surveys in western Kenya and Uganda indicated that varieties with dark coloured seeds and compact heads had more blast resistance than lighter coloured and open headed varieties (Takan et al., 2004). Narayanan et al. (2002) found that the major blast resistance gene Piz-5 in finger millet can exclude most *Pyricularia grisea* Sacc. lineages. Mantur and Madhukeshwara (2001) screened and found finger millet genotypes in categories identified as highly resistant (0.0% disease incidence), resistant (1.0-2.0% disease incidence), moderately resistant (2.1-10.0% disease incidence), moderately susceptible (10.0-25.0% disease incidence) and susceptible (>25% disease incidence). This implied the presence of both major gene and genes conferring partial resistance in finger millet because major gene resistance tends to confer immunity as compared to genes conferring partial resistance that leads to a gradation of resistance (Fasoula and Fasoula, 1997).

The foregoing indicates variability for blast resistance, which can be incorporated in breeding programmes, exists in finger millet germplasm. However, host-pathogen relations that are critical to breeding for durable partial resistance have not been studied in finger millet. Studies of these relations in finger millet could be inferred from the much studied rice blast host-pathogen relations. It appears both minor and major genes exist for finger millet blast disease resistance that could be bred into agronomically desirable varieties.

Breeding for blast disease resistance

Techniques for artificial culture of finger millet blast pathogen and screening for host plant resistance have not been developed, yet these are critical to effective breeding for resistance (Holt, 2000). Breeders have frequently bred for vertical resistance controlled by hypersensitivity genes whose resistance often breaks down (Roumen, 1992), compared to durable partial resistance (Yeh and Bonman, 1986). This could be due to the difficulty to select for partial resistance genes because of mixtures of pathogen races in the field,

complicating screening because of epistatic effects of vertical resistance genes on the expression of partial resistance genes (Notteghem, 1993). Greenhouse screening using one pathotype with many virulence genes was recommended by Niizeki (1967) and Sakurai and Toriyama (1967). This is not possible for finger millet blast at the moment because of lack of adequate pathotype information. Selection for general resistance, which is frequently vertical resistance, will continue though vertical resistance genes are prone to frequent breakdowns (Roumen, 1992), because blast resistance has been detected in finger millet germplasm and hence it should be possible to identify resistantance gene sources. Breeding for blast resistance will need to incorporate early farmer participatory evaluation of resistant material for effective deployment of resistant varieties (Chipili et al., 2002). The farmers need to come into selection exercise early so that the identified resistant varieties also carry the other farmer-desired traits for ease of adoption. According to Chipili et al. (2002), strategic deployment of identified resistances in an integrated manner is also critical to the success of disease control by resistant varieties and has led resistance in rice variety Oryzica Llanos 5 to last 10 years in Columbia and reduction of blast disease in China. In finger millet, deployment of blast disease resistant varieties together with management of other major biotic constraints such as weeds, especially close relatives of the crop like *E. Indica* and *E. Africana* that carry blast pathogens, is likely to be more successful.

STRIGA **PEST ON FINGER MILLET**

Striga species are obligate parasites, which cannot survive on their own to maturity because their seed has limited resources that barely support germination, hence without a host, the seedling will die in a few days (Chang and Lynn, 1987). The seedling must therefore germinate some millimetres close to a host root which exudes a *Striga* germination stimulant (Parker and Riches, 1993). The fact that Africa is the centre of origin of *Striga* (Kim et al., 2004; Wolfe et al., 2005) underscores the problem of *Striga* on finger millet. Finger millet is parasitized by *S. asiatica* (L) Kuntze,, *S. densiflora* (Benth.), *S. hermonthica* (Del.) Benth., and *S. lutea* Lour. (Duke,1983). No literature exists on the damage caused by *Striga* or breeding for *Striga* resistance in finger millet. *Striga* grain yield losses of up to 100% are possible on susceptible sorghum cultivars under high infestation levels (Haussmann et al., 2000).

Striga **control strategies**

Complete control of *Striga* on cereals has been a challenge to scientists for a long time and the search for farmer satisfying strategies strategies continues. Some *Striga* control strategies were developed and tested on-farm in western Kenya including intercropping, crop-rotation, catch-cropping, hand-weeding, inorganic fertilizer and manure application,

resistant varieties and improved fallow management (Oswald, 2005). Many researchers, however, suggest that integrated *Striga* control or management (ISC or ISM) is the best strategy for short and long-term *Striga* control (Aliyu et al., 2004 and Van Mourik, 2007) and needs to involve concerted effort of all stakeholders (Oswald, 2005). According to Ejeta and Gressel (2007) *Striga* management strategies revolve around the options of control, containment, or eradication with eradication being almost impossible. Based on effect on *Striga* population, Haussmann et al. (2000) grouped *Striga* control measures into three categories: (i) reduction of the soil seed bank; (ii) limitation of *Striga* seed production; and (iii) reduction/ prevention of *Striga* seed dissemination to uninfested fields. In most cases, these control measures have had limited success and Kuiper et al. (1998) contend that effective and affordable control measures for *Striga* are scarce.

It is believed that the use of resistant crop cultivars is the most economically feasible and environmentally friendly means of *Striga* control (Kim, 1991; Kim et al., 2004; Ejeta and Gressel, 2007). Stable genetic resistance in adapted productive cultivars is central in integrated *Striga* management (Haussmann et al., 2000 and Omanya et al., 2004), but *Striga* resistance genes have not been identified in many crops and potential sources could be in wild grasses (Kuiper et al., 1998). Some genetic resistance has been found in some crops like rice, sorghum and to a degree maize, but no immunity has been identified (Harahap et al., 1993; Kim et al., 1999; Oswald, 2005; Ejeta and Gressel, 2007). According to Oswald (2005), resistance is mainly qualitative and breaks down with increased infestation and virulence. The presence of significant genetic variation for *Striga* resistance in Sorghum has been reported by many, among them Mumera (1983) and Obilana et al. (1991), but no literature exists on finger millet.

A variety of *Striga* control strategies exist and it appears none has been found effective against *Striga* on its own and most workers advocate an integrated approach. Among the control strategies is development and use of resistant crop cultivars. Variability for *Striga* has been reported in some crops and resistance genes have been found in a few crops, most of which are qualitative with potential to break down. It appears the hunt for better resistance genes continues in many cereal crops and this needs to be started on finger millet as well.

Breeding for *Striga* resistance

Screening for *Striga* resistance is difficult and most screening techniques are unreliable (Omanya et al., 2004) and mechanisms of resistance and genetics are not yet fully understood (Haussmann et al., 2000; Oswald, 2005). Parasitic weeds resistance in host

plants is expressed either before or after host-parasite vascular bridge formation (Rispail et al., 2007). Several *Striga* resistance mechanisms in sorghum have been proposed, some of which are tagged as potential (Haussmann and Hess, 2001), and reported by several workers (Ejeta and Butler, 1993; Berner et al., 1995; Haussmann et al., 2000). Among the mechanisms is low *Striga* germination stimulant production by the host plant, mechanical barriers to parasitisation, host production of germ tube inhibitors, host production of defense chemicals (Antibiosis), post parasite attachment incompatibility, insensitivity of host to *Striga* toxin, and avoidance by development of few roots in the top soil. Of these resistance mechanisms the production of low *Striga* seed germination stimulant is the most understood and is detected by differential crop varieties root exudates to stimulate *Striga* seeds germination on agar/water gel assay (Vogler et al., 1996). A single nuclear recessive gene controls this mechanism in sorghum variety SRN 39 (Vogler et al., 1996). Mechanical barriers (e.g., lignification of cell walls) mechanism involves localised necrosis of host tissue that hinders parasite penetration of host tissue (Ejeta, 2007). Inhibition of germ tube exoenzymes by root exudates mechanism involves production of some plant exudates that inhibit the host root penetration enzymes of the parasite, hence retarding the germ tube (Mohamed et al., 2001). The existence of such mechanisms in finger millet needs to be verified with progression in breeding for *Striga* resistance in finger millet.

Haussmann et al. (2000) outlined three categories of *Striga* screening methods. Laboratory Screening involves screening individual resistance mechanisms and two approaches exist – (a) agar-gel assay (Hess et al., 1992). According to Haussmann et al. (2000) and Omanya et al. (2004) this is a useful, fast, indirect selection method for screening for low stimulant character, but correlation analysis showed that this resistance mechanism was ineffective in some environments, pointing to the necessity of field evaluation. (b) paper roll assay method (Ejeta, 2000) allows observations of the early stages of *Striga* infection and is effective for identifying early post-infection resistance mechanisms, i.e., hypersensitivity reaction or incompatibility. The method still needs modification for large-scale application (Ejeta, 2000). The pot screening method involves screening genotypes in pots in controlled environments. Haussmann et al. (2000) and Omanya et al. (2004) found the method to result in low heritability estimates and moderate to low correlations to *Striga* resistance when identified resistances are screened under field conditions. This made the method less useful in breeding programs.

According to Haussmann et al. (2000) and Omanya et al. (2004) field screening is still the most reliable technique to produce stable resistance to *Striga*. However, it is complex and expensive. It is hampered by high soils micro variability, heterogeneity of natural

infestations, and concomitant large environmental effects on *Striga* emergence and is difficult, but is still the most reliable approach (Haussmann et al., 2000 and Omanya et al., 2004). The fact that resistance to *Striga* can be greatly affected by environmental factors such as drought, soil type and fertility levels (Ejeta, 2007 and Amusan et al., 2008) does not make screening for *Striga* any easier. An improved field testing methodology should include one or several of the following practices: field inoculation with *Striga* seeds; appropriate experimental design that allow high replication for example lattice designs for nursery screening followed by randomised complete block design (RCBD) on fewer genotypes; specific plot layout; use of appropriate susceptible and resistant checks; evaluation in adjacent infested and uninfested plots; and the use of selection indices derived from emerged *Striga* counts, *Striga* vigor, and grain yield or a host plant damage score. Multi-location screening to obtain materials with stable performance is recommended due to the extreme variability of the parasite and significant genotype x environment interaction effects (Bebabwi, 1981; Haussmann et al., 2000; Omanya et al., 2004; Oswald, 2005).

In addition to multi-locational testing, many breeding strategies have been put forward by several workers (Ramaiah, 1987; Kim, 1994; Ejeta and Butler, 1993; Efron, 1993; Berner et al., 1995; Haussmann, 2000). Among these is characteriztion of crop germplasm and identification of sources of resistance and their improvement for agronomic performance. This would be the beginning for finger millet work as there has never been a study on *Striga* resistance in finger millet. Other strategies like search for resistance among wild relatives, gene transfer and pyramiding, and development and deployment of molecular markers would follow as finger millet breeding develops.

On the overall it appears breeding for effective and durable host plant resistance to *Striga* is still a challenge in many crops but variability for resistance and single gene resistance mechanisms have been identified, especially in sorghum. Not all resistance mechanisms are well understood and laboratory-identified resistances have often failed under field conditions. Field screening considering a wide array of factors appears to be still the most reliable. However, an approach incorporating most resistance mechanisms and screening approaches would be the way forward as the overall management of *Striga* needs to be an integrated approach.

PROGRESS IN FINGER MILLET BREEDING

The Second International Small Millets Workshop recommended that the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) takes up finger millet as one of its mandate crops (Riley et al., 1993), a recommendation that has hardly been implemented. A

number of useful research recommendations were made at the First International Small Millets Workshop (Riley et al., 1989) but it appears they were hardly implemented as well. Among these recommendations were:

(i) Because small floret size in small millets limits cross breeding and limitations of the contact and hot water emasculation methods, use of gametocides needed to be studied and standardized together with study of genetic male sterile systems, and mechanisms like protogyny and,

(ii) Being inbreeders, all small millets have least been bred, hence the need to work on application of various breeding procedures and assessing their relative efficiency. The low breeding status could have been due to the low research input confounded by the difficulty in breeding self pollinated crops. This could be reversed with research input and breeding will exploit techniques developed on other high value self-pollinated crops like wheat, barley, and rice.

There is no evidence of implementation of these recommendations.

The NRC (1996) identified plant breeding as one of the research needs of finger millet and reported that its genetic development as a crop was at the level of wheat in 1890s at about 500kg ha^{-1}, but have since increased ten-fold to over 4,000kg ha^{-1}. According to NRC (1996) finger millet yield could rise to similar levels and more quickly because it is a C_4 plant compared to wheat, a C_3 photosynthesizer and advanced breeding methodologies developed on other crops already exist. There is hardly any report on breeding to attain the 'green revolution' yields in finger millet, especially a record of breeding progress resulting from hybridisation and selection from segregating populations. This is despite the wide diversity and variability that exists in finger millet to benefit breeding programs. Some traits that could be tapped in finger millet breeding include: genes for blast resistance, robust growth, early vigour, large panicle size, high finger number and branching, and high-density grain (NRC, 1996). De Milliano (1983) thought that inclusion of genotypes of diverse origins and diverse characteristics in a breeding program could improve on the adaptability of selected progeny. The immediate plant-breeding need of finger millet is to fine-tune today's varieties with objectives to breed for resistance to blast, helminthosporium, *Striga*, lodging, soil and moisture stresses, and improve grain quality (NRC, 1996). This need could be easily realised if hybridisation was possible to supplement the genotypic variability existent today.

Finger millet hybridisation

Hybridization is pertinent in plant breeding for three objectives: combination breeding (backcrossing to transfer traits across genotypes), transgressive breeding (genetic variation

or diversity creation) and hybrid varieties (House, 1985). The ease with which hybridization is attained depends on the crop, mode of pollination and floral architecture and a nick between parents to be crossed is mandatory (House, 1985). The floral architecture of finger millet makes it almost 100% self pollinating (Hilu and deWet, 1980; CAB, 2005) and very difficult to emasculate and hybridise. This has limited breeding in finger millet to pure line-based selection from germplasm accessions.

There are many plant emasculation techiques that may be used depending on species genetics and floral architecture. These include: hand emasculation, hot water treatment, plastic bag, suction, cold treatment, genetic, and chemical emasculation (House, 1985). Hand emasculation involves manual removal of anthers without damaging the pistil. This is practically almost impossible in finger millet considering the microscopic florets and delicate pistils.

Hot and cold-water emasculations depend on higher sensitivity of the stamens to both genetic and environmental factors than the pistil. This property is utilized to kill the pollen grains with hot or cold water or other agents without damaging the pistil. These techniques have limitations in small millets (Riley et al., 1989), probably due to the delicate pistils in small millets that are to a larger part protected by glumes. The plastic bag technique works because the high humidity created in the plastic bag prevents anther dehiscence when florets open and anthers emerge without shedding pollen (House, 1985). Such anthers can then be tapped off the ear and the ear cross pollinated. This may not work in finger millet where anthers collapse and open before the florets open. Suction emasculation technique involves use of a thin rubber or glass tube attached to a suction hose to suck anthers from the flowers, including pollen that may fall on stigma. This method may not work with finger millet because the finger millet florets open after the anthers have shed and self pollinated the pistils.

Genetic emasculation involves use of nucleus (GMS) or cytoplasmic male sterility (CMS) genes to make designated female parent plants male sterile in hybridization. Genetic male sterility is caused by failure of pollen production due to one or more nuclear genes and CMS by blockage of pollen production due to a mitochondrial gene defect (House, 1985). Recessive GMS was identified in finger millet line INFM 95001 GMS allele *ms1*, through mutation breeding by ICRISAT and collaborators in Zimbabwe and released in 1996 (Shiferaw et al., 2004), but has not been studied and applied. Verma and Kumar (1978) listed disadvantages that may accompany GMS as: (i). it may involve transfer of GMS gene to suitable agronomic background, (ii) it may involve annual increase of MS and maintainer

stocks, (iii) it involves plant by plant scrutiny in a short time between ear emergence and anthesis, (iv.) ultimately the GMS gene has to be eliminated before yield testing the lines, where always ¼ of segregating offspring are lost at F_2 and, (v) undesirable linkages with GMS gene, if any, may create additional problems. Thus, even though GMS may cut labour costs, it adds to the work of the breeder. Cytoplasmic male sterility that has been exploited extensively in open pollinating maize but least developed on self pollinating cereals has not yet been found in finger millet.

Exploration for new genetic emasculation systems continues and male sterility systems like environment sensitive genetic male sterility (EGMS) (Anon., 2002; Wijk, 1994) including photoperiod genetic male sterility (PGMS) and thermo-sensitive genetic male sterility (TGMS) available in rice have not been discovered in finger millet. Sources of PGMS and TGMS are rare and by 1994, only 12 had been identified (Anon., 2002; Wijk, 1994). The one-line system, apomixis, common in weeds but rare in crops has not been identified in small millets. Other methods of inducing sterility like the genetic engineering SeedLink system6 in rice are technologically beyond the level of advancement in small millets.

Use of chemical hybridising agents

Chemicals that selectively kill or inactivate flower stamens are called male gametocides, androcides or chemical hybridising agents (CHAs) have been used to attain male sterility in self pollinated crops. Advantages of a good CHA system, especially with 2-chloro-ethyl-phosphonic acid (ethrel or ethapon), are extensive in literature. Foster (1969); Rowell and Miller (1971); De Milliano (1983) indicated that such a system would be rapid, flexible, with no requirement for fertility restoration and would allow exploitation of heterosis for improved yields in wheat and self pollinating species. Heterosis for yield and other traits has been observed in self-pollinated crops like sorghum, wheat, barley, oats, rice, and generally higher in diploids than in polyploids (Baenziger, n.d.). Ethrel is easily and cheaply available and could be effectively used to reduce labour on mass emasculation (Verma and Kumar, 1978). Berhe and Miller (1978) saw the potential of ethrel eliminating the problem of floral sensitivity in manual emasculation of tef. Success of ethrel in finger millet would enhance exploitation of mass selection and even manual crossing.

Interest in CHAs started from observation of selective male gametocidal effect of sodium α, β-dichloroisobutyrate (FW-450) on cotton plants, and since then many chemicals have been investigated for the properties (Foster, 1969). Chopra et al. (1960) reported complete sterility in wheat with high degree of female fertility using maleic hydrazide, which was found by Porter and Wiese (1961) and Kaul and Singh (1967) to also cause female sterility and

damage to the plant. Porter and Wiese (1961) evaluated chemicals FW-450, potassium gibberellate, dalapon, triiodobenzoic acid, dimethylamine salt of trichlorobenzoic acid, naphthalene acetic acid, and ethanol and isopropanol series of amine salt of 2,4-D and found them unsuitable on wheat. Foster (1969) studied (FW-450), maleic hydrazide, 2,4-dichlorophenoxyacetic acid (2,4-D), α-naphthalene acetic acid (N.A.A.), tri-iodobenzoic acid (T.I.B.A.) and dalapon on perennial ryegrass and found only FW-450 to be effective.

Ethrel was discovered as a gametocide by McMurray and Miller (1969) and Robinson et al. (1969) when they noticed the number of pistillate flowers to increase on foliar treatment with ethrel on monoecious cucumber (*Cucumis sativus*) (Stoskopf and Law, 1972). Rowell and Miller (1971) applied ethrel on wheat and observed close to 100% male sterility. Subsequently there have been many reports of complete or near complete male sterility with minimal or no effect on female fertility with ethrel on wheat and barley (Bennett and Hughes, 1972; Law and Stoskopf, 1973; Hughes et al. 1974; Fairey and Stoskopf, 1975; Kumar et al., 1976; Verma and Kumar, 1978; Singh et al. 2000). Berhe and Miller (1978) observed both male and female sterility on ethrel treatment on tef. Thakur and Rao (1988) observed effective male sterility on pearl millet with ethrel application. Plant breeders still hunt for more effective CHAs and recently Chakraborty and Devakumar (2006), reported ethyloxanilates, especially ethyl 4-fluorooxanilate, to cause 100% male sterility in wheat without significantly affecting female fertility, agronomic characters and yield.

The success of ethrel as a male gametocide depends on the crop or variety, concentration, stage of application, and environmental conditions and it has been experimented on and applied in breeding many crops. The concentrations studied ranged from 400-2030ppm with 1,000 to 2,000ppm most studied. Grabowska et al. (2005) applied it successfully to eliminate male flowers in monoecious hemp plant to enhance breeding. Beek (1988) successfully used ethrel as a male gametocide where he found one application of 2,000ppm ethrel a.i. in 1,000L water ha^{-1} at Zadoks (1974) stages 41 - 43 DC in combination with an application of 150ppm gibberellic acid-3 in 500L water ha^{-1} three to four days later was most effective. Depending on environmental conditions and genotype, about 60-80% cross-pollination can be achieved (Beek, 1988). Singh et al. (2,000) found ethrel (400, 700 and 1,000ppm) a more effective gametocide on wheat than maleic hydrazide (600, 1,000 and 1,400ppm) when sprayed at 11-13mm spike length but reduced seed set with increased concentrations. De Milliano (1983), applied ethrel with a knapsack sprayer to plant dripping wetness and observed incomplete male sterility with three applications of 1,500ppm a.i. ethrel on wheat. The degree of male sterility induced is greatly affected by the development stage (DS) at which ethrel is applied (Rowell and Miller, 1971; Bennet and Hughes, 1972).

To obtain maximum male sterility, ethrel should be sprayed before meiosis is initiated in the oldest florets in wheat (Bennet and Hughes, 1972; Hughes et al., 1974; Fairey and Stoskopf, 1975). Ethrel concentrations of between 1,000 and 2,000ppm a.i. caused complete male sterility in wheat (Hughes et al., 1974). Thakur and Rao (1988) found Ethrel concentration of 2,000ppm applied at late boot or early protogyny to be most effective in inducing male sterility on hybrid pearl millet and inhibited pollen germination *in vitro*.

Other than induction of male sterility, ethrel also has side effects on ethrel treated plants. De Milliano (1983) and Thakur and Rao (1988), observed negative ethrel effects on wheat and pearl millet, respectively. The ethrel treated plants in wheat had reduced plant height, incomplete head emergence, showed phytotoxic effects, delayed flowering, reduced spikelets per head, reduced awns, delayed and enhanced tillering, and increased rust disease reaction. On Pearl millet, reduced ear exertion, plant height, panicle length were observed on treatment with 2030ppm ethrel at late boot stage. Reduced yield, plant height, delay in flowering and maturity effects had earlier been reported by Early and Slife (1969) and Slife and Early (1970) in maize and soybean, respectively. Rowell and Miller (1971) observed poor spike emergence and reduced plant height at higher ethrel concentrations. Stoskopf and Law (1972) and Law and Stoskopf (1973) observed reduced plant height, head emergence and delayed heading, in wheat and barley respectively. The most commonly observed morphological abnormalities are: shortening of internodes, dwarfing, and poor spike emergence (Fairey and Stoskopf, 1975). Poor spike emergence may restrict cross pollination, hence defeating the purpose of emasculation. No report was found on ethrel effects on finger millet.

Interference with microsporogenesis, especially before, during or post meiosis stages is the cause of male sterility on ethrel treatment (Kaul and Singh, 1966; Bennet and Hughes, 1972; Berhe and Miller, 1978; Colhoun and Steer, 1983). This is the mechanism of male sterility even in other male sterility systems, including genetic male sterility (Laser and Lersten, 1972; Colhoun and Steer,1983; Vipen and Shukla, 1994). Vipen and Shukla (1994) reported that the balance of the various plant growth regulators, gibberellins, cytokinins, auxins, abscisic acid, and ethylene in plants is responsible for triggering chemical or genetic male sterility, either directly or indirectly.

Bagging emasculated heads without pollination tests efficiency of an emasculation technique where the amount of seed set would indicate the frequency of chance self-fertilization during emasculation (House, 1985). In field experimentation, Rowell and Miller (1971) detected male sterility by comparing seed set on treated plants allowed to self

pollinate and those treated and cross pollinated. Stoskopf and Law (1972) planted rows of untreated plants around treated plots for pollination. De Milliano (1983) observed plastic bags bagging to result in reduced kernels per head, increased ear diseases and premature senescence of wheat ears.

The use of gametocides has some challenges which include choice of CHA, appropriate developmental stage for application; environmental effect that is difficult to control; chemicals failure; difficulty in having crop in field at uniform development stage; weather unpredictability that can hinder application of gametocide at optimal treatment stage; gametocide availability may be limited and /or costly; and CHAs may be unreliable in action and length of action (Chakraborty et al., 2000).

Finger millet is among small millets that have least been bred and hybridization breeding not applied to them because of difficulty in hybridization. Cross breeding is required to improve the productivity of finger millet that is seen to have great potential for improvement. The various methods of emasculation to enable cross breeding have not been tried but the use of CHAs, where ethrel is the most extensively studied, has been singled out to hold potential for finger millet hybridization and needs to be studied.

Genotypic variability in finger millet

Extensive amounts of finger millet germplasm exist according to Bennetzen et al. (2003) - ICRISAT (5,000 accessions), University of Agricultural Sciences in Bangalore (4,500), National Dryland Farming Research Station of Kenya (1,500), Genebank of Kenya (1,000), Plant Genetic Resource Centre in Ethiopia (1,000) and University of Georgia in US (1,500). The existence of large amounts of germplasm provides plant breeders with the necessary building units, in variation, to develop farmer-desired varieties.

Characteristic correlations and path coefficient analysis, determination of characteristic variation, heritabilities and predicted gain on selection have least been applied on finger millet. Bondale et al. (2002), Bezaweletaw et al. (2006) and John (2006) are among the few that have applied both characteristic variability and interrelationships techniques to study finger millet genotypes. Bondale et al. (2002) found grain yield per plant to be significantly influenced by finger length and finger width among finger millet genotypes from diverse regions of India. Bedis et al. (2006) and Bezaweletaw et al. (2006) observed high variability in most finger millet characteristics including days to flowering and maturity, plant height, number of productive tillers, main ear length, finger number per ear and grain yield and recorded high broad sense heritability for grain yield, indicating possibility of genetic advance

from selection. John (2006) reported high genotypic and phenotypic coefficients of variation for number of productive tillers per plant, number of fingers per ear and total dry matter production. He also reported high heritabilities coupled with high expected genetic gain for productive tillers, fingers per ear, test weight, total dry matter and harvest index. Sumathi et al. (2007) reported high broad sense heritabilities for days to 50% flowering, days to physiological maturity, plant height, number of tillers, number of fingers per ear, finger length, 1,000 grain weight and grain yield per plant. Madhukeshwara et al. (2004) identified 714 genotypes resistant to finger millet neck and head blast from screening 2950 finger millet genotypes. Fakrudin et al. (2004) and Das et al. (2007) found high levels of genetic diversity among finger millet genotypes of diverse origin.

Relationships among traits

Understanding characteristic relations in a given crop is critical to its successful breeding. There are two causes of correlation between characters, genetic and environmental, and genotypic correlation is mainly due to pleiotropy (gene affecting more than one character) though linkage may also cause transient correlation, especially in populations from divergent strains (Falconer, 1989). Environmental correlation is caused by characters being influenced by the same environmental conditions and showing similar or dissimilar responses (Bezaweletaw et al., 2006). Coefficient of correlation indicates the relationship between two characteristics, but it does not give information on the extent of change in one characteristic resulting from change in another, a preserve of regression coefficient (Dabholkar, 1992). Dabholkar (1992) further explained that often more than two characteristics are interrelated in biological systems. Simple correlations do not clearly indicate the importance of each component in determining a character of interest unlike path coefficient analysis, which divides correlation coefficients into direct and indirect effects (Guler et al., 2001; Garcia del Moral et al., 2003; Das et al, 2004). Many workers use genotypic correlations in path coefficient analysis. However, in studies involving many genotypes, replication and plots with many plants, phenotypic correlations have been used. Dewey and Lu (1959) calculated phenotypic and genotypic correlations, which agreed closely in yield components of crested wheatgrass and they explained it in large number of replications and plants within plots (11) that they used. Ahuja et al. (2006) found similar results for components of fibre yield and quality in cotton. Many workers have used phenotypic correlations to disentangle characteristic relationships in different crops (Guler et al., 2001, Jasso de Rodriguez et al., 2001; Garcia del Moral et al., 2003; Surek and Beser, 2003; Das et al, 2004; Okuyama et al., 2004).

The steps of constructing and solving path diagrams, a method developed by Wright in 1920, are collectively called path analysis (Loehlin, 2004). According to Kang (1994) and Board et al. (1997), correlation coefficients alone should be applied with care in making decisions on indirect selection criteria. A number of studies have demonstrated the value of using correlation coefficients in conjunction with path coefficient analysis in understanding characteristic relationships and for better decisions on indirect selection in breeding (Dewey and Lu, 1959; Sidwell et al., 1976; Kang et al., 1983; Diz et al., 1994; Board et al., 1997; Bezaweletaw et al., 2006). Path coefficient analysis is abundantly used to illuminate components of yield in many cereals, but little literature exists on the same in finger millet. Bezaweletaw et al. (2006), found finger millet grain yield per plant to be significantly negatively correlated to days to heading and days to maturity. However, through path coefficient analysis, they found days to heading to have high positive direct effect on grain yield per plant and days to maturity had very high negative direct effect. Large numbers of finger millet germplasm exist but have least been studied using methods like characteristic correlations and path coefficient analysis, determination of characteristic variation, heritabilities and predicted gain on selection, especially on African and specifically Kenyan germplasm.

Application of diallel analysis in finger millet genetic studies

Diallel analysis results from diallel crosses, which are a set of crosses produced by involving 'n' lines in all possible combinations (Singh and Chaudhary, 1985). The analysis of such crosses is referred to as diallel analysis. Diallel mating designs are used in plant breeding to study quantitative inheritance and estimate general combining ability (GCA), specific combining ability (SCA), narrow and broad sense heritabilities and generally provide information on the nature and amount of genetic parameters (Singh and Chaudhary, 1977; Topal et al., 2004). The commonly used diallel analysis approaches are the Hayman (1954); Jinks (1954); and the Griffing (1956). The Hayman (1954) diallel method has six assumptions (Nassar, 1965; Dabholkar, 1992): (i) diploid segragation in parents (no autopolyploidy); (ii) no difference between reciprocal crosses; (iii) homozygous parents; (iv) no multiple alleles at a locus; (v) no non-allelic interaction (no epistasis); (vi) non-correlated gene distribution between the parents (no linkage).

Finger millet is an allotetraploid and allotetraploids that are fertile and produce viable gametes show diploid meiosis (Moore, 2002 and Feldman and Levy, 2005). Finger millet being largely self-pollinating, pure line varieties are largely homozygous and thus meet the requirement of homozygosity of parents when used in diallel hybridization. The assumptions of no epistasis and linkage are difficult to satisfy and it is assumed inclusion of as many

parents as practically possible in the diallel will remove or reduce their distortion of diallel analysis results (Nassar, 1965). On the whole, Hayman (1954) diallel analysis has been applied on allopolyploids such as durum wheat, bread wheat and cotton (Moore 2002; Singh et al., 2003; Dere and Yildirim, 2006; Sayar et al., 2007).

Hayman (1954a) diallel analysis may be applied to any generation of segregating populations, but one has to take into consideration dominance effects that reduce by half every inbreeding generation (Singh and Chaudhary, 1977). Singh and Singh (1984) provided formulae that may be used to estimate degree of dominance using the regression of parent offspring array covariance (Wr) on offspring array variance (Vr) plot at any segregating generation. Lupton (1961), Busch et al. (1974) and House (1985), advocated the use of later generations (F_4 and F_5) in evaluation of crosses, especially when the interest is not to exploit heterosis but to develop pure line varieties, as at these advanced generations linkages have been broken and the true potential for pure line is seen.

Hardly any studies of the genetics of finger millet in terms of trait inheritance and gene action have been done. Such studies are critical in designing efficient breeding programs that are so urgently needed in finger millet.

The role of participatory rural appraisal in finger millet breeding

A few general studies on finger millet covering wide areas have been carried out. However, there is need for targeting farming systems in given communities and components of the systems as each community is unique with defined practices. This is more so in elucidation of variety characteristics and farmer breeding or variety selection practices to incorporate PVS in nascent finger millet breeding programs. Both formal and informal approaches such as the PRA can be used to obtain vital information from the communities. Chambers (1994) defined PRA as a growing family of approaches and methods to enable local people express, enhance, share and analyze their knowledge to plan and act. Many other definitions of PRA carry the involvement of outsiders facilitating the locals to understand their situation as both parties learn (Bhandari (2003), Tracey-White (2003). The methods of PRA were adopted in crop improvement about three decades ago and now form part of a crop improvement approach called participatory crop improvement (PCI) or specifically for plant breeding participatory variety selection (PVS) (Witcombe et al., 1999 and Almekinders and Elings, 2001).

Conventional crop improvement poorly addressed the needs and preferences of farmers, especially peasant farmers who were provided with few options of finished crop varieties,

largely suitable for resource rich and high production environments (Subedi et al., 2002). This led to yield gaps and poor adoption as it ignored the knowledge and participation of farmers (Subedi et al., 2002). Realization of these weaknesses led to PCI that is need-oriented and addresses diverse socio-economic conditions, production environments, and management practices and it has the advantage of involving farmers in all breeding stages (Subedi et al., 2002). To date, participatory breeding has evolved and applied in development and extension of varieties in crops like maize (Jeyaprakash et al., 2004; Urrea et al., 2004; Mwala et al., 2004). Finger millet has started getting attention as well. Riley et al. (1993) used rapid rural appraisal (RRA) to determine potential of finger millet in Nepal and Tsehaye et al. (2006) used PRA to study finger millet farming systems in the Tigray region of Ethiopia. Gowda et al. (2000) demonstrated the value of PRA, using an elaborate checklist, for identifying finger millet cultivars acceptable to resource-poor farmers in India in terms of desirable plant characters.

SUMMARY

1. Finger millet was indigenous to East Africa where wide variability exists.
2. It was an important subsistence crop valued for food, nutritional, feed, cultural, long storability without spoilage, medicinal, malting purposes, and it has industrial and economic potential.
3. Farmers realized low yields because of low research input.
4. Production constraints responsible for the low yields were: pests and diseases (blast and *Striga*), drought, low soil fertility, labour intensity, high weed infestation, low yielding varieties, lodging, and poor attitude to the crop. Five of the eight constraints: blast and *Striga*, drought, low soil fertility, low yielding varieties, and lodging, could be addressed through breeding.
5. Wide array of germplasm that had not adequately been studied for traits that could be exploited in finger millet breeding existed.
6. Existence of blast disease resistance had been reported in Asia, but hardly any studies had been conducted in Africa.
7. There were no reports of any research on *Striga* as a parasite of finger millet.
8. Finger millet breeding was hampered by difficulty to make crosses because of floral architecture and high levels of self pollination.
9. Chemical hybridising agents had been applied successfully in other self pollinating cereals.
10. The constraint of low yielding varieties susceptible to biotic and abiotic stresses could be reduced or eliminated by breeding new high yielding, biotic and abiotic stress

resistant varieties desired by farmers that had hardly been attempted. This will open up the potential of finger millet for the good of communities in Kenya and sub-Saharan Africa.

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CHAPTER 2

Participatory rural appraisal for farmers' finger millet production system, variety preferences, uses and production constraints in western Kenya

ABSTRACT

Finger millet (FM) is an important crop in low input farming systems in East Africa. Information on its status among farmers, especially variety characteristics and turnover in western Kenya is scanty. A participatory rural appraisal was carried out in 2006 in three districts in western Kenya to identify the place of finger millet in the farming system, production constraints, variety diversity, and farmer preferences. Resource poor farmers produced finger millet as inferred from per capita land ownership 0.92 - 23 acres on average, average land allocation to FM of 0.46–1.72 acres, and low yields of 534-655kg ha^{-1}. Many farmers ranked FM among top three crops both as food (12-42%) and cash crops (38-50%). Main FM uses in the districts were food, cash, brewing, and ceremonies, except in one district where brewing was not listed but medicinal value was. Farmers grew five to nine different FM varieties with one most popular variety in each district, Ikhulule in Busia, Aaran in Teso, and Enyaikuro in Nyamira. Many farmers frequently tested and adopted new varieties and discontinued some. The variety selection criteria used by farmers were: high yield potential; early maturity; resistance to blast disease, *Striga*, birds, drought, and lodging; large head size, dark grain colour, and without bitter taste. Constraints to production were blast disease, *Striga*, wild FM, birds, rats, termites, lack of market, labour shortage, and low yield. Farmers frequent testing of new varieties, adopting some and discarding others indicated their relentless search for better varieties and willingness to adopt better varieties, providing an opportunity for researchers to introduce tested superior ones. Results indicated the need for breeding superior varieties which will have maximum impact if accompanied by whole value chain research addressing issues like lack of markets.

Key Words: PRA, western Kenya, finger millet, farmers, varieties, selection criteria

INTRODUCTION

Finger millet (FM) is an important food and food security crop in traditional low input cereal-based farming systems in Africa. It has food, feed, cultural, industrial, medicinal and economic value (Holt**,** 2000; Takan et al., 2002; Haore et al., 2007). Finger millet is grown in Kenya, Tanzania, Uganda, Rwanda, Burundi, Democratic Republic of Congo, Ethiopia, Sudan and Somalia (Holt **,** 2000; Takan et al., 2002; Obilana et al., 2002). It has received low research input and this is partly manifestated in the little effort made to understand its production system and constraints that limit productivity among small scale farmers who are its major producers CGIAR[3], 2001 and Takan et al., 2002). For its food, economic, cultural, nutritional and potential research impact, the crop needs to be improved and knowledge of farmers' circumstances is pertinent to the improvement.

In an effective participatory breeding approach, it is important to start with knowledge of what the farmers already have in their landraces. Participatory rural appraisal (PRA) approaches and methods enable local people express, enhance, share and analyze their knowledge of life and conditions, to plan and to act (Chambers, 1994). It has been used extensively and successfully in developing countries to elucidate systems in rural areas. Tefera (2004) used PRA techniques to elucidate farm management systems in relation to stem borer pest on sorghum in eastern Ethiopia; Chakanda (2000) used PRA techniques to evaluate farmers' variety characterization criteria. However, these useful tools have not been extensively applied on finger millet farming, especially in western Kenya.

Riley et al. (1993) used techniques of one of PRA's precursor approaches, rapid rural appraisal (RRA) (Chambers, 1994) to assess the value of finger millet in the farming system and the improvement needed in Nepal. Tsehaye et al. (2006) used PRA techniques to study finger millet in the farming system of Tigray region of Ethiopia in terms of farmers' practices, variety diversity, crop value, and seed system. Gowda et al. (2000) used PRA with an elaborate questionnaire to understand the needs and preferences of farmers on variety choice and assess the cropping system, economic status, and input–output management in FM farming in India. In terms of variety choice, Gowda et al. (2000) were keen on plant characters farmers looked for in a new variety and they found that farmers valued grain and fodder yield, compact head, medium height (100cm), and early maturity.

In East Africa some exploration of the FM production system focused more on FM blast disease (Obilana et al., 2002 and Audi et al., 2003). They found variability in blast resistance among varieties farmers planted, and districts surveyed varied in blast incidences

[3] Consultative Group on International Agricultural Research

and farmer management strategies. Through a PRA carried out in Kenya and Uganda, Lenne et al. (2006) reported availability of blast resistant FM varieties and listed some traits that FM farmers preferred in FM varieties. They identified early maturity, uniformity in height, high tillering, large non-shattering heads, resistance to lodging, long storability and seed viability, and high yield as agronomic ideotype traits. Stress ideotype traits identified were drought tolerance, wide adaptability, resistance to diseases (blast) and pests. Market ideotype traits were: easy to dry, clean and market; white seeded; palatable; and easily fermentable into alcohol. The varieties identified by Lenne et al. (2006) are yet to undergo extensive testing to determine their suitability for western Kenya. They may, however, be useful as source germplasm for breeding new varieties. Information such as provided by Lenne et al. (2006) for traits farmers want in varieties, the preferred varieties themselves and variety turnover, uses and general production constraints is lacking for most of the important FM growing communities in western Kenya, where most of the finger millet is produced in Kenya (MoA, 1989-2004). This information would be useful in setting up a breeding programme that aims at producing high yielding varieties with most farmer desired traits for ease of adoption.

Objectives

The major objective of this study was to set breeding priorities and goals for a new finger millet breeding programme in Kenya. The specific objectives were as follows:

1. evaluate the position of finger millet among crop enterprises in the farming systems of western Kenya,
2. determine farmers' FM variety preferences and variety selection criteria,
3. determine finger millet cultivar diversity and farmer variety turnover and practices in western Kenya, and
4. determine constraints affecting FM production in western Kenya.

Hypothesis

The hypothesis of the study was that finger millet ranks high among crop enterprises in western Kenya and the farmers know the diversity of varieties and recogise the key attributes and production constraints that can be used to improve the crop through breeding.

MATERIALS AND METHODS

Study Area

The PRA was conducted in 2006 in Teso and Busia districts in Western Province, and Nyamira district in Nyanza Province in western Kenya. These districts are in tropical region with high mean annual rainfall and temperature (Table 1). In Busia the PRA was carried out in Matayos Division in Busibwabo and Bukhayo West locations. In Teso the PRA was done in Amukura division, Amukura and Kotur Locations while in Nyamira the PRA was conducted in Rigoma division, Gesima and Gachuba locations.

Table 1. Geographical information of Busia, Teso and Nyamira districts in western Kenya

Parameter	District		
	Busia	Teso	Nyamira
Latitude	0°27' 16N	0°46' N	0 ^{o} 30' - 0^{o} 45'S
Longitude	34°4' 33E	33°54' W - 34°26'E	34^{o} 45' - 35^{o} 00'E
Altitude (m.a.s.l.)	1130 - 1375	1130 - 1375	1280-2100
Area (km^{2})	1776	559 km²	896.4
Total population	370,608	181,491	492,102
Annual rainfall (mm)	1315	1,500	1650
Average Min. and Max. temperature	18^{o}C and 31.5^{o}C	16℃ and 28℃	15℃ and 24℃

Data source: Wikipedia (2007); Nyamira District Development Plan (2002-2008); Adoyo et al. (1997).

Farmer selection

The farmer group PRA approach (Audi et al., 2003) was used for this study. A preparatory survey was carried out two weeks before the PRA in all areas of the study, in which the research team visited each district agricultural office and with the district crops officer identified the most FM producing division in the districts. The team sensitised the division extension officer to work with the local extension officer to identify one farmer group per location and in two locations of the division for the PRA exercise after two weeks. The extension staff were also sensitised and familiarized with the questionnaire so that they would help administer it during the PRA. The farmer groups were such that most of the farmers of the group grew FM and the groups had a membership of at least 20 people. A farmer in a location farmer group formed the unit respondent. The division extension officer was asked to make sure that the selected farmer groups were active in terms of group activities and that they represented the diverse FM production environments in the division and that they had gender representation. Farmer groups suggested PRA dates and times for the exercise to avoid conflicts with their operations.

Survey data collection

The PRA executing team comprised of a plant breeder, socio-economist, a technician and driver from KARI Kakamega and in each district, the district and division crops officers, and local field assistants joined the research team. Therefore at each interview venue, there were six officials. To give maximum time for information evolution and rapport development, each farmer group was given a whole day to allow time for farmer suggested activities like farm and transect walks. The PRA was conducted between 7th and 21st December 2006 in the selected locations and a total of 164 farmers participated (Table 2).

Table 2. Participating farmers groups, dates of PRA, and attendance

Group	District	Division	Site	No. of participating farmers	PRA Date
Emolokony Women Group	Teso	Amukura	Amukura	34	07/12/2006
Akudo Farmers Group/ Focal Area Development Committee	Teso	Amukura	Kotur	30	08/12/2006
Busibwabo Widows and Orphans Self Help Group	Busia	Matayos	Busibwabo	26	13/12/2006
Nasirumbi Wesi Temakho Women Group	Busia	Matayos	Bukhayo West	20	14/12/2006
Gieseri Self Help Group	Nyamira	Rigoma	Gesima	20	20/12/2006
Kegima Women Group	Nyamira	Rigoma	Gachuba	34	21/12/2006

At each venue of the PRA, the local extension agent led contact with the groups, including introductions on the part of the PRA team after assembly of group members (Figure 1). The introduction on the part of the farmer groups was lead by the officials of the groups. The plant breeder who was the lead member of the PRA team led the discussion of the mission and subsequently the PRA. After familiarization and rapport development, each member of the PRA team interviewed two farmers independently using the questionnaire (Figure 2). A total of 12 farmers completed the questionnaire at each farmer group meeting, except at Gesima where 13 questionnaires were completed. After individual farmer interviews, a plenary session followed for discussion of issues that arose in the questionnaire. The PRA team provided refreshments to everyone who attended the PRA sessions. However, the farmer groups were very generous and offered heavy lunch to the PRA team in most instances, indicating a high level of rapport was established between farmers and researchers.


Figure 1. Introduction of the PRA exercise to farmers of Gesieri Self Help Group in Gesima Nyamira District and Akudo/FADC in Kotur Teso District.


Figure 2. Individual farmer interviews of Busibwabo Widows and Orphans Self Help and Nasirumbi Wesi Temakho farmer groups in Busibwabo and Bukhayo West locations of Busia District, respectively.

Data from the PRA were coded and analysed using SPSS 15.0 (2006) statistical package using the report case summary, frequency, table of frequency, and mean comparison features of the programme.

RESULTS

Demographic and farm socio-economics

There was generally high women membership in the groups and more women attendance in the PRA than men (Table 3). Analysis of variance showed no significant difference between groups and districts in terms of age of participating members ($p \leq 0.05$), which ranged from 25

to 80 years (Tables 4 and 5). However, mean age of participating members appeared higher for Busia district than other districts.

Table 3: Farmer group membership and attendance by gender

	Membership			Attendance			Percent attendance		
Group	Total	Women	Men	Total	Women	Men	Women	Men	Total
Emolokony	34	17	17	22	11	11	65	65	65
FADC/Akudo	30	17	13	22	14	8	82	61	73
Busibwabo W.O.S.H.G	26	17	9	24	15	9	88	100	85
Nasirumbi Wesi Temakho	20	16	4	17	15	2	94	50	85
Gieseri	20	14	6	17	12	5	86	83	85
Kegima	34	24	10	18	10	8	42	80	53
Total/Average %	164	105	59	120	77	43	76	73	74

Table 4. Mean age of participating farmers by group

Farmer group	Mean	Std. Deviation	Range
Emolokony	42	12.43	25 - 66
Akudo/FADC	43	12.55	26 - 60
Gesieri Self Help Group.	39	8.69	32 - 62
Kegima	45	7.80	33 - 53
Nasirumbi Wesi Temakho Women Group	56	11.15	31 - 63
Busibwabo Widows and Orphans	43	10.83	29 - 80

Table 5. Mean age of respondents by district

District	Mean	N	Std. Deviation	Min.	Max.
Busia	49.25	24	13.39	29	80
Teso	43.87	24	11.12	25	66
Nyamira	44.60	25	8.15	32	62
Total	45.89	73	11.16	25	80

There were significant differences ($p \leq 0.01$) in the mean size of land owned by participating farmers from different districts. Teso had the highest mean acres of land owned per farmer and Nyamira had the least (Table 6).

Table 6. Mean Farm size in acres owned by participating farmers by district

District	Mean	Std. Deviation	Minimum	Maximum
Busia	3.74	1.95	0.25	8.00
Teso	11.15	12.79	2.00	54.00
Nyamira	2.25	1.69	0.50	7.00
Average	5.71	5.47	0.92	23

Participating farmers grew maize, beans, FM, sorghum, cassava, bananas, sweet potato, groundnuts, exotic vegetables, local vegetables, tomatoes, wheat and rice as food crops

(Table 7). Maize, FM, sorghum and cassava were the crops that received number one food crops ranking in each district. Cassava received the most number one ranking in Busia and Teso and maize in Nyamira. Finger millet and cassava tied in Teso for number one ranking. Finger millet was ranked number one by 17%, 42%, and 12% of participating farmers in Busia, Teso and Nyamira, respectively.

Table 7. Food crops with 1 to 3 ranks assigned by participating farmers by district in western Kenya

		Busia (n=24)	Teso (n=24)	Nyamira (n=25)
Rank	Crop	%	%	%
1	Maize /beans intercrop	8.3		4.0
	Maize pure stand	25.0	16.7	84.0
	Finger millet	16.7	41.7	12.0
	Sorghum	4.2		
	Cassava	45.8	41.7	
2	Maize /beans intercrop	4.2		
	Maize pure stand	12.5	20.8	12.0
	Beans pure stand	4.2		
	Finger millet	12.5	16.7	72.0
	Bananas			4.0
	Sorghum	29.2	12.5	
	Sweet potatoes	12.5		
	Cassava	25.0	45.8	
	Groundnuts		4.2	
	Exotic Vegetables			8.0
	Local vegetables			4.0
3	Maize pure stand	12.5	29.2	
	Beans pure stand		12.5	44.0
	Finger millet	16.7	29.2	
	Bananas			24.0
	Sorghum	25.0	12.5	
	Sweet potatoes	16.7	4.2	4.0
	Cassava	8.3	8.3	
	Groundnuts		4.2	
	Exotic Vegetables	4.2		12.0
	Local vegetables	16.7		16.0

The leading cash crops across the districts were: Finger millet, sweet potatoes, cassava, exotic vegetables, tomatoes, sugar cane, napier grass, tea and cotton. Finger millet was ranked number one as a cash crop by 38% and 50% of participating farmers in Busia and Teso, respectively (Table 8), but was ranked second by 33% of participating farmers in Nyamira, where tea was unanimously ranked number one. It is significant to note that some crops such as FM, cassava and maize were ranked high both as food crops and cash crops.

Table 8. Cash crops with 1 to 3 ranks assigned by participating farmers by district in western Kenya

Rank		Busia (n=24) %	Teso (n=24) %	Nyamira (n=25) %
1	Maize pure stand	23.8	13.6	
	Finger millet	38.1	50.0	
	Sweet potatoes	4.8		
	Cassava	14.3		
	Exotic Vegetables	4.8		
	Tomatoes		9.1	
	Sugarcane	9.5	4.5	
	Napier grass	4.8		
	Tea			100.0
	Cotton		22.7	
2	Maize /beans intercrop	6.7		
	Maize pure stand	13.3	15.8	
	Beans pure stand		26.3	5.6
	Finger millet	26.7	15.8	33.3
	Bananas			16.7
	Sorghum	6.7	5.3	
	Sweet potatoes	6.7		
	Cassava	20.0	10.5	
	Groundnuts	6.7	5.3	
	Exotic Vegetables		5.3	
	Local vegetables			5.6
	Tomatoes	6.7		
	Coffee			22.2
	Blue gum			5.6
	Rice		10.5	
	Cotton	6.7	5.3	
	Pyrethrum			11.1
3	Maize pure stand	8.3	16.7	
	Beans pure stand		11.1	33.3
	Finger millet	8.3	5.6	16.7
	Sorghum	16.7	5.6	
	Sweet potatoes	16.7	11.1	
	Cassava	25.0	16.7	
	Groundnuts	8.3	5.6	
	Exotic Vegetables	8.3	5.6	
	Local vegetables	8.3	11.1	25.0
	Tomatoes		5.6	
	Sugarcane			8.3
	Fruit tree crops			16.7
	Cotton		5.6	

Finger millet production

The districts showed significant differences in both areas planted and FM produced per season ($p \leq 0.01$). Participating farmers reported to plant FM only in the LR season in Busia and Teso, but Nyamira farmers reported to plant two seasons in a year (Table 9). However, the mean production per farmer was higher in the LR than the short rain (SR). Only 17% of participating farmers in Busia district did not plant FM in the LR season, citing reasons such as shortage of labour, poor market and lack of technical advice. The area planted in the LR season ranged from 0.1 to 7.5 acres. The largest mean area planted per farmer in the LR

season was in Teso and the least in Busia. The range of area planted was 0.1–2 acres in Busia and Nyamira and 0.25 – 7.5 acres in Teso.

Table 9. Participating farmers area of land planted with FM in the LR and SR seasons by district

	Busia (n=24)		Teso (n=24)		Nyamira (n=25)	
	%		%		%	
Acres	LR	SR	LR	SR	LR	SR
0.00	16.7	100.0		100.0		4.2
0.10					8.3	12.5
0.13					25.0	8.3
0.20					8.3	4.2
0.25	29.2		4.3		20.8	37.5
0.30						4.2
0.50	25.0		4.3		16.7	20.8
0.75						4.2
1.00	16.7		34.8		12.5	4.2
1.50			26.1		4.2	
2.00	12.5		17.4		4.2	
3.00			8.7			
7.50			4.3			

The range of production among participating farmers who planted in the LR season was Busia 20 – 1,080 kg, Teso 40 – 1,800kg, Nyamira 0.4 – 700kg and in the SR season finger millet was only planted in Nyamira with a range of production of 10 – 360kg.

On average finger millet area (acres) was 0.62 producing about 134kg in the LR in Busia, 1.71 in Teso producing 448kg and 0.46 producing 122kg in Nyamira (Table 10). The Nyamira SR average acreage was 0.32 producing 73.20kg. This translated to yields of 534kg ha^{-1} in Busia, 647kg ha^{-1} in Teso and 655 kg ha^{-1} in Nyamira during the LR. The yields in the SR in Nyamira were estimated at 574kg ha^{-1}.

Table 10 Mean land area planted, kilograms produced, and yield by participating finger millet farmers by district

District	LR acres	LR production (acres)	LR estimated yield (kg ha^{-1})	SR acreage	SR production	SR estimated yield (kg ha^{-1})
Busia	0.62	133.54	534	0.00	0.00	0.00
Teso	1.72	448.18	647	0.00	0.00	0.00
Nyamira	0.46	122.03	655	0.32	73.20	574
Total	0.93	234.58	612	0.11	25.42	574

Finger millet uses

Finger millet use as food was ranked first by the majority of participating farmers across the districts (Table 11). In order of importance, selling, brewing and ceremonies followed.

Table 11. Participating farmers finger millet uses ranking by district

Rank		Busia (n=24)	Teso (n=24)	Nyamira (n=25)
		%	%	%
1	Food	75.0	95.8	88.0
	Sell	25.0	4.2	12.0
2	Food	28.6	4.2	13.0
	Brewing	28.6	25.0	
	Sell	42.9	66.7	87.0
	Ceremonies		4.2	
3	Brewing	75.0	69.6	100.0
	Sell	25.0	26.1	
	Ceremonies		4.3	

Comparative advantage of finger millet

The advantages listed for FM over other crops were high storability, high nutritional value, tolerance to low soil fertility, marketable, tolerance to drought, and medicinal (Table 12a). From the frequency of the ranking, many farmers appreciated the nutritional value of FM.

Table 12a. Frequency of comparative advantage listing of finger millet by participating farmers by districts

Listing Order	Advantage	Busia (n=24)	Teso (n=24)	Nyamira (n=25)
		%	%	%
1	Good storability	25.0	50.0	20.0
	High nutritional value	37.5	41.7	68.0
	Does well without fertilizer			4.0
	Marketable	33.3	8.3	4.0
	Drought tolerant	4.2		4.0
2	Good storability	10.0	10.0	27.3
	High nutritional value	50.0	35.0	18.2
	Does well without fertilizer	10.0	10.0	4.5
	Marketable	30.0	45.0	40.9
	Medicinal			9.1
3	Good storability	60.0	40.0	40.0
	High nutritional value	20.0	20.0	20.0
	Does well without fertilizer	10	30.0	
	Marketable	10.0	10.0	30
	Medicinal			10

On the disadvantages, high labour requirements were overwhelmingly the biggest disadvantage (Table 12b). Other disadvantages mentioned were the need to blend with other crops in food preparation to improve taste, low yield, bird damage, and poor market.

Table 12b. Frequency of comparative disadvantage listing of finger millet by participating farmers by districts

		District		
		Busia (n=24)	Teso (n=24)	Nyamira (n=25)
Listing Order	Disadvantage	%	%	%
1	Labour intensive	95.7	90.0	96.0
	Birds damage		5.0	
	Needs blending with other crops	4.3		
	Low yields		5.0	4.0
2	Labour intensive		50.0	
	Birds damage	100.0		28.6
	Low yields		50.0	28.6
	Poor market			42.9
3	Poor market		100	

Finger millet varieties grown and their ranking

Majority of participating farmers in Busia and Teso districts planted one variety in a season, 67 and 58%, respectively, unlike in Nyamira where 92% planted more than one variety in a season (Table 13). It was found that in Nyamira where farmers planted two seasons of FM in a year, they planted the same varieties in both seasons. Each time they planted they were looking for varieties that were to give them high yield, mature early and tolerate drought. Among those who planted more than one variety in a season, majority planted the varieties in pure stand, in Busia (83%), Teso (61%), and Nyamira (96%). Majority of the farmers who planted more than one variety planted two varieties. In Teso, the farmers who planted mixtures of varieties planted up to three varieties together. Teso had more farmers who planted more than one variety in mixtures than the other districts but generally farmers who planted more than one variety in mixture were few.

Table 13. Participating farmers' planting more than one and one variety in a season by district.

No. of varieties grown	Busia	Teso	Nyamira
	Planting one or more than one variety		
	(n=21)	(n=24)	(n=25)
	%	%	%
>One	33.3	41.7	92.0
One	66.7	58.3	8.0
Total	100.0	100.0	100.0
	Planting more than one in pure stand in a season		
	Busia (n=5)	Teso (n=1)	Nyamira (n=22)
2	83.33	100.0	63.6
3	16.67		27.3
4			9.1
Total	100	100	100
	Planting more than one in mixed stand in a season		
	Busia (n=2)	Teso (n=8)	Nyamira (n=1)
2	100	57.14	100
3		42.86	
Total	100	100	100

Participating farmers in the three districts listed a number of varieties they normally plant. In Busia they listed five varieties Ikhulule, Madere Kesabare, Nafusi, Namala, and Agriculture. Among these, they ranked Ikhulule, Madere Kesabare and Nafusi their top varieties (Table 14). Farmers in Teso listed 9 varieties Emumware, Ebunit, Ebuluu, Epalata, Aaran, Emugogoloit, Oleuro, Ekajua, and Obokorit. Among the Nine, Aaran, Emumware and Epalat were their top three varieties. In Nyamira farmers listed eight varieties Enyaikuro, Marege, Enyankundi, Enyaikuro Empya, Omokomoni, Enyandabu, Ekeberanchera and Kababa. Among these, Enyaikuro was ranked as their number one variety, followed by Marege and Enyankundi. No varieties were common among the three districts, at least by name and more farmers acknowledged their top ranked variety in Nyamira, followed by Teso and last Busia.

Table 14. Participating farmers variety ranking by district

Rank	Variety	Busia (n=24) %	Teso (n=24) %	Nyamira (n=25) %
1.	Emumware		16.7	
	Ebunit		12.5	
	Ebuluu		4.2	
	Ikhulule	33.3		
	Madere kesabare	33.3		
	Nafusi	27.8		
	Enyaikuro			72.0
	Marege			16.0
	Enyankundi			12.0
	Epalata		16.7	
	Aaran		41.7	
	Emugogoloit		8.3	
	Namala	5.6		
	Total	100	100	100
2.	Emumware		9.1	
	Ebunit		22.7	
	Ebuluu		9.1	
	Ikhulule	50.0		
	Madere kesabare	20.0		
	Nafusi	30.0		
	Enyaikuro			13.0
	Enyaikuro new			4.3
	Marege			39.1
	Enyankundi			13.0
	Omokomoni			4.3
	Enyandabu			17.4
	Ekebareranchera			4.3
	Epalata		22.7	
	Oleuro		4.5	
	Aaran		13.6	
	Emugogoloit		9.1	
	Ekajua		4.5	
	Obokorit		4.5	
	Kababa			4.3
	Total	100.0	100.0	100.0
3.	Emumware		14.3	
	Ebunit		21.4	
	Ebuluu		21.4	
	Ikhulule	20.0		
	Madere kesabare	60.0		
	Enyaikuro			6.7
	Enyaikuro new			6.7
	Marege			33.3
	Enyankundi			13.3
	Omokomoni			6.7
	Enyandabu			13.3
	Ekebareranchera			6.7
	Epalata		14.3	
	Aaran		28.6	
	Namala	20.0		
	Kababa			13.3
	Total	100.0	100.0	100.0

Top ranked varieties in the districts were acquired at different times. The top ranked variety in Busia, Ikhulule, had been in the area as the oldest participating farmer could remember acquiring it in 1951, and it appeared to be the oldest in the three systems. Teso and Nyamira acquired their best varieties, Aaran and Enyaikuro in the mid 1970s.

All participating farmers in Busia were certain their top ranked variety Ikhulule was their local variety, while 94% in Teso thought their top ranked variety Aaran was local and 6% thought it was improved. In Nyamira, 95% of farmers knew their top ranked variety Enyaikuro as local and 5% thought it was improved.

Farmers acquired the top ranked varieties from either the common market or neighbour/ relative across the three districts (Table 15). Majority, however, acquired from neighbour/ relatives (67% in Busia, 83% in Teso and 86% in Nyamira). Majority of farmers acquired their seasonal seed from their own stocks. All Teso farmers acquired their seed from their own stocks, Nyamira up to 96% acquired from their own stocks. It is only in Busia where substantial percentage of farmers acquired their seasonal seed from the local market (34%). Majority of participating farmers were still cultivating the top ranked varieties. Few farmers who had discontinued cultivating the top ranked variety in Busia cited lack of labour, lack of seed, and poor dark colour as their reasons for discontinuation. The only farmer who was not cultivating Enyaikuro in Nyamira cited lack of seed. There was no reason for stoppage of cultivation of top ranked variety in Teso. Generally a negligible number of farmers had stopped growing the best variety in the district.

Table 15a. Participating farmers source of seed for top ranked variety on acquisition and seasonally, continuing planting, discarded and year of discarding by district

	Busia (Ikhulule) (n=24)	Teso (Aaran) (n=24)	Nyamira (Enyaikuro) (n=25)
Source	%	%	%
	Initial seed source		
Open market	33.3	17.6	13.6
Neighbour/relative	66.7	82.4	86.4
Total	100.0	100.0	100.0
	Seasonal seed source		
Own seed	58.3	100.0	95.5
Open market	33.3		4.5
Neighbour/Relative	8.3		
Total	100	100	100

Farmer preferences and attributes of top ranking varieties

Participating farmers from Busia listed desirable attributes in their top ranking variety of Ikhulule as high yielding, early maturing, no bitter taste, blends with cassava/maize to

appealing brown colour, and resistant to bird damage (Table 15b). Teso farmers listed desirable attributes in their top ranked variety Aaran as high yielding, early maturing, large head size, no bitter taste, and blends with cassava/maize to improve palatability of food products. Nyamira farmers listed the desirable attributes in their top ranking variety Enyaikuro as high yielding, early maturing, blast disease resistant/tolerant, dark brown grain colour, tolerant to drought, and no bitter taste. Participating farmers in Busia listed negative attributes in their top ranked variety Ikhulule as black colour, low yield, hard to thresh, and late maturing (Table 15b). Hard to thresh and late maturity were the biggest negatives attributes for Ikhulule. The negatives in Aaran as listed by Teso farmers were bitter taste, lodging, disease attack, low yield and hard to thresh, with hard to thresh being the biggest negative followed by lodging and disease attack. In Nyamira, hard to thresh was the biggest negative followed by low yield in their top ranked Enyaikuro.

Table 15b. Participating farmers list of good and bad attributes for the top ranked variety by district

	Busia (n=24)	Teso (n=24)	Nyamira (n=24)
	Ikhulule	Aaran	Enyaikuro
Variety Attribute	%	%	%
Desirable attributes of top ranked variety			
High yielding	54.5	5.9	72.7
Early maturing	9.1	76.5	9.1
Disease resistance/tolerant			4.5
Large ear size		5.9	
Dark brown grain color			4.5
Drought tolerance			4.5
Not bitter to taste	9.1	5.9	4.5
Blends with cassava/maize into palatable brown dishes	18.2	5.9	
Resistant to birds damage	9.1		
Total	100	100	100
Negative attributes of top ranked variety			
Bitter taste		11.1	12.5
Colour (Dark brown)	12.5		
Lodging characteristics		22.2	
Disease attack		22.2	12.5
Low yield	12.5	11.1	25.0
Hard to thresh	37.5	33.3	37.5
Late maturity	37.5		12.5
Total	100	100	100

Attributes, preferences and varieties turnover

A total of 33% participating farmers in Busia, 63% in Teso and 40% in Nyamira reported to have discontinued planting varieties at one time or another (Table 16a). Varieties Ikhulule,

and Madere Kesabare were the most listed as dropped in Busia, Emumware and Epalata in Teso and Marege in Nyamira. Top ranked varieties above were rarely discontinued, except Ikhulule in Busia. Aaran in Teso and Enyaikuro in Nyamira were listed as discontinued by only one person each.

Table 16a. Participating farmers list of discontinued varieties by district

	Busia (n=8)	Teso (n=15)	Nyamira (10)
Variety	%	%	%
Emumware		33.3	
Ebunit		13.3	
Ebuluu		6.7	
Ikhulule	37.5		
Madere kesabare	37.5		
Enyaikuro			10.0
Marege			60.0
Nyakundi			20.0
Nyandabu			10.0
Agriculture	12.5		
Namala	12.5		
Epalata		26.7	
Emumware, Eleuro & Ebuluu		6.7	
Emumware, Ebunit & Aaran		6.7	
Emumware		6.7	
Total	100.0	100.0	100.0

Majority of farmers discontinued varieties after two years, except in Nyamira where many discontinued after one year (Table 16b).

Table 16b. Participating farmers years of cultivating a variety before dropping it by district

	Busia (n=8)	Teso (n=15)	Nyamira (n=10)
Years of cultivation	%	%	%
1	14.3	21.4	37.5
2	42.9	28.6	25.0
3	14.3	14.3	25.0
5	14.3	7.1	
9		7.1	
10			12.5
15		7.1	
16		7.1	
20		7.1	
52	14.3		
Total	100	100	100

Reasons for discontinuing a variety are listed in Table 16c and suggest attributes farmers would not like to have in their varieties. Late maturity was the attribute most listed by farmers as reason for discontinuing a variety across the districts.

Table 16c. Participating farmers reasons for discontinuing a variety by district

	Busia (n=8)	Teso (n=14)	Nyamira (n=10)
Reason for dropping variety	%	%	%
Late maturity	25.0	64.3	30.0
susceptable to diseases	12.5	7.1	10.0
Lodging characteristics		7.1	30.0
Low yield & bird damage	12.5		20.0
Lack of seed	12.5	7.1	
Small grain size	12.5		
Bitter taste	12.5	7.1	10.0
Susceptability to drought	12.5		
Low market price		7.1	
Total	100.0	100.0	100.0

Varieties ranked number one above were the varieties listed as most adopted, except Ikhulule in Busia (Table 16d). Aaran was listed by 40% of respondents as newly adopted in Teso and Marege and Enyaikuro by 63% of the respondents in Nyamira.

Table 16d. Participating farmers new adopted varieties by district.

	Busia (n=7)	Teso (n=15)	Nyamira (n=11)
New Variety	%	%	%
Emumware		6.7	
Ebunit		6.7	
Ebuluu		6.7	
Ikhulule	14.3		
Madere kesabare	28.6		
Nafusi	42.9		
Nyaikuro			9.1
Marege			9.1
Nyakundi			9.1
Ekebareranchera			9.1
Namala	14.3		
Aaran		40.0	
Epalat		13.3	
Ebunit & Aaran		6.7	
Epalata, Ebuluu & Ebunit		6.7	
Aaran & Epalat		6.7	
Epalata, Ebunit & Aaran		6.7	
Enyaikuro & Marege			63.6
Total	100.0	100.0	100.0

Attributes listed as reasons for taking up a new suggested attributes farmers desired in their varieties and high yield and resistance to bird damage were the most cited attributes in Busia, early maturity was the most cited in Teso and high yield in Nyamira (Table 17e).

Table 16e. Participating farmers reasons for adopting new varieties by district.

	Busia (n=8)	Teso (n=15)	Nyamira (n=11)
Reason for new variety	%	%	%
High yield		13.3	45.5
Early maturity	25.0	73.3	36.4
Tolerant to lodging			9.1
Drought tolerance	12.5		
High yield and Resistance to bird damage	50.0	6.7	
Taste & Marketable	12.5		
Early maturity & High yielding		6.7	9.1
Total	100.0	100.0	100.0

Finger millet production constraints

Participating farmers listed blast disease caused by *Pyricularia grisea*, *Striga hermonthica*, wild FM (*Eleusine Africana* or *Eleusine indica*), birds, rats, termites, lack of market, labour shortage, and low yield as their FM production constraints. The farmers listed what they thought were causes for blast disease, *Striga* and wild FM. In Busia, two of three who responded thought it was drought and one thought it was soil borne pathogens. In Teso, of the seven people who responded, two thought it was heavy rains. In Nyamira, 5 out of 10 who responded thought it was heavy rain and three thought it was weather changes. For *Striga*, majority of those who responded (12 in Busia and 12 in Teso) thought it was caused by low soil fertility. Farmers in Nyamira did not list *Striga* as a constraint. Wild FM was listed as a problem only in Teso and farmers there thought it was caused by low soil fertility.

Participating farmers coping strategies for finger millet production constraints

Farmers list of coping strategies for the various production constraints they faced in FM cultivation is presented in Table 17 below. For blast, majority of farmers had no solution. For *Striga*, the farmers' strategy was uprooting. For wild FM, the farmers who responded across the districts manage it by uprooting. Bird damage is another constraint to farmers and majority of the farmers mentioned scaring as a strategy to manage the problem. A few farmers mentioned availability of resistant varieties. Other significant constraints farmers mentioned were labour shortage, lack of markets, and low yields.

Table 17 Participating farmers listing of coping strategies for finger millet production constraints by district.

		Busia (n=24)	Teso (n=24)	Nyamira (n=25)
Constraint	Coping strategy	%	%	%
1. Blast	Early planting	12.5	10	
	Planting resistant varieties		10	10
	Nothing	75	40	80
	uses ash	12.5		
	Uproot affected plants		40	10
	Total	100	100	100
2. *Striga*	Uprooting	70.6	94.4	
	Manure application	23.5	5.6	
	Crop rotation	5.9		
	Total	100	100	
3. Wild f. millet	Uprooting	100	100	100
	Total	100	100	100
4. Birds	Scaring	90.9	92.3	100
	Bird resistant varieties	9.1	7.7	
	Total	100	100	100
5. Rats	Trapping	100		100
	Total	100		100
6. Termites	Chemical control	100		
	Total	100		
7. Lack of market	Sell at farm gate			100
	Value addition		100	
	Total		100	100
8.Labour shortage	Hire labour	37.5	40.0	25
	Use family labour	37.5	20	50
	Reduce f. millet acreage	25	40	25
	Total	100	100	100
9. Low yield	-	-	-	-

Participating farmers sources of information on finger millet production

The majority of farmers across the districts mentioned that they got some external information on FM cultivation (67% in Busia, 58% in Teso and 80% in Nyamira). They mentioned extension agents, research scientists, non-governmental organizations and other sources as sources of information in their FM cultivation and ranked them as in Table 18 below. Other sources, which included other farmers and neighbours, seemed to be the most important sources of information on FM cultivation. Farmers mentioned that they learn from their information sources matters on general FM cultivation and value addition.

Table 18. Participating farmers ranking of their FM production sources of information

		Busia (n=19)	Teso (n=22)	Nyamira (n=23)
Rank	Source	%	%	%
1.	Extension agent	21.4	35.7	25.0
	Research scientist	7.1		5.0
	NGO's		14.3	
	Other farmers	71.4	50.0	70.0
2.	Extension agent	33.3	37.5	
	Research scientist	33.3		
	NGO's		12.5	
	Other farmers	33.3	50.0	100.0
3.	NGO's	100.0		

DISCUSSION

Demographic and farm socio-economics

The high turn out of farmers of both gender during the PRA enabled successful execution of the exercise. Views of a wide adult age range (25 - 80 years) were obtained and were important in elucidation of finger millet cultivation and trends. The high turn-out indicated the willingness of farmers in the three districts to work with development agencies.

On the basis of land ownership and pieces of land placed under finger millet each season, on average ranging from 0.92–23.00 acres and 0.42–1.72 acres across the districts, respectively, finger millet farmers in the three districts fitted the description of peasant farmers despite slightly larger per capita land ownership in Teso. This confirmed the wide held belief that finger millet is cultivated by small scale peasant farmers (CGIAR, 2001 and Takan et al., 2002). This indicated that new varieties developed had to be productive under low input conditions.

The position of finger millet in the farming systems

Finger millet was still a very important crop in the three districts as seen in its high ranking as a food crop and cash crop, especially in Teso district where it shared the number one ranking with cassava as a food crop. In Teso and Busia districts, FM is mixed with cassava to make flour used to make ‘Ugali’ or ‘Uji’ (porridge), the two staple foods in the region. Finger millet was the number one cash crop for most farmers in the districts except in Nyamira where it mostly ranked second after tea. The high ranking of FM, cassava and maize in the three districts as both food crops and cash crops underscores their importance in the region as earlier reported (Holt **,** 2000; Takan et al., 2002; Obilana et al., 2002). The

value of the crop in the communities is also reflected in the number one ranked advantages over the other crops the farmers cultivated. The much acknowledged excellent storability (Lenne, 2006) and nutritional value (NRC, 1996) were rated high as advantages. This high ranking of finger millet among crop enterprises calls for effort to improve the crop's productivity through breeding.

Finger millet varieties grown and variety selection criteria

The study revealed that farmers had a wide range of varieties in the communities, but most plant one variety that they deem to offer the best potential for yield and market value in a season, especially in Busia and Teso. In Nyamira farmers tended to plant more than one variety in a season but in pure stands for the same reason, potential for high yield and market value. This observation is in line with that of Bellon (1996) that small-scale farmers choose to grow more than one variety of a given crop simultaneously to address numerous concerns, which no single variety would satisfy. This finding suggested that development of new varieties with most farmer desired traits needed to take center stage in a finger millet breeding program.

The many varieties listed in a district would reflect the effort of farmers in trying to find the best options. Farmers ranking of varieties were based on the good attributes they contained. The ranking criteria attributes reflect what the farmers would want in their varieties. These results indicated that for any variety to be acceptable in these areas, they have to be, as a matter of priority, high yielding. The need for high yielding varieties was seen in the observed low average yields of between 500 and 700kg ha^{-1} recorded in the study against a potential of 5,000 – 6,000kg ha^{-1} (NRC, 1996). Many finger millet farmers landraces have characteristic low yields and farmers frequently identify it as a need in their varieties (Riley et al., 1993; Gowda et al., 2000; Lenne et al., 2006).

Early maturity was the next important attribute, especially in Teso where the majority cited it as the most important attribute of Aaran, their best variety. This was in line with the conventional breeding wisdom of breeding for early maturing varieties (Valdez, 2007) that escape drought, diseases and pests and other adverse environmental conditions, on top of early harvests that save communities from hunger. Early maturity trait was also found to be valued among farmers by Gowda et al. (2000) and Lenne et al. (2006). Taste was also an important attribute across the districts and farmers preferred varieties without bitter taste. Large head size, a component of yield, was unique to Teso, resistance to birds was unique to Busia, and dark grain colour, disease and drought tolerance were unique to Nyamira. The finding that farmers in Nyamira value the attribute of disease resistance is in line with Lenne

et al. (2006) who found blast resistance as an attribute farmers preferred in their variety, but at variance with Lenne et al. (2006) finding that farmers preferred white grained varieties. The variance could be due to diversity of uses in different communities. Generally unique regional varietal requirement would require breeding different varieties for different regions. However, the findings in this study indicated that unique requirements were not the kind to lead to variety rejection but rather reflected the gravity of a constraint in one region relative to another. For, example, the need for blast resistance in Nyamira was mainly due to the high prevalence of the disease in Nyamira due to climatic conditions and does not mean a blast resistant variety will be rejected in the other districts.

Farmers identified negative attributes in their best varieties in each district, which suggested what they did not want in their ideal variety. Farmers' identification of negative attributes in their best varieties suggested that farmers recognised the need for improvement of their cultivars and breeding of better varieties of finger millet is still a priority. Farmers' failure to mention *Striga* susceptibility as a negative attribute in their varieties could be due to their failure to see it as a variety property. Most of them saw *Striga* susceptibility as an environmental rather than a crop property as most mentioned *Striga* to be caused by low soil fertility. They however noted *Striga* as the second important constraint in Teso and Busia, where it is prevalent.

The presence of many varieties and history of new varieties adoption and discontinuation of old ones in a district farming system would indicate the continuous effort of farmers to get the best varieties possible for their cultivation and recognition of the need to improve their varieties, echoing reports by Oosterhout (1993) and Teshome et al. (1999) that traditional farmers are researchers in their own rights. Farmers were able to identify both positive and negative attributes in their high ranked varieties. This was additional evidence that farmers make informed decisions in as far as variety adoption or discontinuation was concerned and further emphasised the need to breed new and better varieties. The appearance of some attributes listed as both desirable and undesirable among district best varieties is a reflection of different farmers' expectation for each variety.

The top ranked varieties were acquired in the systems at varied time periods. Busia district's Ikhulule had stayed in the system longest, first reported to have been acquired in 1951. The highest ranked varieties in Nyamira and Teso, acquired in mid 1970s, were recent acquisitions compared to Busia. The finding of varieties staying in a system for many years indicates the potential of introduced good varieties staying long in the farming systems. The reasons for dropping a variety suggested what the farmers did not want in their ideal variety

while the reasons for adopting new varieties suggested what they wanted in an ideal variety. Varieties ranked best in the districts were rarely reported as discontinued except in Busia where Ikhulule, the best-ranked variety also recorded a high frequency of having been discontinued. Most farmers, who reported adopting a new variety, cultivated the variety for two seasons before dropping it, if they did not continue cultivating it. This would indicate that most farmers took up a variety on trial basis and if it did not satisfy their expectations in two seasons they dropped it. This variety turnover in the three districts would reflect the high potential for uptake of new and better varieties from research agencies and underscores the need for continuous improvement of cultivars. The high variety turnover could also indicate that the varieties farmers tried out were varieties that had not gone through formal research to establish their superiority hence high frequency of failure to meet farmers' expectations. This would be expected because no sound breeding programme existed previously in Kenya and KARI had not formally released finger millet varieties.

Finger millet production constraints

Farmers had several constraints in their finger millet cultivation and some coping strategies. For blast, majority of farmers had no solution. This means that research has to work with speed to find a solution, either breed new varieties with blast resistance or some control method. Breeding for resistant varieties looks a viable option considering the poverty status of FM farmers as reported by Roumen (1992). For *Striga*, the farmers' strategy was uprooting. The problem is that the farmers have been practicing uprooting *Striga* plants from the colonial times but the problem has never gone away. A viable solution needs to be found, either development of workable cultural control methods (Oswald, 2005) or breeding for varieties with resistance to *Striga* attack (Kim et al., 2004; Ejeta and Gressel, 2007). Breeding for resistance to *Striga* in finger millet has never been reported and may probably take off through work reported herein. Farmers in Nyamira did not recognize *Striga* as a constraint because Nyamira is a highland district with temperate climate and *Striga* being a tropical hot climate lowland weed does not grow there.

For wild FM, the farmers who responded across the districts manage it by uprooting. This is probably the only way to control this grass, which resembles FM (Haore et al. 2007) and can only be distinguished at flowering thus causing a lot of crop loss. Bird damage is another constraint to farmers and majority of the farmers mentioned scaring as a strategy to manage the problem. A few farmers mentioned availability of resistant varieties and probably this is something for breeders to follow up. Other significant constraints farmers mentioned were labour, lack of markets and low yields. For labour, it is a challenge to researchers to look for cultural practices that would alleviate the intensity of labour required in cultivating FM e.g.

appropriate row spacing and even investigate the possibility of using herbicides in weeding. The possibility of mechanization to ease operations like weeding, harvesting and post harvest processing may need investigation. For lack of market, farmers justifiably add value, which needs to be bolstered by government policies in favour of the crop. For low yield, the challenge again is for researchers to develop high yielding varieties and cultural practices that enhance yield e.g. optimal plant population densities, use of fertilizers and other soil amendment practices.

Some observations came out that would have a bearing on breeding and dissemination of new varieties. The lack of common variety names across the districts would suggest that farmers in the three districts planted different varieties. However, if one looked at what the names describe like Nafusi in Busia, Ebunit in Teso and Enyankundi in Nyamira, all of them refer to fist i.e. fist headed in Luhya language in Busia, Teso language in Teso and Kisii language in Nyamira. There could be a chance that these represent one variety. Variety descriptive names such as was observed was noticed by Tsehaye et al. (2006) in the Tigray region of Ethiopia. It would be interesting to follow up this study with a study of the varieties with names that mean the same in the three languages of the three districts. In this light, it may not be necessary to start breeding for each region independently, but test elite material in the communities to identify varieties suited for the regions.

The source of acquired new varieties would give an indication on placement of new varieties in farming communities for easy spread. From this study, majority of farmers acquired the varieties from neighbours/relatives. New varieties would, therefore, best spread if they were introduced through fellow farmers e.g. farmer managed on-farm demonstrations. The fact that majority of farmers acquired their seasonal seed from their own stocks would rule out seed business as an avenue for new varieties and use of hybrid varieties. Most farmers also indicated that they got most of information on finger millet cultivation from fellow farmers.

CONCLUSIONS

Finger millet was important among the crop enterprises of farmers in Busia, Teso, and Nyamira districts and was evident in its high ranking by participating farmers both as a food and cash crop. It was valued for its special attributes long storability, high nutritional value, good marketability and tolerance to drought and low fertility conditions. Several finger millet varieties were planted in a district, but each district had a most popular variety and Ikhulule was the most popular In Busia, Aaran in Teso and Enyaikuro in Nyamira. Farmers tested new varieties and discarded old ones based on the following selection criteria: high yield potential; early maturity; resistance to blast disease, *Striga*, birds, drought, and lodging; large

head size; dark grain colour; and lack of bitter taste. High variety turn-over among farmers indicated their willingness to experiment with new varieties. Farmers' encountered the following constraints in FM cultivation: blast disease, *Striga* weed, wild FM (weeding), birds damage, rats as a pest, termites, lack of market, labour shortage, and low yield. These findings underscored the need for enhanced finger millet research, especially breeding of new superior varieties.

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CHAPTER 3

Finger millet genotypic variability and path analysis of yield components

ABSTRACT

Finger millet (*Eleusine coracana* (L.) Gaertn. ssp. *coracana*) is an important food, food security and cash crop in Africa. However productivity is low and little research has been done on the crop. The objectives of this study were to determine finger millet trait variability and association and to identify genotypes with high potential for use as sources of desirable traits for breeding new varieties. Some 310 local and international accessions were evaluated at two sites in a 24 row x 16 column arrangement with three check varieties uniformly interspersed at each site during the 2005 long rain (LR) season in western Kenya. There was wide trait genotypic variation for yield and secondary traits. Yield ranged between 31 and 7,833kg ha^{-1} with the best accessions KNE 072, GBK 028463, GBK 029661, FMBT ACC#42 obtaining record yields greater than 6,000kg ha^{-1}. Eighteen accessions were highly resistant to foliar blast, 20 to neck and head blast (NHB), 13 to shootfly, 16 did not support *Striga*, 109 did not lodge, 10 flowered between 64 and 68 days and 7 matured in 100 days. Seedling vigour, plant height, lodging, plant stand and single plant yield (SPY) were significantly correlated with grain yield. Foliar blast, *Striga* counts at flowering (SCF) and at maturity (SCM) significantly negatively affected yield. Foliar blast affected yield more than NHB and SCF affected yield more than SCM. The wide trait variability indicated high potential to breed new and better finger millet varieties. Yield could be selected for directly because of its wide variability while its indirect selection would exploit seedling vigour, which was highly correlated to yield and had direct and indirect positive effects on yield through plant height and SPY.

Key words: Finger millet, genotypic variation, path analysis, yield, blast, *Striga*

INTRODUCTION

Finger millet is an important food, food security and cash crop in Africa that is indigenous to East Africa. Mitaru et al. (1993) reported farmer grain yield of 500-750kg ha^{-1} in Kenya which is very low compared to 5,000-6,000kg ha^{-1} attainable under ideal irrigated and research conditions (National Research Council, USA (NRC), 1996; Duke, 1978). The low yields are a manifestation of the poor attitude and low research input accorded the crop (Fakrudin et al. 2004; Bedis et al., 2006a; Upadhyaya et al., 2006). Use of poor unimproved landraces susceptible to finger millet blast disease and *Striga* are major contributors to low yields in Kenya. The Consultative Group on International Agricultural Research (CGIAR) (2001) and the NRC (1996) believe more research can lead to yields of 'green revolution' cereals of rice and wheat.

Few workers have applied characteristic interrelationship techniques in a study of finger millet genotypes. Bondale et al. (2002), Bezaweletaw et al. (2006), and John, 2006, are among the few. A few studies have also revealed genetic diversity in finger millet. Fakrudin et al. (2004) and Das et al. (2007) found high levels of genetic diversity among finger millet genotypes and Madhukeshwara et al. (2004) found variability in NHB resistance. All this work on finger millet germplasm studies was done in India on Indian germplasm, except Bezaweletaw et al. (2006) who studied Ethiopian germplasm. No such studies have been carried out on finger millet germplasm from other parts of Africa, even East Africa where the crop is very important. Such studies are required to provide information on which to base finger millet breeding programmes in East Africa, and specifically Kenya.

Information on character correlations and character contribution to yield are pertinent to an efficient breeding scheme (Toker and Cagirgan, 2004) and exploit the tendency of traits to be related in nature (1992). Other than indicating relatedness of traits, path coefficient analysis gives more information than simple correlations by breaking down the relationships into component direct and indirect effects, thus indicating the importance of each component in determining a trait of interest, that is frequently yield (Dewey and Lu, 1959; Guler et al., 2001; Garcia del Moral et al., 2003; Das et al., 2004). The use of correlation coefficients together with path coefficient analysis to understand trait relationships has been extensively reported (Diz et al., 1994; Board et al., 1997; Bezaweletaw et al., 2006), but little literature exists on the same in finger millet, especially in East Africa. Bezaweletaw et al. (2006) found finger millet grain yield per plant to be significantly negatively correlated to days to heading and days to physiological maturity. However, through path coefficient analysis, they found days to heading to have high positive direct effect on grain yield per plant and days to

maturity had very high negative direct effect. Large scale germplasm evaluation was found useful in crop improvement by Annicchiarico et al. (2000) and Upadhyaya et al. (2006) who used among other tools, mean comparisons and frequency distribution methods to characterize finger millet germplasm. Over 300 accessions of finger millet are held at KARI-Kakamega, which if evaluated for trait variability and association would serve as a foundation for the nascent finger millet breeding programme.

Research objectives

To identify germplasm with desirable agronomic and breeding traits with potential to contribute to enhanced finger millet breeding, yield and production in Kenya. The specific objectives for this study were to:

i. Study trait variability among 310 finger millet accessions at KARI-Kakamega and identify genotypes with blast and *Striga* resistance, good agronomic traits and high yield and
ii. Study correlation coefficients among finger millet traits and grain yield components to determine their direct and indirect effects on yield.

Hypothesis

There is large genotypic variability among finger millet germplasm at KARI-Kakamega that can be exploited to develop new high yielding varieties with farmer desired traits and resistance to blast disease and *Striga* pest.

MATERIALS AND METHODS

Experimental design and management

This work was done at the Kenya Agricultural Research Institute Centres of Kakamega (00^{o} 16' N; 34^{o} 45' E; 1585masl) and Alupe (00° 30' 0 N; 34° 7' 50 E; 1170masl) in the western part of Kenya during 2005LR. The soils at Kakamega are Dystro-mollic Nitisol with pH of 5.2, and Ferralo-orthic Acrisol with pH of 5.0 at Alupe (FURP, 1987). The total annual rainfall at Kakamega in 2005 was 1,695mm and at Alupe 1,484mm. Temperature ranged from 14-32℃ at Kakamega and 15-33℃ at Alupe durin g the year.

A total of 310 accessions sourced from KARI-Kakamega, ICRISAT and the Genebank of Kenya were used. This germplasm comprised local and international accessions which had not been described except for the check varieties Gulu-E, U-15, and ACC.# 1,00007. Gulu-E is a tan medium maturity, medium height and high yielding genotype; U-15 is a purple

early maturity, high yielding, and medium height genotype; and ACC. # 1,00007 is a purple blast susceptible early maturity genotype.

The evaluation nursery was laid out in unreplicated 24 row x 16 column arrangement with the three check varieties uniformly interspersed at each site during the 2005LR season (Appendix 1). A plot comprised of two rows of 2m each spaced at 0.3m apart. Intra-row spacing was 0.15m. Between rows spacing within a column was 0.5m and between columns was 1m. The Kakamega nursery served to screen for blast resistance and the Alupe nursery to screen for both blast disease and *Striga* resistance. At Kakamega, known blast disease susceptible varieties KAT FM-1 and Acc.# 1,00007 were used as blast disease spreaders. KAT FM-1 was planted in two rows around the experiment, while Acc.# 1,00007 was one of the check varieties that were uniformly interspersed in the row x column arrangement. At Alupe, the nursery was planted on a field previously inoculated with *Striga hermonthica* seed. Fertilizer rates of 20kg ha^{-1} each of N and P_20_5 were applied and the crop kept clean by hand weeding.

Seedling vigour, plant colour and ear shape were rated on a scale of 1-3:

Where seedling vigour	1 = highly vigorous,
	2 = vigorous and
	3 = low vigour.
Plant colour	1 = green,
	2 = purple and
	3 = other.
Ear shape	1 = open headed,
	2 = incurved and
	3 = fist.

Plant height, the length from ground level to the tip of the head, was measured at physiological maturity on three representative plants in a plot and the average recorded. Lodging percentage was the number of lodged plants in a plot expressed as a percentage of plant stand. Finger branching was the absence = 1 or presence = 2 of spike branching in the plot. In scoring for shootfly and foliar and neck and blast (NHB) disease incidence, the scale used by Mantur and Madhukeshwara (2001) was adopted where:

1	=	0.0% disease incidence	=	highly resistant;
2	=	1.0-2.0% disease incidence	=	resistant;
3	=	2.1-10.0% disease incidence	=	moderately resistant;
4	=	10.1-25.0% disease incidence	=	moderately susceptible;
5	=	>25% disease incidence	=	susceptible.

Days to 50% flowering (D50) and days to physiological maturity (DPM) were the number of days from planting to when 50% of plants in a plot flowered and reached physiological maturity, respectively. *Striga* counts were taken at 50% flowering and at physiological maturity by uprooting and counting all *Striga* plants within and 25 cm around the plot. Plant stand was a count of the number of plants per plot at harvest. Yield per plot was the weight of clean grain resulting from threshed and winnowed plot harvest. Single plant yield (SPY) was determined by dividing yield per plot by plant stand. Yield in kg ha^{-1} was estimated from yield per plot using the formula:

$$Y = \frac{1{,}0000 \times (X/1{,}000)}{A}$$

Where Y = yield in kg ha^{-1},

X = plot yield in g

A = Plot area = no. of rows x row spacing x row length (2x0.3mx2m)

Data analysis

Pearson correlation coefficients between traits were generated using the SAS PROC CORR procedure (SAS Institute, 2003) over the two locations. Path coefficient analysis for yield was carried out as demonstrated by Dewey and Lu (1959), but in the light of the many accessions studied over two locations and Sumathi et al. (2007) observation of little environment role in expression of finger millet traits, phenotypic correlations were used. Frequency distributions and range were used to study characteristic variation (Upadhyaya, 2006).

Five traits, seedling vigour, plant height, finger branching, SPY and plant stand were included in the path coefficient analysis for yield. Simultaneous equations were drawn as per Dabholkar (1992) as below:

$$r_{10} = P_{10} + P_{20}r_{12} + P_{30}r_{13} + P_{40}r_{14} + P_{50}r_{15}$$
$$r_{20} = P_{10}r_{21} + P_{20} + P_{30}r_{23} + P_{40}r_{24} + P_{50}r_{25}$$
$$r_{30} = P_{10}r_{31} + P_{20}r_{32} + P_{30} + P_{40}r_{34} + P_{50}r_{35}$$
$$r_{40} = P_{10}r_{41} + P_{20}r_{42} + P_{30}r_{43} + P_{40} + P_{50}r_{45}$$
$$r_{50} = P_{10}r_{51} + P_{20}r_{52} + P_{30}r_{53} + P_{40}r_{54} + P_{50}$$

Where 0 = Dependant variable = Yield;

1 - 5 were independent variables

1 = seedling vigour,

2 = plant height,

3 = finger branching,

4 = single plant yield

5 = plant stand, respectively.

r = Correlation Coefficient and

P = Path Coefficient.

Simultaneous equations in the analysis were solved by matrix method (Dabholkar, 1992), where the information in the simultaneous equations above was arranged in a matrix form as:

$$\begin{bmatrix} 1 & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & 1 & r_{23} & r_{24} & r_{25} \\ r_{31} & r_{32} & 1 & r_{34} & r_{35} \\ r_{41} & r_{42} & r_{43} & 1 & r_{45} \\ r_{51} & r_{52} & r_{53} & r_{54} & 1 \end{bmatrix} \quad \begin{bmatrix} P_{10} \\ P_{20} \\ P_{30} \\ P_{40} \\ P_{50} \end{bmatrix} = \begin{bmatrix} r_{01} \\ r_{02} \\ r_{03} \\ r_{04} \\ r_{05} \end{bmatrix}$$

A B C

Where matrix A is symmetrical on the diagonal unity, replacing the direct effects of 1, 2, 3, 4, and 5, respectively. The elements of the column matrix B specify the path coefficients to be estimated and column matrix C represents the correlation coefficients between the dependent variable and component variables. Estimates of the unknown path coefficients were calculated by the relationship:

$B = A^{-1}C$

Where A^{-1} is the inverse of matrix A.

The inverse of the matrix was obtained using the QuickMath Algebra Automatic Math Solutions on the Internet at:

http://www.hostsrv.com/webmab/app1/MSP/quickmath/02/pageGenerate?site=quickmath&s1=matrices&s2=inverse&s3=basic

Residual causes of variation, the multiple causes of a variable that are external to the path diagram (Loehlin, 2004) effect was solved as illustrated by Dabholkar (1992) as:

$$P^2_x = 1 - P^2_{10} - P^2_{20} - P^2_{30} - P^2_{40} - P^2_{50} - 2P_{10}P_{20}r_{12} - 2P_{10}P_{30}r_{13} - 2P_{10}P_{40}r_{14} - 2P_{10}P_{50}r_{15} - 2P_{20}P30r23 - 2P_{20}P_{40}r_{24} - 2P_{20}P_{50}r_{25} - 2P_{30}P_{40}r_{34} - 2P_{30}P_{50}r_{35} - 2P_{40}P_{50}r_{45}.$$

RESULTS

Genotypic variation

Simple statistics for all data analysed for characteristic variation and correlation during 2005 LR are presented in Table 1. All traits were recorded over 720 observations, except lodging and *Striga* counts, recorded at only one location, were over 356 observations. All score data ranged from minimum to maximum score. This was true for seedling vigour, shootfly, foliar blast, NHB, ear shape, plant colour, and finger branching. This was true also of lodging where the minimum was 0 and maximum 100%.

Table 1. Simple statistics for all data analysed for 2005LR finger millet blast and *Striga* nursery

Variable	N	Mean	Std Dev	Minimum	Maximum
Seedling vigour (score)	739	2.34	0.66	1	3
Shoot fly (score)	741	1.84	0.65	1	5
Foliar blast (score)	740	2.25	1.37	1	5
Days to 50% flowering	721	83.80	10.43	55	125
Striga count at flowering (no.)	356	32.78	49.72	0	258
Neck and head blast (score)	733	2.15	0.78	1	5
Plant height (cm)	729	85.29	17.30	39	134
Lodging (%)	356	12.74	23.10	0	100
Striga count at maturity (no.)	356	16.96	27.14	0	179
Ear shape (score)	718	1.92	0.75	1	3
Days to phys. maturity	736	115.92	9.99	76	145
Plant stand (no.)	740	25.70	10.85	1	30
Single plant yield (g)	731	16.02	12.80	1	168
Yield (kg ha^{-1})	731	2841.00	1622.00	31	7917
Plant colour (score)	736	1.22	0.42	1	2
Finger branching (score)	738	1.80	0.40	1	2

Frequency distribution charts for yield, foliar blast, SCT and lodging are presented in Figures 1-4. Figure 1 frequency chart drawn from 8 yield categories has a trend curve of regular bell shape normal distribution of yield range from the least category 0-1,000kg ha^{-1} to the 4000-5000kg ha^{-1} yield. Figure 2 generated from five categories reflecting the blast score range of 1-5 also generated an almost regular bell shape except for category 4.1-5, which was an outlier. The total *Striga* count frequency distribution showed a positive skew with most genotypes falling to the left (Figure 3). Majority of the genotypes supported less than 150 *Striga* plants per plot, with very few supporting over 250 plants per plot. Lodging was even more positively skewed with most genotypes in the 0-10% lodging category (Figure 4).

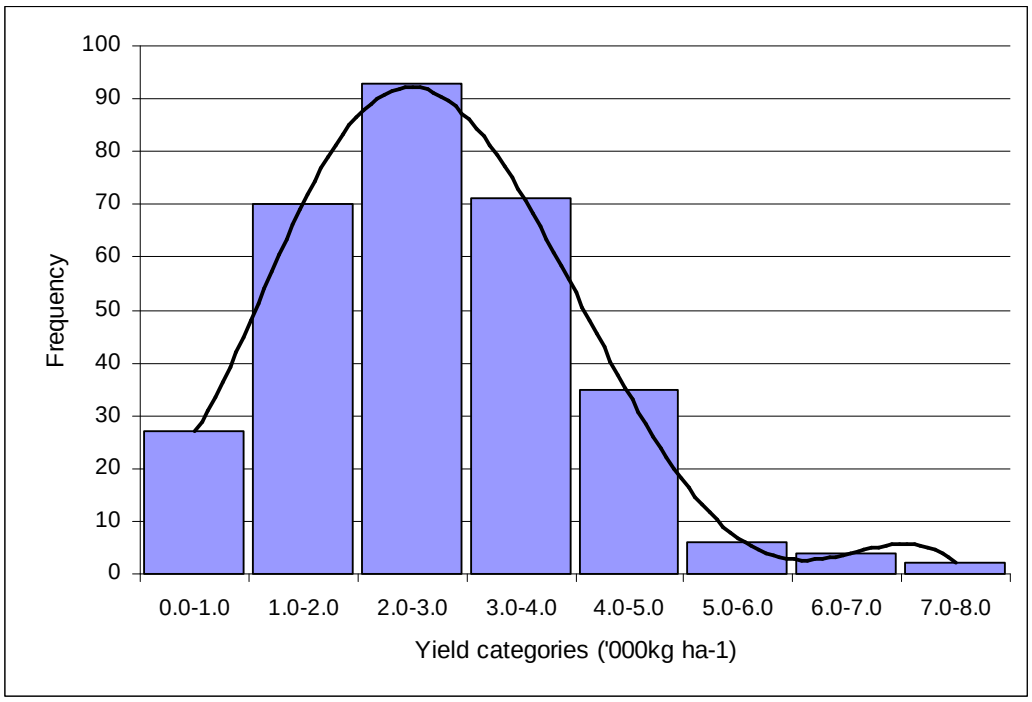


Figure 1. Finger millet yield frequency distribution for 310 accessions

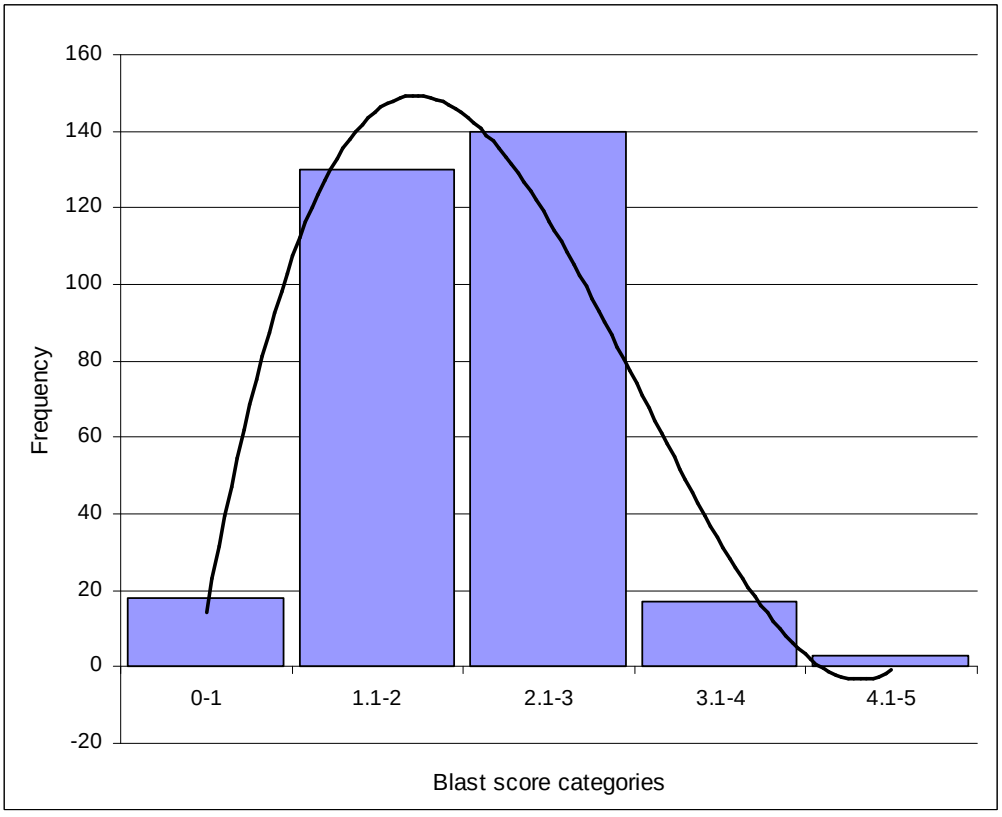


Figure 2. Finger millet foliar blast incidence frequency distribution for 310 accessions

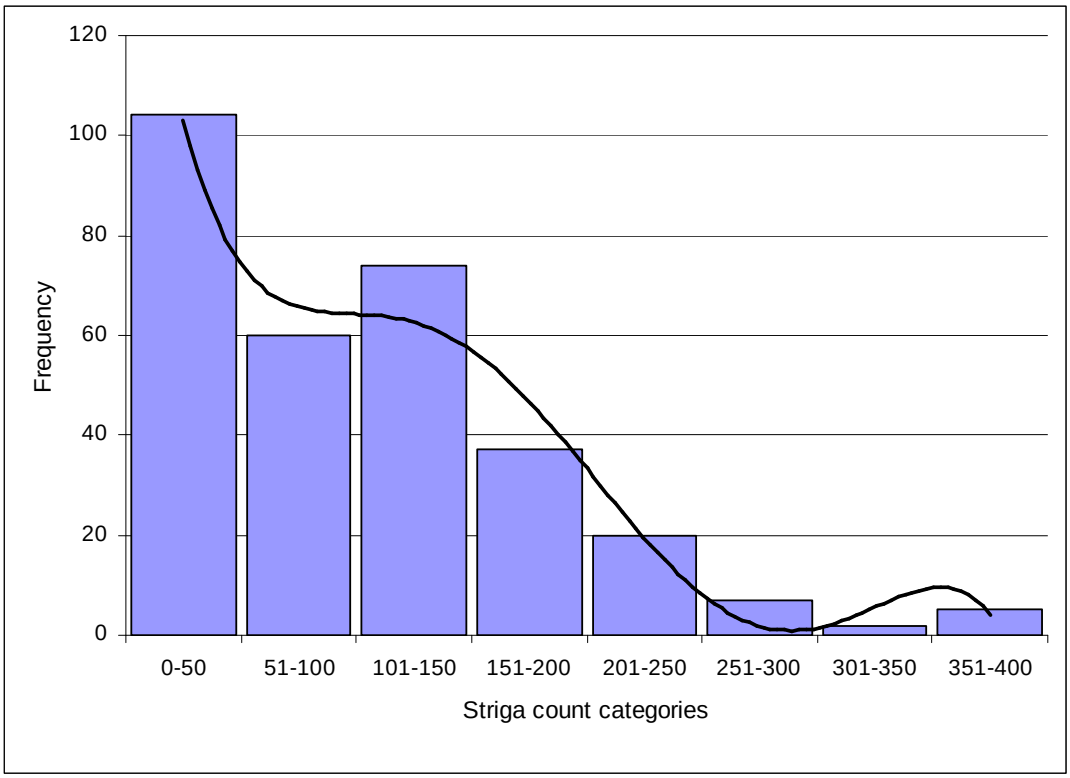


Figure 3. Finger millet *Striga* count frequency distribution for 310 accessions

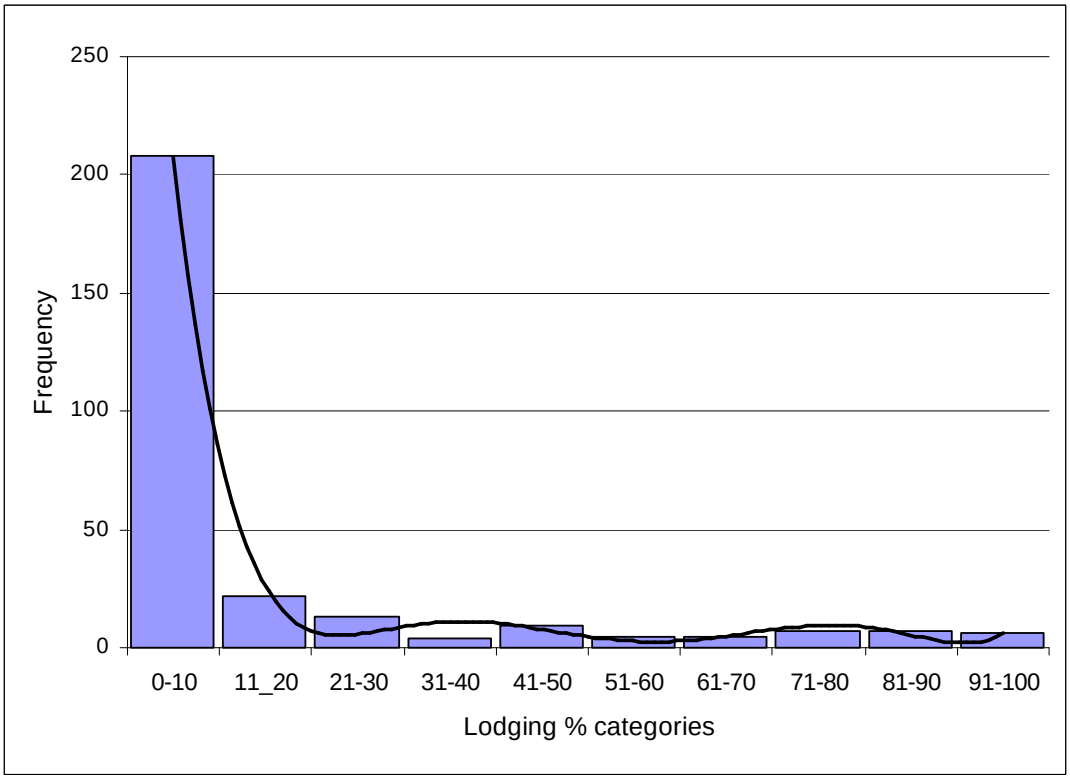


Figure 4. Finger millet lodging frequency distribution for 310 accessions

Mean Performance

The top and bottom 12 accessions for economic traits of yield, foliar blast, *Striga* counts and lodging are presented in Table 2. The top 12 accessions yield ranged from 5,408- 7,833kg ha^{-1} and bottom 12 ranged from 31- 658kg ha^{-1}. All check varieties yielded below the top 12 accessions. The best check Gulu-E yielded 4,026kg ha^{-1} and another adapted variety P-224, 4,805kg ha^{-1}. All checks were better than the bottom 12 and the worst check ACC. # 1,00007 yielded 2,085kg ha^{-1}. Of the top 12 yielding accessions, four were resistant to foliar blast: KNE 072, FMBT ACC.#42, GBK 029628F and GBK 027116. One accession did not lodge, GBK 027116. Seven of the top 12 yielding accessions did not support *Striga*. For every economic trait, there were over 12 accessions superior to all checks. The top yielding KNE 072 had seedling vigour of 1 (highly vigorous), shootfly score of 2 (resistant), foliar blast of 1(highly resistant), flowered in 91 days (medium), had zero *Striga* support at flowering. It also had NHB score of 2(resistant), plant height of 123cm (tall), lodged 30%, zero *Striga* support at maturity, open ear shape, matured in 118 days (medium), had fair plant stand of 23, had finger branching, and a high single plant yield of 41g. The second highest yielding GBK 028463 had poorer seedling vigour of 3 (low), shootfly (1.5), higher foliar blast (2.5), moderate to flower (81 days), higher *Striga* support at flowering (50), higher NHB (2.5), same lodging (30%), higher *Striga* support at maturity (27), fist head shape, moderate maturity (114 days), shorter (96cm), high plant stand (33), low single plant yield (25g), had finger branching. The third ranked GBK 029661 had features like second ranked but had very high lodging (80%).

Some poor yielding accessions did not support *Striga* - FMBT ACC.#22, KAT FM-1 and FMBT ACC.#75. Two top yielding accessions were among 12 with high lodging – GBK 029661 (6.666kg ha^{-1}) had 80% lodging and FMBT ACC#42 (6,566kg ha^{-1}) had 95% lodging. Poorest yielding FMBT ACC#56 had foliar blast of 5. Accession GBK 029782F among poorest yielding accessions (477kg ha^{-1}) was also among 12 most *Striga* infested (294 *Striga* plants per plot). Across accessions, 18 accessions were highly resistant to foliar blast and included accessions KNE 072 (7,833kg ha^{-1}), FMBT Acc.# 42 (6,566kg ha^{-1}), and GBK 02962 (5,636kg ha^{-1}). Twenty accessions were highly resistant to NHB, including GBK 029759 with 4,084kg ha^{-1} yield. Thirteen accessions were highly resistant to shootfly. Sixteen accessions did not support *Striga* at all, and these included GBK 029661 (6,666kg ha^{-1}). A total of 109 accessions, including high yielding GBK 027116 (5,536kg ha^{-1}) did not lodge. Ten accessions flowered between 64 and 68 days with the best accession Acc.# FMBP/01 WK3 yielding 4,828kg ha^{-1}, and seven accessions matured in 100 days including KNE 980 yielding.

Table 2. Yield, foliar blast, lodging, and *Striga* support means for top and bottom 12 and check finger millet accessions, 2005 LR.

Yield (kg ha^{-1})		Foliar blast (score)		Lodging (%)		*Striga* support (no.)	
	Yield	Accession	Foliar blast score	Accession	Lodging	Accession	Total *Striga*
Top 12 high yielding and resistant							
KNE 072	7833	KNE 072	1	GBK 027116	0	KNE 072	0
GBK028463	7085	FMBT ACC#42	1	FMBT ACC# 53	0	GB K029661	0
GB K029661	6666	GBK029628F	1	FMBT ACC#20	0	FMBT ACC#42	0
FMBT ACC#42	6566	GBK 027116	1	FMBT ACC#7	0	E-KR-228	0
E-KR-228	6555	FMBT ACC#17	1	KNE 828	0	P-221	0
GBK 027300	6029	GBK 033357	1	A/CSMIP 3	0	GBK029628F	0
GBK 026938	5838	FMBT ACC#81	1	FMBT ACC#17	0	GBK 027116	0
GBK 033439	5791	FMBT ACC#8	1	Pagiwande	0	KNE 828	0
P-221	5702	GBK 03937	1	GBK 027191	0	FMBT	0
GBK029628F	5636	GBK 037854	1	FMBT ACC#51	0	FMBT ACC#22	0
GBK 027116	5536	FMBT GULU E	1	FMBT ACC#9	0	KAT FM-1	0
FMBT ACC#50	5408	FMBT ACC# 66	1	Okhale-1	0	FMBT ACC#75	0
Resistant			19		109		16
Checks							
P-224	4805		2		5		150
GULU-E	4026		1.8		0		66
U-15	3459		1.7		3		114
ACC#1,00007	2085		2.6		3		94
Bottom 12 low yielding and susceptible							
FMBT ACC#22	658	FMBT ACC#69	3.5	GB K029661	80	FMBT ACC#11	274
KNE 617	613	GBK027091	3.5	GBK032247	80	FMBT ACC#3	279
GBK033560	588	FMBT ACC73	3.7	GBK 032081	85	GBK033484	288
FMBT KNE1162	502	ACC.# 18FMBP/01WK	4	GBK027186	90	GBK 029782F	294
GBK 029782F	477	ACC.# ? FMBP/01WK	4	UNKNOWN 44	90	FMBT ACC#85	300
FMBT S#77SADCC	448	GBK033240	4	GBK 027765F	90	GBK038231	304
GBK 029163	336	GBK 022355	4	FMBT ACC#42	95	GBK029126	343
UNKNOWN 47	308	GBK027141	4	GBK032044F	95	UNKNOWN 49	354
GBK027091	263	GBK 029163	4	UNKNOWN29	95	FMBT KNE1087	356
KAT FM-1	208	KNE 1015	5	GBK032282F	95	ACC. # ? FMBP/01WK	376
FMBT ACC#75	32	FMBT KNE1087	5	GBK 029784	95	KNE 671	383
FMBT ACC#56	31	FMBT ACC#56	5	UNKNOWN 38	100	KNE 820	398

Phenotypic correlation coefficients

Trait phenotypic correlation coefficients are presented in Table 3. There was highly significant positive correlation between grain yield and seedling vigour, plant height, lodging, plant stand, and SPY. There was significant positive correlation between yield and shootfly. There was also highly significant negative correlation between yield and foliar blast, SCF, and SCM. Yield and SPY had similar correlations for all traits but differed in D50, NHB, lodging, and DPM. Single plant yield was more positively correlated to shootfly than yield. There was highly significant positive correlation between seedling vigour and plant height, lodging, and SPY and highly significant negative correlation with foliar blast, SCF and SCM. Shootfly had highly significant positive correlation with D50, plant height, and DPM and highly negative correlation with foliar blast, SCF, SCM, plant stand and finger branching. Foliar blast had highly significant positive correlation with seedling vigour, SCF, SCM, plant stand and finger branching and highly negative correlation with shootfly, D50, plant height, DPM, SPY and yield. Days to 50% flowering had highly significant positive correlation with shootfly, plant height, DPM and SPY and highly negative correlation with foliar blast, SCF, lodging, SCM, plant stand, finger branching. *Striga* count at flowering had highly significant positive correlation with foliar blast, SCM, plant stand, finger branching and high negative correlation with seedling vigour, D50, plant height, DPM, SPY, and yield. Neck and head blast had only highly significant positive correlation with lodging. Plant height had highly significant positive correlation with seedling vigour, shootfly, D50, lodging, DPM, SPY and yield and high significant negative correlation with foliar blast, SCF and SCM. Lodging had high significant positive correlation with seedling vigour, NHB, plant height, and yield and high significant negative correlation with D50 and ear shape. *Striga* count at maturity had highly significant positive correlation with foliar blast, SCF and plant stand and highly signficant negative correlation with seedling vigour, shootfly, D50, DPM, SPY and yield. Ear shape had only significant positively correlation with D50 and significant negative correlation with FB, NHB and lodging. Days to physiological maturity had highly significant positive correlation with shootfly, plant height, and SPY and highly negative significant correlation with foliar blast, SCF, SCM, plant stand, and finger branching. Plant stand had highly significant positive correlation with foliar blast, SCF, SCM, and yield and highly significant negative correlation with shootfly, D50, DPM and SPY. Finger branching had highly significant positive correlation with foliar blast, SCF, and highly significant negative correlation with shootfly, D50, DPM and SPY. Looking at the total number of significant correlations, SCF, SCM 14 (each with 10 negative and 4 positive), plant height 14 (5 negative and 9 positive) had the highest followed by foliar blast and plant stand at 13 (9

negative and 4 positive and 5 negative and 8 positive, respectively), finger branching, D50, and DPM followed at 12.

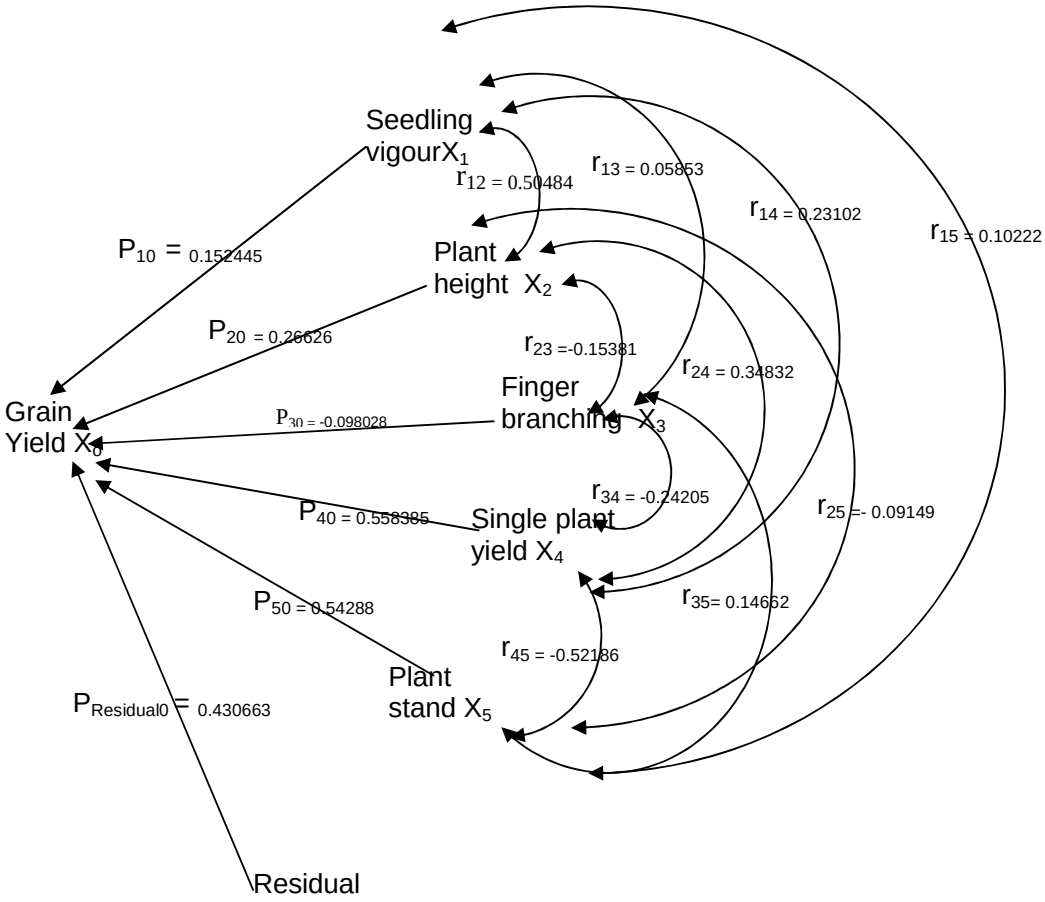
Table 3: Finger millet characteristic correlation coefficients over Kakamega and Alupe for 310 accessions, 2005 LR

	SV	SF	FB	D50	SCF	NHB	PH	LG	SCM	ES	DPM	PS	SPY	Yield	PC	FBr
Seedling vigour (SV)	1	-0.06	0.24**	0.03	0.28**	-0.05	-0.50**	-0.27**	0.25**	0.01	0.01	-0.10*	-0.23**	0.47**	-0.08*	0.06
Shootfly (SF)		1	-0.36**	0.48**	-0.28**	0.07	0.26**	-0.00	-0.29**	0.05	0.47**	-0.24**	0.17**	0.07*	0.01	-0.20**
Foliar blast (FB)			1	-0.46**	0.71**	-0.02	-0.54**	-0.02	0.53**	-0.11**	-0.52**	0.30**	-0.46**	-0.47**	-0.13**	0.28**
Days to 50% flow. (D50)				1	-0.38**	-0.14**	0.35**	-0.22**	-0.37**	0.19**	0.83**	-0.49**	0.27**	-0.04	-0.05	-0.24**
Striga count at flow. (SCF)					1	-0.15**	-0.60**	-0.02	0.66**	-0.09*	-0.45**	0.31**	-0.42**	-0.44**	-0.11**	0.27**
Neck and head blast (NHB)						1	0.14**	0.22**	-0.18**	-0.19**	-0.07	0.08*	-0.06	0.05	0.06	-0.03
Plant height (PH)							1	0.26**	-0.54**	0.04	0.42**	-0.09*	0.35**	0.50**	0.08*	-0.15**
Lodging (LG)								1	.	-0.24**	-0.20**	0.15**	0.06	0.25**	0.08	-0.11*
Striga count at maturity(SCM)									1	-0.08*	-0.44**	0.31**	-0.36**	-0.34**	-0.12**	0.26**
Ear shape (ES)										1	0.18**	-0.05	0.06	0.04	-0.17**	-0.10**
Days to phy. Maturity (DPM)											1	-0.42**	0.25**	0.05	-0.10**	-0.26**
Plant stand (PS)												1	-0.52**	0.23**	-0.04	0.15**
Single plant yield (SPY)													1	0.43**	0.06	-0.24**
Yield														1	0.09*	-0.19**
Plant colour (PC)															1	0.02
Finger branching (FBr)																1

*, ** significant at the 0.05 and 0.01 levels of probability, respectively.

Path Coefficient Analysis

A path coefficient analysis diagram and table are presented in Figure 5 and Table 4, respectively. Figure 5 illustrates independent variable direct effects on dependent variable and correlation coefficients among independent variables, while Table 4, in addition, gives indirect effects for each independent variable on the dependent variable. Among the five independent traits (causal), four of them had positive direct effect on yield (dependent). These were seedling vigour (0.15), plant height (0.27), single plant yield (0.56), and plant stand (0.54). Finger branching had negative direct effect (-0.10). Single plant yield had the largest direct effect on yield, followed by plant stand, plant height, seedling vigour and last, finger branching. Single plant yield also had high indirect negative effect through plant stand (-0.28). Plant stand had the highest indirect negative effect through SPY (-0.28). Seedling vigour had fairly high indirect positive effect through plant height (0.13) and SPY (0.13). The combined indirect seedling vigour effect through plant height and single plant yield was larger than seedling vigour direct effect. Even though the direct effect of seedling vigour looks low, its indirect effects through plant height and single plant yield, is significant. All other traits effects through it were positive.



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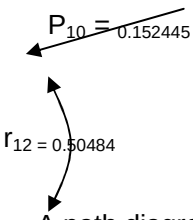

Direct effect of independent variable on the dependent

Correlation coefficient between two independent variables

Figure 5. A path diagram and coefficients of factors influencing grain yield in finger millet

Table 4. Path analysis for grain yield in finger millet

Correlation	Path	Path Component	Effect
Yield and seedling vigour		r_{10}	0.47
	Direct	P_{10}	0.15
	Indirect effect of seedling vigour via plant height	$P_{20}r_{12}$	0.13
	Indirect effect of seedling vigour via finger branching	$P_{30}r_{13}$	-0.01
	Indirect effect of seedling vigour via single plant yield	$P_{40}r_{14}$	0.13
	Indirect effect of seedling vigour via plant stand	$P_{50}r_{15}$	0.06
Yield and plant height		r_{20}	0.50
	Direct	P_{20}	0.27
	Indirect effect of plant height via seedling vigour	$P_{20}r_{21}$	0.08
	Indirect effect of plant height via finger branching	$P_{30}r_{23}$	0.02
	Indirect effect of plant height via single plant yield	$P_{40}r_{24}$	0.19
	Indirect effect of plant height via plant stand	$P_{50}r_{25}$	-0.05
Yield and finger branching		r_{30}	-0.19
	Direct	P_{30}	-0.10
	Indirect effect of finger branching via seedling vigour	$P_{10}r_{31}$	0.01
	Indirect effect of finger branching via plant height	$P_{20}r_{32}$	-0.04
	Indirect effect of plant height via single plant yield	$P_{40}r_{34}$	-0.14
	Indirect effect of plant height via plant stand	$P_{50}r_{35}$	0.08
Yield and single plant yield		r_{40}	0.43
	Direct	P_{40}	0.56
	Indirect effect of single plant yield via seedling vigour	$P_{10}r_{41}$	0.04
	Indirect effect of single plant yield via plant height	$P_{20}r_{42}$	0.09
	Indirect effect of single plant yield via finger branching	$P_{30}r_{43}$	0.02
	Indirect effect of single plant yield via plant stand	$P_{50}r_{45}$	-0.28
Yield and plant stand		r_{50}	0.23
	Direct	P_{50}	0.54
	Indirect effect of plant stand via seedling vigour	$P_{10}r_{51}$	0.02
	Indirect effect of plant stand via plant height	$P_{20}r_{52}$	-0.02
	Indirect effect of plant stand via finger branching	$P_{30}r_{53}$	-0.01
	Indirect effect of plant stand via single plant yield	$P_{40}r_{54}$	-0.29
Residual Causes of variation		P^2_x	0.43

DISCUSSION

Genotypic variation

The presence of full range variation for score data implies the presence of many genotypes and by extension genes controlling the traits in the population. The classical selection theory in breeding for quantitative traits heavily depends on availability of variation in the population for prediction of response to selection (Bernardo, 2002). The classical selection theory is the

most important tool in the design of efficient breeding programs (Frisch and Melchinger, 2005). The presence of variability for most traits is in agreement with Upadhyaya et al. (2006) and Das et al. (2007) who found wide variability in finger millet germplasm, and provides adequate variation upon which to establish a breeding program.

Mean Performance

The mean performance of the top 12 highest yielding accessions of 5,408- 7,833kg ha^{-1} range covered and surpassed the reported irrigation and research yields range of 5000 – 6000kg ha^{-1} (NRC, 1996; Duke, 1978). The 12 genotypes, KNE 072, GBK028463, GB K029661, FMBT ACC#42, E-KR-228, GBK 027300, GBK 026938, GBK 033439, P-221, GBK029628F, GBK 027116, FMBT ACC#50, with yields of 5,000kg ha^{-1} that fell in the positive skew region of the distribution curve could hold the key to increase yield and breed for increased yield in finger millet. Bedis et al. (2006a) also reported wide variability for yield in finger millet germplasm. The almost normal distribution curves for yield and foliar blast give an indication of possible selection gains in breeding for these traits in finger millet.

Striga support and lodging frequency distribution curves showed prominent positive skews where most accessions were on the few *Striga* support and low lodging sides. This is a desirable observation in these traits, as breeding would focus on low *Striga* support and low lodging. The skew was most prominent in lodging where about 60% of accessions lodged less than 10%. The skew in the two traits suggests that the accessions under study have been selected for resistance to *Striga* and lodging, narrowing the variation and potential progress on selection. This would be expected as most accessions came from either research organizations or landraces and in agreement with Asfew (1997) observation that farmers tend to discard genotypes with undesirable traits and keep those with desirable ones. These results are in consonance with the findings of Mnyenyembe and Gupta (1998), Bedis et al. (2006a) and Bezaweletaw et al. (2006) who observed high variability in most finger millet traits they studied e.g., D50 and DPM, plant height, grain yield and NHB. Madhukeshwara et al. (2004) found wide variability in resistance to NHB, including genotypes that were completely free of NHB.

Accessions with high yield and desirable agronomic traits were found, the best of which was KNE 072, followed by GBK028463, which supported more *Striga* but earlier in maturity. These accessions performance could be verified and directly released to farmers. The negative traits in the highest yielding KNE 072 like excessive height and moderate maturity and high *Striga* support in the second highest yielding accession could be fixed in a breeding

programme. It was evident that few accessions were good for all traits and some of the worst yielding accessions had some good traits. For instance, three poor yielding accessions did not support *Striga*, suggesting they could be carrying *Striga* resistance genes but deficient in yield conferring genes. Only GBK 027116 of the top 12 yielding accessions had high yield, no foliar blast, zero lodging, and zero *Striga* support. Two top yielding accessions were among 12 with high lodging – GBK 029661 (6,666kg ha^{-1}) had 80% lodging and FMBT ACC#42 (6,566kg ha^{-1}) had 95% lodging. The variability for different desirable traits implies possibility of breeding desirable traits present in low yielding accessions into high yielding backgrounds to develop better varieties. Most top 12 yielding accessions were good for all desirable traits. Top yielding KNE 072 would only need reduction of plant height from 123 cm to about 100 cm and DPM to about 100-110 days. The second yield ranked GBK 028463 would need improvement in seedling vigour, foliar blast and NHB, and Striga resistance. Accessions GBK 029661 (80%), FMBT ACC#42 (95%), and GBK 026938 (60%) would need serious improvement in lodging resistance. The rest of the top 12 yielding accessions would qualify for further testing in their current state.

Phenotypic correlations

Grain yield

All the traits positively correlated to yield, SPY, seedling vigour, plant height, lodging, and plant stand are desirable in production except lodging. This is because SPY, seedling vigour, plant height, and plant stand contribute to yield without a negative management effect unlike lodging which contributes to yield but makes manual harvesting difficult. Furthermore, tall plants without lodging make manual harvesting easier. Grain yield was also significantly negatively correlated to foliar blast and *Striga* counts as expected, for the two biotic stresses are known economic constraints (Haussmann et al., 2000; Prabhu et al., 2003). Grain yield is the ultimate characteristic of interest in any cereal crop breeding and in a breeding program to increase finger millet grain yield, indirect selection could exploit high seedling vigour, plant stand, SPY, and plant height for their high positive correlation and direct and indirect effects on yield, as proposed in the classical selection theory (Bernardo, 2002). This is because yield often shows low heritability in most crops (Johnson et al., 1983; Annicchiarico and Pecetti, 1998; Toker and Cagirgan, 2004). These findings are in agreement with the NRC (1996), who listed robust growth, early vigour, resistance to *Striga* and blast disease as important traits in finger millet breeding. The results are also in agreement with Duke (1978) report that yield is directly related to plant height. The possibility of indirect selection for yield in finger millet is an added breeding tool in successful breeding of finger millet.

Single plant yield

The finding of SPY positive correlation with D50 contrasts John (2006) finding of negative correlation between these traits. These positive correlations with yield, seedling vigour, D50, plant height, and DPM implies that tall genotypes with high seedling vigour and late maturity tended to have high SPY and yield. These are all desirable breeding traits except late maturity, as many farmers prefer early maturing varieties (see PRA, Chapter 2). Single plant yield negative correlation to biotic stresses of blast and *Striga* was expected as was plant stand. This is because the stresses reduce plant performance and increased plant stand increases competition between plants lowering individual plant performance. The negative correlation between SPY and finger branching was interesting. This finding is in contrast to the NRC (1996) listing of finger branching as an important characteristic in finger millet breeding. It was also significant that SPY did not fully correlate in similar fashion with traits that correlated with yield and one would conclude that selecting for SPY is not fully the same as selecting for yield per given land unit.

Seedling vigour

Seedling vigour is an important characteristic in many cereals for its yield and biomass determining property and breeding programs have been set up to specifically improve it (Botwright et al., 2002; Richards and Lukacs, 2002; Rebetzke et al., 2004). In this study there was significant positive correlation between seedling vigour and yield and yield correlated characters plant height, lodging, and SPY. Seedling vigour had highly significant negative correlation with foliar blast and *Striga* counts at both flowering and maturity, traits that also had negative correlation with yield. These correlations suggest that a genotype with high seedling vigour is likely to be tall, high yielding, and resist foliar blast and *Striga* infestation but would probably lodge. This would agree with Roozrokh et al. (2002) findings on chickpea. Except for lodging, such genotypes would be highly desirable in breeding.

Shootfly incidence

The weak significant positive correlation between shootfly and yield is in contrast to Nwanze et al. (1995) and Tarekegne et al. (1997) reports that shootfly is one of the pests that cause significant yield loses in sorghum and barley, respectively. The positive correlation, indeed, suggests that shootfly infestation is good for yield, especially under favourable environmental conditions probably due to icreased tillering after damage of the main shoot. This needs further investigations. Shootfly positive correlation to D50 and DPM could be explained in late maturing genotypes growing slowly hence seedlings remaining vulnerable to shootfly build up for long periods. It is notable that plant height was positively correlated

to maturity traits of D50 and DPM and also positively correlated to shootfly, thus affirming the speculation of late genotypes increased susceptibility to shootfly. The negative correlation between shootfly and foliar blast could be explained in shootfly reducing foliage on which foliar blast could thrive, while negative correlation with *Striga* could be explained in *Striga* killing most plants in susceptible accessions hence reducing plants available to host shootfly. The negative correlation between shootfly and plant stand may actually imply shootfly kills some plants. The negative correlation between shootfly and finger branching is difficult to speculate.

Foliar blast and neck and head blast incidence

The negative correlation between foliar blast incidence and SPY and yield was expected because foliar blast is known to cause significant yield loses (Prabhu et al., 2003). Its positive correlation with plant stand could be explained in high plant density providing suitable conditions for disease spread as both logarithmic and linear relationships exist between disease severity and host frequency (Mundt, 2002). Foliar blast's positive correlation with *Striga* counts could be explained in foliar blast and *Striga* causing similar plant foliar symptoms of reduced growth and development that sometimes result in total plant death (Prabhu et al., 2003). *Striga* susceptible genotypes in *Striga* conditions may score highly for foliar blast. *Striga* infestation may also enhance foliar blast infection due to weakened plants. Foliar blast negative relationship with shootfly, D50, plant height, DPM, and yield would be expected as foliar blast affects plant leaves that contribute to growth leading to reduced plant performance. Increase in shootfly will kill foliage hence the surface upon which blast could thrive.

The positive correlation between NHB and lodging implies that NHB enhances finger millet plant lodging. This probably happens when NHB cuts off the head (sink) from upper leaves (source) by the neck region rotting off and killing the plant early. The interesting observation is the lack of significant correlation between NHB and foliar blast, and NHB and yield. Lack of significant association between NHB and yield does not reflect the yield loss of up to 45% due to NHB reported by Prabhu et al. (2003) on rice and Takan et al. (2004) finding of genetic similarity between foliar blast and NHB causing *P. grisea* pathogen. And lack of NHB correlation with foliar blast is in contrast with a report by Carreres et al. (1995) in rice showing high correlation between. The variance could be due to differences between the two crops. The negative correlation between blast and plant colour (both foliar and neck and head) reflected the finding by Takan et al. (2004) in a survey in western Kenya and

Uganda that dark seeded compact headed varieties were more resistant to blast than lighter seeded open headed ones.

The negative correlation between foliar blast and yield and lack of significant correlation between NHB and yield implies foliar blast is a more serious disease than NHB. The more serious effect of foliar blast to yield would explain why Obilana (2002) and Takan et al. (2002) found NHB more common in Busia, Teso and Kisii districts of Kenya than foliar blast. This would be that farmers selected out varieties susceptible to foliar blast more regorously than those susceptible to NHB because NHB caused little yield loss. This difference in correlation to yield between foliar blast and NHB could be due to the different parts of the plant attacked as Takan et al. (2004) found isolates causing foliar blast and NHB to be genetically similar, suggesting the same strains cause the different symptoms under suitable conditions. Foliar blast is a more serious disease probably because it affects leaves, which are the photosynthetic sites and it comes early while NHB comes after grain filling.

Days to 50% flowering and physiological maturity

These traits were positively correlated to SPY, shootfly, plant height and between them, but were not correlated to yield, contrary to Bedis et al. (2006b) report. The positive correlation between D50 and DPM was high as expected because the two are maturity traits. This is in agreement with the findings of Bedis et al. (2006b); John (2006). The positive correlation with shootfly implies that genotypes that mature late tended to be susceptible to shootfly and this as explained earlier could be due to prolonged seedling stage exposing the genotypes to shootfly pest build up. The positive correlation with plant height and SPY indicates that late flowering genotypes tended to be taller and exhibited higher SPY as reported by Bedis et al. (2006b); John (2006). The D50 characteristic was negatively correlated to foliar blast, NHB, lodging, plant stand, finger branching, SCF and SCM. These correlations suggest that late flowering genotypes tended to resist *Striga*, blast, and lodging but they did not establish plant stand well, showed reduced finger branching, and tended to show higher SPY, probably due to reduced plant stand. The positive correlation with SPY is in agreement with Duke (1978), but not for yield, which was not significantly correlated to D50.

***Striga* counts at flowering and maturity**

Striga counts at flowering and at maturity were highly positively correlated and the two were significantly negatively correlated to SPY and yield. This is in agreement with Haussmann et al. (2000) report that *Striga* is a deleterious parasitic weed on cereals. The positive correlation between *Striga* counts was expected as a *Striga* susceptible genotype is likely to

show susceptibility at all stages of plant development. The negative correlation between *Striga* counts and shootfly implies *Striga* infestation reduces shootfly infestation, probably due to reduced plant population or unpalatability of *Striga* infested plants. The high positive correlation between *Striga* counts and foliar blast could be explained in foliar blast and *Striga* causing similar plant foliar symptoms of reduced growth and development that sometimes results in total plant death (Prabhu et al., 2003). The positive correlation between plant stand and *Striga* counts was also expected, as more plants will stimulate germination of more *Striga*. The implication of negative correlation between *Striga* counts and seedling vigour is either that *Striga* infestation reduces seedling vigour or genotypes with high seedling vigour tend to resist *Striga* infestation (Roozrokh et al., 2002). The latter implication would be desirable in breeding for *Striga* resistance. The negative correlation between *Striga* counts and D50, plant height, DPM, SPY and yield, all point to the deleterious effect of *Striga* on finger millet (Haussmann et al., 2000).

Plant height

The positive correlation between plant height and SPY and yield were observed in rice (Araujo et al., 2000) in contrast to lack of significant correlation between plant height and SPY in finger millet reported by Bezaweletaw et al. (2006). Wright et al. (1983) reported significant positive correlation between seedling vigour and plant height in eastern gamagrass. The positive correlations between plant height, lodging, seedling vigour, DPM, and yield suggest taller genotypes tend to be vigorous, mature late, yield more and lodging more. The positive correlation between lodging and plant height is common (Crook and Ennos, 1994). Except for lateness and lodging, taller genotypes would be the choice in a breeding program. The positive correlation between plant height and shootfly implies that taller genotypes are susceptible to shootfly infestation. This could be due to plant height positive correlation with maturity traits, which may prolong seedling stages exposing them to shootfly outbreaks. The positive correlation between plant height and DPM is in agreement with findings of John (2006). The negative correlation between plant height and the biotic stresses of foliar blast and *Striga* implies the stresses reduce plant height.

Lodging

Positive correlations between lodging and yield, seedling vigour, NHB, and plant height suggest tall genotypes with high seedling vigour, high yield and susceptible to NHB tend to lodge. The positive correlation between lodging and yield is in contrast to findings in wheat and barley, where lodging causes up to 40% yield losses (Kelbert et al., 2004). This could be due to the heavy heads associated with high yield in finger millet toppling tall plants, also

positively correlated to yield (Duke, 1978). Judging from the correlations it would seem high seedling vigour leads to tallness and tall plants with heavy heads leads to raised plant centre of gravity hence increased lodging. Neck and head blast aggravates lodging probably by rotting off the neck region and killing the plant. The negative correlation between lodging and D50 suggests late flowering genotypes are less prone to lodging.

Plant stand

Plant stand establishment is an important characteristic in wheat and is highly correlated to plant height (Bacaltchuk and Ullrich, 1983). In this study it was not significantly correlated to plant height. Its positive correlation with yield implies full stands will yield more. Plant stand positive correlation with foliar blast and *Striga* counts implies that the more the finger millet plants, the higher the incidence of foliar blast and *Striga* infestations, reflecting increase in pest/disease severity with increased host density as reported by Mundt (2002). There was low but significant positive correlation between plant stand and lodging in line with common knowledge that lodging increases with increasing plant density (Stapper and Fischer, 1990). As expected, the negative correlation between plant stand and SPY is due to plants suffering competition under high-density conditions as reported by Fasoula and Tollenaar (2005). The breeding implication here is that it is better to select on plots rather than single plants because SPY is not always representative of yield.

Ear shape and plant colour

The negative correlation between ear shape and lodging implies open headed genotypes are more prone to lodging than the fist headed genotypes. There is no previous report on this relationship and it is probably due to open heads offering resistance to wind and also the susceptibility of open headed genotypes to NHB as NHB was negatively correlated to ear shape (increased with tendency to open headedness). The low but significant correlations between plant colour and seedling vigour, plant height, and yield, and low significant negative correlation with foliar blast, SCF, SCM, could reflect superiority of purple genotypes over tan genotypes as reported by Pedersen and Toy (2001) for yield and grain weight.

Finger branching

The negative correlation between finger branching and SPY and yield is in contrast with the NRC (1996) listing of the characteristic as one of the important traits in finger millet breeding. Probably, finger branching characteristic needed to be studied on a finer scale quantifying the level of branching. However, the current findings were in conformity with Rawson and Ruwali (1972) report that spike branching could confer yield advantage only if frequency of

sterile spikelets on branched types was reduced, indicating that spike branching does not always translate to high yield.

Path Coefficient Analysis

Among the five independent traits, four had positive direct effect on yield - seedling vigour, plant height, SPY, and plant stand. Finger branching had low negative direct effect. Bedis et al. (2006b) found plant height to have positive direct effect on yield. The low negative direct effect of finger branching in effect means that just the presence of finger branching is not an indicator of high yield and may not have value in selection for yield. Considering characteristic correlations and path analysis results, important traits for finger millet indirect selection for yield would be seedling vigour, plant stand, SPY and plant height. Seedling vigour has been found to be an important trait in yield and biomass determination in other crops (Botwright et al., 2002; Richards and Lukacs, 2002; Rebetzke et al., 2004) and Adetimirin (2008) observed high broad sense heritability for vigour score (71.5%) and vigour associated seedling height (90.0%) in a maize population. It would also be very valuable in finger millet in that it would allow early screening out of potentially poor yielding genotypes in early generation or nursery stages of germplasm evaluation, thereby saving breeding costs. Seedling vigour is also associated with resistance to biotic and abiotic stresses as reported by Roozrokh et al. (2002) on chickpea, hence using it as indirect selection criterion for yield, one would also be indirectly selecting for stress resistance. Plant stand establishment is correlated to plant height in barley and is an important characteristic in wheat (Bacaltchuk and Ullrich, 1983). It is also positively correlated to seedling vigour and yield. Seedling vigour, plant stand, and plant height could be combined to effectively indirectly select for yield, a trait usually known for low heritability (Toker and Cagirgan, 2004). These traits with value for indirect selection in finger millet have not been studied in finger millet and need to be investigated for heritability and genetic control to confirm their value. It is important to note that the study did not consider all traits that affect yield and the residual effect was large (0.43). Inclusion of other traits to this study would be recommended.

CONCLUSION

Wide variation existed in most traits, indicating a germpalsm base that might support a finger millet breeding programme to produce varieties with high yield, resistance to *Striga*, blast, lodging, and with general agronomic desirability. Some genotypes were good enough for further testing to release to farmers directly, but many could be improved through breeding, exploiting the diversity seen in many traits. There was significant correlation between yield

and many agronomic traits. Though direct selection for yield was possible because of the wide variation for yield, indirect selection was also possible. Indirect selection would use seedling vigour because of its high correlation with yield (0.47) and direct positive effect on yield (0.15), indirect effect on yield through plant height (0.13) and SPY (0.13). Second in consideration would be plant height with r = 0.50, positive direct (0.27) and indirect through SPY (0.19) effects. Single plant yield with r = 0.47 and high direct effect (0.56) and plant stand with r = 0.23 and high direct effect (0.54) would follow in descending order. The presence or absence of finger branching was not useful as a yield selection criterion.

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APPENDIX 1. Finger millet germplasm evaluation nursery for 310 accessions layout at Alupe, 2005LR

R_{24}	KNE 1163	ACC. #1,00007	Unknown 13	GBK 028449	GBK 033451	KNE 980	U-15	Dalle-1	KNE 808	GBK 033398	ACC. # 26 FMBP/01WK	GULU-E	ACC. # 77 FMBP/01WK	ACC. # 18 FMBP/01WK	Ex-Meru (Black)	GBK 032050F
R_{23}	GBK 033173	BU-3 'b'	U-15	GBK 029163	Serere-1	KNE 846	GBK 028482	GULU-E	KNE 479	GBK027245	ACC. # 68 FMBP/01WK	ACC. # 69 FMBP/01WK	ACC. #1,00007	ACC. # 56 FMBP/01WK	KNE 669	KNE 617
R_{22}	GBK 031937	GRU/ICR E 8	E-KR-227	GULU-E	KA-2	GBK 02726	Unknown 38	KNE 657	ACC. # 1,00007	S-4	ACC. # 14 FMBP/01WK	KNE 711	S #77 SADC	U-15	KNE 900	Unknown 25
R_{21}	GBK 026938	Okhale-1	GBK 032052	GBK 031895	ACC. #1,00007	GBK 032101	GBK 032042F	GBK 038231	GBK A029628F	U-15	ACC. # 31 FMBP/01WK	ACC. # 40 FMBP/01WK	ACC. # 67 FMBP/01WK	S#261	GULU-E	GBK 033240
R_{20}	GULU-E	GBK 027184	GBK 026992	GRU/ICR E 49	BU-3 'a'	U-15	GBK 027091	KNE 612	KNE 961	ACC. #37 FMBP/01WK	GULU-E	KNE 1034	ACC. # 9 FMBP/01WK	KNE 883	KNE 388	ACC. #1,00007
R_{19}	KAT FM-1	ACC. #1,00007	KNE 822	I.E. 1022 'a'	GBK 029275	GBK 027242	GULU-E	GBK 027765F	ACC. #29 FMBP/01WK	Unknown 47	ACC. # 33 FMBP/01WK	ACC. #1,00007	ACC. # 64 FMBP/01WK	GBK 031896	KNE 6689	GBK 029773
R_{18}	KNE 825	GBK 032044F	U-15	GBK 032067F	GBK 029126	Unknown 2	KNE 657	ACC.#1,00007	ACC. #41 FMBP/01WK	ACC. #34 FMBP/01WK	ACC. # 19 FMBP/01WK	ACC. # 20 FMBP/01WK	U-15	KNE 1060	Engeny 'a'	ACC. #82 FMBP/01WK
R_{17}	GRU/ICR E 37	Chemoibeimimik	FAO-495-34-027	GULU-E	GBK 033627	GBK 029764F	KNE 671	GBK 033329	U-15	KNE 1072	ACC. # 15 FMBP/01WK	ACC. # 16 FMBP/01WK	ACC. # 30 FMBP/01WK	GULU-E	ACC. # 86 P-224	GBK 028275
R_{16}	GBK 033310	GBK 031882	Unknown 19	GBK 027170	ACC. #1,00007	KNE 612	Unknown 49	KNE 626	ACC. #44 FMBP/01WK	GULU-E	L-22	GBK 033498	ACC. # 89 Local mkt	KNE 1015	ACC. # 1,00007	MOBREREK KIPSIONGIK
R_{15}	U-15	GBK 027129	GBK 029797	GBK 033374	GBK 033305	U-15	GBK 027116	Unknown 36	Unknown 29	Unknown 31	ACC.# 1,00007	ACC. # 39 FMBP/01WK	ACC. # 54 FMBP/01WK	GBK 032043F	ACC. # 57 FMBP/01WK	U-15
R_{14}	GBK 032044	GULU-E	GRU/ICR E 48	GBK 033552	GBK 033484	GBK 032282F	GULU-E	GBK 027203	KNE 434	GBK 027186	Unknown 53	U-15	ACC. # ? FMBP/01WK	ACC. # 61 FMBP/01WK	ACC. # 62 FMBP/01WK	Unknown 1
R_{13}	GBK 029784	A/C SMIP3	ACC. #1,00007	GBK 032247	GBK 033589	GBK 027070	KNE 1026	ACC. #1,00007	Buseke	GBK 027243	ACC. # 3 FMBP/01WK	ACC. # ? FMBP/01WK	GULU-E	GBK 029759	KNE 1087	KNE 626 'b'
R_{12}	P-224	GBK 011041	GBK 028452E	U-15	SN-7	GBK 033531	Ex-Kapsakwany	Unknown 39	U-15	Unknown 15	ACC. # 11 FMBP/01WK	ACC. # 60 FMBP/01WK	ACC. # 49 FMBP/01WK	ACC. #1,00007	KNE 1149	KNE 922
R_{11}	KNE 629 'a'	FAO-394-27-34	GBK 032104F	GBK 032090	GULU-E	GBK 027234	KNE 786	Unknown 27	GBK 027153	GULU-E	Gbk 022355	ACC. # 24 FMBP/01WK	ACC. # 73 GULU-E	ACC. #88 Seremi-2	U-15	GBK 033515
R_{10}	ACC. #1,00007	GBK 027198	GBK 027138	P-221 'b'	GBK 028452F	ACC. # 1,00007	DR 28	Unknown 45	GBK 032081	ACC. # 27 FMBP/01WK	ACC. #1,00007	ACC. # 23 FMBP/01WK	ACC. # 53 FMBP/01WK	ACC. # 72 FMBP/01WK	GBK 027189	GULU-E
R_{9}	GBK 033560	U-15	Unknown 14	GBK 0271912	DR 26	GBK 027134	U-15	KNE 688	I.E. 1023	ACC. # 1 FMBP/01WK	ACC. # 71 FMBP/01WK	U-15	ACC. # 80 FMBP/01WK	GBK 031890	ACC. # 65 FMBP/01WK	GBK 027141
R_{8}	GBK 033502 'b'	KNE 820	GULU-E	KNE 620	GBK 028475	GBK 032235	GBK 032067	GULU-E	Enyaikuro	Unknown 26	ACC. # 63 FMBP/01WK	ACC. # 85 U-15	GULU-E	S#1752 SDFM (white)	ACC. # 45 FMBP/01WK	GBK 033311
R_{7}	Unknown 51	KNE 383	GBK 032103	ACC. #1,00007	DR 35	GBK 031854	GBK 033347	Serere-1	ACC. #1,00007	GBK 029782F	ACC. # 21 FMBP/01WK	ACC. # 73 FMBP/01WK	KNE 814	ACC. #1,00007	ACC. # 76 FMBP/01WK	Okhale-1
R_{6}	Enyandabu	Unknown 16	GBK 029863	GBK 033308	U-15	GBK 032220	KNE 921	GBK 027251	GBK 028463	U-15	ACC. # 43 FMBP/01WK	ACC. # 78 FMBP/01WK	KNE 392	ACC. # 70 FMBP/01WK	U-15	I.E. 1010
R_{5}	Gulu-E	Unknown 44	Unknown 52	GBK 029834	GBK 033522	GULU-E	GBK 11049	HAMSA	KNE 1115	ACC. # 13 FMBP/01WK	GULU-E	ACC. # 32 FMBP/01WK	KNE 648	KNE 1162	GRU/ICR E 50	GULU-E
R_{4}	Unknown 22	ACC. #1,00007	KNE 889	GRU/ICR E 51	Buwanga	GBK 028546	ACC. #1,00007	KNE 625	KNE 810	ACC. # ? FMBP/01WK	ACC. # ? FMBP/01WK	ACC. #1,00007	KNE 741	ACC. # 75 FMBP/01WK	Ex-Kapsakwany	Enyandabu
R_{3}	KNE 988	GBK 027191	U-15	Pagiwande	P-283	GBK 013183	B1(A)	U-15	Unknown 23	I.E. 934	ACC. # ? FMBP/01WK	I.E. 933	U-15	Engeny 'b'	ACC. # 79 FMBP/01WK	I.E. 1023
R_{2}	GBK 033384	GBK 027176	GBK 033463	GULU-E	GBK 033448	KNE 828	KNE 629	GBK 029822F	GULU-E	GBK 033439	ACC. # 7 FMBP/01WK	ACC. # ? FMBP/01WK	ACC. # 59 FMBP/01WK	GULU-E	ACC. # 50 FMBP/01WK	P-283
R_{1}	KNE 618 'C'	GBK 027300	KNE 618 'b'	E-KR-228	ACC. #1,00007	GBK 029661	GBK 033411	KNE 382	P-221	ACC. #1,00007	Nanjala Brown	ACC. # 51 FMBP/01WK	I.E. 1010	ACC. # 55 FMBP/01WK	ACC. 1,00007	SN-7
	C_{1}	C_{2}	C_{3}	C_{4}	C_{5}	C_{6}	C_{7}	C_{8}	C_{9}	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}

Coloured boxes represent plots assigned to the standard checks

CHAPTER 4

Finger millet hybridisation using ethrel chemical hybridising agent

ABSTRACT

Finger millet is an important subsistence and food security crop in eastern and southern Africa. Little breeding has been done on the crop partly because it is difficult to hybridise, a prerequisite in creating variability. The efficacy of ethrel (2-chloro-ethyl-phosphonic acid) as a male gametocide for crossing finger millet was studied under greenhouse conditions in 2004 in making 8x8 diallel crosses of elite varieties and subsequently under field conditions during 2005-2007. In the field, four levels of ethrel and three levels of development stage of gametocide application were studied in a factorial arrangement in a split plot design on ten varieties. Ethrel levels (GL) were 700, 1,000, 1,500, and 2,000ppm and Zadoks development stages (DS) of application were 39, 45 and 50. A control treatment of zero GL was added. Varieties were the main plot factor and GLxDS the sub-plot factor. All 28 half-diallel crosses produced true F_1 plants at success rates of 0.19-8.63% and field studies resulted in male sterility of 15-38% at between 1,500ppm-2,000ppm GL. There were no significant factor interaction effects. Ethrel did not significantly affect yield, female fertility, days to heading, days to anthesis, and days to physiological maturity. However, on average, it significantly reduced plant height and ear exertion by 25 and 50%, respectively. Further testing of ethrel for enhanced chemical hybridising agent effects on finger millet for application in heterosis breeding and development accompanying appropriate finger millet development scale are recommended.

Key words: Finger millet, gametocide, emasculation, hybridization, ethrel, development stage.

INTRODUCTION

Finger millet *(Eleusine coracana* (L.) Gaertn. ssp. *Coracana* (Hilu et al., 1979), is an important subsistence and food security crop in eastern and southern Africa, especially important for its nutritive and cultural value (Takan et al., 2002). However, there are challenges in improving this crop. The floral architecture of finger millet makes it almost 100% self pollinating (Hilu and de Wet, 1980; CAB, 2005) and very difficult to emasculate and hybridise. Hybridization is pertinent for accomplishment of any of the three key plant breeding objectives: combination breeding, transgressive breeding (genetic variation or diversity creation) and heterosis (hybrid) varieties (House, 1985). Genetic improvement has thus been limited to pure line selection from germplasm acquisitions.

Emasculation is essential in bisexual flowers of self-pollinating plants for successful hybridization. Available emasculation techniques including hand emasculation, hot water treatment, plastic bag, suction, and cold treatment have all been found unsuitable for finger millet (Riley, 1989). Genetic male sterility identified in finger millet line INFM 95001 (Shiferaw et. al., 2004) has not been studied and applied in addition to inherent complications that come with genetic male sterility.

The First International Small Millets Workshop recognized the difficulty to cross finger millet and inefficiency of other emasculation methods and recommended investigation of applicability of gametocides (Riley et al., 1989), but the recommendation had not been implemented to date. Gametocides have been found to work on other self-pollinating cereals and the advantages of a successful gametocide system, especially with 2-chloro-ethyl-phosphonic acid (ethrel) have been extensively espoused in literature. Rowell and Miller (1971) indicated that such a system would be rapid and flexible and has no requirement for fertility restoration and thus would allow exploitation of heterosis and improve yields in wheat. Earlier, Foster (1969) had also seen its potential in exploitation of heterosis in self pollinating species. Verma and Kumar (1978) observed that ethrel is easily and cheaply available on the market and could be effectively used to cut down labour on mass emasculation. Berhe and Miller (1978) had seen the potential of an ethrel system eliminating the problem of floral sensitivity experienced in manual emasculation of tef. de Milliano (1983) observed that gametocides are easier to use and can be applied to any genotype and their effects are not heritable. Success of such a system in finger millet would enhance the exploitation of mass selection and even selected parents' manual crossing.

The degree of male sterility induced is greatly affected by the concentration and development stage (DS) at which ethrel is applied. Maximum male sterility is obtainable if

ethrel was applied before meiosis initiation in the oldest florets in wheat (Bennet and Hughes, 1972; Hughes et al., 1974; Fairey and Stoskopf,1975). Ethrel concentrations of between 1,000 and 2,000ppm a.i. caused complete male sterility in wheat (Hughes et al., 1974). Thakur and Rao (1988) found ethrel concentration of 2,000ppm applied at late boot or early protogyny to be most effective in inducing male sterility on hybrid pearl millet. They also reported that *in vitro*, ethrel at 2,000ppm inhibited pollen germination.

Ethrel also causes undesirable effects on plants. Rowell and Miller (1971), Stoskopf and Law (1972), and de Milliano (1983) observed poor ear exertion, reduced plant height, delayed heading and anthesis, reduced spikelets per head, reduced awns, delayed and enhanced tillering and reduced panicle length, that seemed to increase with increased ethrel concentration in wheat. Law and Stoskopf (1973) and Thakur and Rao (1988) observed similar negative ethrel effects in barley and pearl millet, respectively. Early and Slife (1969) had earlier reported the same effects in maize. According to Fairey and Stoskopf (1975) the most commonly observed morphological abnormalities of ethrel treatment are: shortening of internodes, dwarfing, and poor ear exertion. Poor ear exertion may restrict cross pollination, hence defeating the purpose of emasculation.

Based on the fact that other emasculation techniques have limitations for use in hybridisation of small millets (Riley et al., 1989), male gametocide ethrel was used and investigated in this study.

Objectives

The objectives of the study were as follows:

1. To determine feasibility of crossing finger millet using ethrel;
2. To determine the appropriate ethrel concentration for effective emasculation in finger millet;
3. To determine the appropriate development stage to apply ethrel gametocide for effective emasculation in finger millet;

Research hypotheses

1. Ethrel is an effective male gametocide with no effect on female fertility in finger millet.
2. Finger millet genotypes respond similarly to ethrel treatment.

MATERIALS AND METHODS

Experimental sites

The 8x8 diallel crosses were done at the African Center for Crop Improvement (ACCI), University of KwaZulu Natal, Pietermaritzburg Campus, in South Africa in 2004 under green house conditions. Subsequent field studies were done at the Kenya Agricultural Research Institute Centre of Kakamega in Kenya during 2005-2007. Kakamega has mean annual rainfall of about 2,010mm and mean monthly temperatures of 28^{o}C and soil types are described as Dystro-mollic Nitisol with pH of 5.2 (FURP, 1987).

Finger millet genotypes

Six western Kenya elite and two exotic varieties were used in the preliminary study at the University of KwaZulu Natal. The exotic varieties were withdrawn from the field study and replaced with four other local varieties. The eight lines that were used in the preliminary studies were Gulu-E , P-224, P-283, U-15, Okhale-1, Nanjala Brown, FMV-1, and MS. Lines added for the field study were I.E. 1010, Enyandabu, E-KR-228 and SN-7. The full list of lines used for the two studies is presented in Table 1 below.

Preliminary greenhouse crossing study

In February 2004, the eight finger millet varieties were planted in trays in a greenhouse. The trays were watered daily until seedlings were transplanted after two weeks. The seedlings were transplanted to pots and the potted varieties paired randomly in an 8x8 diallel scheme with each variety pair having six plant pairs as follows:

i. Designated female and male plants and the reciprocal to be sprayed with ethrel at 1,000ppm gametocide level (GL);

ii. Designated female and male plants and the reciprocal to be sprayed with ethrel at 2,000ppm GL;

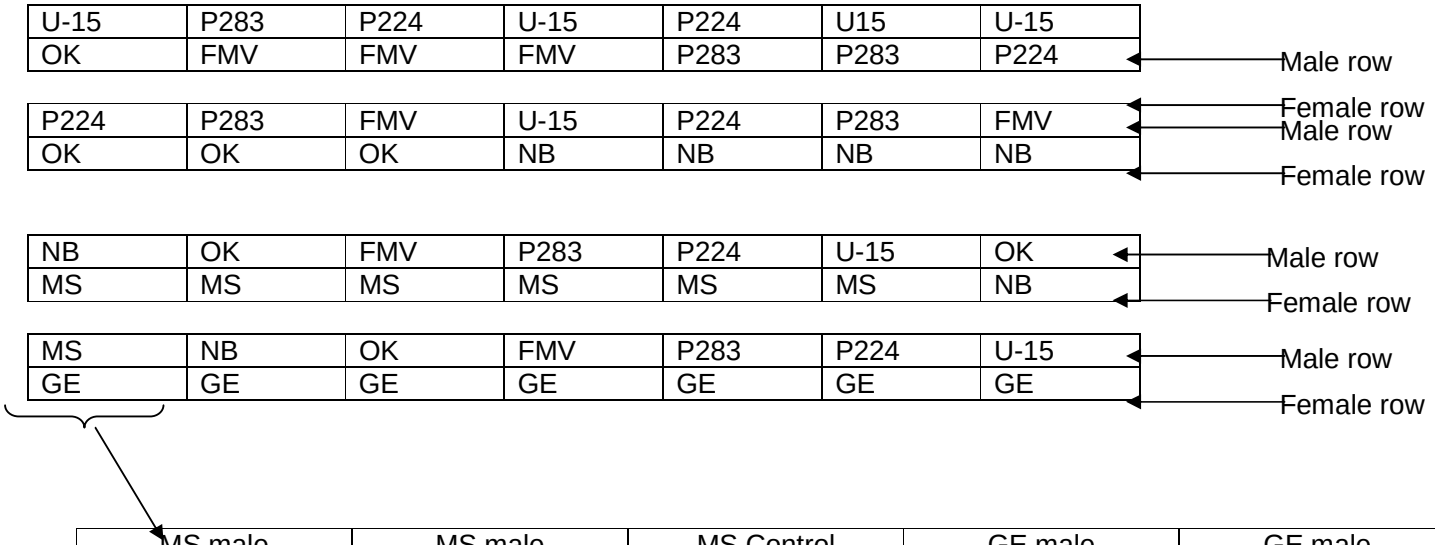
iii. Designated female and male plants and the reciprocal for hand emasculation; and

iv. Control pair to receive no emasculation (zero ppm ethrel and no hand emasculation).

Table 1. Finger millet genotypes used in ethrel gametocide studies

Variety	Abbreviated name	Origin	Key Traits	Reference
Okhale-1	OK	Nepal	- Purple plant pigmentation - High yield, - Resistant to *Striga*, lodging and blast	Riley, 1997
P-224	P-224	Uganda	-Green with no plant pigmentation -High yield - susceptible to *Striga*, lodging and blast	Von Brook, 1990
U-15	U-15	Uganda	-Purple plant pigmentation - high yield -short	-
P-283	P-283	Uganda	-Green with no plant pigmentation -moderate yield -resistant to lodging	-
Gulu-E	GE	Uganda	-Green with no plant pigmentation -High yield -Resistant to blast and lodging	-
Nanjala Brown	NB	Local selection	-Purple plant pigmentation -Tall -Moderate yield -susceptible to *Striga*, lodging and blast	-
FMV-1	FMV-1	Zimbabwe	-Green with no plant pigmentation -High yield -Susceptible to blast, and lodging	Shiferaw et al., 2004
I.E. 1010	I.E. 1010	ICRISAT	-Green with no plant pigmentation	-
Enyandabu	Enyandabu		-Green with no plant pigmentation -White seeded	-
E-KR-228	E-KR-228	ICRISAT	-Green with no plant pigmentation -Susceptible to blast, and lodging	-
SN-7	SN-7		-Green with no plant pigmentation -Resistant to lodging	-
INFM 95001	MS	ICRISAT	-Green with no plant pigmentation -Genetic male sterility	Shiferaw et al., 2004

The diallel layout is shown in Figure 1 below. The pots were kept under greenhouse conditions with overhead nutrient water irrigation three times in a day. Between heading and flowering, plants were sprayed with their designated GL. Because of different variety maturity periods, they received gametocide at varied finger millet development stages ranging between Zadoks scales 33 (3rd node detectable) and 69 (flowering complete). The 1,000ppm GL was applied at day 71 after planting and the 2,000ppm a day later. The GL to be applied was calculated from container label dilution instructions given as 5ml chemical in 100 litres water gave 350ppm active ingredient (a.i.).



MS male	MS male	MS Control	GE male	GE male	GE Hand Emasculation
GE female 1,000ppm ethrel	GE female 2,000ppm ethrel	GE control	MS female 1,000 ppm ethrel	MS female 2,000ppm ethrel	MS Hand Emasculation

Figure 1: Genotypes arrangement in the greenhouse for 8x8 diallel mating.

After ethrel treatment, each female plant was labelled with a plastic tag indicating applied GL, cross, and date of cross. Treated plants were monitored daily for heading and as heads emerged on the main stalk of female plants, they were covered with a pollination bag. Female plant heads were monitored daily towards flowering and when they opened and stigmas stuck out, the heads were pollinated. Pollination was done in the morning, between 8.00 and 10.00am, when pollen was evident on the designated male plant head. Where there was disparity in parent pair maturity, tillers of the early variety were used to provide pollen or serve as female heads. The female head remained covered until grain filling was advanced before the bags were opened to avoid negative effects on the panicle. At maturity, the bagged heads were harvested independently, each in its own labelled bag, dried, threshed and seed packaged and stored safely.

Screening F_1 from selfs

Evaluation on hybridization success on F_1 was done in 2005 long rain season (LR) at Kakamega. All the crosses were planted, with each head planting a row of 20m long. Heads from each parent pair were planted in a block in which the first row was one parent variety followed by two rows from heads where it was the female parent (1,000ppm and then 2,000ppm GL). The fourth row was planted with the male parent in the preceding two rows. The fifth and sixth rows were reciprocals of the first two rows. The seventh row was the parent variety planted in the first row. This meant a total of about 133 unscreened F_1 plants per row, 533 per parent block and 14,933 for all 28-parent blocks. The parent varieties were planted to help elucidate true F_1s in the population. Plants intermediate between male and female parent in terms of morphological features like plant colour, ear shape, plant height and flowering period were taken to be true F_1s. Plants that looked like the maternal parent were considered to be selfed plants and were rejected.

Field gametocide study

Five levels of ethrel (GL) (700, 1,000, 1,500, and 2,000ppm) plus zero ppm check were studied on ten randomly selected finger millet varieties P-224, GE, U-15, I.E. 1010, P-283, E-KR-228, OK, NB, SN-7, and Enyandabu at three DSs (Zadok's scale 39[1], 45[2], and 50[3]). The ethrel chemical used was bought from the Bayer Company dealers in Kenya, Amiran Kenya Limited.

[1] Zadok's DS 39 = cereals development stage when the flag leaf ligule/collar is just visible
[2] Zadok's DS 45 = cereals development stage when boots are just swollen
[3] Zadok's DS 50 = cereals development stage when the first spikelet of inflorescence is visible

A split plot design was used in this study where the 10 varieties formed the main plot factor and the ethrel GL x plant DS (4 GLs x 3 DSs plus one unsprayed check plot = 13 subplots) formed the sub-plot factor. The trial was replicated twice each season and done in 2005LR 2006LR, 2006 short rain (SR), and 2007LR. Varieties were planted in each replication in blocks, each made up of plots of 5 rows of two meters each. The inter-row spacing in each plot was 0.3m; inter-plot spacing within a block was 0.5m; and inter block spacing was 1m. In the middle of the inter-block space (0.50m from either block) a row of the variety in the preceding block was planted and was not treated with ethrel to provide pollen. Two border rows were also planted around the experiment to make sure that there was adequate pollen in the air during anthesis. The fields were kept clean by hand weeding and insects controlled by insecticides. Fertilizer rates were 20kg ha^{-1} each of N and P_2O_5 at planting and top dressing at second weeding. Thinning was carried out to 0.15m inter-plant spacing within a row during first weeding.

Determination of development stages in finger millet presented a challenge as the stages are not as distinct as in wheat, barley or sorghum. The stalk of finger millet is laterally compressed and at inception of reproductive phase, neither the flag leaf nor the boot is evident until head emergence. To overcome this problem, head emergence was used to estimate the developmental stages. After the second weeding, the plots in blocks were monitored on a daily basis for head emergence and treated with ethrel as below:

i. In any block when the first spikelet appeared in any plot, all the plots assigned DS 39 were sprayed with their respective GL.
ii. Development stage 45 assigned plots received their respective GL when the first spikelet appeared in the plot.
iii. Development stage 50 assigned plots received their respective GLs when 50% of heads in the plots had emerged.

Ethrel was applied using a knapsack sprayer to plant dripping wetness. To attain uniform plant wetness in a plot, the amount of water needed to wet all plants in a plot to dripping wetness was first determined. Two litres per plot was found adequate for the purpose and subsequently the chemical for each concentration was added to 2 litres of water in a knapsack sprayer using a pipette, mixed and applied to the respective plots. On each sub-plot, middle row main heads were bagged using custom made pollination bags before flowering on both treated and untreated plots to determine emasculation.

Data collection

On the preliminary greenhouse study, data were recorded on days to heading (DH), days to anthesis (DA), productive tillers, ear exertion, and plant height on individual plants. The number of true F_1 plants per row in the F_1 screening exercise was recorded. Data were subjected to analysis of variance using Genstat in completely randomized design (CRD) (Payne et al. 2007) of 8 varieties x 3 gametocide levels factorial treatment arrangement. The zero ppm GL data was the average of all plants in a genotype pair that did not receive gametocide treatment.

On the field gametocide study, data were taken on two rows of a sub-plot, on either side of the middle row. Data taken included plant height (cm), ear exertion (mm), yield per plot of two side rows (this was taken to elucidate female fertility and is henceforth herein referred to as FF), yield per plot of the covered middle row (this was taken to measure percent partial emasculation and is henceforth herein referred to as PEMS), number of empty heads on the covered row (was taken to elucidate complete emasculation and herein referred to as CEMS) and days to physiological maturity (DPM). Covered empty heads was to detect 100% emasculation and was taken on covered middle row main heads. If ethrel treatment attained 100% emasculation, then all covered heads on the particular row were to be empty and record more empty heads than the covered untreated plots. One covered row yield was a measure of grain yield from the middle row whose main heads were covered before flowering, on both ethrel treated and untreated plots on each variety. Ideally if a GL caused emasculation on covered heads, it was expected that there would be a corresponding reduction in the yield of the middle row of that treated plot, which should be less than that of the covered untreated plot of the same variety. This would represent the fraction of the emasculated florets that did not fill grain. To confirm that female fertility remained intact, FF in the treated plot should approach that of FF of untreated plot of the same variety, considering that the treated heads were exposed to abundant pollen from surrounding plots and pollen rows. The parameter FF was also meant to measure the effect of ethrel on finger millet yield. Therefore, a reduction in treated PEMS compared to untreated and lack of difference in treated FF and untreated would represent successful emasculation without interference with female fertility. Data collected were subjected to analyses of variance using SAS PROC GLM (SAS Institute, 2003).

RESULTS

Preliminary ethrel gametocide study

Screening for F_1 resulted in 487 true F_1 plants representing on average 3.26% and range of 0.19-8.63% cross success rate per female head (Table 2), 248 of them from 1,000ppm GL treatment and 239 from 2,000ppm GL treatment. All 28 crosses produced true F_1 plants in a range of 1-46 per four heads. Crosses that involved MS had generally higher cross rates with GExMS having the highest at 8.63%, MSxP-224 4.69% and U-15xMS 4.32%.

Table 2. Percentage of successful F_1 crosses

Cross	Percent success per head	Cross	Percent success per head
NBxU-15	1.88	P-224xP-283	3.75
OKxP-283	1.50	OKxNB	3.56
FMV-1xP-283	3.75	P-283xNB	5.07
U-15xMS	4.32	OKxU-15	2.25
U-15xP-224	2.63	OKxP-224	2.25
P-283xU-15	6.57	MSxP-224	4.69
NBxP-224	0.19	FMV-1xP-224	3.19
FMV-1xGE	3.56	FMV-1xOK	1.88
GExMS	8.63	U-15xFMV-1	0.56
FMV-1xNB	7.32	MSxP-283	1.69
MSxFMV-1	2.06	MSxOK	1.88
GExP-283	3.56	P-224xGE	3.94
OKxGE	2.25	NBxGE	1.31
NBxMS	4.50	U-15xGE	2.44
Mean	3.26		3.26

Field gametocide study

The variety x GL and variety x DS interaction effects were not significant (Table 3). Gametocide levels were significantly different for PEMS parameter in 2005LR, 2006LR and 2006SR but not significantly different in 2007LR and were significantly different for parameter FF only in 2005LR. There was no significant GL x DS interaction effect for all gametocide efficacy parameters in all the four seasons. Development stages only showed significant differences for FF in 2007LR. Varieties were not significantly different for all gametocide efficacy parameters except PEMS in 2006SR.

Over the seasons, GLs were not significantly different ($p \leq 0.05$) for gametocide efficacy parameters except PEMS (Table 4). Development stages for gametocide application were not significantly different for all gametocide efficacy parameters. Varieties were significantly different for PEMS and FF, but not for CEMS. There was no GL x DS interaction for all

gametocide efficacy parameters and neither were variety x GL nor variety x DS interaction. The coefficients of variation for CEMS were high and ranged from 83 to 150% in the seasons. The coefficients of variation for PEMS were moderate and varied narrowly in seasons between 28 and 30%. The coefficients of variation for FF were also moderate but varied more in seasons between 21 and 41%.

Table 3: Seasonal Analyses of variance mean squares for measured gametocide efficacy determining parameters of finger millet.

		2005LR			2006LR			2006SR			2007LR		
Source	DF	CEMS	PEMS	FF	CEMS	PEMS	FF	CEMS	PEMS	FF	CEMS	PEMS	FF
Replication (L)	1	7.5	4618.4	128978.9	19212.4**	171136.8**	538874.9**	41707.1**	133793.9**	866422.2**	10649.6**	58607.5**	126621.2**
Variety (V)	9	2.2	20833.6	75970.7	1343.2	1708.3	6793.5	1330.2	19294.7**	45493.2	515.0	4528.7	12408.4
R*V (Error a)	9	2.5**	10499.5**	43862.8**	1091.2	1355.3**	5767.7**	1641.8	1721.3	21775.8	614.6	3649.5**	7653.4*
GL	3	0.7	8748.1**	16090.0*	60.7	649.4*	2109.4	77.0	586.0*	2729.1	124.4	735.1	8247.3
DS	2	0.6	3191.6	2483.0	46.4	211.0	999.1	347.0	279.5	23667.1	7.5	132.0	18783.1**
GL*DS	6	0.4	3554.7	10776.2	103.9	51.9	349.7	110.4	1472.4	7571.6	71.6	252.5	3017.2
V*GL	27	0.5	1705.8	3956.9	154.4	258.2	898.0	99.3	1086.6	15213.5	56.3	538.7	1801.5
V*DS	18	0.4	2146.2	4790.3	123.4	130.0	935.1	143.8	1330.8	14107.8	69.1	362.6	4042.2
V*GL*DS	54	0.5	2289.9	6347.0	73.1	202.3	865.5	124.1	1791.7	16648.4	68.5	492.7	3853.1
Error b	120	0.5	2391.3	5346.1	105.6	248.7	962.5	119.2	1417.4	15975.0	62.1	511.8	3349.1
Total Corrected	259												

*, **, significant at the 0.05 and 0.01 levels of probability, respectively. And CEMS=complete emasculation; PEMS =partial emasculation; FF=female fertility

Table 4. Analyses of variance mean squares for gametocide efficacy parameters of finger millet over 2005LR, 2006LR, 2006SR and 2007LR

Source	DF	CEMS	PEMS	FF
Season	3	8364.7**	813998.6**	3113990.9**
Replication(Season)	4	17894.1**	92039.1**	434045.4**
Variety	9	1834.8	31050.5**	76073.8**
Season*replication*Variety (error a)	72	852.8**	8659.4**	34372.7
Gametocide Level	4	115.8	10141.7**	9410.0
Development stage	2	33.2	769.7	15266.3
Gametocide Level*Development stage	6	46.2	2250.6	3760.1
Variety*Gametocide Level	36	73.7	1228.7	6283.1
Variety*Development stage	18	75.8	825.9	5849.8
Variety*Gametocide Level*Development stage	54	64.2	1282.5	7355.4
Error b	840	72.5	4017.4	6687.3
Total Corrected	1039			

CEMS=complete emasculation; PEMS (g) =partial emasculation; FF (g) =female fertility

Seasonal gametocide level effects

All CEMS means were not significantly different ($p \leq 0.05$) for all seasons (Table 5). The means for FF were significantly different for all seasons but 2006SR at $p \leq 0.05$. However, no GL was consistently highest in FF across seasons and 0 GL was the highest mean only in 2006LR. The principal parameter PEMS had significantly different means for GLs for all seasons and in each season zero GL had significantly the highest mean. Gametocide level 1,500 and 2,000ppm each had the least PEMS means twice in the seasons. In 2005LR, 1,500ppm had the least PEMS mean but was not significantly different from the other means except zero ppm and 700ppm GLs. It also had the least mean in 2006SR but not significantly different from the rest of the means including zero ppm GL. Gametocide level 2,000ppm had the least means in 2006LR and 2007LR and in both instances significantly lower than the zero ppm GL and also not significantly different from 1,500ppm GL.

Table 5: Gametocide level efficacy parameter means and percentage effect of most effective gametocide level

	2005LR			2006LR			2006SR			2007LR		
GL	CEMS	PEMS	FF	CEMS	PEMS	FF	CEMS	PEMS	FF	CEMS	PEMS	FF
0	0.60	179.71	322.15	12.60	51.26	99.16	13.50	155.55	251.50	8.20	86.31	259.45
700	0.35	178.81	355.37	12.77	39.75	78.35	14.02	128.22	261.37	9.43	81.45	269.29
1,000	0.50	164.34	335.74	11.77	34.83	77.96	13.23	127.45	252.97	6.57	79.22	248.35
1,500	0.55	149.38	315.34	10.72	36.68	68.09	13.72	121.72	264.62	6.40	75.91	253.91
2,000	0.33	161.78	337.63	10.63	31.90	67.70	11.48	123.47	250.40	6.73	73.54	221.13
LSD	**0.29**	**20.92**	**31.27**	**4.40**	**6.74**	**13.27**	**4.67**	**16.10**	**54.06**	**3.37**	**9.68**	**31.50**
CV (%)	**150.4**	**29.7**	**21.8**	**88.9**	**28.5**	**41.3**	**83.1**	**29.5**	**49.2**	**107.1**	**28.9**	**23.4**
% EMEGL	**27**	**16.88**	**2.11**	**16.76**	**37.77**	**31.72**	**3.71**	**21.75**	**-5.22**	**13.04**	**14.80**	**14.77**

Where GL=Gametocide level; % EMEGL=Percent effect of most effective GL; CEMS=complete emasculation; PEMS (g) =partial emasculation; FF (g) =female fertility.

Seasonal development stage of gametocide application effects

In all seasons DS had no significant effects on CEMS (Table 6). In PEMS, DSs were significantly different in all seasons with DS 0 being the highest. Development stage 45 had the least PEMS in 2005LR, 2006LR and 2007LR and was significantly different from DS 0 in all seasons but not significantly different to the other DSs. In 2006SR, DS 50 had the least PEMS and was not significantly different from DS 45 in all seasons. In FF, DSs were significantly different for each season but none was consistently different from the others across seasons, including DS 0.

Table 6: Development stage efficacy parameter means and percentage effect of most effective gametocide level

	2005LR			2006LR			2006SR			2007LR		
DS	CEMS	PEMS	FF	CEMS	PEMS	FF	CEMS	PEMS	FF	CEMS	PEMS	FF
0	0.60	179.71	322.15	12.60	51.26	99.16	13.50	155.55	251.50	8.20	86.31	259.45
39	0.34	170.43	330.24	12.35	35.11	77.03	11.08	124.30	254.78	7.63	79.00	269.99
45	0.46	158	341.35	11.04	34.62	70.37	15.24	127.36	275.68	7.04	76.66	240.34
50	0.50	162.3	336.47	11.03	37.65	71.67	13.03	123.98	241.56	7.19	76.93	230.46
LSD	**0.28**	**20.25**	**30.28**	**4.26**	**6.53**	**12.85**	**4.52**	**15.59**	**52.34**	**3.26**	**9.37**	**30.75**
CV (%)	**150.4**	**29.7**	**21.8**	**88.9**	**28.5**	**41.3**	**83.1**	**29.5**	**49.2**	**107.1**	**28.9**	**23.4**
% MEDSE	**-16.67**	**12.08**	**-2.51**	**12.46**	**32.46**	**29.03**	**12.89**	**20.30**	**3.95**	**6.95**	**11.18**	**14.64**

Where DS=development stage; % MEDSE=Percent effect of most effective DS GL; CEMS=complete emasculation; PEMS (g) =partial emasculation; FF (g) =female fertility.

Seasons combined gametocide level and development stage of application effects

Over the seasons, gametocide levels only significantly differed for PEMS among gametocide efficacy determining parameters (Table 7). The control 0 GL had the highest PEMS and the least was 1,500ppm GL. All GLs had significantly lower PEMS than zero GL. Means for GLs were not significantly different for FF parameter.

Over the seasons, development stages only significantly differed for PEMS among gametocide efficacy determining parameters. On PEMS, DS 45, 50 and 39 were not significantly different, but were all significantly lower than DS 0.

Table 7. Combined seasons 2005LR, 2006LR, 2006SR, and 2007LR gametocide level and development stage efficacy determining parameters means

Gametocide level				Development stage			
GL	CEMS	PEMS	FF	DS	CEMS	PEMS	FF
0	8.73	118.21	230.13	0	8.73	118.21	230.13
700	9.14	107.06	238.25	39	7.85	102.21	229.6
1,000	8.02	101.46	226.68	45	8.44	99.16	231.4
1,500	7.85	95.92	223.32	50	7.93	100.21	219.04
2,000	7.30	97.67	219.11				
LSD	1.81	7.23	18.15	LSD	1.75	7.00	17.60
CV (%)	104.80	33.48	36.03	CV (%)	104.80	33.48	36.03
%EMEGL		18.86	8.03	% MEDSE	3.32	16.12	4.82

Where GL=Gametocide level; DS= development stage; % EMEGL=percent effect of most effective GL; CEMS=complete emasculation; PEMS (g) =partial emasculation; FF (g) =female fertility.

Figure 2 below is a histogram representation of seasonal and combined seasons comparison of untreated PEMS versus the most effective GL. All GLs had reducing effect over zero ppm GL on PEMS. However, 1,500ppm GL had the most effect in 2005 LR, 2006SR, and in combined seasons analysis while 2,000ppm had the most effect in 2006LR and 2007LR. The best GL effect ranged from 14.80% to 37.77%.

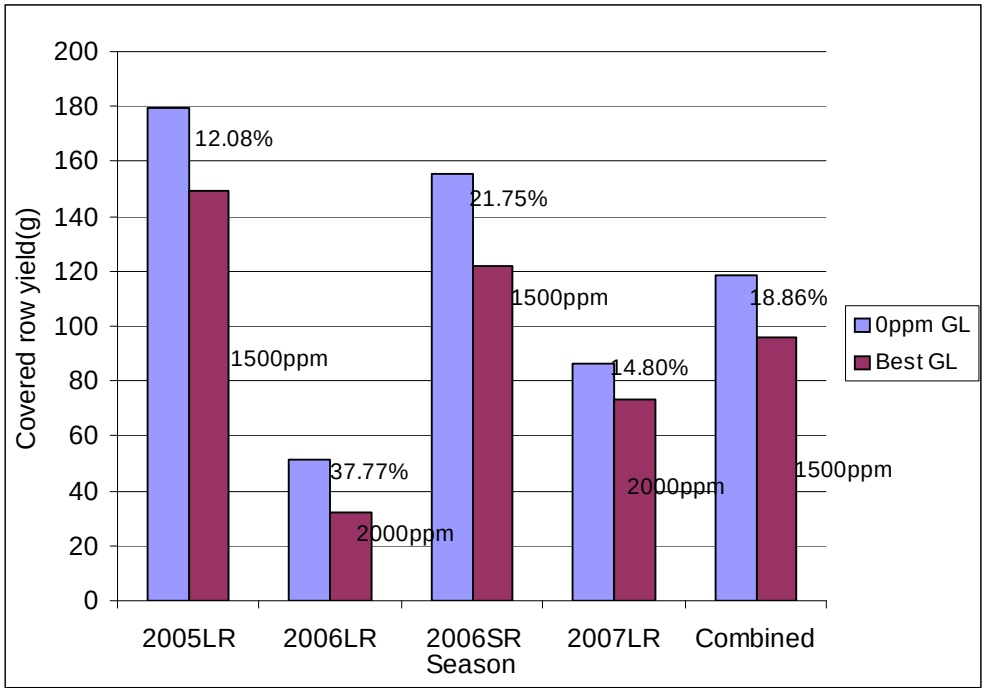


Figure 2. Observed mean maximum male gametocide effect

Figure 3 below is a histogram representation of seasonal and combined seasons comparison of untreated PEMS versus the DS with most treatment effect. Application of gametocide at all DS had reducing effect over untreated PEMS. However, treatment at DS

45 had the most effect in all seasons and seasons combined except in 2006SR when DS 50 had the most effect. The most effect of DS of application ranged from 11.18 to 32.46%.

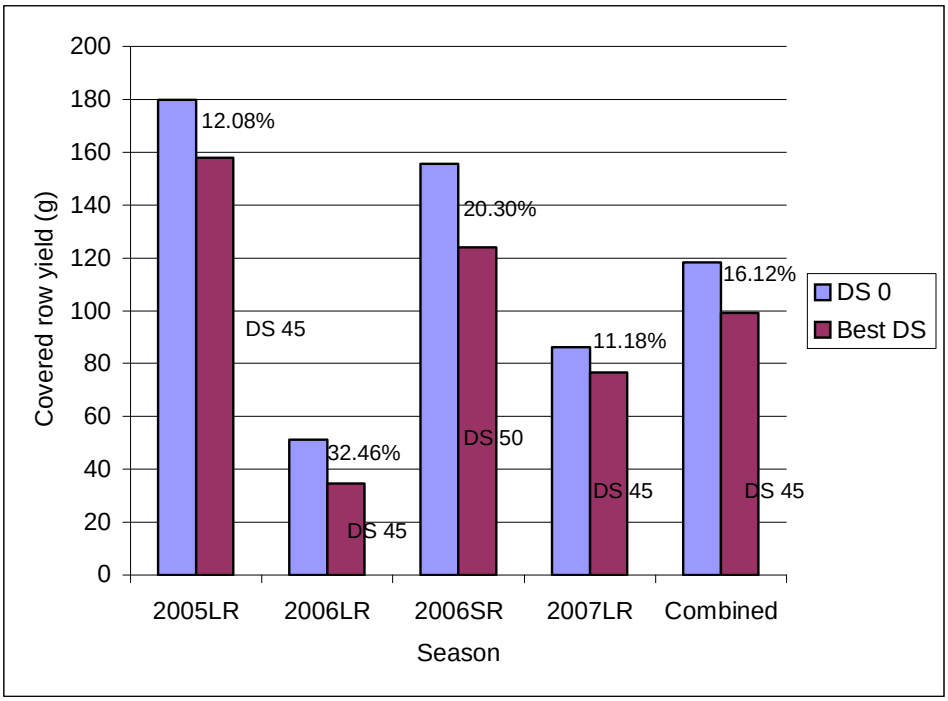


Figure 3. Observed mean development stage with the best gametocide effect

Ethrel effect on agronomic traits study

Preliminary greenhouse crossing study

There was significant variety x GL interaction for DA, productive tillers, and ear exertion ($p \leq 0.05$) (Table 8). Varieties and GLs showed significant differences for all traits except GL for maturity traits DH and DA. Means for GL main effects on DH, DA, productive tillers, plant height and ear exertion are presented in Table 9. The most drastic ethrel effect was seen on ear exertion, and between zero ppm and 1,000ppm. There was generally limited difference between GL 1,000 and 2,000ppm except on plant height and ear exertion.

Table 8: Analysis of variance for five agronomic traits of eight finger millet varieties treated with three levels of ethrel gametocide.

		Mean squares				
Source	df	DH	DA	plant height	productive tillers	ear exertion
Variety (V)	7	199.47**	326.60**	3679.9**	40.004**	1854.6**
Gametocide (GL)	2	0.43	3.60	6912.3**	14.291**	73195.2**
VxGL	14	21.16	33.19*	199.8	4.238*	721.7**
Error	144	19.90	1.78	124.9	2.080	308.5
Total	167					

*, **, significant at the 0.05 and 0.01 levels of probability, respectively; DH=days to heading; DA=days to anthesis; productive tillers=productive tillers; plant height=plant height; ear exertion=ear exertion

Table 9: Means for three GLs effect on five agronomic traits of eight finger millet varieties under greenhouse conditions.

GL (ppm)	DH (days)	DA (days)	productive tillers (no.)	plant height (cm)	ear exertion (mm)
0	73	81	4	100	78
1,000	73	81	3	80	17
2,000	73	81	3	81	13
Mean	73	81	3	87	36
LSD (0.5)	1.7	1.6	0.3	4.2	6.6
CV%	6.1	5.3	43.9	12.9	48.6

Where DH=days to heading; DA=days to anthesis; productive tillers=productive tillers; plant height=plant height; ear exertion=ear exertion

Field study

Varieties were not significantly different for all traits in 2005LR and 2006LR except DPM in 2005LR (Table 10). In 2006SR, varieties showed significant difference in plant height, and ear exertion. In 2007LR varieties were significantly different for plant height and DPM. Variety x GL and variety x DS interaction effects were not significant for all traits in all seasons except ear exertion in 2005LR for variety x GL and variety x DS in 2005LR and plant height in 2006LR and 2006SR. Significant differences existed for GLs in plant height and ear exertion in 2006LR and ear exertion in 2006SR. Development stages differed significantly for plant height in 2005LR, ear exertion in 2006LR, and plant height in 2007LR. GL x DS effects were only significant in 2005LR for plant height. There were no variety x GL interaction effects in all seasons for all traits except ear exertion in 2005LR. Variety x DS was significant only for ear exertion in 2005LR, plant height in 2006LR and 2006SR.

Over seasons gametocide levels were significantly different for all traits except DPM (Table 11). Development stages were only significantly different for plant height. Varieties were significantly different for plant height and DPM. There were no significant GL x DS for all traits except plant height, no variety x GL interaction for all traits, and significant variety x DS interactions for plant height and ear exertion and not for DPM.

Table 10: Seasons analyses of variance mean squares for some agronomic traits of finger millet.

		2005LR			2006LR			2006SR			2007LR		
Source	DF	plant height	ear exertion	DPM	plant height	ear exertion	DPM	plant height	ear exertion	DPM	plant height	ear exertion	DPM
Replication (R)	1	15610.1**	2267.37**	7134.8**	495.7	144.9*	5990.4**	280.4	31.9	-	6156.7**	1297.4**	398. 8*
Variety (V)	9	1021.2	26.8	545.7*	238.1	28.5	755.0	1431.4**	27.5*	-	1524.2*	27.0	419.3**
R*V (Error a)	9	633.1**	55.1**	110.5**	249.2**	15.7**	498.1**	241.4**	7.1	-	399.0**	13.8	62.5**
GL	3	218.6	18.0	15.6	106.1*	39.2**	2.7	145.4	46.9**	-	331.5	8.3	7.0
DS	2	349.6*	33.6	9.6	27.7	15.3*	15.3	1693.3**	23.9**	-	1473.4**	24.2	13.7
GL*DS	6	105.7	13.0	7.3	5.3	3.0	10.4	188.4*	10.7*	-	141.0	12.9	10. 8
V*GL	27	41.9	34.5*	6.1	30.0	3.5	7.7	40.6	5.8	-	128.0	8.3	7.2
V*DS	18	124.3	38.1*	12.8	58.0*	7.2	10.1	135.1*	7.3	-	184.1	14.1	8. 9
V*GL*DS	54	74.8	24.2	11.3	36.1	4.9	9.6	46.7	3.9	-	125.6	12.2	7.5
Error b	120	83.4	21.5	9.0	30.6	4.9	6.9	72.6	4.8	-	134.7	10.2	8.6
Total Corrected	259												

*, ** significant at the 0.05 and 0.01 levels of probability, respectively; plant height=plant height; ear exertion=ear exertion; DPM=days to physiological maturity; GL=gametocide level; DS=development stage.

Table 11. Combined 2005LR, 2006LR, 2006SR, and 2007LR seasons analyses of variance mean squares for agronomic traits of finger millet.

Source	DF	Plant height	Ear exertion	DF	Days to physiological maturity
Season	3	44596.87**	113.55**	3	2728.22**
Reps (Season)	4	5635.69**	935.38**	3	4507.98**
Variety	9	3050.43**	46.67	9	1434.78**
Season*Replication*variety (Error a)	72	761.72**	26.93**	63	407.61**
Gametocide Level	4	4994.24**	444.02**	4	3.13
Development stage	2	2249.40**	4.10	2	17.84
Gametocide Level*Development. Stage	6	204.4*	11.6	6	9.05
Variety*Gametocide Level	36	71.98	12.05	36	5.68
Variety*Development Stage	18	184.72**	22.11**	18	9.30
Variety*Gametocide*DevelopmentxStage	54	76.44	12.73	54	8.12
Error	840	81.67	11.19	720	7.99
Total Corrected	1039				

Seasonal ethrel effects on finger millet agronomic traits

Gametocide level means were significantly different for plant height and ear exertion in all seasons, except DPM where it was recorded (Table 12). Gametocide level 2,000ppm had the least plant height means in all seasons except 2005LR where 1,500ppm GL had the least mean. All GLs had significantly lower plant height than zero GL. In ear exertion, GL 1,500ppm had the least mean in two seasons, 2005LR and 2006SR and GL 2,000ppm had the least ear exertion mean in 2000LR and 1,000ppm in 2007LR. Generally ethrel effect on plant height and ear exertion reduction increased with increasing GL. The highest ethrel effect was seen on ear exertion ranging between 38 and 58% maximum reduction across seasons, followed by plant height, which was around 25%. No significant effect was observed on DPM.

Table 12: Gametocide level mean effect on finger millet agronomic traits

	2005LR			2006LR			2006SR			2007LR		
GL (ppm)	PH	EE	DPM	PH	EE	DPM	PH	EE	DPM	PH	EE	DPM
0	81.54	13.69	115.05	47.15	9.30	122.65	73.75	10.75	-	79.65	10.09	118.95
700	65.57	7.10	115.25	37.67	7.33	122.78	59.22	6.43	-	63.15	6.95	119.98
1,000	64.53	7.42	115.15	35.40	6.15	122.52	58.10	5.87	-	60.26	6.20	119.82
1,500	61.10	6.29	115.2	34.97	6.04	123.03	56.75	4.57	-	63.75	6.95	119.33
2,000	63.84	6.39	114.18	34.80	5.38	122.78	55.65	4.79	-	58.81	6.93	120.12
LSD	**3.91**	**1.98**	**1.28**	**2.37**	**0.95**	**1.12**	**3.64**	**0.93**	**-**	**4.96**	**1.36**	**1.25**
CV (%)	**14.02**	**63.25**	**2.60**	**15.12**	**34.31**	**2.13**	**14.52**	**37.50**	**-**	**18.46**	**45.49**	**2.44**
Max. effect(%)	**25**	**54.05**	**-0.02**	**26.19**	**42.15**	**-0.31**	**24.54**	**57.49**	**-**	**26.16**	**38.55**	**-0.98**

Where GL=Gametocide level; Max. effect=percent maximum effect; PH=plant height (cm); EE=ear exertion (cm); DPM=days to physiological maturity.

Seasonal DS of ethrel application effects on finger millet agronomic traits

The effects of the DS of gametocide application are presented in Tables 13. The control DS 0 had significantly higher means than other DSs for plant height and ear exertion across seasons. Development stage 39 had the least plant height mean in 2005LR, 2006SR and 2007LR while DS 45 had the least mean in 2006LR. In all seasons, DS 39 and 45 were not significantly different in effect on plant height. On ear exertion, DS 45 had the least mean in 2005LR, DS 50 in 2006LR and 2006SR and DS 39 in 2007LR. In all seasons DSs in which ethrel was applied had means that were not significantly different except in 2006SR when DS 50 had the least mean. All DS means were not significantly different from DS 0 in DPM, except in 2007LR when DS 0 had the least DPM and DS 50 the highest.

Table 13: Development stage of gametocide application mean effect on finger millet agronomic traits in four seasons

DS	2005LR			2006LR			2006SR			2007LR		
	PH	EE	DPM	PH	EE	DPM	PH	EE	DPM	PH	EE	DPM
0	81.54	13.69	115.05	47.15	9.30	122.65	73.75	10.75	-	79.65	10.09	118.95
39	61.84	6.76	115.19	36.38	6.73	123.00	53.75	5.91	-	58.84	6.30	119.36
45	63.44	6.17	115.1	35.26	6.04	123.06	55.95	5.50	-	59.19	7.37	119.90
50	65.99	7.47	114.55	35.49	5.91	122.28	62.59	4.83	-	66.44	6.61	120.18
LSD	**3.78**	**1.92**	**1.24**	**2.29**	**0.92**	**1.08**	**3.53**	**0.90**	**-**	**4.81**	**1.32**	**1.21**
CV (%)	**14.02**	**63.25**	**2.60**	**15.12**	**34.31**	**2.13**	**14.52**	**37.50**	**-**	**18.46**	**45.49**	**2.44**
Max. effect(%)	**24.16**	**54.93**	**-0.12**	**25.22**	**36.45**	**-0.34**	**27.12**	**55.07**	**-**	**26.13**	**37.56**	**1.03**

Where DS=development stage; Max. effect=Maximum DS effect; PH=plant height (cm); EE=ear exertion (cm); DPM=days to physiological maturity.

Combined seasons GL and DS of ethrel application effects on agronomic traits means

In the combined analysis, 2,000ppm GL had the least means for plant height, ear exertion and DPM (Table 14). For plant height and ear exertion, all GL means were significantly different from zero GL mean and the effect of ethrel of reducing plant height and ear exertion increased with increasing GL. Gametocide levels means for DPM were all not significantly different from zero ppm GL mean and ethrel effects were negligible. On plant height and ear exertion, GLs 2,000, 1,500, and 1,000ppm were not significantly different, as 1,000 and 700ppm were. The highest GL effects were observed on ear exertion (46.44%), and plant height (24.26%).

Development stage 39 had the least mean for plant height, which was not significantly different from DS 45 (Table 14). All DSs were however significantly lower in plant height than DS 0 mean. Development stage 50 had the least mean for ear exertion, but all DS means were not significantly different apart from DS 0. All DS means were not significantly different for DPM, and neither did they have significant effect. The highest DS effects were

on ear exertion (43.43%) and plant height (25.27%) while they were negligible on DPM (-0.22%).

Table 14. 2005LR, 2006LR, 2006SR, and 2007LR combined mean gametocide level and development stage of gametocide application effect on agronomic traits

Gametocide level				Development stage			
GL	PH	EE	DPM	DS	PH	EE	DPM
0	70.52	10.96	118.93	0	70.52	10.96	118.93
700	56.40	6.95	119.19	39	52.70	6.42	119.15
1,000	54.57	6.41	119.00	45	53.46	6.27	119.19
1,500	54.14	5.96	119.05	50	57.63	6.20	118.73
2,000	53.27	5.87	118.86				
LSD	1.91	0.71	-	LSD	1.85	0.68	-
CV (%)	16.18	50.25	2.37	CV (%)	16.18	50.25	2.37

Where GL=Gametocide level; PH=plant height; EE=ear exertion (cm); DS=development stage, and DPM=days to physiological maturity.

DISCUSSION

Preliminary ethrel crossing gametocide study

Isolation of true F_1 plants after hybridisation of finger millet varieties using ethrel indicated its potential in finger millet breeding as reported on other self-pollinating cereal crops of wheat and barley (Bennett and Hughes, 1972**;** Law and Stoskopf, 1973; Hughes et al., 1974; Fairey and Stoskopf, 1975; Kumar et al., 1976; Verma and Kumar, 1978; de Milliano,1983; Singh et al., 2000). The levels of success of 0.19-8.63% may have been low because of lack of synchronization of appropriate ethrel concentration and development stage of application, a requirement reported by Fairey and Stoskopf (1975) and Chakraborty et al. (2000), but this was good enough for a start and it could be improved with rigorous controlled studies. The higher success rates involving MS parent could be due to some MS female plants showing male sterility.

Field gametocide study

Lack of significant differences between GL and DS for CEMS in seasons and across seasons implied no GL x DS treatment combination attained 100% emasculation, hence lack of difference with the untreated check. The empty heads counted may have been due to other factors, mostly stalkborer, which also appeared on uncovered rows. This finding is in agreement with Fairey and Stoskopf (1975) who argued that in the light of need to exact ethrel application and DS, complete sterility was practically impossible because florets in a spikelet and in turn spikelets on a spike do not mature simultaneously.

The significant differences in GL in 2005LR, 2006LR and SR and across seasons and all treated means consistently significantly lower than untreated means for PEMS suggested ethrel effectiveness as a gametocide in finger millet. In the light of the observed lack of significant differences between treated and untreated GL and DS for FF, ethrel could be said to have caused male sterility leaving female fertility intact. The consistent significant difference of treated and untreated GL and DS means for PEMS implies that ethrel killed or diasbled some male gametes on the treated and covered plants reducing fertilized florets and resulting in reduced covered row yield. On the uncovered treated two rows, the disabled male gametes were made up for by open pollination from pollinator rows, resulting in no FF difference between uncovered treated and untreated. Ethrel could, therefore, cause male sterility of between 15 to 38% on finger millet when applied at concentrations of between 1,500 to 2,000ppm at DS 45. This level of emasculation would substantially help in crossing, previously almost impossible to cross, finger millet to create variation. This would rely on physical markers to differentiate F_1 plants from selves. The low levels would not be adequate for exploitation of heterosis in finger millet as selfs would mask the desirable heterosis. The consistent lack of variety x GL and variety x DS interactions implied that finger millet genotypes responded in the same manner to ethrel and, therefore, the optimum GL and DS will apply on most finger millet genotypes. The observation of ethrel induced male sterility with no effect on female fertility explained the partial crossing in the green house experiment. The greenhouse cross success rate range of 0.19-8.63% was lower than emasculation observed in the field study of 15-38%. This again could be attributed to lower synchronization of chemical concentration and DS of application in the greenhouse. These emasculation rates are in the lower range of reported rates on wheat and barley where male sterility recorded ranged from 2% to 98% at various GL levels and DS (Fairey and Stoskopf, 1975; Verma and Kumar, 1978; de Milliano, 1983; Beek, 1988; and Singh et al. 2000). Berhe and Miller (1978) observed male sterility on ethrel treatment on tef, but it was accomapnied by female sterility. Thakur and Rao (1988) observed effective male sterility on pearl millet on ethrel application. More work needs to be done to increase percentage cross in finger millet to make crossing easier and workable for both variation creation and hetorosis breeding.

Ethrel effect on finger millet agronomic traits

The lack of significant differences between treated and untreated GL and DS for FF implied ethrel gametocide applied in the range of 700ppm and 2,000ppm at DS range of 39 to 50 did not significantly reduce finger millet yield. Reports of ethrel application reducing yield in the presence of adequate pollen are rare. Early and Slife (1969) reported reduction of yield on

maize. The lack of significant negative effect on yield is encouraging. It is not, however, in consonance with the greenhouse observation of ethrel reducing the number of productive tillers, a trait found to be a major component of yield in finger millet (Duke, 1978; Bezaweletaw et al., 2006).

The lack of GL significant differences for DH and DA in the greenhouse study and the same for DPM in the field study implied ethrel application in the range of 700 to 2,000ppm did not affect finger millet maturity. Maturity period is a very important trait in finger millet, and many farmers prefer early maturing varieties (see PRA, Chapter 2). These findings thus implied that ethrel could be used without compromising maturity period in finger millet. These findings were in contrast to findings by Early and Slife (1969) who reported delayed flowering and maturity in maize, Stoskopf and Law (1972) and De Milliano (1983) who observed delayed heading on wheat, and Law and Stoskopf (1973) who observed delayed heading in barley. The general absence of variety x GL and GL x DS for these traits implied ethrel affected these traits similarly across varieties and DS. The absence of variety x GL interaction for these traits is in contrast with Beek (1988) observation of gametocide effect varying with genotypes. The presence of significant variety differences in both greenhouse and field study for many traits was expected as the varieties were of diverse backgrounds.

Lack of GL and DS significant differences for ear exertion in 2005LR and 2007LR could have been due to all levels reducing the trait in similar magnitudes in the seasons, but the GLs were generally significantly different for ear exertion (Table 10). The lack of significant GL x DS interaction in all seasons and across seasons, except 2006SR, for ear exertion implied GLs affected ear exertion in a similar manner irrespective of DS with 2,000ppm reducing ear exertion the most by 46.44% over seasons. Greenhouse and field study results showed ethrel had a big reducing effect on ear exertion, the most ethrel influenced trait. Any GL between 700 and 2,000ppm applied at any DS between DS 39 and DS 50 could cause significant reduction of ear exertion, but among the GLs and DSs, GL 1,500 to 2,000 could cause the most reduction when applied between DS 45 and 50. This effect is not desirable, especially in heterosis breeding and it has been observed consistently in many reports of ethrel application on cereals (Rowell and Miller, 1971; Stoskopf and Law 1972; Law and Stoskopf 1973; Fairey and Stoskopf, 1975; de Milliano, 1983). According to Fairey and Stoskopf (1975), this is not good in heterosis breeding as it will counter full panicle pollination, hence reduce seed yield.

The consistent reducing effect of ethrel on plant height in the greenhouse and field studies indicated any of the four GLs caused significant reduction in plant height. It causes up to

25% reduction in plant height, with 2,000ppm applied at DS 39 causing the most effect. Development stage 39 was the earliest stage of gametocide application and the fact that it had the most plant heigh reducing effect was probably due to incomplete inter-nodal elongation at this stage. The plant height reduction effects were in agreement with negative effects observed on other crops: Early and Slife (1969) on maize; Rowell and Miller (1971), Stoskopf and Law (1972), de Milliano (1983), and Law and Stoskopf (1973) on barley. Significant reduction in plant height would be a major drawback in the use of ethrel for heterosis breeding as it would make harvesting seed cumbersome. Reports by Fairey and Stoskopf (1975) that application of granular ethrel reduces negative effects and Chakraborty and Devakumar (2006) that Ethyloxanilates are effective CHAs without negative agronomic effects are worth investigation on finger millet.

CONCLUSION

Ethrel can be used as a CHA to successfully make crosses in finger millet, though percent cross success and emasculation levels were low, 0.19-8.63% and 15-38%, respectively, without female infertility. Because ethrel did not cause 100% emasculation, screening crosses from selfs at F_1 generation using morphological characters was necessary. Gametocide levels 1,500 and 2,000ppm conferred the most male sterility. Gametocide level and development stage of application were independent and DS 45 was the most appropriate development stage to apply ethrel. The effect of ethrel on finger millet was independent of genotype implying that appropriate GL and DS will work for most varieties. Ethrel had no significant effect on yield, implying that applied at the studied levels, it did not affect female fertility. It also did not significantly affect maturity characters of DH, DA and DPM. However, plant height and ear exertion were significantly affected with ear exertion consistently most affected effect. These two negative effects would highly compromise the value of ethrel in heterosis (hybrid) breeding. However, ethrel showed value for combination and transgressive breeding as it would enhance successful crossing by hand pollination. The work with ethrel on finger reported above is pioneering and follow-up investigations to enhance its efficacy are recommended.

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CHAPTER 5

Studies of genetic components of agronomic traits and resistance to blast disease and *Striga* in six elite finger millet varieties of western Kenya

ABSTRACT

Finger millet is an important food crop in low input farming systems in Africa, but hardly any cross breeding has been done to study its genetics and exploit its genetic potential. Six western Kenya elite varieties were crossed in a 6x6 diallel to determine gene action conditioning yield and agronomic traits and to identify crosses with potential for further development into superior pure line varieties. Segregating populations were advanced in western Kenya to F_3 before selection on F_3 and F_4 at 5% intensity. Selected F_5 lines were then evaluated at three sites and analysed in a half diallel using both the numerical and graphical Hayman's approach. Additive gene effects were found solely responsible for the control of yield and finger branching among the six parent elite varieties, underscoring the potential of yield gain on further selection. Both additive and partial dominance effects were significant for neck and head blast (NHB), days to 50% flowering (D50%), ear shape and days to physiological maturity (DPM). Overdominance gene effects were significant for plant height, lodging, and plant stand establishment. Dominant gene effects conferred resistance to NHB and lodging, higher plant stand establishment and fist ear shape. Recessive gene effects conferred early maturity and open ear shape. Both dominant and recessive genes controlled days to 50% flowering and plant height. There was no evidence of significant genetic variation for resistance to shootfly, foliar blast and *Striga* in these germplasm. Parent lines OK, GE, and U-15 displayed large additive effects for yield, which was reflected in good performance of lines from crosses OKxGE, P-224xOK, and U-15xGE. These crosses will be exploited in the breeding program to develop new and better varieties.

Keywords: Additive gene effects, blast resistance, finger millet, yield, *Striga* resistance.

INTRODUCTION

Finger millet (*Eleusine coracana* (L.) Gaertn. ssp. *coracana*) (Hilu et al., 1979) is an important food crop in traditional low input cereal-based farming systems in sub-Saharan Africa. In particular, finger millet is a major crop in Eastern Africa - western Kenya, western and southern Tanzania, and Uganda, where it commands higher market prices than other cereals (Holt**,** 2000, Takan et al., 2002). However, like other crops, it is faced with prospects of less land allocation due to limited agricultural land and competition from more researched and established crops. In such circumstances, the need to improve its productivity cannot be over-emphasized. Breeding for better varieties is the most viable option to increase productivity in the resource poor farming systems where the crop is largely produced on small land units. Generally, little research has been done on finger millet and its potential has not been fully exposed to farmers, especially in sub-Saharan Africa. Mitaru et al. (1993) reported low farmer grain yields of 500-750kg ha^{-1} in Kenya which have been confirmed in a PRA study (see Chapter 2). This yield range is very low compared to 5,000-6,000kg ha^{-1} attainable under ideal irrigated and research conditions (NRC[1], 1996; Duke, 1978). Use of unproductive local varieties which are susceptible to blast disease and *Striga* is a major factor compromising grain yield in finger millet (Bezaweletaw, 2006).

The immediate breeding objective in finger millet is to improve current varieties (NRC, 1996). The improvement through breeding could focus on resistance to blast, *Striga*, Helminthosporium, lodging, poor soil and moisture conditions; robust growth; early vigour; large head size with many branching fingers; and good quality high-density grain (NRC, 1996; Gurdev, 2001). Finger millet yield has been reported to be influenced by variety duration to maturity, plant height, tillering capacity, length and width of fingers, and main ear grain weight (Duke, 1978 and Bondale et al., 2002). Bezaweletaw et al. (2006) reported similar associations but grain yield per plant was negatively associated with maturity period. They found genotypic variability in many traits including 1,000 grain weight, finger number and productive tillers, which were the major contributors to single plant grain yield. Das et al. (2007), using molecular techniques, found Indian genotypes to have a wide genetic base which could be exploited for breeding. Sumathi et al. (2007) observed high heritabilities for yield and yield components on finger millet F_1 hybrids, indicating that yield could be improved through selection in segregating generations.

[1] National Research Council, USA

Blast caused by the fungus *Pyricularia grisea* is the most serious disease of finger millet (NRC, 1996 and CGIAR[2], 2001). It is the most important disease of finger millet in western Kenya where it causes grain yield losses of up to 50% (Obilana et al., 2002 and Takan et al., 2002). Fungicides are not an option for the peasant finger millet farmers in Kenya and the rest of sub-Saharan Africa because of cost. Resistant varieties are commonly used in control of many plant diseases. Resistance to blast disease exists in finger millet (Mantur and Madhukeshwara, 2001; Narayanan et al., 2002; Jain & Yadava, 2003) and can be exploited in developing new varieties for deployment in blast infested areas in sub-Saharan Africa. Little research has been carried out to contain this disease on finger millet in sub-Saharan Africa. Surveys in western Kenya and Uganda indicated dark seeded finger millet varieties with compact heads to be more resistant to blast disease than lighter colour seeded and open headed varieties (Takan et al., 2004).

Striga causes significant yield losses in cereals, especially in Africa and Asia, but effective affordable control measures are scarce and resistance genes have not been identified in many crops (Kuiper et al., 1998) that have been investigated. *Striga* effect and availability of resistance have not been investigated on finger millet. Breeding for resistance to Striga in many cereals has been a difficult undertaking because of *Striga* ecology involving complex interactions between host, parasite, and the environment (Ejeta, 2007). According to Duke (1983) *S. asiatica, S. densiflora, S. hermonthica,* and *S. lutea* parasitize finger millet. In western Kenya *Striga hermonthica* is the other major biotic problem to finger millet farmers after blast disease and no studies have been carried out on its effects and control.

Cross breeding has hardly been attempted on finger millet in Africa. For effective breeding in any crop, an understanding of the nature and the magnitude of genetic variability for important traits is critical in developing an effective breeding strategy. Prediction of genetic gains that could be useful for a given set of parent varieties for a breeding programme is important (Dwivedi et al., 1980). Diallel cross analysis is a handy tool for this purposes and is used to study the genetics of quantitative traits, especially in self-pollinated crops. The Hayman (1954a, 1954b) and Jinks (1954) approaches have frequently been used for rapid evaluation of parental genetic relationships (Stoner and Thompson, 1966; Dwivedi et al., 1980). These have been applied on allopolyploid crops like durum wheat and wheat (Singh et al., 2003; Hakizimana et al., 2004; Dere and Yildirim, 2006; Sayar et al., 2007). Lupton (1961); Busch et al. (1974) and House (1985), advocated the use of later generations (F_4 and F_5) in evaluation of crosses. This fits in well with the objective of development of pure line varieties rather than hybrids. The current focus of finger millet breeding has been to

[2] Consultative Group on International Agricultural Research

generate purelines for the small-holder farmers in developing countries as researchers have suggested that hybrid varieties have no place among predominantly poor peasant finger millet farmers (Holt **,** 2000 and Takan et al., 2002). However, it has not been investigated whether F_1 heterosis can be exploited in finger millet. Because the breeding programme in western Kenya aims to generate pure line varieties, diallel analysis was carried out on segregating F_5 generation populations. At this level, many linkages between the genes could have been broken, an important requirement in diallel mating.

General objective

The general objective was to determine the potential of six western Kenya elite finger millet varieties to contribute to breeding new higher yielding varieties for improved yield and production of finger millet in Kenya. The specific objectives of the study were to:

1. Determine gene action controlling key finger millet traits of yield; plant height; resistance to lodging, resistance to blast disease, and *Striga*; days to flowering and maturity; and ear shape.
2. Identify crosses among six elite parent varieties with the best genetic potential for development of new superior pure line varieties for deployment in western Kenya and similar environments in sub-Saharan Africa.

Hypothesis

Key finger millet traits of elite varieties from western Kenya are controlled by additive gene action showing adequate variation, which can be used to breed better varieties.

MATERIALS AND METHODS

Germplasm

Six elite finger millet varieties from western Kenya, Gulu-E (GE), P-224, P-283, U-15, Okhale-1 (OK), and Nanjala Brown (NB) were used as parents in this study. The six varieties were part of a bigger 8x8 diallel cross done at the African Center for Crop Improvement of the University Of KwaZulu Natal South Africa, in 2004 under green house conditions. The 6x6 diallel was extracted and analysed as suggested by Curnow (1980). Subsequent advancements and evaluation of the F_1 to F_5 generations were carried out at KARI-Kakamega, KARI-Alupe and Inungo in western Kenya during 2005 to 2007. The segregating materials were advanced from F_1 (487 plants) to F_3 (62,742 plants) through natural self pollination without selection. Visual selection was applied at an intensity of 5%

on F_3 (3,350 plants selected) and F_4 (180 families selected) for yield and all desirable agronomic characteristics. The top 46 F_5 lines from 18 progeny populations were evaluated in a replicated trial and analysed in a half diallel.

Experimental design and management

The 46 lines together with six parental varieties and 29 other genotypes were evaluated in a 9x9 simple lattice design at three locations of KARI-Kakamega, KARI-Alupe and Inungo during the long rain in 2007. Plot size at each location was three rows of 2m each spaced at 0.3m apart and 0.15m within rows. Fertilizer was applied at planting and second weeding at 20kg ha^{-1} each of N and P_2O_5. At planting furrows were made according to row spacing, and fertilizer, then seed applied in the furrows by drilling. At KARI-Alupe, the trial was planted on a *Striga* sick plot and artificially inoculated with 570g of *Striga* seed/sand mixture prepared by mixing 20g of *Striga* seed with 5kg of sand. The inoculation was by drilling the mixture in the furrows before application of fertilizer and seed. According to Berner et al. (1997), this contains about 454,183 *Striga* seeds per plot. First weeding was done two weeks after emergence and second weeding two weeks later, before *Striga* emergence, as Andrianjaka et al. (2007) reported *Striga* emergence to start after 4 weeks on sorghum. The experiment was not protected against any insect pest or disease to reflect farmers' management practice.

The scale used by Mantur and Madhukeshwara (2001) in visual evaluation of finger millet germplasm for blast resistance was adopted to rate genotypes for disease (blast) and shootfly resistance based on incidence as follows:

1	=	0.0% disease incidence	=	highly resistant;
2	=	1.0-2.0% disease incidence	=	resistant;
3	=	2.1-10.0% disease incidence	=	moderately resistant;
4	=	10.1-25.0% disease incidence	=	moderately susceptible;
5	=	>25% disease incidence	=	susceptible.

Emerged *Striga* plants per plot were counted at vegetative, flowering and physiological maturity of finger millet lines. The days of 50% flowering and physiological maturity were recorded on each plot when 50% of plants in the plot attained the respective stages. Physiological maturity was marked with prominent hard grain that did not crush into "milk" when rolled between thumb and forefinger. Plant height (cm) was measured on three representative plants in a plot (ground level to tip of plant) at physiological maturity and the average recorded. Lodging percentage was calculated as number of lodged plants in a plot

divided by plant stand expressed as a percentage. Yield was recorded as the mass of grain after thorough uniform drying, threshing and winnowing in grams per plot and converted to kg ha^{-1}. Ear shape was measured in accordance with IBPGR descriptors (IBPGR[3], 1985) on the basis of head architecture as follows:

1 = open headed,
2 = incurved, and
3 = fist.

Finger branching was measured using scores of 0 = absence (0) or 1 = presence of spike branching. Plant stand was maeasured as the number of plants in a plot at harvesting.

Data analysis

Data from the simple 9x9 lattice design experiment were subjected to analysis of variance using the general linear models (GLM) procedure in SAS (SAS Institute, 2003). The 6x6 half diallel was subjected to a Hayman's analysis using a procedure developed by Jones (1965) in GenStat computer package (Payne et al., 2007). The means from each site were used to analyse the diallel across the three sites. Three missing crosses were estimated using the formula of Eckhardt (1952):

$ab = (n-1)(T'a + T'b) - 2T'/n^2 - 5n + 6$

Where ab = the missing cross to be estimated,
n = number of parental lines in the diallel
T'a and T'b = the row totals of parent lines a and b missing one data point (cross) each and
2T' = Grand total of the diallel table without the missing cross.

In the diallel cross effects were partitioned into variation due to additive genetic effects (a) and overall dominance effects (b) according to Hayman (1954b). Dominance effects were further portioned into b_1, b_2 and b_3, where b_1 indicates an overall direction of dominance relative to the mid-parent value, b_2 indicates asymmetric distribution of dominant genes in the parents and b_3 indicates dominance interaction between specific genotypes (Kurt and Evans, 1998). Similarly site x cross interaction effects were subdivided into site x a, site x b interaction effects and site x b interaction component further partitioned into site x b_1, site x b_2, and site x b_3 interaction effects.

[3] International Board for Plant Genetic Resources

The model below incorporating replication (Walters and Morton, 1978) was adopted:

Yij = m + gi + gj + gij + eij For crosses and

Yii = m + 2gi + eii For parental lines

Where

Yij	=	off diagonal elements (crosses)
Yii	=	along diagonal elements (parental lines)
m	=	mean response level,
gi and gj	=	additive contribution of ith and jth parental lines, respectively,
gij	=	dominance effects
eij and eii	=	experimental error.

The F ratios were then calculated by dividing each component by its interaction with sites (Singh and Chaudhary, 1977). Where the 'b' component was significant, Hartley (1950) test of homogeneity of variances was used to test heterogeneity or homogeneity of the 'b' components interaction with sites before testing their significance against either their individual interaction with sites or the 'b' component interaction with sites (Singh and Chaudhary, 1977). The 'a' and 'b' interaction with sites was similarly tested. The variance of arrays (Vr) and arrays covariance with parental lines (Wr), mean variance and mean covariance of arrays, variance of the mean of arrays, parental mean, and difference of mean of progeny and parent statistics were also calculated in Genstat computer package. Validity of assumptions for diallel analysis were tested by a t-test using the regression coefficient of Wr/Vr and associated standard errors at (n-2) = 4 degrees of freedom (where n = number of parents in diallel) and ANOVA of Wr-Vr to determine homogeneity or heterogeneity of the parameter. The Wr/Vr plot is the relationship between the array variances (Vr) and the parent-offspring covariances (Wr). This plot was used to provide further information about the average degree of dominance and the relative genetic constitution of the parental lines in terms of dominant and recessive genes (Kurt and Evans, 1998; Filho et al., 2002) within the parabola limit. Beyond the parabola limit dominance cannot be deduced (Sood and Kalia, 2006). The Wr-Vr statistic ANOVA was used to test satisfaction through homogeneity of the statistic of the additive-dominance model conditions of no epistasis, no heterozygosity, two alleles at a locus, and no correlation between gene distributions at a locus in parental lines (Hayman, 1956). Heterogeneity of the statistic implied failure to satisfy the additive-dominance model due to any of the four conditions. Where there was heterogeneity, the arrays Wr-Vr statistics were separated using least significant difference of the statistic means and sequentially eliminated the most variable array until homogeneity of the statistic was attained. For plant height NB and GE were sequentially eliminated before homogeneity,

for D50 NB and then GE, for plant stand GE and then U-15, and for DPM, U-15 follwed by NB.

Singh and Singh (1984) formulae were used to determine degree of dominance at F_5 using Wr/Vr regression plots when the intercept was between origin and tangent of parabola limit, parallel to the regression line:

$X = (½)^{n-1}AB$

where X = critical point on Wr axis if the regression line intercepts above it at F_3 and above generations, then it is partial dominance, if it intercepts below it, then it is overdominance and if it intercepts at the exact critical point, then it is complete dominance.

n= the filial generation

A= tangent point intercept on Wr axis

B= regression line Wr intercept.

RESULTS

Genotypic variation

Analyses of variance of population evaluation data showed significant genotype differences for all traits recorded except shootfly and *Striga* counts (Table 1). There was significant GxE interaction for all traits except DPM necessitating individual sites analyses. There were significant differences ($p \leq 0.05$) for all traits at all sites except shootfly, foliar blast resistance, plant height, and *Striga* counts at Alupe, shootfly at Kakamega and plant stand at Inungo. The diallel analyses of variance showed additive gene effects were significant for yield, neck and head blast, D50, finger branching, ear shape and days to physiological maturity (Table 2). Dominance gene effects were not significant for yield and finger branching but they were significant for neck and head blast resistance, D50, ear shape, plant height, resistance to lodging, plant stand establishment and days to physiological maturity. Both additive and dominance gene effects were significant for D50, ear shape, DPM and resistance to NHB. Only dominance gene effects had significant interaction with sites for only plant height and resistance to lodging. Analysis of the 'b' component where it was significant revealed b_1 to be significant only for plant height and b_2 and b_3 were significant for all the traits where 'b' was significant, except ear shape for b_2 and plant stand for b_3.

Table 1. Analysis of variance mean squares for agronomic traits of 81 finger millet genotypes evaluated over three sites in western Kenya during 2007 LR.

		Mean Squares							Mean Squares						Mean Squares	
Source	DF	Shootfly	Foliar Blast	Days to 50%Flow.	Finger Branch.	Ear Shape	Days to Phys. Maturity	DF†	Neck and Head Blast†	Plant height†	Lodging†	Plant stand†	Yield†	DF‡	Total *Striga* counts‡
Site (S)	1	165468.16**	230.03**	3074.09	0.00	7.41**	160.568**	2	3.951**	13022.27**	32919.14**	2269.76**	22600**		
Rep (R) [S]	1	3560.11	0.37	15.12	0.89	0.00	2.07	2	0.85	16.74	141.24	122.50	210	1	7509.93
Block(S*R)	32	60.93	0.17	4.98	0.19	0.19	7.45	48	0.17	85.71	205.08	25.32	200	16	463.27
Row(S*R)	32	72.58	0.24	10.57	0.12	0.18	4.27	48	0.26	79.72	203.39	14.39	170	16	430.75
Entry (E)	80	54.20	0.32**	49.42**	0.29**	1.27**	16.05**	80	1.19**	163.38**	726.94**	14.29**	520**	80	254.74
S*E	80	52.49	0.31**	10.14*	0.22**	0.22*	5.96	160	0.32**	75.66**	300.45**	12.75*	150**		
Error	96	66.43	0.17	6.55	0.12	0.15	5.33	143	0.13	44.94	169.42	8.85	90	48	228.27
Total Corr.	323	196903.91						484						161	

*, ** significant at the 0.05 and 0.01 levels of probability, respectively; and †, ‡ data collected at 3 and 1 locations, respectively.

Table 2. A 6x6 diallel analysis of finger millet for yield and agronomic traits across three sites in western Kenya during 2007LR.

Source	d.f.	Mean squares				
		Yield (kg ha^{-1})	Neck and head blast	Plant height	Lodging	Plant stand
Site	2	3176580.778**	0.382**	1629.400**	3343.189**	205.286**
Entries	20	243288.930**	0.855**	158.213**	281.623**	9.537
a	5	726537.694*	2.428**	386.585	595.217	6.753
b	15	82206.009	0.330**	82.089**	177.091**	10.464*
b_1	1	66343.214	0.136	59.863**	13.768ns	8.767
b_2	5	74734.450	0.235*	115.778**	182.563*	21.607**
b_3	9	88119.407	0.405**	65.843**	181.087**	4.462
SitexEntry	40	68860.827	0.100	36.755	97.470	5.274
Sitexa	10	144282.503	0.205	123.982	231.258	6.468
Sitexb	30	43720.269	0.065	7.680**	52.874*	4.876
$Sitexb_1$	2	365810.433	0.116	10.152	18.706	10.769
$Sitexb_2$	10	19813.258	0.045	6.592	39.378	6.158
$Sitexb_3$	18	21214.146	0.071	8.009	64.169	3.509

Table 2. Continued

Source	d.f.	Mean squares				
		Foliar blast	Days to 50% flowering	Finger branching	Ear shape	Days to physiological maturity
Site	1	21.764**	526.681**	0.309	0.939*	10.703
Entries	20	0.200	38.244**	0.154	0.797*	23.096**
a	5	0.426	43.467*	0.239*	2.205**	27.910*
b	15	0.125	36.504**	0.126	0.328**	21.491**
b1	1	0.195	9.492	0.109	0.091	3.270
b2	5	0.081	41.212**	0.228	0.334	25.493**
b3	9	0.142	36.889**	0.071	0.350**	21.293**
SitexEntry	20	0.145	6.283	0.081	0.139	4.317
Sitexa	5	0.366	8.867	0.066	0.295	4.361
Sitexb	15	0.072	5.422	0.086	0.087	4.302
Sitexb1	1	0.002	0.733	0.253	0.376	7.575
Sitexb2	5	0.026	6.543	0.169	0.136	6.660
Sitexb3	9	0.105	5.320	0.022	0.027	2.628

*, ** significant at the 0.05 and 0.01 levels of probability, respectively

The means for all crosses and parental lines for 11 traits are presented in Table 3 below. Parent OK ranked ninth was the highest mean yielding parental line, then P-224 ranked 17, NB ranked 38, GE ranked 41, U-15 ranked 42, and P-283 was the least yielding ranked 52. Parents GE, U-15 and OK had the least NHB scores, then P-224 and P-283 and NB had the highest. Parent U-15 had earliest D50, then P-224, GE, NB, OK and P-283 the latest. Parent U-15 had the earliest DPM, then P-224, NB, P-283, GE and OK the latest. Parent NB had open ear shape, OK and P-224 had incurved ear shape, and GE, P-283, and U-15 had fist ear shape. Parents P-283 and OK did not consistently have finger branching while GE, P-224, U-15, and NB consistently had branched fingers. Parent U-15 was the shortest, then GE, P-224, P-283, OK and NB the tallest. Parent GE lodged least, then P-283, OK, U-15, P-224 and NB had the most lodging. Parent OK had highest plant stand, then GE, P-224, U-15, P-283 and NB had the least stand.

Table 3. Agronomic traits means of 52 finger millet genotypes over three sites in western Kenya in 2007LR

Genotype	*Striga* (no.)	NHB	Foliar blast	D50	Finger branching	Ear Shape	DPM	Plant height (cm)	Lodging	Plant stand (no.)	Yield
NBxU-15 F_4SB1R2(R3)	12.50	4.00	2.00	84.50	0.50	1.00	114.00	83.83	27.17	32.50	1440.67
U-15xNB F_4SB1R8(R10)	33.00	2.50	2.25	81.00	0.50	2.00	111.50	73.18	8.67	32.67	1598.33
U-15xNB F_4SB1R7(R6)	13.50	2.00	2.50	77.00	1.00	3.00	111.00	75.73	5.67	36.83	1466.33
OKxP-283 F_4SB2R6(R5)	26.00	2.00	2.50	84.50	1.00	3.00	111.00	77.60	7.50	32.17	1288.17
U-15xMS F_4SB4R11(R16)	35.50	2.00	2.50	75.50	1.00	3.00	113.50	67.63	7.83	34.83	1714.50
U-15xMS F_4SB4R3(R3)	32.00	2.00	2.00	88.25	0.5	1.50	113.50	78.25	23.00	32.50	1062.17
U-15xP-224 F_4SB5R5(R7)	6.00	2.00	2.00	75.50	1.00	2.00	113.00	67.72	27.00	34.33	1871.17
U-15xP-224 F_4BSB5R3(R2)	34.00	3.00	2.50	78.75	0.00	2.00	111.50	74.27	22.00	30.67	1352.00
U-15xP-224 F4BSB5R7(R9)	18.00	2.00	2.00	77.25	0.00	2.50	111.50	71.42	42.33	32.33	1776.50
U-15xP-224 F_4BSB5R8(R8)	28.00	2.00	2.00	83.25	0.50	1.50	112.00	72.57	15.00	33.33	1525.83
U-15xP-283 F_4SB6R22(R2)	41.50	2.00	2.25	78.25	0.50	1.50	112.00	72.57	9.83	32.33	1476.33
U-15xP-283 F_4BSB6R29(R5)	14.00	2.00	2.25	76.25	1.00	2.50	112.00	71.65	28.17	34.83	2116.50
U-15xP-283 F_4BSB6R31(R7)	47.00	3.50	3.00	74.25	0.00	3.00	111.00	73.63	11.67	30.33	1278.67
U-15xP-283 F_4BSB6R36(R13)	33.00	3.00	2.00	75.00	1.00	3.00	111.00	76.83	51.83	32.67	1632.17
FMV-1xGE F_4SB8R13(R10)	37.50	2.00	2.25	80.00	1.00	3.00	113.50	74.27	3.50	32.67	1281.83
FMV-1XGE F_4SB8R19(R12)	40.00	2.00	2.25	78.50	1.00	3.00	114.50	74.63	9.50	34.17	1591.67
GExMS F_4SB9R3(R3)	24.50	2.00	2.00	79.25	1.00	2.50	115.00	80.93	10.17	32.00	1574.17
GExMS F_4BSB9R5(R8)	31.50	2.00	2.25	79.25	0.50	2.00	113.00	79.62	24.17	35.67	2062.83
GExMS F_4BSB9R9(R10)	38.00	2.00	2.25	84.50	0.50	1.00	119.00	79.42	10.50	33.83	1724.17
GExMS F_4SB9R23(R17)	45.00	2.00	2.00	79.75	1.00	2.50	114.50	78.73	7.83	35.17	1570.17
FMV-1xNB F_4SB10R5(R5)	27.50	2.00	2.25	86.25	0.00	1.50	122.00	83.75	16.50	32.67	1675.17
GExP-283 F_4SB12R5(R2)	27.50	2.00	2.00	78.50	1.00	3.00	114.50	76.30	12.50	34.50	1569.00
OKxGE F_4SB13R7(R20)	18.00	2.50	2.75	80.50	1.00	2.50	113.00	86.12	12.17	32.83	2133.67
OKxGE F_4SB13R4(R5)	21.50	2.00	1.75	86.25	0.50	1.50	118.50	78.55	1.00	33.50	1567.33
OKxGE F_4SB13R5(R7)	5.50	1.50	1.75	83.00	1.00	2.00	114.50	82.72	9.50	35.67	2163.83
OKxGE F_4BSB13R6(R13)	20.00	2.50	2.00	75.00	1.00	1.00	113.00	84.98	20.00	34.83	1968.33
OKxGE F_4BSB13R7(R17)	32.50	2.00	2.00	82.50	1.00	1.00	115.00	96.90	14.00	31.67	1434.50
OKxGE F_4BSB13R10(R25)	22.50	2.00	2.25	79.00	1.00	1.50	113.00	84.07	33.00	32.83	1911.17
OKxGE F_4SB13R10(R27)	27.00	2.00	2.00	78.50	1.00	1.50	111.00	78.60	12.67	36.50	2292.67
OKxGE F_4BSB13R10(R30)	26.50	2.50	2.25	80.00	1.00	1.50	111.00	82.53	23.67	35.83	2106.00
OKxGE F_4BSB13R10(R31)	8.50	2.00	2.25	75.50	1.00	1.50	111.00	80.35	11.67	34.33	2402.33
OKxNB F_4SB16R9(R4)	26.00	2.00	2.00	82.25	0.00	1.50	114.50	85.93	13.00	33.50	1761.00
OKxNB F_4BSB16R18(R11)	39.00	2.00	2.00	85.50	0.50	1.00	116.50	83.25	4.67	34.33	1562.83
P-283xNB F_4BSB17R6(R3)	38.00	3.50	2.50	78.50	1.00	2.00	114.50	84.27	20.83	32.33	1074.50
OKxU-15F_4BSB18R6(R4)	26.00	2.00	2.50	83.25	0.50	1.50	117.50	82.78	10.17	34.67	1856.50
U-15xOK F_4BSB18R14(R6)	43.00	2.00	2.25	80.25	0.50	2.00	114.50	79.27	14.50	32.50	1862.67
OKxP-224 F_4SB19R9(R2)	45.00	2.00	1.75	81.00	1.00	1.00	111.50	75.60	20.33	31.00	1802.17
P-224xOK F_4BSB19R4(R7)	34.00	2.00	2.25	81.25	0.00	2.00	113.00	81.98	34.17	32.17	1770.50
P-224xOK F_4SB19R14(R7)	20.00	2.00	2.00	79.50	1.00	2.00	113.00	79.48	43.00	32.33	2119.33
MSxP-224 F_4SB20R7(R2)	21.00	2.50	2.75	82.75	1.00	2.00	118.50	72.23	30.67	31.50	1248.50
OKxFMV-1 F_4BSB22R12(R5)	20.50	4.00	2.25	78.25	0.50	2.00	115.00	70.60	22.00	32.33	1404.17
GExP-224 F_4SB26R22(R11)	80.50	2.00	2.75	79.25	1.00	3.00	111.50	75.47	5.50	33.17	1506.33
U-15xGE F_4SB28R5(R5)	28.00	3.00	2.25	81.00	1.00	3.00	112.00	75.60	11.67	33.33	1482.33
U-15xGE F_4SB28R4(R4)	22.00	2.00	2.50	76.25	1.00	2.00	111.50	85.57	17.17	33.83	2117.67
U-15xGE F_4SB28R6(R12)	30.00	2.00	2.00	80.75	0.50	2.00	115.00	85.40	17.00	34.33	1476.83
U-15xGE F_4SB28R11(R16)	42.00	2.00	2.25	79.50	0.50	3.00	113.00	72.10	13.17	32.33	1269.00
Gulu-E	27.50	2.00	2.00	82.50	1.00	2.50	119.50	72.27	5.17	34.17	1422.67
P-224	21.50	2.50	3.00	82.25	1.00	2.00	111.50	74.50	31.00	33.50	1788.17
U-15	22.00	2.00	2.00	78.50	1.00	3.00	111.00	71.27	20.00	33.17	1415.17
P-283	19.00	2.50	2.50	86.50	0.50	2.50	117.00	77.75	12.33	32.67	890.50
NB	27.00	4.00	2.00	82.75	1.00	1.00	114.50	86.75	41.67	28.50	1465.17
OK	9.50	2.00	1.75	84.00	0.50	1.50	123.00	85.63	13.83	34.67	2103.33

Adequacy of additive-dominance model

The variances and covariances calculated for each site and over sites are presented in Table 4 below. Analysis of variance for Wr-Vr statistics of traits with significant dominance effects is presented in Table 5. Neck and head blast, lodging and ear shape showed homogeneity of Wr-Vr parameter over all arrays. Plant height showed homogeneity of Wr-Vr after elimination of NB and GE arrays, plant stand after elimination of GE and U-15, D50 after elimination of NB and GE and DPM after elimination of U-15 and NB arrays. This indicated that these parents had non-allelic effects for plant height, plant stand, and DPM, respectively. Regression of off-spring parent covariance (Wr) on parent array variance (Vr) (Wr/Vr plots) for traits with significant dominance effects are presented in Figures 1-7 below. In these traits, the adequacy of the additive-dominance model was only reflected graphically in NHB, lodging, plant height and plant stand through Wr/Vr regression, but D50%, ear shape, and DPM did not.

Neck and head blast

Figure 1 displays Wr/Vr plot for NHB which is linear and slope not significantly different from unity (b=0.6097 and r^2 = 0.5716) intercepting the Wr axis slightly above origin. The high r^2 value indicated that the regression accounted for most of the variation and hence the likely relation. Except P-224, array points were widely scattered and within parabola limit indicating genetic diversity of the parents and dominance effects. The Wr/Vr plot for NHB showed parent OK and U-15 to have most dominant genes, P-283 and NB most recessive and P-224 and GE had almost equal frequency of dominant and recessive. Mean NHB score showed parents GE, U-15 and OK had the least scores, and then P-224 and P-283 and NB had the highest. The Wr intercept was between origin and tangent and above the critical point for F_5 indicating partial dominance gene action.

Table 4. Site values of statistics for studied traits of 56 finger millet genotypes over three sites in western Kenya in 2007LR.

Trait	Days to Maturity			Yield				Neck and head blast				Days to 50% Flowering		
Statistic	Alupe	Kakamega	Mean	Alupe	Kakamega	Inungo	Mean	Alupe	Kakamega	Inungo	Mean	Alupe	Kakamega	Mean
MSE	-	-	4.316	-	-	-	68861	-	-	-	0.100	-	-	6.283
Vp = Variance of parents	21.942	4.075	13.008	343470	194560	112985	166270	0.067	0.542	0.6	0.403	11.3	6.7	9
Vr = Mean Array variance	18.140	8.776	13.458	93527	121574	40958	51911	0.126	0.442	0.236	0.268	23.556	22.655	23.105
Wr = Mean Array Parent Covariance	3.15	1.206	2.178	142813	84216	31597	63923	0.040	0.319	0.261	0.207	1.493	2.270	1.882
Vr = Variance of Array Means	3.383	1.614	2.498	66715	44233	10339	27891	0.049	0.207	0.135	0.130	6.702	3.173	4.938
$(mL_1 - mL_0)^2$ = (Parental Mean – Progeny Mean)^2	-1.558^2 = 0.311	0.322^2 = 0.104	0.208	60^2= 3624	370^2 =136629	-214^2 = 45939	71^2 = 5160	0.281^2 = 0.079	0.071^2 = 0.005	-0.044^2 = 0.002	0.029	-0.760^2= 0.578	-1.345^2= 1.808	1.193

Table 4. (Continued)

Trait	Ear Shape				Plant Height				Lodging				Plant Stand			
Statistic	Alupe	Kakamega	Inungo	Mean	Alupe	Kakamega	Inungo	Mean	Alupe	Kakamega	Inungo	Mean	Alupe	Kakamega	Inungo	Mean
MSE	-	-	-	0.139	-	-	-	36.755	-	-	-	97.470	-	-	-	5.274
Vp = Variance of parents	0.542	0.642	0.592	0.442	59.350	109.667	94.042	87.686	16.200	655.900	208.700	293.600	15.642	6.300	8.242	10.061
Vr = Mean Array variance	0.266	0.427	0.347	0.300	40.049	60.673	71.172	57.298	10.436	265.543	91.033	122.337	9.584	4.554	4.118	6.085
Wr = Mean Array Parent Covariance	0.220	0.316	0.268	0.230	23.268	48.909	55.931	42.703	3.213	222.730	53.593	93.179	3.162	-0.443	-0.061	0.886
Vr = Variance of Array Means	0.134	0.210	0.172	0.156	19.557	29.551	41.893	30.334	2.332	96.674	18.400	39.136	2.126	0.322	0.203	0.884
$(mL_1 - mL_0)^2$ = (Parental Mean – Progeny Mean)^2	0.106^2 = 0.011	-0.312^2 = 0.098	0.054	-0.103^2 =0.011	0.587^2 = 0.344	3.667^2 = 13.315	2.224^2 = 4.946	6.202	- 0.580^2 = 0.336	-3.392^2 = 11.505	-4.425^2 = 19.578	-2.975^2 = 10.473	1.377^2 = 1.895	2.062^2 = 4.252	-0.961^2 = 0.924	2.357

- Site means used as reps hence no site MSE for individual sites

Table 5. Wr-Vr analyses of variance.

Source	df	df†	df‡	Mean squares						
				NHB	Lodging	ES	PH†	PS†	D50‡	DPM‡
Site	2	2	1	0.035	2209	0.013	214.6	0.900	10.23	80.75
Wr-Vr	5	3	3	0.035ns	2175ns	0.020ns	88.8ns	9.767ns	142.44ns	168.55ns
Error	10	6	3	0.010	3291	0.006	126.0	3.021	70.54	59.14

ns= not significant at p≤0.05, † analysed with 2 arrays eliminated, ‡ analysed with 2 arrays eliminated at 2 sites.

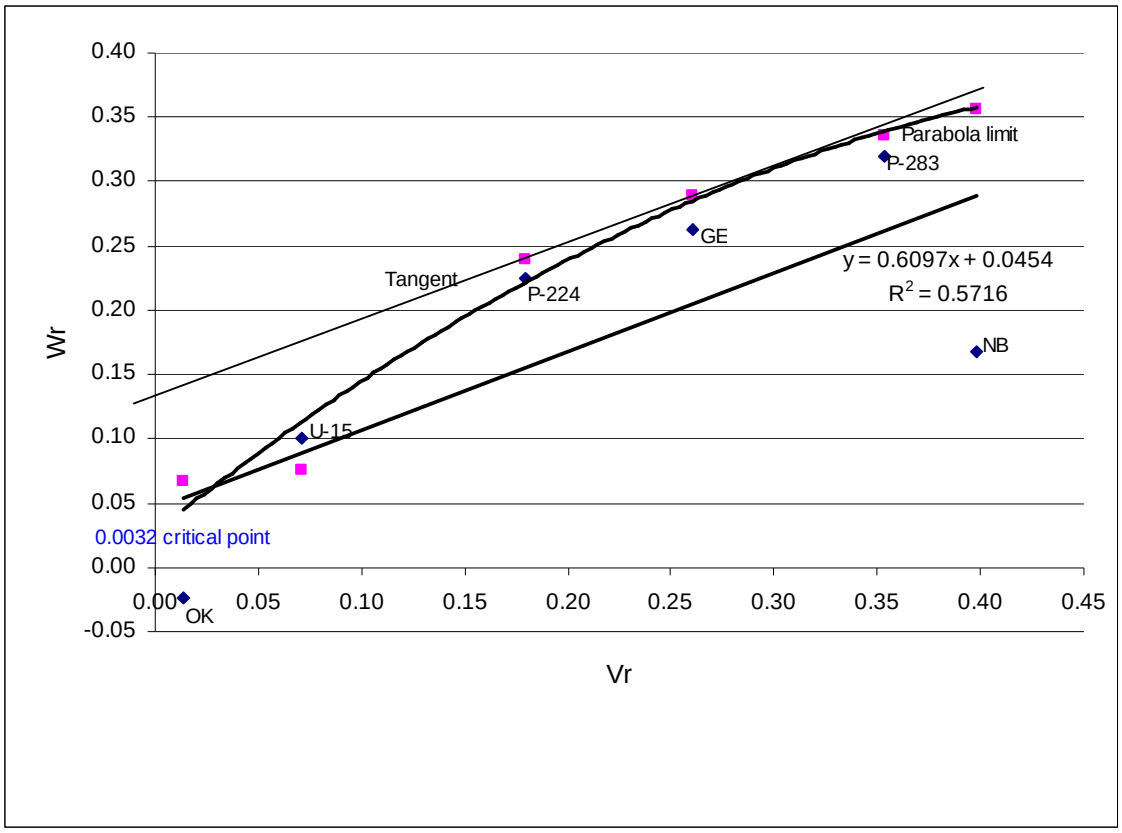

Figure 1. Wr/Vr plot for neck and head blast and corresponding parabola limit

Resistance to lodging

Figure 2 displays the lodging Wr/Vr regression line with a slope very close to unity (b=0.9591 and r^2=07189) satisfying the additive-dominance model. The high r^2 value implied the regression explained most of the variation and that this was the likely relationship. All the parent arrays were very close to the best fit line and below the parabola limit. The array points were also widely scattered suggesting genetic diversity among parents for this trait. The line had a negative Wr axis intercept, implying overdominance gene action and parent U-15 had the most dominant genes, then GE, OK, P-283, P-224, and NB had the most recessive genes. Parental mean lodging showed GE had the least lodging, and then P-283,

OK, U-15, P-224 and NB had the most lodging. The expected resistance to lodging was OK, P-283, GE, U-15, P-224 and NB with most susceptibility.

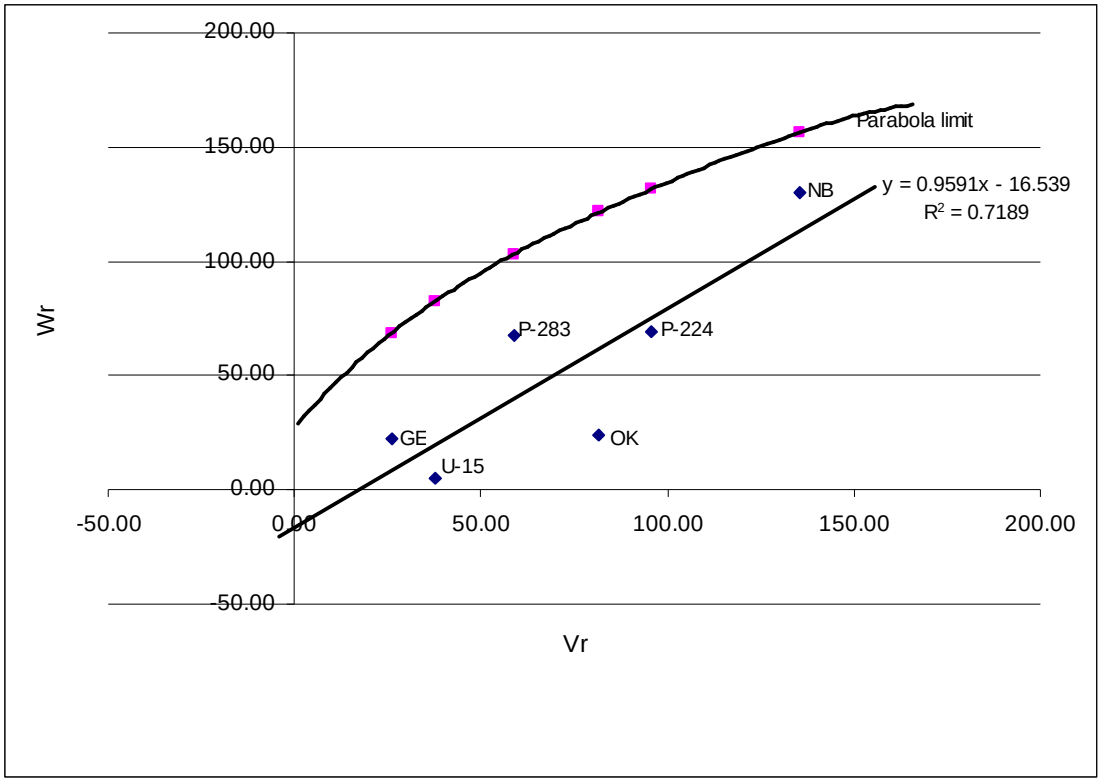

Figure 2. Wr/Vr plot for lodging and corresponding parabola limit

Plant height

Figure 3 represents Wr/Vr plot for plant height with NB and GE arrays eliminated to satisfy the additive-dominance model. The Wr/Vr regression line had a slope not significantly different from unity (b=0.6941 and r^2=0.8854), implying satisfaction of the additive dominance model after elimination of parents with non-allelic interactions. The high r^2 value implied the regression explained most of the variation and that this was the likely relationship. All array points were within the parabola limit implying dominance. The array points were also widely scattered implying genetic diversity of the parents. Parent OK array was the nearest to the origin suggesting it had the most dominant genes followed by U-15 and P-283 and P-224 had the furthest array point from the origin implying it had most recessive genes. Parental means showed U-15 was the shortest, then GE, P-224, P-283, OK and NB the tallest. The expected order was U-15 shortest, then P-224, GE, OK, P-283 and NB. The intercept was between origin and tangent but slightly below the critical point hence indicating overdominance gene action for plant height.

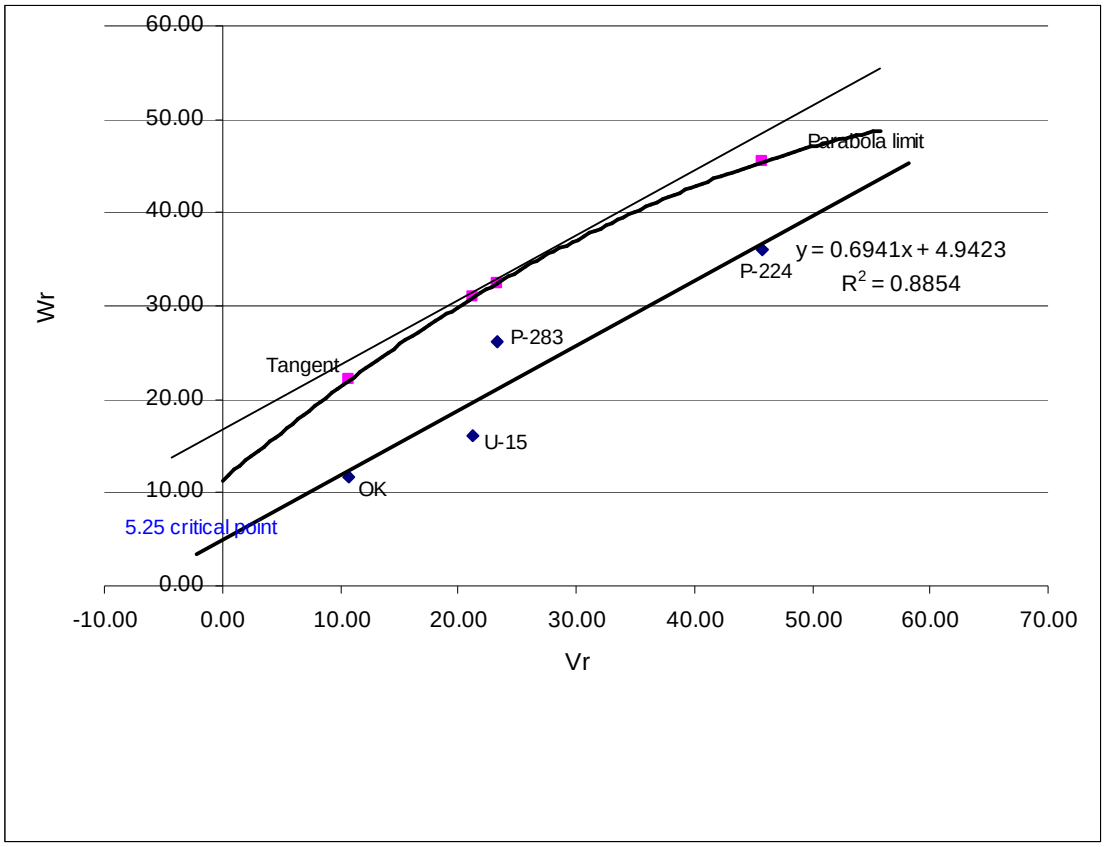

Figure 3. Wr/Vr plot for plant height with NB and GE arrays eliminated and corresponding parabola limit

Mean days to 50% flowering

Figure 4 below represents a Wr/Vr plot for days to 50% flowering with NB and GE arrays eliminated. The best-fit regression line (b=0.1078 and r^2=0.0475) had a slope far off unit slope, failing to satisfy the additive-dominance model by the Wr/Vr regression approach thus indicating presence of non-allelic interactions. The low r^2 value implied the regression did not explain most of the variation and that this relationship was not very likely. The array points were widely scattered implying parental varieties genetic diversity. Parents OK and U-15 array points were closest to the origin indicating they had more dominant genes, while parents P-283 and P-224 array points were furthest from origin indicating they had more recessive genes. This order did not reflect the mean D50 and expected parent rating where U-15 had earliest D50, then P-224, GE, NB, OK and P-283 the latest. The intercept was between origin and tangent and above the critical point indicating partial dominance gene action at F_5.

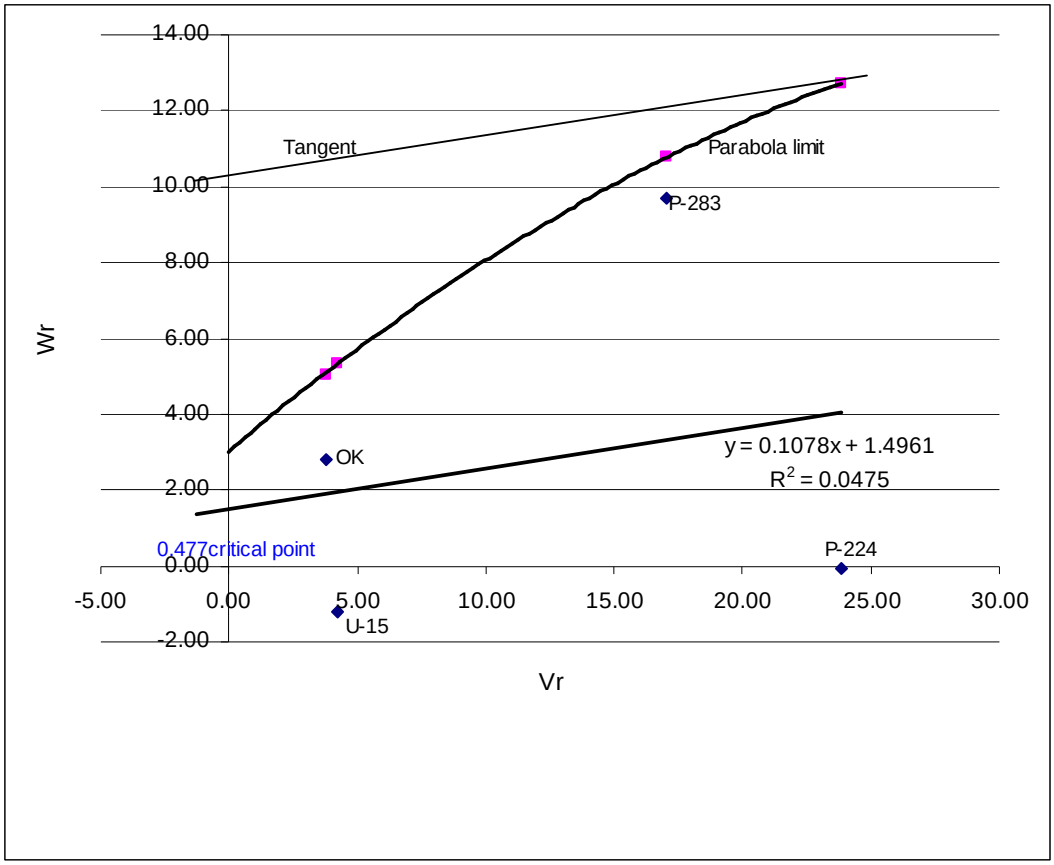

Figure 4. Wr/Vr plots for days to 50% flowering with NB and GE arrays eliminated and corresponding parabola limit.

Ear Shape

Figure 5 below represents the Wr/Vr plot for ear shape. The best-fit regression line had a slope far off the unit slope (b=0.3388 and r^2=0.2416) indicating failure of the additive-dominance model. The low r^2 value implied the regression explained only 24% of the variation and that this was not the most likely relationship. The array points were widely dispersed along the line but all under the parabola limit, indicating genetic diversity of the parents and dominance for this trait. Parent NB array point was closest to the origin suggesting it had most dominant genes followed by U-15 and GE while P-283 and OK had intermediate frequencies of dominant and recessive alleles and P-224 had most recessive genes. Mean ear shape score showed NB with open ear shape, OK tended to open, P-224 had intermediate ear shape, GE and P-283 tended to fist headedness, and U-15 had fist ear shape. This was close to expected ear shape rating except that P-224 usually displays most open headedness and OK and NB intermediate ear shape. The intercept was between

origin and tangent and above the critical point indicating partial dominance gene action for the control of ear shape.

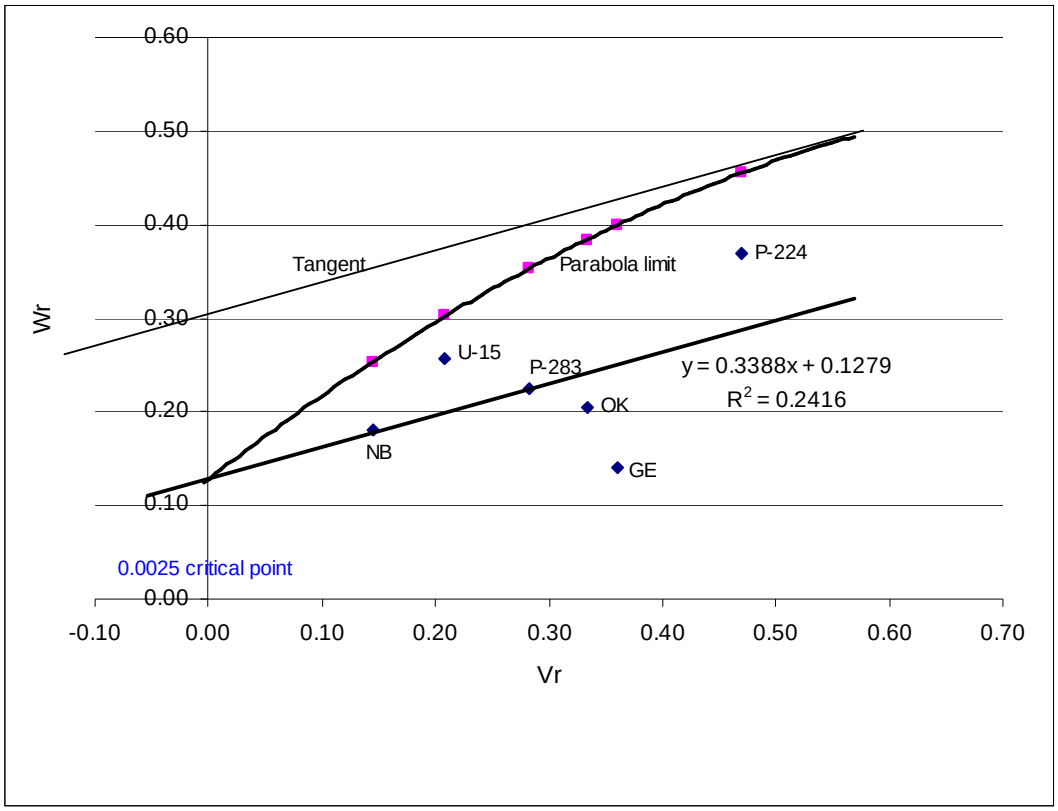

Figure 5. Wr/Vr plot for ear shape and corresponding parabola limit.

Figure 6 below represents Wr/Vr plot for plant stand with parents GE and U-15 arrays eliminated. The regression line had a slope not significantly different from unity (b=0.6962 and r^2=0.6077), satisfying the additive dominance model. The high r^2 value implied the regression explained most of the variation and that this was the likely relationship. All array points were below the parabola limit indicating dominance. Three of the four array points OK, P-224, and P-283 clustered around the origin indicating they had many dominant genes, but not genetically diverse for this trait. Only parent NB array point was furthest from the origin indicating it had recessive genes. Mean stand establishment showed parent OK had highest plant stand, then GE, P-224, U-15, P-283 and NB had the least stand as expected. The Wr intercept was below the origin pointing to overdominance gene action in the control of plant establishment.

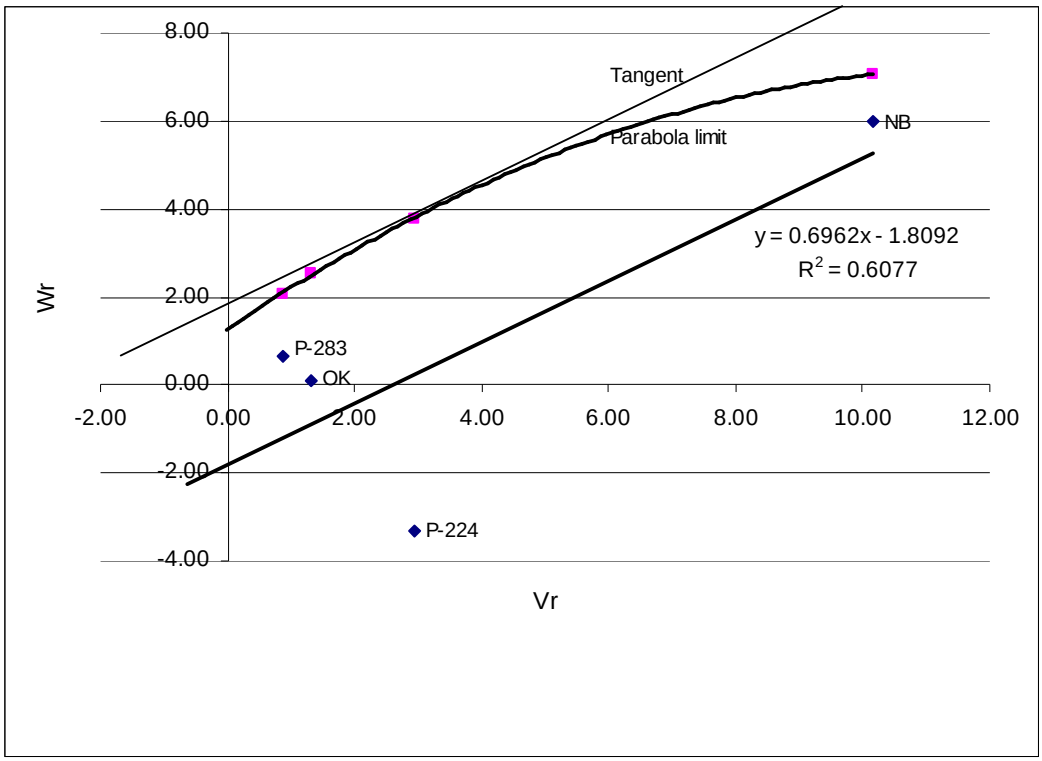

Figure 6. Wr/Vr plot for plant stand with GE and U-15 arrays eliminated and corresponding parabola limit.

Mean days to physiological maturity

Figure 7 below represents Wr/Vr plot for days to physiological maturity with parents U-15 and NB arrays eliminated. The regression line had a negative slope that significantly deviated from unity (b=0.3456 and r^2=0.9555) with a positive Wr intercept implying failure of the additive-dominance model and the significance of non-allelic interactions in the dominance control of the trait. The high r^2 value implied the regression explained most of the variation and that this was the likely relationship. This strongly indicated the significance of non-allelic interactions in the control of DPM in the analysed parents. All array points were below the parabola limit suggesting dominance. Parents OK and P-283 were close together and closest to the origin suggesting they mostly carried dominant genes while GE and P-224 were also close together and furthest from origin suggesting they carried mostly recessive genes. This means there were only two clusters of diversity, the early P-224 and GE and the late OK and P-283 and they corresponded to mean DPM rating where parent U-15 was earliest to mature, then P-224, NB, P-283, GE and latest OK, almost as expected only that GE was expected to mature earlier than NB. The tangent line intercept was outside the graph limit. The negative slope of the Wr/Vr regression line and departure from unit slope would suggest that Wr-Vr homogeneity was due to the balancing effects of the values,

but the trait control did not fit the additive-dominance model. Non-allelic interactions are therefore significant in dominance control of this trait.

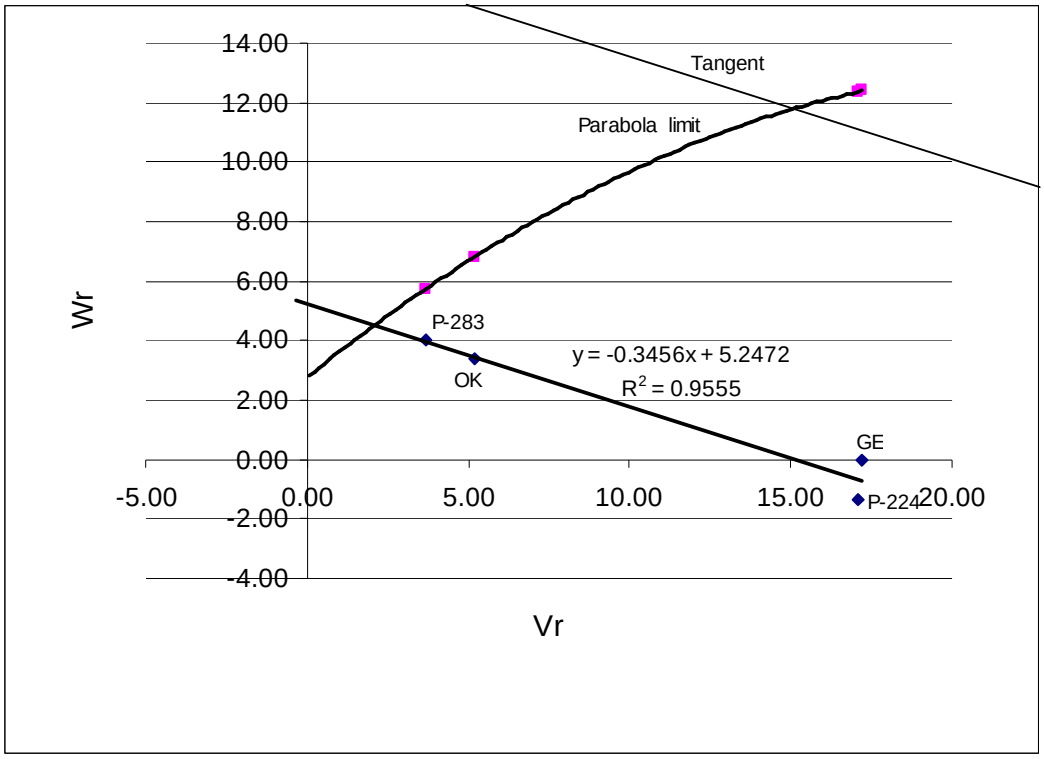

Figure 7. Wr/Vr plot for days to physiological maturity with U-15 and NB arrays eliminated.

Parent variety and array means

Table 6 below gives a comparison of parent variety and array means for nine traits and the mean yield of the best line for each parent cross. Parent array mean yields were superior to parent mean yields for all parents except OK and P-224. For each variety, at least a line was identified from its crosses that were superior in yield to itself and its array mean. In terms of parent yield, OK had the highest mean yield, followed by P-224, NB, GE, U-15, and P-283 the least. This is the order they perform in western Kenya, except NB that normally ranks below GE and U-15. In terms of mean array yield, OK array again had the highest mean yield, followed by P-224, GE, U-15, NB, and P-283 the least. Array mean ranking was similar to parent yield ranking only that NB took its expected position after U-15. Parent OK was a parent in four of the best lines from each parent, GE in three, U-15 in two and P-224 and NB in one each. Parents OK and GE had the least neck and head blast mean incidence, followed by U-15, P-283, P-224, and NB, had the most incidence as expected. Array mean NHB incidence ranking was similar to parent NHB ranking with OK array with least incidence, followed by U-15, GE, P-224, P-283, and NB array with most incidence. In

terms of lodging resistance, parent GE was the most resistant, followed by P-283, OK, U-15, P-224, and NB was the most susceptible. Array resistance to lodging was about similar with GE array the most resistant followed by OK, P-283, U-15, NB, and P-224 array had the highest mean lodging susceptibility.

Table 6. Parent variety trait and array means compared across sites to the best cross line

Parent	Days to 50% flowering	Neck and head blast score	Ear shape score	Days to physiological maturity	Plant height (cm)	Lodging (%)	Plant stand (no.)	Yield (kg ha^{-1})	Best line yield (kg ha^{-1})
Gulu-E	82.50	2.00	2.75	117.25	72.27	5.17	34.17	1422.67	OKxGE
Array	**82.25**	**2.40**	**2.44**	**116.10**	**81.23**	**11.67**	**34.48**	**1608.83**	**2402.33**
P-224	82.25	2.50	1.50	113.75	74.50	31.00	33.50	1788.17	P-224xOK
Array	**81.76**	**2.51**	**1.92**	**115.19**	**76.92**	**24.71**	**33.27**	**1640.50**	**2119.33**
U-15	78.50	2.17	2.50	111.75	71.27	20.00	33.17	1415.17	U-15xGE
Array	**79.18**	**2.38**	**1.96**	**113.18**	**75.34**	**18.81**	**33.23**	**1603.72**	**2117.67**
P-283	86.50	2.33	2.75	117.75	77.75	12.33	32.67	890.50	U-15xP-283
Array	**80.40**	**2.59**	**2.48**	**114.52**	**76.44**	**17.39**	**32.67**	**1302.50**	**2116.50**
NB	82.75	3.50	1.25	115.00	86.75	41.67	28.50	1465.17	OKxNB
Array	**85.20**	**3.08**	**1.53**	**117.65**	**87.10**	**21.48**	**33.74**	**1487.72**	**1761.00**
OK	84.00	2.00	1.75	120.00	85.63	13.83	34.67	2103.33	OKxGE
Array	**82.45**	**2.06**	**1.64**	**115.77**	**81.92**	**15.05**	**33.40**	**1801.56**	**2402.33**

DISCUSSION

Genotypic variation

The variability of genotypes was evident in individual sites and across the sites as reflected by significant genotype differences for most traits. The absence of significant genotype differences for shootfly and *Striga* resistance implied either the screening was not rigorous enough to detect differences or little variation for these traits in the finger millet genotypes tested. According to Haussmann et al. (2000), *Striga* resistance is difficult to evaluate making selection difficult. Although artificial inoculation was applied in the current study, containment of heterogeneity of *Striga* inoculum under field conditions was reported to be difficult (Haussmann et al., 2000). For shootfly, the lack of inoculation and dependence on natural infestation may not have provided uniform and adequate pressure across the plots to discriminate the genotypes according to resistance resulting in large experimental errors. The presence of genotype x environment interaction for most traits implied the environment played a major role in determining trait expression. Gene effects, however, did not show interaction with environment except plant height and lodging indicating the mode was gene action was not influenced by the environment.

Gene action

Significance of additive gene effects for yield, neck and head blast, days to 50% flowering, finger branching, ear shape and days to physiological maturity indicates that there is potential of improving finger millet varieties through selection to accumulate genes for yield and its associated traits in segregating finger millet progenies. According to Fasoula and Fasoula (1997), additive gene effects determine yield through cumulative genes effects. Secondary traits that have been identified to influence finger millet yield such as duration to maturity and ear size (Duke, 1978; Bondale et al., 2002) were controlled by genes with additive gene effects, suggesting they can also be improved through selection. The observation of additive gene action for the control of neck and head blast resistance in finger millet was consistent with previous findings for blast resistance in finger millet (Mantur & Madhukeshwara, 2001; Narayanan et al.. 2002;, Jain and Yadava, 2003). Observation of large additive effects also suggests that heritability is large for these traits, which is in conformity with previous reports of large heritability estimates for grain yield and yield components on finger millet varieties and finger millet hybrids (Bezaweletaw et al., 2006 and Sumathi et al., 2007).

The lack of significance of dominance gene action for yield at F_5 did not reflect heterosis exploited in some self pollinating crops (Singh and Chaudhary, 1977), but reflected Singh and Singh (1984) report of diminishing dominance with generation advance. This suggests that yield at this generation, is mainly controlled by additive effects with minimal dominance effects. This could be probably explained in the fact that the parents involved in the diallel were elite varieties in the region that had all been selected for high yield. Finger millet being a highly self pollinated crop, all alleles in the parents had been fixed for the genes determining yield hence very little dominance on hybridization of the varieties. The presence of dominance gene effects for neck and head blast resistance, days to 50% flowering, ear shape, plant height, resistance to lodging, plant stand establishment and days to physiological maturity, indicates dominance at some of the loci that control the trait. The persistence of dominance effects for these traits at this advanced generation could be due to the diversity of the traits in the parent varieties as these had not been specifically selected for as was yield.

Dominance effects

Partitioning of the dominance effects 'b' further into 'b_1', 'b_2', and 'b_3' provides information on the relationships of the genes involved and proportions, where significance of 'b_1' indicates unidirectional dominance relative to the mid-parent value, 'b_2' asymmetric distribution of

dominant genes in parents and 'b_3' indicates dominance interaction between specific genotypes (Hayman, 1954; Singh and Chaudhary, 1977; Kurt and Evans, 1998). Only plant height with all three dominance components significant displayed unidirectional dominance, asymmetric dominant genes distribution in parents, and dominance interaction between specific genotypes. This implies some of the genes controlling the trait had distinct dominant expression and some of the parent varieties, especially OK because of its closeness to the origin in the Wr/Vr plot, had more doses of the genes than others and that some of the genotypes interacted to affect trait expression. Neck and head blast, lodging, D50 and DPM dominance effects were only significantly controlled by genes that are asymmetrically distributed among the parents and who's some of the genotypes interacted to elicit expression of the trait. This is on top of additive effects for neck and head blast, days to 50% flowering and days to physiological maturity. Dominance genes asymmetrically distributed among the parents controlled plant stand. Genes with dominance effects together with additive gene effects controlled ear shape. The traits solely controlled by dominance effects would be difficult to further advance through selection as dominance effects are not heritable.

In general, therefore, neck and head blast, days to 50% flowering, and days to physiological maturity at the F_5 generation were controlled by both additive and b_3 dominance effects where some dominance conferring alleles were more frequent in certain crosses than others. Ear shape was genetically controlled by both additive and b_3 dominance effects, where interaction of some genotypes conferred dominance effects. Traits that had an additive effects component would, therefore, gain from further selection due to the additive gene effects. The non-significance of the b_1 dominance component in these traits implied the alleles at most of the loci acted in the same direction. Dominance effects involving the three types of dominance effects, (b_1, b_2 and b_3), directional dominance, and asymmetry of alleles at loci in parents and interaction of some genotypes controlled plant height. Lodging was controlled by mainly dominance effects of types b_2 and b_3, where some dominance conferring alleles were more frequent in certain crosses than others and interaction of some genotypes contributing to expression of the trait. Mainly dominance effects of type b_2, where some dominance conferring alleles were more frequent in certain crosses than others, controlled plant stand. Traits solely significantly controlled by dominance gene effects would be difficult to further advance through selection as dominance effects are difficult to predict (Sleper and Poehlman, 2006).

Dominant and recessive traits in the six parent varieties

According to Singh and Chaudhary (1977), the regression of Wr on Vr can be studied at any filial generation in the same way as it is done at F_1, only that the contribution of dominance components is halved on every inbreeding generation. Regression lines deviation from the expected unit slope for some traits indicated some degree of non-allelic interaction of genes or some genes lack of 100% independent distribution among the six parents. However, for most traits, especially resistance to lodging, the slopes of the line did not show a significant deviation from unity, indicating adequacy of the additive-dominance model. The graphic method of diallel analysis is used to detect the adequacy of the additive-dominance model and subsequently the degree of dominance and parent genetic diversity through parent array point distribution on the plot (Hayman, 1954a; Singh and Chaudhary, 1977; Dwivedi et al., 1980; Singh and Singh, 1984; Dabholkar, 1992; Fronza et al., 2004).

Most traits showed a scattered array of points on the plot. This indicated genetic diversity of the parents for the traits (Hayman, 1954a; Dabholkar, 1992; Fronza et al., 2004) confirming the working hypothesis of the study that the six elite varieties of finger millet in western Kenya are genetically diverse. This genetic diversity is in agreement with findings by Bezaweletaw et al. (2006) and Das et al. (2007) of variability in many finger millet traits that contribute to yield. The finding of OK and U-15 with most dominant genes, P-283 and NB most recessive and P-224 and GE with almost equal frequency of dominant and recessive genes tallied with mean and expected NHB rating indicated that NHB resistance was conferred by dominant genes and susceptibility by recessive genes. There was no previous literature on finger millet yet, but work has been done on similar disease in rice. Wu et al. (2005) found blast disease in a rice variety to be controlled by multiple major genes and minor genes with epistatic effects and Sharma et al. (2007) found blast disease resistance in a rice variety to be controlled by a single dominant gene. Further investigation is required to pin point the exact genes responsible for blast resistance in finger millet and their modes of action.

The failure of Wr/Vr array distribution to reflect mean D50 and expected parent varieties rating implied the genes conferring D50 did not act in the same fashion. The array distribution suggested that there were dominant genes that conferred early flowering in U-15 and at the same time dominant genes that conferred lateness in OK and conversely recessive genes that conferred late flowering on P-283 and earliness to P-224. This implied different sets of genes that acted differently to confer time to flowering in the four parent lines. Array distribution relative to mean and expected DPM rating suggested dominant genes conferred late maturity and recessive genes early maturity in the six parent varieties.

No literature exists on the genetic control of days to flowering and days to maturity in finger millet. Torres and Geraldi (2007) reported days to flowering in rice to be controlled by both additive and non-addition gene effects. Rohman et al. (2006) found both additive and dominance gene effects to control days to maturity in barley, where dominant alleles conferred the trait.

Array distribution relative to mean and expected plant height rating suggested dominant genes conferred shortness in U-15 and tallness in OK and recessive genes conferred shortness in P-224, in a trait controlled by overdominance gene effects. Intermediate plant height in P-283 was conferred by about equal frequencies of dominant and recessive genes. These findings suggested different sets of genes acting differently to confer plant height in the four parents and also implied non-allelic interaction, considering that b_3 dominance effects were significant for plant height. Rohman et al. (2006) found plant height to be controlled by both additive and dominance gene effects in early generations of barley as Torres and Geraldi (2007) found in rice. Overdominance gene effects also significantly controlled lodging, a trait frequently correlated to plant height. Parent varieties distribution relative to mean and expected parent varieties lodging suggested resistance to lodging was conferred by dominant genes and susceptibility by recessive genes. No literature exists on genetic control of lodging in finger millet. Verma et al. (2005) found various major genes associated with plant height and yield control to determine lodging in bread wheat.

Generally array distribution relative to mean and expected ear shape rating suggested fist headedness was conferred by dominant genes while open headedness by recessive genes, a situation that was observed on the F_1 cross OKxP-283 (Figure 8). There is no literature on genetic control of ear shape in finger millet. Torres and Geraldi (2007) found the characteristic of ear length controlled by both additive and dominance effects in rice.

Figure 8. F_1 ear shape of a cross between open ear shaped OK and fist ear shaped P-283

Array distribution relative to mean and expected ear shape rating suggested dominant genes conferred high plant stand establishment. Redona and Mackill (1996) found additive and overdominance gene effects determined by dominant genes to be responsible for high seedling vigour that significantly determines plant stand establishment in rice (Zhang et al., 2004). The relationships of these outcomes to finger millet are not known.

Generally, traits that are controlled by recessive genes would be easy to select for once fixed and make rapid progress (Henning and Teuber, 1996). In this case therefore, only early maturity and and open headedness would be easy to select for and make rapid progress because recessive genes are easy to fix.

Potential breeding value of the elite varieties

The comparison of parent variety and array means and the mean of the best line for each parent cross showed that a variety deficient in a trait could be improved by crossing it to one with higher levels of the trait and this was true for most traits measured in the six parent varieties. The ranking of parent performance for most traits reflected what they are known for in western Kenya. In terms of yield, OK, P-224, GE and U-15 were the best parents and P-283 and NB the least yielding among the elite varieties. In terms of neck and head blast resistance, OK, GE and U-15 were the most resistant to neck and head blast and P-224 and NB the least resistant. In terms of lodging resistance, GE, P-283 and OK were the most resistant. The array order following the same trend for these traits indicated that the genotypes differences for the various traits were genetic. In the control of yield, the genetic differences were additive, in neck and head blast they were both additive and partial dominance, and in lodging, they were mainly overdominance. The superiority of array means over parent means for most traits reflects well on the potential of these parent

varieties in the breeding of better finger millet varieties in western Kenya in the long term and the identification of lines superior to their parents from each parent means in the short term, better finger millet varieties will be released. Parents OK, GE, and U-15 seem to have large additive gene effects and parent combinations OKxGE, P-224xOK, and U-15xGE offer good potential for development of pure line varieties because of their large additive gene effects and good performance of their lines. The superiority of these lines to their parents indicated isolation of transgressive segregants and accumulation of additive genes for yield.

CONCLUSIONS

Additive gene action was solely responsible for the control of yield and finger branching among the six elite varieties at F_5 generation, underscoring the potential of gain on further selection for yield. Neck and head blast, days to 50% flowering, ear shape and days to physiological maturity were controlled by both additive and dominance effects with the dominance due to partial dominance gene action in the traits. Genes displaying overdominance effects solely controlled plant height, lodging, and plant stand establishment. Dominant genes conferred resistance to NHB, lodging resistance, higher plant stand establishment and fist ear shape and recessive genes conferred early maturity and open ear shape. Both dominant and recessive genes conferred days to 50% flowering and plant height. Results did not support existence of genetic variation for shootfly, foliar blast and *Striga* resistance among the six parents. The differences among the six elite finger millet varieties in western Kenya are largely genetic with varieties OK, GE, and U-15 having large additive effects. Crosses OKxGE, P-224xOK, and U-15xGE displayed good potential to yield superior pure lines judging from their high yielding F_5 lines. The potential to develop good pure line varieties from these parent varieties both in the short and long term is high. The promising cross populations would be advanced through to F_7 and high yielding lines resistant to blast disease and lodging isolated for further testing with a view to release the best lines in the short term. Parent varieties with large additive effects for most traits need to be incorporated in the expanded finger millet breeding programme for continued breeding improvement of finger millet germplasm in western Kenya.

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CHAPTER 6

Breeding progress based on F_5 progenies of western Kenya elite finger millet varieties

ABSTRACT

Finger millet (*Eleusine coracana* (L.) Gaertn. ssp. *coracana*) is important for food and cash in Africa, yet its productivity is low and is hardly bred. Six Kenyan elite and two exotic varieties were crossed in an 8x8 diallel in 2004. F_1s were advanced to F_2 in 2005 short rain (SR) and F_2s advanced to F_3 in 2006 long rain (LR). Selections were at 5% intensity on F_3 and F_4 (2006SR) for yield and farmer desired traits. In 2007LR, 46 selected F_5 lines, eight parents, and 27 checks were evaluated at three sites in a 9x9 simple lattice design. There were significant line differences for foliar blast, days to 50% flowering (D50), neck and head blast (NHB), finger branching, ear shape, days to physiological maturity (DPM), plant stand, plant height, lodging and yield. Genotype x environment (GxE) interaction effects were significant for all traits except shootfly and DPM. Heritability estimates were high for D50, ear shape, DPM, NHB, lodging, plant height, and yield but only ear shape, NHB, lodging and yield showed significant expected genetic advance (EGA). Phenotypic correlations, heritability, and EGA revealed no suitable yield indirect selection criteria as no trait correlated to yield had higher heritability and EGA bigger than yield. Shootfly and lodging were significantly positively correlated with yield, but foliar blast and *Striga* were negatively correlated with yield. All traits responded to selection with realised mean yield gain of 5.84%. On average progeny lines had experimental, parental, and checks means RGY superiority of up to 154.95%, 170.76% and 173.48%, respectively. Resistance to lodging had the highest gain of 21.03%. The best three genotypes: OKxGEF4BSB13R10(R31), OKxGEF_4SB13R10(R27) and GBK033439 had resistance to blast and lodging (except GBK 033439) and high yield >2250kg ha^{-1}, representing 9-170% superiority over parents. Results indicated high breeding progress for most traits on selection in segregating populations.

Key words: Breeding progress, finger millet, yield, blast, *Striga*, segregating populations.

INTRODUCTION

Finger millet is an important food, food security, cash, health and cultural crop in Africa (Holt**,** 2000; Takan et al., 2002; Upadhyaya et al., 2006). However, little has been done to improve its productivity (Fakrudin et al., 2004; Bedis et al., 2006; Upadhyaya et al., 2006). Farmers' yields are low. Mitaru et al. (1993) reported a yield range of 500 - 750kg ha^{-1} in Kenya, which was confirmed in the PRA study of this project (see Chapter 2). Research, especially plant breeding, can help raise farmers' yields (NRC, 1996; CGIAR[1], 2005), as there is potential to improve yields with farmers' adoption of improved varieties and crop management (Oduori, 2000). The poor yields in Kenya are largely due to use of poor varieties with low genetic yield potential and susceptible to blast disease and *Striga*. Low research input and the difficulty to make crosses in the crop are responsible for lack of better varieties. Use of resistant varieties is a traditional disease-management strategy for many diseases and this forms a major breeding objective for finger millet. Blast disease resistance exists in finger millet (Mantur and Madhukeshwara, 2001; Narayanan et al., 2002; Jain & Yadava, 2003, Madhukeshwara et al., 2004), but it has not been exploited in Africa. No reports exist on breeding for *Striga* resistance in finger millet.

Blast resistance; robust growth; early vigor; large panicle size; high finger number and branching; heavy grain; grain quality and; resistance to *Striga*, lodging, stressful soil and moisture conditions are potentially important traits in finger millet breeding (NRC, 1996). Duke (1978) and Bondale et al. (2002) reported DPM, plant height, tillering capacity, main ear grain weight, open headedness, and finger size to be positively correlated to finger millet yield. Many workers have reported high phenotypic and genotypic variation and high heritabilities for many finger millet characteristics: D50, DPM, plant height, productive tillers, main ear length, finger length, finger number per ear, total dry matter production, 1,000 grain weight, grain yield per plant, and grain yield per unit area of land (Fakrudin et al., 2004; Bedis et al., 2006; Bezaweletaw et al., 2006; John, 2006; Sumathi et al., 2007; Das et al., 2007). The reports suggest high EGA on selection, but little is published on finger millet breeding for yield and its components, especially in Sub Saharan Africa. All the reports are of work done in India on Indian germplasm, except Bezaweletaw et al. (2006) that was done in Africa and on African (Ethiopian) germplasm. There is need to study African finger millet germplasm more and breed for better varieties. The reported high variability for yield and other finger millet traits, their correlation to yield, and high H^2 indicate high potential to improve yield and resistance to biotic and abiotic stresses and general agronomic desirability. The main objective for this study was to study trait variation, association and

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heritability in segregating populations and determine the level of breeding progress achievable in improvement of finger millet.

Hypothesis

Finger millet segregating populations from crosses of elite varieties and blast and *Striga* resistance selections have wide trait variability to elicit breeding progress in finger millet.

MATERIALS AND METHODS

Research sites

Hybridisation was done at the University of KwaZulu Natal, South Africa in 2004. Subsequent work was done at the Kenya Agricultural Research Institute Centres of Kakamega (Latitude 00^{o} 16' N; Longitude 34^{o} 45' E; 1585masl) and Alupe (Latitude 0° 30' 0 N; Longitude 34° 7' 50 E; 1170masl), and Inungo vil lage (00 19 N; Longitude 34 19' 0 E; 1240masl) in western Kenya from 2005 to 2007. The soils at Kakamega are Dystro-mollic Nitisol with pH of 5.2, Ferralo-orthic Acrisol with pH of 5.0 at Alupe, and Sandy loam with 15% clay at Inungo. The total rainfall at Kakamega in 2005 was 1,695mm and at Alupe 1,484mm. In 2006, total rainfall at Kakamega was 2,330mm and at Alupe 1996mm. In 2007, total rainfall at Kakamega was 2446mm and at Alupe 1999. Average temperature ranged from 14-32^{o}C at Kakamega and 15-33^{o}C at Alupe. Weather data was not available for 2007 at Inungo when an experiment was carried out there but the annual mean total rainfall in the area is 1600mm (Bossio et al., 2005). At Alupe the experimental plots were on a *Striga* infested field and were also inoculated with *Striga* seed. Due to higher moisture, Kakamega has higher blast disease incidence than Alupe and Inungo.

Finger millet parent genotypes

Six western Kenya elite varieties and two exotic lines were inter-crossed in this study (Table 1).

Hybridisation and generation of F_3 progenies

In February 2004, the eight finger millet varieties were crossed in an 8x8 full diallel using ethrel as a chemical hybridizing agent (CHA). Head to row planting and reference to parent rows were used to screen F_1 for true crosses at KARI-Kakamega in 2005LR. The F_1 were advanced to F_2 in 2005SR at KARI-Kakamega by self-pollination. All F_2 plants that formed seed (62,742) were advanced to F_3 by single seed descent method in 2006LR at Alupe to maintain the full genetic variation at F_2, the generation with maximum number of gene recombination (Chohal and Gosal, 2002).

Table 1. Finger millet parent genotypes

Variety	Abbreviated name	Origin	Key Traits	Reference
Okhale-1	OK	Nepal	- Purple plant pigmentation - High yield, - Resistant to *Striga*, lodging and blast	Riley, 1997
P-224	P-224	Uganda	-Green with no plant pigmentation -High yield -Susceptible to *Striga*, blast and lodging.	Von Brook, 1990
U-15	U-15	Uganda	-Purple plant pigmentation - high yield -Resistant to *Striga* and blast -short	-
P-283	P-283	Uganda	-Green with no plant pigmentation -Susceptible to *Striga* and blast -moderate yield -resistant to lodging	-
Gulu-E	GE	Uganda	-Green with no plant pigmentation -High yield -Resistant to blast and lodging	-
Nanjala Brown	NB	Local selection	-Purple plant pigmentation -Tall -Susceptible to blast, *Striga* and lodging -Moderate yield	-
FMV-1	FMV-1	Zimbabwe	-Green with no plant pigmentation -High yield -Susceptible to blast, andlodging	Shiferaw et al., 2004
INFM 95001	MS	ICRISAT	-Green with no plant pigmentation -Genetic male sterility	Shiferaw et al., 2004

Pedigree Selection

The F_3 generation was planted in parent pair blocks but in head to hill (hole) in a row rather than head to row. Planting holes were spaced at 0.3m with rows spaced at 0.5m apart for ample plant spacing for maximum genotype expression. Each hill was thinned to one best seedling to achieve the single seed descent advance of F_2 to F_3 and 62,742 plants. Standard cultural practices, including fertilizer application at 20kg ha^{-1} each of N and P_2O_5 and weeding twice, were followed in all nurseries. Visual pedigree selection started at F_3 with farmer selection criteria (Chapter 2 PRA) including potential for high yield (looking at yield components of productive tillers, head size, and grain filling); early maturity; resistance to blast disease, *Striga*, shootfly and lodging; and against all plant expressions that would compromise yield. Potential high yield was the main motivating factor in selection and yield-correlated traits were expected to respond similar to yield. To assess *Striga* resistance at Alupe, 22,709 *Striga* seeds in one tablespoon of a sand/*Striga* seeds mixture (28.5g),

prepared by mixing 20g of *Striga* seed with 5kg fine sand, were placed in the holes. The *Striga* seed inoculation rate was estimated from the maize breeding rate of 3,000-6,000 *Striga* seeds per host plant (Kim et al., 1999; Kim and Adetimirin, 2001), considering *Striga* seed weight of $5x10^{-6}$g (Berner et al., 1997) and number of finger millet seed planted per hole. On average a selection intensity of 5.34% was applied. Selected F_3 (3,350) plants were characterized for morphological traits and their main heads harvested independently.

The F_4 seed from selected F_3 families were planted head to row at Alupe and Kakamega. These were planted in parent pair blocks at each site during 2006SR in rows of 8m length spaced at 0.5m. Intra-row spacing was 0.15m leading to about 53 plants per row. At Alupe, *Striga* mix was applied by drilling uniformly at 769.5g (approximately 613,147 *Striga* seeds) per row. Visual selection was carried out as at F_3 between rows and within selected rows. The best three plants were selected in a selected row (180 selected rows) and their main heads used for advancement to F_5 family head to row evaluation (540 plants). The remainder of heads on the three selected plants in a row were harvested and the seed bulked to form seed for F_5 replicated population trials of the top 46 lines.

Experimental design and management of evaluation trials

The 46 selected F_5 inbred genotypes were evaluated during 2007LR in a replicated trial at Kakamega, Alupe and Inungo together with 27 accessions and the eight parental genotypes included as checks to make 81 entries. The F_5 genotypes were from 18 populations (crosses). The experiments were laid out as a 9x9 simple lattice design. At each site a plot consisted of three rows of 2m length spaced at 0.3m. At Alupe the trial was planted on a *Striga* sick plot and artificially inoculated with 570g of *Striga* seed/sand mix (with approximately 454,183 *Striga* seeds) per plot. The trials were not inoculated with *Striga* seed at other sites. All data were collected at Kakamega and Alupe but only lodging, plant height, yield and plant stand were collected at Inungo for logistical reasons.

Plant height was measured as the average length from ground level to the tip of the head of three plot representative plants at physiological maturity. Lodging percentage was plot number of lodged plants expressed as a percentage of plant stand. Finger branching was the absence (1) or presence (2) of spike branching in a plot. Ear shape was rated as 1 = open headed, 2 = incurved and 3 = fist (IBPGR, 1985). Shootfly damage at Alupe and blast incidence were measured using an incidence scale used by Mantur and Madhukeshwara (2001) as follows:

1 = 0.0% disease incidence = highly resistant;

2	=	1.0-2.0% disease incidence	=	resistant;
3	=	2.1-10.0% disease incidence	=	moderately resistant;
4	=	10.1-25.0% disease incidence	=	moderately susceptible;
5	=	>25% disease incidence	=	susceptible.

At Kakamega shootfly was assessed on percentage incidence. *Striga* counts were taken at vegetative stage (six weeks from germination), 50% flowering and at physiological maturity by uprooting and counting all *Striga* plants within and 25cm around the plot. Plant stand was number of plants per plot at harvest. Yield per plot was weight of clean grain from each plot harvest. Yield in kg ha^{-1} was estimated using the formula:

$$Y = \frac{1{,}0000 \times (X/1{,}000)}{A}$$

Where Y = yield in kg ha^{-1},

X = plot yield in g

A = Plot area = no. of rows x row spacing x row length (3x0.3mx2m)

Data Analyses

All data were subjected to general analysis of variance (ANOVA) using SAS GLM procedure (SAS Institute, 2003) in the following model:

$$Yijklm = \mu + Gi + Cj + Rk + Bl + Sm + GSim + \varepsilon ijklm$$

Where *Yijklm* = the observed effect made up of:

μ = Overall mean

Gi = genotypic main effect

Cj = column effect

Rk = row effect

Bl = Block effect

Sm = Site main effect

GS = Genotype x site interaction effect

εijklm = Experimental error (environmental effect).

Variance components were estimated using REML in Genstat (Payne et al., 2007). Broad sense heritabilities were estimated as follows:

$$H^2 = \frac{V_G}{V_G + V_E}$$

and adjusted for replication as suggested by Burton and DeVane (1953):

$$H^2 = \frac{H^2}{H^2 + \frac{1 - H^2}{N}}$$

where N = number of replications and H^2 the unadjusted heritability.

Genetic gain was estimated by Johnson et al. (1955) formula:

GA = $kH^2\sigma'_p$

Where k = selection intensity for 5% = 2.06, and

σ'_p = phenotypic standard deviation of trait.

Phenotypic, genotypic and error coefficients of variation (PCV, GCV and ECV, respectively) were estimated for foliar blast, finger branching, ear shape, DPM, NHB, plant height, lodging, plant stand, and yield using formulae used by Kumar et al. (1985) as follows:

$$GCV = \frac{100x\,\sigma'_G}{\overline{X}}; \quad PCV = \frac{100x\sigma'_P}{\overline{X}}; \quad ECV = \frac{100x\sigma'_E}{\overline{X}}$$

Where $\overline{X}$ = mean of the trait;

σ'_G = Genotypic standard deviation;

σ'_P = Phenotypic standard deviation;

σ'_E = Error standard deviation;

Mid parent heterosis (MPH) was estimated as follows:

$$MPH\ (\%) = \frac{(\text{Progeny mean} - \text{Mid Parent Value})}{\text{Mid Parent Value}} \times 100$$

Head to head analyses were carried out by calculating the percentage performance of lines relative to parent varieties and the trial mean. Trait phenotypic (r_P) correlations were calculated using PROC CORR procedure of SAS (SAS Institute, 2003). Yield relative to experimental mean (RGY) and rank analysis were also used to compare genotypes across sites.

RESULTS

Trait variation and means among genotypes

Summary statistics and site, genotype, and genotype x site mean squares for significantly different traits over three sites are presented in Table 2 below. Shootfly and *Striga* counts were not significantly different. There was significant GxE interaction for all traits except DPM, necessitating individual sites analyses, sites genotype ranking and rank analyses across sites. There were significant differences ($p \leq 0.05$) for all traits at all sites except

shootfly, foliar blast, plant height, and *Striga* counts at Alupe, shootfly at Kakamega and plant stand at Inungo.

Grain yield mean

Significant positive rank correlations ($p \leq 0.05$) between sites existed. Alupe and Kakamega and Alupe and Inungo correlations were at r= 0.53 and Kakamega and Inungo was r=0.48. The correlations were not absolute thus mean rank over sites did not fully represent individual site ranking. Figure 1 below shows yield frequency distribution for the 81 genotypes with parent varieties indicated in bars where their mean yield fell.

All top 10 genotypes by mean rank were recombinants except GBK 033439, and were each ranked in the top third at each site and together with two parents had RGY >100% with fairly low rank averages (Table 3). Only three recombinants were in the bottom ten genotypes. Progeny means were higher than experimental, checks and parental means across and over sites, except at Inungo. Okhale-1, ranked eleventh, was the best parent and had five of its progeny with GE among top 10. The top mean yielding OKxGEF$_4$BSB13R10(R31) had 154.95% RGY and 14.22% superior to OK. Only nine (11%) genotypes were in the 0-1200kg ha^{-1} yield categories. The mode category 1200-1,500kg ha^{-1} had 31 genotypes. The overall yield trial mean was in the 1501-1800kg ha^{-1} category, beyond the mode and 48% of the genotypes were superior to the overall trial mean. All the 10 genotypes in the top two categories were recombinants except parent OK and check GBK 033439. Generally the yield frequency distribution showed a negative skew. Kakamega had highest yield mean (1923.8kg ha^{-1}) then Inungo (1550.7kg ha^{-1}) and Alupe (1176.8kg ha^{-1}).

The highest mean yield at Alupe was 2458.1kg ha^{-1} by OKxGEF$_4$BSB13R10(R31), followed by OKxGE F$_4$SB13R5(R7) and OK with mean yields of 2319.8 and 2177.5kg ha^{-1} respectively, and the least mean yield was 457.5kg ha^{-1} by U-211 followed by P-283 and U-15xP-283 F$_4$BSB6R31(R7) at 481.7 and 508.1kg ha^{-1}, respectively. At Kakamega check accession GBK 033439 had the highest mean yield (3034kg ha^{-1}) followed by OKxGEF$_4$SB13R7(R20) and OKxGEF$_4$BSB13R10(R31) with 2910 and 2896.9kg ha^{-1}, respectively, and SFMC 585 (late maturing) followed by U-211 and MS at 282.2, 885.9 and 903.8kg ha^{-1} respectively had the least.

Table 2. Summary statistics and environment, genotype and genotype x environment mean squares for 10 finger millet traits studied over three sites in western Kenya, 2007LR

Variable	N	Mean	Std Dev	Min.	Max.	MS Site	MS Genotype	MS Genotype x Environment
Foliar blast score	324	2.16	1.00	1	5	230.03**	0.32**	0.31**
Days to 50% flowering	324	81.94	5.87	69	107	3074.09	49.41**	10.14*
Neck and head blast (Score) †	485	2.35	0.70	1	5	3.95**	1.19**	0.32**
Finger branching (Score)	324	0.68	0.47	0	1	0.00	0.29**	0.22**
Ear shape (Score)	324	1.95	0.78	1	3	7.41**	1.27**	0.22*
Plant height (cm) †	486	78.47	12.81	25.7	116	13022.27**	163.38**	75.66**
Lodging (percentage) †	486	20.50	22.87	0	100	32919.14**	726.94**	300.45**
Days to physiological maturity	322	115.01	3.14	110	125	160.57**	16.05**	5.96
Plant stand at harvest (no.) †	486	33.27	5.04	13	50	2269.76**	14.29**	12.75*
Yield (kg ha^{-1}) †	486	1,550	620	180	3,370	22270305.13**	762092.41**	189788.21**

N= no. of observations; Min. and Max. = Minimum and Maximum, respectively; *, ** significant at the 0.05 and 0.01 levels of probability, respectively; () = 3 sites df ; † = tested at 3 sites.

At Inungo, GBK 033439 had the highest mean yield of 2279.6kg ha^{-1} followed by OKxGE F_4SB13R10(R27), and OKxGE F_4BSB13R6(R13), with mean yields of 2186.8 and 2143kg ha^{-1}, respectively and late maturing SFMC 585, followed by FMV-1xGE F_4SB8R13(R10) and SFMC 4 with 480.3kg ha^{-1}, 903.2 and 1032.3kg ha^{-1}, respectively, had the least.

Table 3. Yield means of F5:6 progenies of top and bottom ten and parent finger millet genotypes over three sites in western Kenya during 2007LR

		Yield (kg ha^{-1})				(%)	Rank	
Entry	Line	Alupe	Kak.	Inungo	Mean	RGY	Rank avg.	Rank
	Best 10 selections							
56	OKxGE F_4SB13R10(R27)	1834.50	2857.00	2186.50	2292.67	147.87	3.67	1
4	GBK 033439	1553.00	3034.50	2279.50	2289.00	147.64	6.67	2
58	OKxGE F_4BSB13R10(R31)	2458.00	2897.00	1852.00	2402.33	154.95	7.00	3
66	P-224xOK F_4SB19R14(R7)	1484.00	2765.50	2108.50	2119.33	136.69	10.00	4
71	U-15xGE F_4SB28R4(R4)	1655.50	2661.00	2036.50	2117.67	136.59	10.33	5
39	U-15xP-283 F_4BSB6R29(R5)	1790.00	2575.00	1984.50	2116.50	136.51	11.00	6
50	OKxGE F_4SB13R7(R20)	1812.00	2910.00	1679.00	2133.67	137.62	11.67	7
57	OKxGE F_4BSB13R10(R30)	2114.00	2156.00	2048.00	2106.00	135.83	12.00	8
45	GExMS F_4BSB9R5(R8)	1757.50	2536.50	1894.50	2062.83	133.05	12.67	9
52	OKxGE F_4SB13R5(R7)	2397.50	2343.00	1751.00	2163.83	139.56	13.67	10
	Parental genotypes							
79	OK	2177.50	2045.00	2087.50	2103.33	135.66	14.00	11
75	P-224	1239.50	2091.50	2033.50	1788.17	115.33	24.33	17
76	U-15	1240.00	1412.50	1593.00	1415.17	91.28	44.00	46
78	NB	844.50	1674.00	1877.00	1465.17	94.50	44.00	47
74	Gulu-E	817.00	1959.00	1492.00	1422.67	91.76	49.67	56
80	FMV-1	827.50	1349.50	1492.00	1223.00	78.88	58.67	68
81	MS	745.00	903.50	1191.50	946.67	61.06	74.00	78
77	P-283	481.50	958.00	1232.00	890.50	57.44	76.00	79
	Bottom 10							
67	MSxP-224 F_4SB20R7(R2)	868.50	1539.00	1338.00	1248.50	80.53	61.00	70
10	U-43	806.00	1448.00	1411.00	1221.67	78.80	62.67	71
3	SX8	810.00	1484.50	1390.00	1228.17	79.21	63.00	72
9	SFMC 252	361.50	1493.00	1378.50	1077.67	69.51	68.00	73
61	P-283xNB F_4BSB17R6(R3)	626.00	1313.50	1284.00	1074.50	69.30	70.67	74
27	SFMC 4	740.50	1436.00	1032.50	1069.67	68.99	72.00	75
33	U-15xMS F_4SB4R3(R3)	562.00	1492.00	1132.50	1062.17	68.51	72.33	76
16	P-318	787.00	1071.50	1168.00	1008.83	65.07	73.33	77
26	U-211	457.50	886.00	1051.00	798.17	51.48	79.33	80
23	SFMC 585	555.00	282.00	480.00	439.00	28.31	79.67	81
Parental mean		**1046.56**	**1549.13**	**1624.81**	**1406.83**			
Checks mean		**975.72**	**1691.11**	**1487.49**	**1384.77**			
Progeny mean		**1317.55**	**2125.60**	**1574.84**	**1672.66**			
Mean		**1176.8****	**1923.8****	**1550.7****	**1550.44****			
LSD (0.05)		**675.2**	**772.30**	**515.30**	**482.87**			
Min.		**361.50**	**282.00**	**480.00**	**439.00**			
Max.		**2458.00**	**3034.50**	**2279.50**	**2402.33**			
CV		**21.66**	**20.33**	**13.32**	**19.01**			

*, ** significant at the 0.05 and 0.01 levels of probability, respectively; RGY=relative grain yield over the experimental mean.

Lines of OKxGE population ranked in top three at the three sites with OKxGE F_4BSB13R10(R31) topping at Alupe and third at Kakamega and giving the highest mean yield, despite its overall third place ranking.

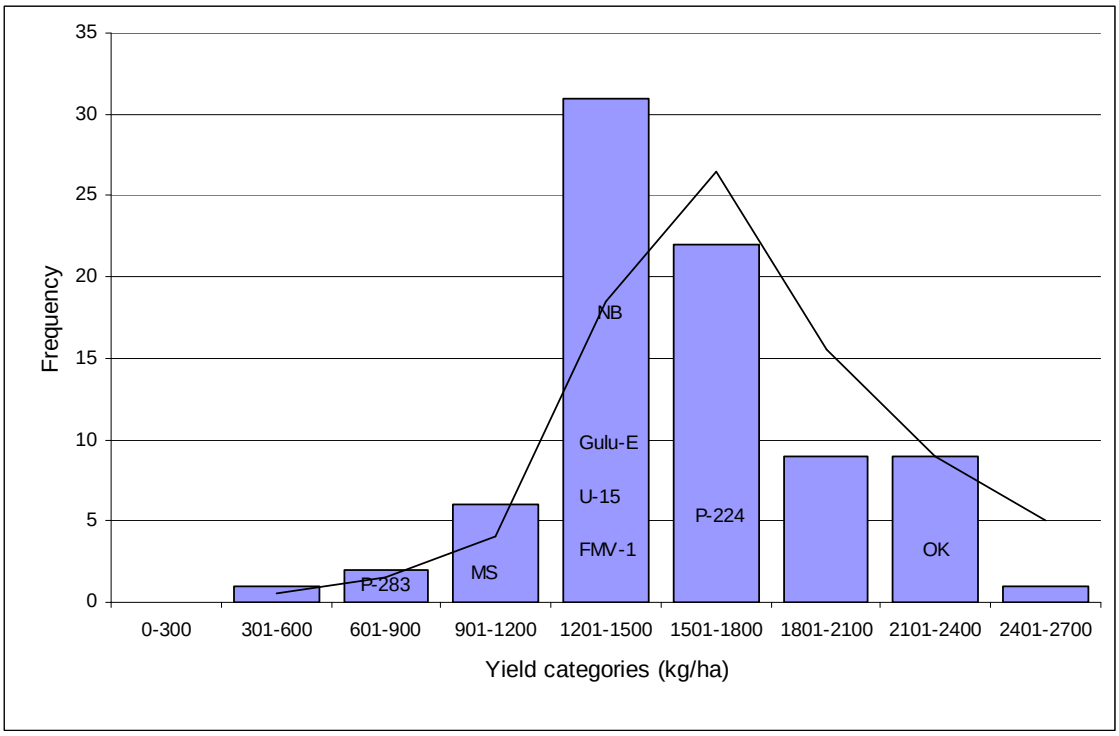

Figure 1. Yield frequency distribution for 81 selected finger millet genotypes, over Alupe, Kakamega, and Inungo, 2007LR, showing parent variety distribution in bars

Foliar and neck and head blast

Alupe had higher foliar blast incidence than Kakamega. At Kakamega 45 genotypes had foliar blast mean score of 1 (highly resistant) and the highest was 3 on parent FMV-1. Over sites, foliar blast ranged from 1.5-3.5. Figure 2 below shows the frequency distribution of foliar blast and NHB among the 81 genotypes and the foliar blast and NHB categories of parent varieties. Only two genotypes SFMC 867 and SFMC 585 had foliar blast mean score of 1.5 across sites, better than all parents but poor in yield, with 1617 and 439kg ha^{-1} respectively. Four parent varieties OK, GE, U-15, and NB were in the second category of 1.6-2.0 (resistant), which was also the mode category. Parent varieties MS and P-283 were in the 2.1 - 2.5 category (resistant to moderately resistant). The worst parents in terms of foliar blast were P-224 in category 2.6-3.0 (moderately resistant) and FMV-1 in category 3.1-3.5 (moderately resistant to moderately susceptible) mean foliar blast and were also the worst genotypes. The best parent in mean foliar blast was OK, which was also the best parent in yield. The frequency distributions for foliar blast and NHB showed positive skews

towards susceptibility. The means for both foliar blast and NHB were in the category greater than the mode in the susceptibility direction. The highest mean yielding OKxGEF$_4$BSB13R10(R31) and the highest yield ranked OKxGE F$_4$SB13R10(R27) ranked fourth and third in foliar blast with mean scores of 2.25 (resistant to moderately resistant) and 2 (resistant), respectively.

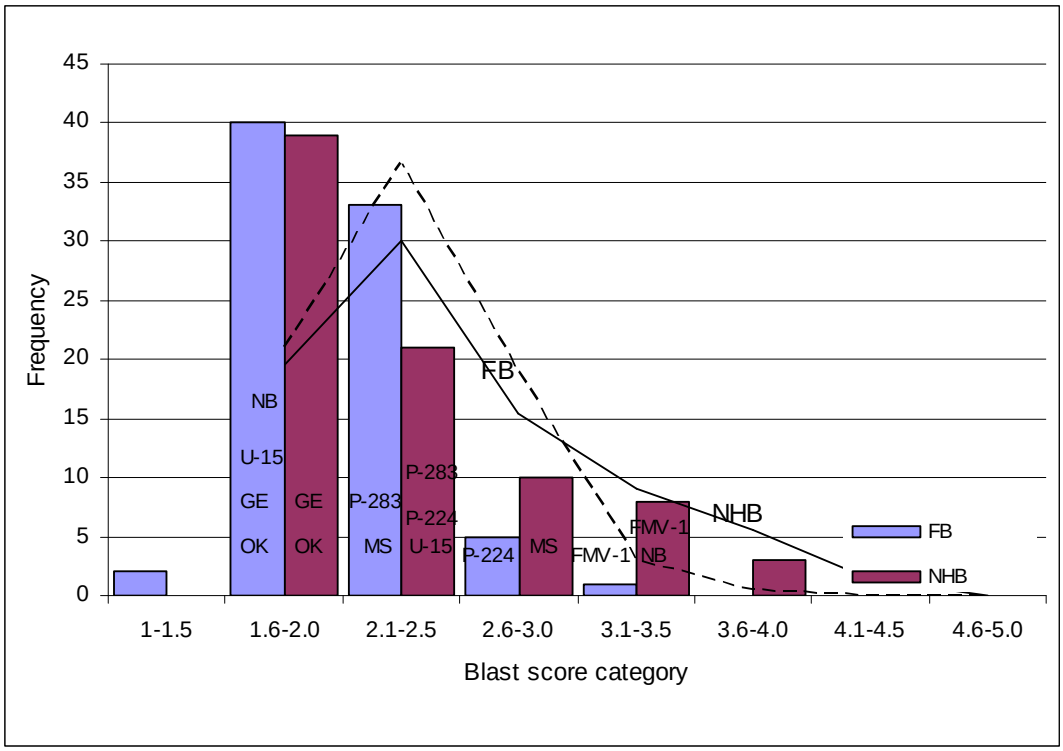

Figure 2. Foliar and neck and head blast frequency distributions for 81 selected finger millet genotypes over Alupe, Kakamega and Inungo, 2007LR, showing parent variety distribution in bars.

Of the top yield ranked genotypes, GBK 033439 and OKxGEF$_4$SB13R5(R7) had foliar blast mean score of 1.75 (highly resistant to resistant). Most of the top 10 yielding genotypes had moderate resistance to foliar blast (2.25-2.75).

Neck and head blast incidence was highest at Kakamega, followed by Inungo and least at Alupe, unlike foliar blast where incidence was higher at Alupe than Kakamega. No genotype showed a mean score of 1 for NHB at the three sites. The least mean score at Alupe was 2 on 57 genotypes and the highest was 3.5 on two genotypes. The highest NHB mean score at Kakamega was 5 (susceptible) on P-318 and the least 1.5 on GBK 028044F and FMV-1xGEF4SB8R13(R10). At Inungo the least mean NHB was 1.5 on three genotypes GBK 028044F, OKxGEF4SB13R5(R7) and GBK 031895 and the largest was 5 on SFMC 4. No genotypes were in 1-1.5 mean NHB category but there were 39 in the mode 1.51-2.0 category, including best parents GE and OK with a score of 2. Three parent varieties U-15,

P-283 and P-224 were in 2.1 - 2.5 category (resistant to moderately resistant) in which mean NHB was. Parent varieties FMV-1 and NB, the worst parent varieties, were in category 3.1-3.5 (moderately resistant). The NHB frequency distribution had a longer positive skew tail towards susceptibility than foliar blast. The highest mean yielding OKxGEF$_4$BSB13R10(R31) and top yield ranked OKxGEF$_4$SB13R10(R27) with mean NHB scores of 2.17 (resistant to moderately resistant) and 2 (resistant) respectively, were ranked similar to foliar blast ranking. Of the top 10 yield ranked genotypes, five GExMSF$_4$BSB9R5(R8), OKxGEF$_4$SB13R5(R7), OKxGEF$_4$SB13R10(R27), P-224xOK F$_4$SB19R14(R7) and U-15xGEF$_4$SB28R4(R4) were ranked jointly third with the best parents OK and GE. The rest of parent varieties had NHB mean scores of 2.17 - 2.67 (moderately resistant). None of the bottom 10 yielding genotypes were in the bottom 10 NHB susceptible genotypes. Parent NB showed the biggest change over in categories from category 1.6-2.0 in foliar blast to category 3.1-3.5 in NHB. Only genotype U-15xP-283F$_4$BSB6R31(R7) was in the bottom 10 most susceptible for both foliar blast and NHB.

Days to 50% flowering and days to maturity

On average genotypes matured earlier at Alupe than Kakamega. The earliest genotype at Alupe, a progeny of early parent U-15 (U-15xP-283 F$_4$BSB6R31(R7) flowered in 70 days and 78.5 days at Kakamega. The earliest to flower at Kakamega was also a progeny of U-15 (U-15xMSF$_4$SB4R11(R16) and flowered in 77 days. The latest line at both sites SFMC 585 flowered in 90 and 107 days at Alupe and Kakamega, respectively. Mean D50 ranged from 74 to 99 days across sites giving a mean interval of 25 days. Sixty genotypes (74%) flowered in 85 days or less. The top 10 early flowering genotypes were mostly the early parents FMV-1 and U-15 and their crosses. The earliest genotype to flower was U-15xP-283F$_4$BSB6R31(R7) at 74.25 days. The 10 latest flowering genotypes mainly came from the checks and SFMC 585 and SFMC 867 were the latest. Four of the top 10 yielding genotypes were among the top 10 early flowering and included the highest yield ranked OKxGEF$_4$SB13R10(R27) and highest mean yielding OKxGEF$_4$BSB13R10(R31), U-15xGEF$_4$SB28R4(R4), and U-15xP-283F$_4$BSB6R29(R5).

The earliest genotype at Kakamega, FMV-1, on average, matured in 110.5 days and the latest SFMC 867 in 122.5 days. The earliest eight genotypes at Alupe matured in 111 days and included top 10 yielding OKxGEF$_4$BSB13R10(R30), OKxGEF$_4$BSB13R10(R31), OKxGEF4BSB13R10(R27), and parent U-15. Parent OK matured latest at Alupe in 123. Over Alupe and Kakamega 46 genotypes (57%) matured in less than 115 days and 33 genotypes (41%) in 115-120 days. Only 2 genotypes (2%) matured in 120.5 days on average. Early maturing parents U-15 and FMV-1 and their progeny dominated the top ten

early maturing genotypes as with D50. All top ten yield ranked genotypes on average matured in under 115 days except GBK 033439 and OKxGEF$_4$SB13R5(R7) that matured in 116.75 and 115.5 days, respectively. Parent varieties U-15 and FMV-1 on average matured in 111.75 days, NB in 115, MS in 116.75, GE in 117.25, P-283 in 117.75, and OK, the latest, in 120 days. The mean range of D50 of 25 days was wider than that for maturity period of 9 days.

Striga counts at Alupe

Flowering stage had the highest mean *Striga* support ranging from 0.5 to 72 *Striga* plants per plot, then maturity stage with zero to 12, and vegetative stage with zero to 2. At vegetative stage 64 (79%) of the genotypes had no *Striga*. No genotype showed immunity to *Striga* and the mean least total *Striga* support was 3.5 and the highest was 80.5 *Striga* plants per plot. Nineteen top 10 least *Striga* supporting genotypes including high yielding GBK 033439 were all checks except two which also were in the top 10 yield ranked genotypes, OKxGEF$_4$SB13R5(R7) and the highest mean yielding OKxGEF$_4$BSB13R10(R31). Only FMV-1 and OK parent varieties were in the top 10 least *Striga* supporting genotypes with 7.5 and 9.5 *Striga* plants per plot, respectively. Figure 3 below shows frequency distribution for the 81 finger millet genotypes in *Striga* support categories of 10 *Striga* plants interval. It showed a positive skew with 56 (70%) of the genotypes in the mode and mean category and below.

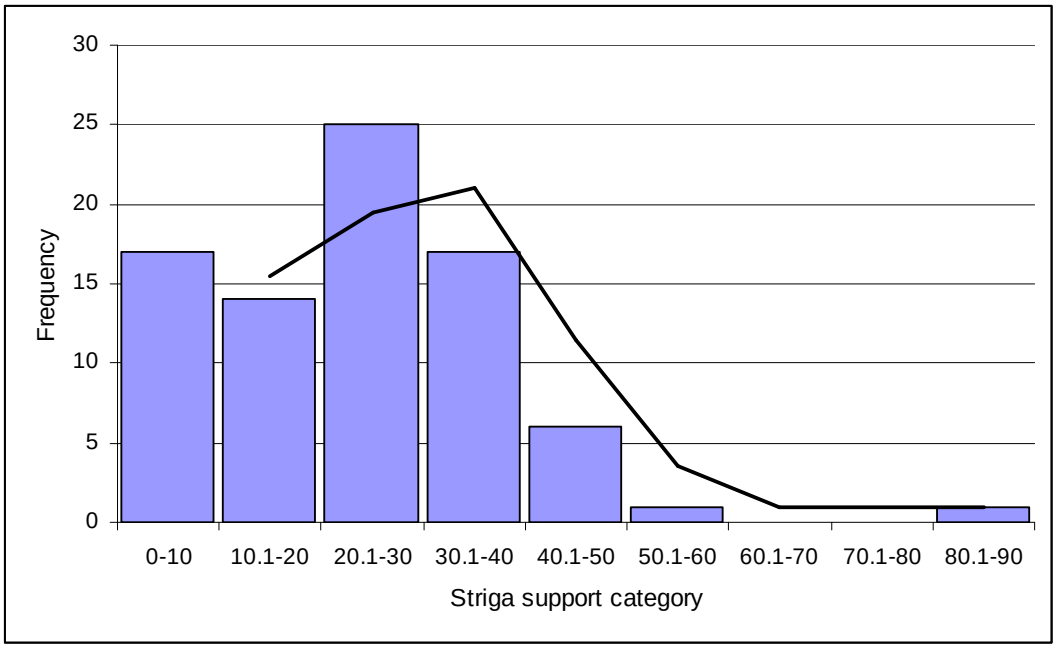

Figure 3. Frequency distribution for *Striga* support for 81 finger millet genotypes at Alupe, 2007LR

Finger branching

Almost all genotypes at Alupe and Kakamega displayed finger branching. Only five genotypes consistently had no finger branching and 22 consistently had finger branching at both sites. Sites did not differ in finger branching. All the top 10 yield ranked genotypes had finger branching, four of which, including the top yield ranked OKxGE F_4SB13R10(R27) consistently had finger branching at both sites. All parent varieties had finger branching, but only NB and FMV-1 consistently had it at both Alupe and Kakamega.

Ear shape

None of the eight genotypes consistently showing open heads at both sites were among top 10 yield ranked. However, the top 10 yield ranked genotypes OKxGEF_4SB13R10(R27), OKxGEF_4BSB13R10(R31), and OKxGEF_4BSB13R10(R30) were consistently open headed at Kakamega and almost incurved at Alupe. Only parent FMV-1 was consistently open headed at the two sites. Ten genotypes were consistently fist headed at the two sites, none of which were among the top 10 yield ranked genotypes. Parents GE and P-283 were consistently fist headed at Kakamega and tended to fist headedness at Alupe. Genotypes displayed more open headedness at Kakamega than Alupe.

Plant height

Kakamega had highest mean plant height of 86.13cm, followed by Inungo 80.67cm, and Alupe lowest at 68.61cm. None of the top 10 yield ranked genotypes was in the top 10 shortest, but two, GBK 033439 and OKxGEF_4SB13R7(R20) were in the top 10 tallest.

Lodging percentage

Lodging was highest at Inungo, then Kakamega, and lowest at Alupe. Genotypes GBK 028044F and GBK 033439 were among highest lodging at Inungo and Kakamega. Sites mean lodging ranged from 1–66% and the least lodging genotype was OKxGE F4SB13R4(R5) and GBK 028044F the most. Four of the top 10 yield ranked genotypes, OKxGEF_4SB13R10(R27), OKxGEF_4BSB13R10(R31), OKxGEF_4SB13R7(R20), and OKxGEF_4SB13R5(R7), all from OKxGE population, were among 10 least lodging. Two of the top 10 yield ranked GBK 033439 and P-224xOKF_4SB19R14(R7) were among top 10 most lodging. Parent varieties GE, MS, P-283 and OK were among top 10 least lodging and NB among top 10 most lodging. On average 65 (80%) genotypes lodged 30% or less, 18 of them 10% or less including parent GE.

Plant stand

Expected plant stand at each site was 41. Kakamega had highest mean plant stand of 37.58, Inungo 31.36 and Alupe 30.86. The highest mean plant stand at Alupe was 37 by GExP-283F_4SB12R5(R30), then OKxGEF_4SB13R7(R20) and OKxGEF_4SB13R10(R27) in top 10 yield ranked genotypes with 36.5 each. At Kakamega, five genotypes had maximum mean plant stand of 42 including OKxGEF_4BSB13R10(R30) in top 10 yield ranked genotypes. Six of top 10 yield ranked genotypes were among top 10 with highest plant stand: OKxGEF_4SB13R10(R27), U-15xP-283F_4BSB6R29(R5), OKxGEF_4BSB13R10(R30), GExMSF_4BSB9R5(R8), OKxGEF_4SB13R5(R7) and parent OK. None of top 10 yield ranked genotypes were among bottom 10 least plant stand and neither were parents except NB.

Trait expected mean squares and broad sense heritability

Variance components and H^2 are presented in Table 4. Foliar blast, finger branching, and plant stand had negative genetic variances (V_G). All traits had high H^2 (>60%) except negative V_G traits.

Table 4. Expected mean square components and broad sense heritability for 10 traits of 81 finger millet genotypes

	Mean square				
Trait	Error	Genotype x Environment	Genotype	Vg	H^2
Foliar blast (score)	0.17	0.31	0.32	-0.16	-
Days to 50% flowering	6.55	10.14	49.41	32.72	0.91
Finger branch. (score)	0.12	0.22	0.29	-0.05	-
Ear shape (score)	0.15	0.22	1.27	0.9	0.92
Days to phy. maturity	5.33	5.96	16.05	4.76	0.64
Neck and head blast	0.13	0.32	1.19	0.74	0.92
Plant height† (cm)	44.94	75.66	163.38	42.78	0.66
Lodging† (%)	169.42	300.45	726.94	257.07	0.75
Plant stand† (no.)	8.85	12.75	14.29	-7.31	-
Yield†	122204	189788	762092	450100	0.88

- = heritability not estimable due to negative genetic variance.

Phenotypic, genotypic and error coefficients of variability and genetic advance

Table 5 below shows trait PCV, GCV, ECV and EGA. Grain yield had moderate PCV, GCV and ECV. Lodging had highest EGA (172%) then ear shape (75.45), yield (72.49%) and DPM least (3.87%). Neck and head blast showed fairly high EGA.

Table 5. Range, phenotypic, genotypic, error coefficients of variability and genetic advance of 7 traits of 81 f. millet genotypes

Trait	Range	PCV%	GCV%	ECV%	EGA	EGA (% of mean)
50%Flowering	69 - 107	7.16	6.98	3.12	10.99	13.41
Ear Shape	1 - 3	39.7	48.43	19.80	1.47	75.45
Days to Phy. Maturity	110 - 125	2.73	1.90	2.01	4.45	3.87
Neck and Head Blast †	1 - 5	29.75	36.72	15.42	1.32	56.30
Plant height†	25.7 - 116	16.32	8.34	8.54	17.30	22.04
Lodging†	0 - 100	111.55	78.20	63.49	35.44	172.85
Yield†	18 – 3370	56.92	43.27	22.55	1123.9	72.49

Phenotypic correlations

Trait phenotypic correlations ($p \leq 0.05$) were mostly highly significant but low (Table 6). Yield had highly significant positive correlations with shootfly, plant height, plant stand, and lodging and positive significant correlation with finger branching. There was notable yield high positive correlation with shootfly. No significant correlation existed between yield and D50 and DPM. Yield had highly significant negative correlated with all *Striga* counts, ear shape (reduced with incurving), and foliar blast. Neck and head blast negative correlation with yield was not significant just as the positive correlation was in unselected germplasm evaluation (Chapter 6). Besides yield correlations, shootfly and foliar blast (-0.78) (highest correlation), foliar blast and *Striga* counts, shootfly and D50 (0.49), *Striga* counts negative correlation to shootfly, plant height and lodging were prominent.

Table 6. Pearson Correlation Coefficients among 15 traits for 81 finger millet genotypes over three sites in western Kenya

	SF	FB	D50	SCV	NHB	SCF	FBr.	ES	SCM	SCT	PH	LG	DPM	PS	YLD
Shootfly	1.000	-0.78**	0.49**	-0.18**	0.19**	-0.57**	0.01	-0.20**	-0.50**	-0.04	0.60**	0.55**	0.23**	0.60**	0.55**
Foliar blast		1.000	-0.55**	0.14**	-0.15**	0.55**	0.00	0.21**	0.46**	0.06	-0.58**	-0.52**	-0.30**	-0.55**	-0.46**
Days to 50% flow.			1.000	-0.15**	-0.01	-0.38**	-0.22**	-0.16**	-0.32**	-0.11	0.36**	0.19**	0.6**	0.23**	-0.03
Veg. *Striga* count				1.000	-0.09	0.35**	-0.06	0.04	0.14*	0.34**	-0.16**	-0.11*	-0.08	-0.10	-0.17**
Neck and head blast					1.000	-0.17**	0.09	-0.15**	-0.12*	-0.08	0.14**	0.16**	-0.03	0.08	-0.06
Flow. *Striga* count						1.000	-0.16**	0.10	0.35**	0.99**	-0.55**	-0.38**	-0.23**	-0.47**	-0.52**
Finger branching							1.000	0.06	0.03	-0.28**	0.15**	0.04	-0.17**	0.14**	0.14*
Ear shape								1.000	0.15**	-0.03	-0.21**	-0.10	-0.14**	-0.17**	-0.14**
Maturity *Striga* count									1.000	0.16*	-0.31**	-0.31**	-0.16**	-0.28**	-0.24**
Total *Striga* count										1.000	-0.32**	-0.28**	-0.15	-0.14	-0.40**
Plant height											1.000	0.42**	0.30**	0.37**	0.51**
Lodging												1.000	0.09	0.07	0.40**
Days to Phy. Maturity													1.000	0.10	-0.05
Plant stand														1.000	0.43**
Yield															1.000

*, ** significant at the 0.05 and 0.01 levels of probability, respectively.

Realized breeding progress

Realized breeding gain was in the desirable direction for all traits except foliar blast (Table 7). Even in foliar blast, six out of the 18 populations had desirable gain (-11- ¯18%). Yield had 5.84% mean gain and 11 of the 18 populations had positive gains (zero to 47%). Neck and head blast and lodging had mean desirable gains of -2.54% and –21.03%, respectively. Mean population gains over mid-parent values were lower than the best lines within populations over their mid-parent values.

Table 7. Percentage realized breeding progress in two cycles of selection F_3 – F_4 in 10 finger millet traits between 2006LR – 2007LR

	F_5 Population	NHB	PH	DPM	FBr	ES	FB	D50	LG	PS	YLD
1	P-283Xge	-2.05	1.72	-2.55	100.00	9.09	-11.11	-7.10	-21.68	2.32	35.68
2	P-283xU-15	18.59	-4.70	-2.40	20.00	-11.90	5.56	-7.95	-22.91	-0.42	37.61
3	P-283xNB	25.71	2.45	-1.61	33.33	-25.00	11.11	-7.24	-20.05	3.29	-8.77
4	P-283xOK	-7.69	-5.01	-3.26	0.00	22.22	17.65	-0.88	-26.85	-1.48	-13.93
5	GExU-15	14.00	11.01	-0.87	40.00	-9.52	17.19	-1.40	-11.70	8.05	9.61
6	GexOK	14.72	6.23	-3.76	72.22	-35.80	12.59	-3.87	-11.08	6.07	13.34
7	GExP-224	-3.70	2.84	-1.73	100.00	41.18	10.00	-3.79	-20.84	2.88	-6.17
8	GExMS	-15.56	12.45	-1.60	37.50	-28.26	14.17	-3.37	-10.95	8.34	46.27
9	GExFMV-1	-23.23	-2.40	-0.22	33.33	46.67	-18.18	0.63	-23.92	-0.15	8.62
10	U-15xNB	-5.96	-1.80	-0.26	-4.76	-11.11	12.50	0.26	-22.07	0.65	2.23
11	U-15xOK	-4.00	3.28	0.22	-40.00	-35.29	26.67	0.62	-19.87	3.24	4.03
12	U-15xP-224	3.64	-1.91	0.17	-40.00	-18.75	-15.00	-2.10	-21.04	0.89	0.05
13	U-15xMS	-13.55	3.67	0.22	40.00	-13.64	5.88	0.46	-19.10	3.33	14.77
14	NBxOK	-27.27	-1.85	-1.49	-83.33	-25.00	6.67	0.60	-23.83	0.08	-6.83
15	NBxFMV-1	-35.00	0.27	6.28	-100.00	11.11	-18.18	9.35	-22.96	0.91	24.65
16	OKxP-224	-9.26	-1.58	-2.82	16.67	-12.82	-15.79	-3.06	-22.50	0.65	-2.48
17	OKxFMV-1	41.94	-14.50	-1.40	-33.33	9.09	-14.29	-1.57	-32.25	-5.75	-15.56
18	P-224xMS	-3.03	0.36	2.60	0.00	11.11	4.76	-0.75	-22.10	1.61	-8.71
	Mean Gain	**-2.54**	**0.40**	**-0.83**	**2.96**	**-5.19**	**1.54**	**-1.78**	**-21.03**	**1.81**	**5.84**

Where NHB=neck and head blast; PH=plant height; DPM=days to physiological maturity; FBr=Finger branching; ES=ear shape; FB=foliar blast; D50= days to 50% flowering; SCT=total *Striga* count; LG=lodging percentage; PS=plant stand; YLD=yield in kg ha^{-1}.

There were selected progenies superior in relative grain yield to the experimental mean, best parent, parental mean, best check, and mean of checks (Table 8). A total of 29 progeny lines had RGY superior to experimental mean by as much as 154.95%, eight superior to the best parent by up to 114.22%, 37 superior to the parental mean by as much as 170.76%, two superior to the best check (also a new selection) by 104.95%, and 38 superior to the mean of checks by as much as 173.48. On average, progeny mean was superior to trial mean, parental mean, and mean of checks.

Table 8. F_5 Progeny means and relative grain yield over trial, best parent, best check, and checks mean

		Percent relative grain yield (RGY)				
F_5 Lines	Line Mean yield kg ha^{-1}	To trial Mean	To best Parent	To parental mean	To best check	Checks mean
OkxGE F4BSB13R10(R31)	2402.33	154.95	114.22	170.76	104.95	173.48
OkxGE F4SB13R10(R27)	2292.67	147.87	109.00	162.97	100.16	165.56
OkxGE F4SB13R5(R7)	2163.83	139.56	102.88	153.81	94.53	156.26
OkxGE F4SB13R7(R20)	2133.67	137.62	101.44	151.66	93.21	154.08
P-224xOK F4SB19R14(R7)	2119.33	136.69	100.76	150.65	92.59	153.05
U-15xGE F4SB28R4(R4)	2117.67	136.58	100.68	150.53	92.51	152.93
U-15xP-283 F4BSB6R29(R5)	2116.50	136.51	100.63	150.44	92.46	152.84
OkxGE F4BSB13R10(R30)	2106.00	135.83	100.13	149.70	92.01	152.08
GexMS F4BSB9R5(R8)	2062.83	133.05	98.07	146.63	90.12	148.97
OkxGE F4BSB13R6(R13)	1968.33	126.95	93.58	139.91	85.99	142.14
OkxGE F4BSB13R10(R25)	1911.17	123.27	90.86	135.85	83.49	138.01
U-15xP-224 F4SB5R5(R7)	1871.17	120.69	88.96	133.01	81.75	135.12
U-15xOK F4BSB18R14(R6)	1862.67	120.14	88.56	132.40	81.37	134.51
OkxU-15F4BSB18R6(R4)	1856.50	119.74	88.26	131.96	81.11	134.07
OkxP-224 F4SB19R9(R2)	1802.17	116.24	85.68	128.10	78.73	130.14
U-15xP-224 F4BSB5R7(R9)	1776.50	114.58	84.46	126.28	77.61	128.29
P-224xOK F4BSB19R4(R7)	1770.50	114.19	84.18	125.85	77.35	127.86
OkxNB F4SB16R9(R4)	1761.00	113.58	83.72	125.18	76.93	127.17
GexMS F4BSB9R9(R10)	1724.17	111.20	81.97	122.56	75.32	124.51
U-15xMS F4SB4R11(R16)	1714.50	110.58	81.51	121.87	74.90	123.81
FMV-1xNB F4SB10R5(R5)	1675.17	108.04	79.64	119.07	73.18	120.97
U-15xP-283 F4BSB6R36(R13)	1632.17	105.27	77.60	116.02	71.30	117.87
U-15xNB F4SB1R8(R10)	1598.33	103.09	75.99	113.61	69.83	115.42
FMV-1XGE F4SB8R19(R12)	1591.67	102.66	75.67	113.14	69.54	114.94
GexMS F4SB9R3(R3)	1574.17	101.53	74.84	111.89	68.77	113.68
GexMS F4SB9R23(R17)	1570.17	101.27	74.65	111.61	68.60	113.39
GexP-283 F4SB12R5(R2)	1569.00	101.20	74.60	111.53	68.55	113.30
OkxGE F4SB13R4(R5)	1567.33	101.09	74.52	111.41	68.47	113.18
OkxNB F4BSB16R18(R11)	1562.83	100.80	74.30	111.09	68.28	112.86
U-15xP-224 F4BSB5R8(R8)	1525.83	98.41	72.54	108.46	66.66	110.19
GexP-224 F4SB26R22(R11)	1506.33	97.16	71.62	107.07	65.81	108.78
U-15xGE F4SB28R5(R5)	1482.33	95.61	70.48	105.37	64.76	107.05
U-15xGE F4SB28R6(R12)	1476.83	95.25	70.21	104.98	64.52	106.65
U-15xP-283 F4SB6R22(R2)	1476.33	95.22	70.19	104.94	64.50	106.61
U-15xNB F4SB1R7(R6)	1466.33	94.58	69.71	104.23	64.06	105.89
NBxU-15 F4SB1R2(R3)	1440.67	92.92	68.49	102.41	62.94	104.04
OKxGE F4BSB13R7(R17)	1434.50	92.52	68.20	101.97	62.67	103.59
OKxFMV-1 F4BSB22R12(R5)	1404.17	90.57	66.76	99.81	61.34	101.40
U-15xP-224 F4BSB5R3(R2)	1352.00	87.20	64.28	96.10	59.07	97.63
OKxP-283 F4SB2R6(R5)	1288.17	83.08	61.24	91.57	56.28	93.02
FMV-1xGE F4SB8R13(R10)	1281.83	82.68	60.94	91.12	56.00	92.57
U-15xP-283 F4BSB6R31(R7)	1278.67	82.47	60.79	90.89	55.86	92.34
U-15xGE F4SB28R11(R16)	1269.00	81.85	60.33	90.20	55.44	91.64
MSxP-224 F4SB20R7(R2)	1248.50	80.53	59.36	88.75	54.54	90.16
P-283xNB F4BSB17R6(R3)	1074.50	69.30	51.09	76.38	46.94	77.59
U-15xMS F4SB4R3(R3)	1062.17	68.51	50.50	75.50	46.40	76.70
Mean	**1672.66**	**107.88**	**79.52**	**118.90**	**73.07**	**120.79**

Table 9 below shows population's best yielding lines and their superiority over their parents, blast, lodging and SCT traits. These lines were superior to their inferior parents in all populations by 6-138% and to their superior parents in 11 out of the 18 populations by up to 50%. Thirteen of the 18 lines had above average RGY by up to 130% with some resistant to blast, lodging and *Striga*. Table 10 below shows the best three yielding lines superiority over parents. These lines had 8.85-169.72% superiority over parental means. Generally OKxGE population had the best performing lines and parent OK was the best and parent P-283 the poorest in yield.

Table 9. Population best yielding lines mean yield (kg ha^{-1}), percent superiority over parents and their blast, lodging and *Striga* support traits

Entry	Best Line	Mean WP yield	Mean BP yield	Mean yield	% BLS to WP	% BLS to BP	RGY	FB	NHB	LG	SCT
43	FMV-1XGE F_4SB8R19(R12)	1592	1223	1423	30	12	103	2.25	2.00	10	40
48	FMV-1xNB F_4SB10R5(R5)	1675	1223	1465	37	14	108	2.25	2.00	17	28
45	GExMS F_4BSB9R5(R8)	2063	947	1423	118	45	133	2.25	2.00	24	32
69	GexP-224 F_4SB26R22(R11)	1506	1423	1788	6	-16	97	2.75	2.17	6	81
49	GexP-283 F_4SB12R5(R2)	1569	891	1423	76	10	101	2.00	2.17	13	28
67	MSxP-224 F_4SB20R7(R2)	1249	947	1788	32	-30	81	2.75	2.67	31	21
29	U-15xNB F_4SB1R8(R10)	1598	1415	1465	13	9	103	2.25	2.83	9	33
68	OKxFMV-1 F_4BSB22R12(R5)	1404	1223	2103	15	-33	91	2.25	3.67	22	21
58	**OKxGE F_4BSB13R10(R31)**	**2402**	**1423**	**2103**	**69**	**14**	**155**	**2.25**	**2.17**	**12**	**9**
59	OKxNB F_4SB16R9(R4)	1761	1465	2103	20	-16	114	2.00	2.00	13	26
66	**P-224xOK F_4SB19R14(R7)**	**2119**	**1788**	**2103**	**19**	**1**	**137**	**2.00**	**2.00**	**43**	**20**
31	OKxP-283 F_4SB2R6(R5)	1288	891	2103	45	-39	83	2.50	2.00	8	26
63	U-15xOK F_4BSB18R14(R6)	1863	1415	2103	32	-11	120	2.25	2.00	15	43
61	P-283xNB F_4BSB17R6(R3)	1075	891	1465	21	-27	69	2.50	3.67	21	38
71	**U-15xGE F_4SB28R4(R4)**	**2118**	**1415**	**1423**	**50**	**49**	**137**	**2.50**	**2.00**	**17**	**22**
32	U-15xMS F_4SB4R11(R16)	1715	947	1415	81	21	111	2.50	2.00	8	36
34	U-15xP-224 F_4SB5R5(R7)	1871	1415	1788	32	5	121	2.00	2.00	27	6
39	**U-15xP-283 F_4BSB6R29(R5)**	**2117**	**891**	**1415**	**138**	**50**	**137**	**2.25**	**2.33**	**28**	**14**

Where WP=Worst parent; BP=Best parent; BLS=Best line superiority; RGY=Relative grain yield; FB=foliar blast; NHB=neck and head blast; LG=lodging percentage; SCT=total *Striga* count.

Table 10. Parent and top 3 selected lines mean yield (Kg ha^{-1}) and selected lines percent superiority

		Top 3 selected lines yield in kg ha^{-1}					
		OKxGEF4BSB13R10(R31)		OKxGEF4SB13R10(R27)		GBK 033439	
Parent	Mean (kg)	2402.30 (kg)	Percent superiority	2292.70 (kg)	Percent superiority	2289.10 (kg)	Percent superiority
P-283	890.70	1511.60	169.72	1402.00	157.41	1398.40	157.01
GE	1422.70	979.60	68.86	870.00	61.16	866.40	60.90
U-15	1473.00	929.30	63.09	819.70	55.65	816.10	55.40
NB	1465.30	937.00	63.94	827.40	56.46	823.80	56.22
OK	2103.00	299.30	14.23	189.70	9.02	186.10	8.85
P-224	1788.70	613.60	34.31	504.00	28.18	500.40	27.98
MS	947.00	1455.30	153.68	1345.70	142.10	1342.10	141.72
FMV-1	1223.30	1179.00	96.37	1069.40	87.41	1065.80	87.12
Average	1414.2	988.10	83.03	878.50	74.67	874.90	74.40

DISCUSSION

Trait mean

Presence of site and over sites significant genotype differences for most traits indicated high variability of tested genotypes. Significant LxG interaction implied strong environmental influence on foliar blast, NHB, lodging, finger branching, ear shape, plant height, D50, plant stand and yield which results in differential performance of genotypes across environments (Primomo et al., 2002). Lack of significant LxG for DPM agrees with Edmeades et al. (1998) report on other crops that the trait was least affected by cross-over GxE interaction.

Significant GxE may lead to establishment of environment specific breeding programs if it is the genotype rank interaction (cross-over) type (Huhn et al., 1993; Ceccarelli, 1994). However, the high positive significant site genotype yield rank correlations indicate high levels of non-cross over GxE interactions hence possibility of good genotypes performing well across sites. This seemed to be the case as all the top 10 yield ranked genotypes were in the top third at each site, satisfying Fox et al. (1997) top third rank criterion of identifying varieties that would perform well across sites. Using this criterion, the top three lines overall OKxGEF$_4$SB13R10(R27), GBK 033439, and OKxGEF$_4$BSB13R10(R31) would be best for the three sites for yield, with few exceptions.

The lead of Kakamega in site mean yield (1923.8kg ha^{-1}) followed by Inungo (1550.7kg ha^{-1}) and Alupe (1176.8kg ha^{-1}) was expected because of Kakamega's higher rainfall and limited biotic stress as performance declines with declining growth conditions (Simmonds, 1991). Inungo had poorer climatic conditions with termites while Alupe on top of poorer climatic conditions, was planted on *Striga* infested plots and inoculated with *Striga*.

Lack of significant genotype differences for shootfly at Alupe and Kakamega was probably due to inadequacy of natural infestation to provide uniform plots infestation or lack of variability for shootfly in tested genotypes. However, the latter could not be the case as at Kakamega shootfly mean incidence was 29-61% and at Alupe shootfly ranged from immunity to moderately resistant. Shootfly is an important gramineae crops pest causing on average 5% yield loss on Sorghum (Dhillon et al., 2006) and noted at the First International Small Millets Workshop (Riley, 1989) as an important finger millet pest that has not been researched on, hence the need to screen finger millet germplasm for resistance to shootfly.

Lack of significant genotype differences for foliar blast and plant height at Alupe is attributable to *Striga*. *Striga* deleteriously affects its hosts (Haussmann et al., 2000) and retardation of growth on *Striga* infestation may have led to statistical insignificance of

genotype height differences. The wilting and foliar drying up of *Striga* infested plants could also have led to lack of precision in distinction of foliar blast effects. Lack of significant genotype differences for *Striga* counts at Alupe reflects the difficulty in screening for *Striga*, despite the use of the most reliable field screening with artificial inoculation (Haussmann et al., 2000; Omanya et al., 2004) and the visual disparity in *Striga* genotype support (3.5-80.5 $plot^{-1}$ range) and effects. These imply genotypic differences detectable by more rigorous screening techniques exist. Parent OK and its progenies OKxGEF_4SB13R10(R27) and OKxGE F_4BSB13R10(R31) topping genotypes in yield at Alupe, and its top 10 ranking in least *Striga* support suggests it has genes for *Striga* resistance that could be explored for breeding.

Finger millet blast is prevalent in wet humid conditions (Ruiz, 2003), making Kakamega a more blast suitable environment than Alupe and higher foliar blast incidence at Alupe than Kakamega could be due to the effect of *Striga* on foliar blast. Kakamega had highest NHB incidence followed by Inungo and least Alupe as expected, reflecting the humidity gradient due to highest rainfall at Kakamega and Alupe the least (Appendix 1).

The earlier D50 and DPM at Alupe than Kakamega was expected as Alupe is warmer. The mean D50 range of 25 and DPM of 9 days are fairly narrow indicating the difficulty to further select for earliness and reflect May and Van Sanford (1992) report that heading date (a maturity trait) and DPM are not always highly correlated.

Majority of genotypes display of finger branching at Alupe and Kakamega, where only five consistently showed non-finger branching, suggests the trait is common in high yielding finger millet genotypes. Little consistency in genotype ear shape at the two sites and presence of significant GxE implies high environmental influence on the trait (Humphreys, 1991) and the lower ear shape mean of 1.8 at Kakamega than 2.1 at Alupe suggested genotypes tended to open headedness under favourable environmental conditions and vice versa.

Plant height variation across sites implied potential for further plant height selection gain towards optimal of about 110cm. Site mean plant height reflected site growth conditions where Kakamega with the best growth conditions had the tallest plants followed by Inungo and least at Alupe. *Striga* infestation probably significantly reduced plant height at Alupe. Inungo had more lodging than Kakamega with the tallest plants because termites at Inungo damaged plants. Alupe had the least lodging attributable to plant height retardation by *Striga*. The wide lodging mean range of 1-66% suggests potential for further selection gain

against lodging. Kakamega showing the highest plant stand (37.58), followed by Inungo (31.36) and Alupe (30.86) suggested finger millet establishes better stands under good growth conditions.

Trait expected mean squares and broad sense heritability

Negative genetic variances (V_G) for foliar blast, finger branching and plant stand reflected findings by Ashman (1999). Negative variance components are attributable to experimental error and result in abnormal H^2 (Bridges and Knapp, 1987) and suggest close to zero actual variance (Ashman, 1999). Negative V_G and close to zero actual variance suggested exhaustion of genetic variation for these traits, hence little progress on further selection. Except for negative V_G traits, high H^2 seen were also reported by Bedis et al. (2006), Bezaweletaw et al. (2006) and Sumathi et al. (2007) for D50, plant height, DPM and yield, and represent breeders' interests as H^2 represents the heritable portion of variation (Falconer, 1989). The higher the H^2, the larger and faster the breeding progress hence, ideally all traits studied, except foliar blast, finger branching and plant stand, should respond rapidly to further selection. Despite high H^2, the narrow variation for plant height, D50, and DPM, would make further selection progress difficult.

Phenotypic, genotypic and error coefficients of variability and genetic advance

Phenotypic coefficients of variation higher than GCV and ECV for all traits were also reported by Bezaweletaw et al. (2006) and reflect genetic and environment roles in trait expression. High PCVs indicate wide phenotypic variation in a trait and if associated with high GCV, then variation is largely genetic and amenable to selection, especially if associated ECV is low (Singh and Narayana, 1993). Days to 50% flowering and DPM had least PCV, GCV and ECV, implying least variability and difficulty to further select, a finding also reported by Bezeweletaw et al. (2006); Sumathi et al. (2007). Lodging percentage had highest PCV, GCV and ECV implying most variability. As observed by Bezeweletaw et al. (2006); Bedis et al. (2006); Sumathi et al. (2007), yield had moderate coefficients of variation (20 – 50%s). The high EGA for lodging (172%), ear shape and yield reflected their high PCV and GCV. High yield EGA (72.49%) was like the 100.89% reported by Bedis et al. (2006) and unlike the low (38.72%) reported by Bezeweletaw et al. (2006). Based on EGA, yield and lodging would be easier to further select for and make progress. The high EGA for NHB implied significant variation hence potential to create NHB resistant varieties.

Trait phenotypic correlations

Plant breeders often study trait correlations to identify indirect selection criteria for yield (Johnson et al., 1983; Annicchiarico and Pecetti, 1998; Toker and Cagirgan, 2004). All traits positively correlated to yield, shootfly, plant height, lodging, and plant stand, are desirable in production except shootfly and lodging. These traits significant positive correlation to yield were also seen in unselected germplasm evaluation (Chapter 6). Significant shootfly positive correlation to yield contrasted Nwanze et al. (1995); Tarekegne et al. (1997) reports of shootfly pest importance in sorghum and barley, respectively, and could be due to shootfly attack stimulating tillering in finger millet (Braun, 1997) resulting in many productive tillers under good climatic conditions (Bezaweletaw et al., 2006). Positive lodging correlation to yield contrasted Kelbert et al. (2004) report of lodging yield losses in wheat and barley and could be due to heavy heads in high yielding finger millet genotypes toppling plants since high yield was also positively correlated to plant height as reported by Duke (1978). Plant stand positive correlation with yield up to recommendation was in line with reports by Steppuhn (1997) and Holen et al. (2001), and foliar blast and *Striga* counts negative correlation with yield were in line with reports by Haussmann et al. (2000) and Prabhu et al. (2003). As seen in Chapter 6, foliar blast had stronger negative correlation to yield than NHB, implying it was a more serious disease than NHB. The more serious effect of foliar blast to yield would explain why Obilana (2002) and Takan et al. (2002) found NHB more common in Busia, Teso and Kisii districts of Kenya than foliar blast. This would be that farmers selected out varieties susceptible to foliar blast more regorously than those susceptible to NHB because NHB caused little yield loss. This difference in correlation to yield between foliar blast and NHB could be due to the different parts of the plant attacked as Takan et al. (2004) found isolates causing foliar blast and NHB to be genetically similar, suggesting the same strains cause the different symptoms under suitable conditions. Foliar blast is a more serious disease probably because it affects leaves, which are the photosynthetic sites and it comes early while NHB comes after grain filling.

Insignificant correlations of D50 and DPM with yield were also seen in Chapter 6 and contrasted significant positive correlation reported by Bedis et al. (2006). The low ear shape significant negative correlation to yield contrasted lack of significant correlation seen in Chapter 6 and would imply selected high yielding genotypes tended to open headedness as reported by Duke (1978). Low finger branching significant positive correlation with yield among yield selected genotypes and low negative correlation in unselected accessions (Chapter 6) support NRC (1996) association of the trait with high yield.

The strong significant negative correlation between shootfly and foliar blast also observed in Chapter 6 could be due to shootfly reducing the surface on which foliar blast could thrive. High positive foliar blast correlation with *Striga* counts could be explained in foliar blast and *Striga* causing similar plant foliar symptoms of reduced growth and development that may result in total plant death as reported by Prabhu et al. (2003). The significant D50 positive correlation with shootfly, also observed in Chapter 6 could be due to prolonged seedling stage of late flowering genotypes exposing the seedlings to shootfly pest build up. The significant negative correlation between *Striga* counts and shootfly implied *Striga* infestation reduced shootfly infestation, probably due to *Striga* infested seedlings unpalatability to shootfly. The high negative correlations between *Striga* counts with plant height and lodging were expected as *Striga* infestation retards plant growth (Haussmann et al., 2000), reducing plant height and consequently lodging.

Realized breeding progress

Skewed frequency distribution for yield, SCT, foliar blast, and NHB showed desirable response to selection. The dominance of recombinants of top two categories over sites and at individual sites plus progeny lines experimental, parental, and checks RGY superiority underscores the potential of hybridization breeding in finger millet and the potential of the OKxGE cross that produced most of the recombinants in this category. The positive gain for yield in 11 out of 18 populations implied lines better than most parent varieties were isolated and unique traits of parent varieties could be found in a wider range of better yielding lines. This is also evident in the best lines superiority to all their inferior parents and majority superiority to their superior parents. The best three lines recorded between 8.85% and 169.72% superiority over parental means.

The significant positive skew in the direction of susceptibility for foliar blast and NHB indicated most genotypes tended to resistance for the two diseases and selection for foliar blast resistance was more responsive than NHB as seen in a longer NHB tail and the presence of two genotypes in highly resistant category for foliar blast and none for NHB. Days to 50% flowering and DPM reflected selection effect for earliness where 60 (74%) and 46 (57%) flowered in less than 85 days and matured in less than 115 days, respectively. Desirable breeding gain in all traits but foliar blast indicated selection effectiveness and potential to isolate lines superior to parent varieties in all traits. Mean undesirable gain for foliar blast implied limited genetic variability in the populations as seen in its negative genetic variance. With low or absence of genetic variance, H^2 is low and little genetic advance is expected. However, the presence of some populations with foliar blast desired gain implied

variability of parent varieties foliar blast resistance in the populations that combined to result in lines with better resistance. From the foregoing, potential to improve finger millet productivity in western Kenya through this breeding program is high.

CONCLUSION

Significant variation existed among tested selected genotypes for all traits except foliar blast, finger branching and plant stand, on which further selection could be based. Genotypes were significantly different for yield, foliar blast, D50, NHB, finger branching, ear shape, DPM, plant stand, plant height and lodging. Genetic variation accounted for most variation in D50, ear shape, DPM, NHB, lodging, plant height, and yield while the environment accounted for most variation in foliar blast, finger branching, shootfly, and *Striga* counts. Expected genetic advance revealed only ear shape, NHB, lodging, and yield could result in significant gains on further selection. Phenotypic correlations, heritability, and expected genetic advance showed no trait could serve as indirect selection criteria for yield as none had a combination of high correlation to yield, higher heritability than yield and high EGA. Desirable traits plant height and plant stand had high significant positive correlation with yield but lower H^2 and EGA than yield. Undesirable shootfly and lodging had high positive correlation to yield and need investigation for containment or strategic deployment to enhance yield, especially shootfly. Foliar blast and *Striga* had the highest negative yield effect.

All traits showed response to selection and the breeding program is on course to develop new high yielding, agronomically desirable varieties. Realised yield gain across populations was 5.84%. On average progeny lines had experimental, parental, and checks means RGY superiority of up to 154.95%, 170.76% and 173.48%, respectively. Reduction in lodging had the highest gain of 21.03%. The best line in each population was superior to its worst parent by up to 138% and in 11 out of 18 populations they were superior to their best parents by up to 50%. The best three genotypes were: OKxGEF4BSB13R10(R31), $OKxGEF_4SB13R10$(R27) and GBK 033439. OKxGEF4BSB13R10(R31) had 2402kg ha^{-1} mean yield and superior to all parent varieties by 14 to 170%, resistance to moderate resistance to foliar blast, low 12% mean lodging, low *Striga* support (8.5 per plot), finger branching, open headed, tall, good plant stand and early maturing (112 days). On average OKxGE cross produced the best progeny.

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APPENDIX 1. Monthly average maximum and minimum temperatures and accumulated rainfall at KARI-Kakamega and Alupe.

Month	2005			2006			2007		
	Average temperature			Average temperature			Average temperature		
	Max.	Min.	Accumulated rainfall	Max.	Min.	Accumulated rainfall	Max.	Min.	Accumulated rainfall
	---------°C----------		------mm------	---------°C----------		------mm------	---------°C----------		------mm------
January	32.1	18.0	70.0	30.4	15.1	32.4	28.1	14.3	274.0
February	31.8	15.2	67.0	31.2	16.0	98.8	28.2	14.2	84.4
March	29.5	15.8	139.1	28.0	15.4	231.7	29.8	14.1	137.3
April	28.6	15.9	209.1	26.7	15.2	449.1	28.7	15.2	168.6
May	25.5	15.8	209.9	26.9	15.2	201.5	27.5	14.9	223.7
June	26.8	14.2	125.7	26.6	14.4	222.6	25.6	14.8	130.2
July	26.2	14.0	145.4	26.5	14.8	159.1	25.6	14.0	157.1
August	26.8	15.8	261.0	26.9	14.9	111.6	26.0	14.2	316.7
September	27.3	14.3	197.2	29.3	14.1	222.3	26.5	14.4	353.1
October	27.6	16.9	103.1	28.1	14.5	115.2	-	-	-
November	28.2	15.2	120.2	26.1	15.0	291.7	-	-	-
December	29.9	14.4	47.3	26.0	15.2	194.3	-	-	-

APPENDIX 1 continued, KARI-Alupe.

Month	2005			2006			2007		
	Average temperature		Accumulated rainfall	Average temperature		Accumulated rainfall	Average temperature		Accumulated rainfall
	Max.	Min.		Max.	Min.		Max.	Min.	
	---------°C----------		------mm------	---------°C----------		------mm------	---------°C----------		------mm------
January	30.6	18.8	4.1	32.0	18.6	97.6	29.8	18.0	115.8
February	33.4	19.0	52.0	31.7	19.3	112.6	27.9	17.4	85.1
March	31.6	17.6	151.6	29.3	18.6	219.3	28.8	13.2	85.6
April	32.1	18.3	284.6	28.0	18.0	270.4	31.5	12.7	168.2
May	29.8	16.9	205.1	30.5	18.3	154.2	31.9	14.1	201.1
June	28.6	15.7	81.0	30.5	17.0	36.4	30.8	13.8	89.7
July	27.9	14.9	153.2	29.0	16.2	106.7	31.7	15.2	143.1
August	28.6	15.7	130.2	28.9	16.1	74.7	27.1	16.8	186.9
September	30.3	17.3	74.0	30.7	17.3	281.2	-	-	-
October	31.2	18.1	257.0	31.2	19.2	206.0	-	-	-
November	32.0	19.6	80.2	28.9	17.3	194.3	-	-	-
December	32.4	19.8	10.8	27.8	17.1	242.2	-	-	-

CHAPTER 7

Overview

INTRODUCTION

This chapter provides a bird's eye view of the totality of the thesis highlighting the global research objectives, main findings, limitations and challenges, and implications of the results for future research.

The global research objectives were to:

1. identify the place of finger millet in the farming systems, production constraints, variety diversity and farmer preferences in western Kenya,
2. determine the genotypic variability for yield and some agronomic traits, and the correlations among the traits,
3. determine the feasibility of using chemical hybridising agents to cross finger millet varieties,
4. study the inheritance of yield, blast and *Striga* resistance, and other secondary traits in fingermillet,
5. identify elite x elite crosses with potential for use as source germplasm in developing new finger millet pure line varieties, and
6. determine the level of breeding progress achievable in improvement of finger millet.

FINDINGS FROM THE PROJECT

Each of the above objectives was addressed through an independent study. All these were formulated after a literature review. The literature review on finger millet gave an insight into the status of the crop and level of advancement as below.

- Finger millet is indigenous to East Africa where wide variability exists but the crop has wide adaptability and Asia forms a secondary center of diversity.
- It is an important subsistence crop valued for food, nutritional, feed, cultural, long storability without spoilage, medicinal, and malting purposes. The crop has industrial and economic potential emanating from its high nutritional value and malting qualities.
- Finger millet is used in managing diseases in both communities and formal health institutions. It is used to manage measles, anaemia, diabetes and even leprosy and liver disease. This wide medicinal use probably emanates from its high nutritional value. It is more nutritious than other cereals like maize, rice and sorghum, especially in terms of minerals such as calcium, iron, phosphorus, and manganese.

Its protein content (7.4%) is comparable to that of rice (7.5%), but its main protein fraction (eleusinin) has high biological value, with amino acids tryptophan, cystine, methionine, and aromatic amino acids, which are crucial to human health and growth and are deficient in most cereals. Methionine is an important amino acid that can only be obtained through diet, yet it lacks in diets of many poor people.

- Farmers experience very low yields of about 15% of the potential >5,000kg ha^{-1}.
- Production constraints responsible for the low yields were: pests and diseases (blast and *Striga*), drought, low soil fertility, labour intensity, high weed infestation, low yielding varieties, lodging, and poor attitude to the crop. Five of the eight constraints: blast and *Striga*, drought, low soil fertility, low yielding varieties, and lodging could be addressed through breeding new varieties or improving the existing varieties.
- It has also been found that very little research has been conducted on the crop and as a result the following research gaps were identified:
    - there is a wide array of germplasm that has not adequately been studied for traits that could be exploited in finger millet breeding,
    - existence of blast disease resistance has been reported in Asia, but hardly any studies had been conducted in Africa,
    - finger millet breeding is hampered by difficulty to make crosses because of floral architecture and high self pollination yet chemical hybridising agents (CHAs) have been applied successfully in other self pollinating cereals,
    - *Striga* is a major pest on finger millet yet no research has ever been carried out on the crop
- The constraint of low yielding varieties susceptible to biotic and abiotic stresses can be reduced or eliminated by breeding, in consultation with farmer clientele, new high yielding, biotic and abiotic stress resistant varieties desired by farmers that had hardly been attempted.
- Because of the importance of the crop, improvement of finger millet production has great potential to contribute in uplifting the well-being of communities in which it is produced and even to national economies in Kenya and sub-Saharan Africa.

On the basis of the above literature findings, a project was implemented during 2004-2007 with six breeding studies addressing the above-mentioned objectives.

Participatory rural appraisal for farmers' finger millet production system, variety preferences, uses and production constraints in western Kenya

The PRA carried out in 2006 in Busia, Teso and Nyamira districts in western Kenya established the following.

- Finger millet was very important in the farming systems of western Kenya as it ranked among the top three important food as well as cash crops.
- The crop was largely produced by peasant farmers
- Yields were low (534-655kg ha^{-1}) reflecting what was earlier reported by CGIAR (2001), Takan et al. (2002) and Mitaru et al. (1993).
- Farmers highly valued the special attributes of FM of good storability, high nutritional value, good marketability and tolerance to drought and low fertility conditions. They used finger millet for food, cash, brewing, ceremonies, and medicinal purposes.
- Farmers grew five to nine varieties in a district and they kept trying new varieties using high yield; early maturity; resistance to blast disease, *Striga*, birds, drought, and lodging; large head size, dark grain colour, and palatability to taste as selection criteria.
- Constraints to finger millet production were blast disease, *Striga*, wild FM, birds, rats, termites, lack of market, labour shortage, and low yield.
- Farmers across the districts received minimal information from extension agents on finger millet production technologies and relied heavily on farmer-to-farmer communication for new information on finger millet farming.

Finger millet genotypic variability and path analysis of yield components

- The 310 accessions displayed wide variation for most of the traits farmers wanted in varieties: high yield, early maturity, disease resistance/tolerance, large head size and dark grain colour.
- Outstanding high yielding varieties with yields over the previous potential of 5,000 – 6,000kg ha^{-1} reported by Duke (1983) and NRC (1996) were identified. The highest yielding accessions were KNE 072 (7,833kg ha^{-1}), GBK 028463 (7,085kg ha^{-1}), GBK 029661 (6,666kg ha^{-1}), and FMBT ACC#42 (6,566kg ha^{-1}).
- Eighteen accessions were highly resistant to foliar blast,
- Twenty accessions were highly resistant to neck and head blast (NHB),
- Thirteen accessions were highly resistant to shootfly,
- Sixteen accessions did not support *Striga.*
- One hundred and nine not lodge, and
- Ten flowered between 64 and 68 days and 7 matured in 100 days.

- The key trait of yield could be selected for directly or indirectly through seedling vigour, plant height, and single plant yield or plant stand establishment.
- Shoot fly and lodging showed positive correlation to yield

Finger millet hybridisation using ethrel chemical hybridising agent

- An 8x8 diallel mating was accomplished using ethrel CHA at success rates of 0.19 to 8.63%.
- The emasculation rate was higher under field conditions and resulted in male sterility of 15-38% at between 1,500ppm-2,000ppm ethrel concentrations applied at Zadoks development stage 45.
- Ethrel did not significantly affect yield, female fertility, days to heading, days to anthesis and physiological maturity, but significantly reduced plant height and ear exertion by 25 and 50%, respectively.
- Incomplete emasculation required F_1 screening to eliminate selfs using morphological traits like plant colour, ear shape, plant height and general plant stature.

Studies of genetic components of agronomic traits and resistance to blast disease and *Striga* in six elite finger millet varieties of western Kenya

Studies carried out at F_5 revealed:

- Additive gene effects were found solely responsible for the control of yield and finger branching among the six parent elite varieties.
- Both additive and partial dominance effects were significant for neck and head blast, days to 50% flowering, ear shape and days to physiological maturity.
- Overdominance gene effects were significant for plant height, lodging, and plant stand establishment.
- Dominant genes conferred resistance to NHB and lodging, higher plant stand establishment and fist ear shape.
- Recessive genes conferred early maturity and open ear shape.
- Both dominant and recessive genes conferred days to 50% flowering and plant height.
- There was no evidence fpr significant genetic variation for resistance to shootfly, foliar blast and *Striga* in these germplasm.
- The differences among the six elite finger millet varieties in western Kenya were largely genetic with varieties OK, GE, and U-15 having large additive effects and lines from their crosses OKxGE, P-224xOK, and U-15xGE.

Breeding progress based on F_5 progenies of western Kenya elite finger millet varieties

- The lines tested were significantly different for all traits foliar blast, days to 50% flowering (D50), neck and head blast (NHB), finger branching, ear shape, days to physiological maturity (DPM), plant stand, plant height, lodging and yield.
- Genotype x environment (GxE) interaction effects was significant for all traits except shootfly and DPM.
- Heritability estimates were high for D50, ear shape, DPM, NHB, lodging, plant height, and yield but only ear shape, NHB, lodging and yield showed significant expected genetic advance (EGA),
- Undesirable shootfly and lodging had high positive correlation to yield
- All traits responded to selection and realised mean yield gain was 5.84%. Lodging had highest resistance gain of 21.03%. On average progeny lines showed superiority up to 154.95%, 170.76% and 173.48%, respectively over experimental, parental, and non parental checks means relative grain yield (RGY).
- The best three lines: OKxGEF4BSB13R10(R31), OKxGEF_4SB13R10(R27) and GBK033439 had resistance to blast and lodging (except GBK033439) and high yield >2250kg ha^{-1}.
- The best line in each population was superior to its worst parent by up to 138% and in 11 out of 18 populations they were superior to their best parents by up to 50%.
- On average OKxGE cross produced the best progeny.

BREEDING IMPLICATIONS OF THE FINDINGS

- The facts that farmers valued finger millet and that it was mainly produced by resource poor farmers suggests that research into finger millet needs to be taken more seriously than it is today, to positively impact on the farmers and community well-being.
- Farmers continuous change of varieties, variety low yields, and identification of negative attributes in their best varieties suggests that breeding needs to take center stage in finger millet research.
- Farmers continuous change of varieties suggests they are willing to adopt new and better varieties hence breeders should strive to develop superior varieties.
- Farmers ability to identify both good and bad traits in their best varieties and production constraints implies that they are researchers in their own right and a breeding agenda needs to incorporate their contribution and participation to ensure adoption of the developed varieties.

- The new varieties should contain the farmers selection criteria with high yield as the top criterion and address farmers production constraints especially blast disease and *Striga* resistance.
- The lack of extension suggested the need to strength extension contact with the farmers and the importance of farmer to farmer contact in dissemination of new varieties.
- The wide finger millet germplasm variability indicated high potential to breed new and better finger millet varieties with farmer desired attributes.
- Accessions KNE 072, GBK028463, GBK027300, GBK033439 with record yields of over 5,000kg ha^{-1} need to be further tested with farmers and in multi-location environments
- The genotypic study undertaken on finger millet was the first one, more such studies on wider germplasm bases and scope are recommended for further breeding investigation of finger millet.
- Accomplishment of hybridisation with ethrel CHA and partial emasculation meant the hybridisation barrier in finger millet was broken, but screening of F1 using morphological markers to eliminate selfs was necessary.
- The partial emasculation was adequate for selected parents crossing but not for heterosis breeding which requires higher levels of emasculation and also the adverse effects on ear exertion and plant height could complicate the use for heterosis breeding.
- For application of CHA to heterosis, emasculation levels must be increased and the adverse effects on the finger millet plant eliminated. To increase the emasculation level, further investigation of ethrel with concentrations upwards of 1,500ppm at finer intervals need to be investigated and synchronised with the best stage of CHA application. The Zadoks development stages do not exactly fit the finger millet morphological development and needs to be adapted to finger millet. To eliminate the negative effects on the finger millet plant, investigation of application of ethrel in combination with a growth promoter e.g. gibberelic acid (Beek, 1988) or study the use of granular ethrel that was reported by Fairey and Stoskopf (1975) to have longer half-life and less negative effects than the liquid form is required. Another option would be to study the effects of Ethyloxanilates that show limited effects on agronomic characters (Chakraborty and Devakumar, 2006), on finger millet. The work with ethrel on finger millet reported above is pioneering and follow-up investigations to enhance its efficacy are recommended.

- The finding of additive genetic control for yield meant that it was possible to attain farmers demand for high yielding varieties through this breeding programme. This was also possible for the other traits controlled by both additive and dominance effects and also desired by farmers, NHB resistance, early maturity, and fist ear shape. Traits significantly controlled by only dominance effects like plant height, resistance to lodging and plant establishment would be difficult to select for and make rapid progress, especially those mostly conferred by dominant genes like lodging and plant establishment. Traits controlled by dominance gene effects of recessive genes like early maturity and open ear shape would be easy to fix in a breeding programme.
- The lack of evident genetic variation for resistance to key biotic constraints of *Striga*, foliar blast, and shootfly was a drawback and called for exploration for sources of resistance for these traits using more rigorous screening methods. Despite lack of statistical significant differences, there was apparent disparity between genotypes support of *Striga* that would require rigorous screening to isolate them.
- Isolation of lines in the segregating population superior to the elite parents in many traits at F_5 implied farmers desired varieties could be bred within a fairly short time. The promising cross populations need to be advanced through to F_7 and high yielding lines: OKxGEF4BSB13R10(R31), OKxGEF_4SB13R10(R27) and GBK033439 with yield >2250kg ha^{-1} and resistant to blast disease and lodging need to be isolated for further testing with a view to release the best lines in the short term.
- Parent varieties with large additive effects for most traits, OK, GE, and U-15, need to be incorporated in the expanded finger millet breeding programme for continued breeding improvement of finger millet germplasm in western Kenya.

CHALLENGES IN FINGER MILLET BREEDING

- The syndrome of attitude to the crops as a peasant farmer crop needs to be eliminated. As demonstrated from this work, the crop has potential for Kenya and many sub-Saharan countries.
- More resources need to be directed to finger millet to unlock the huge potential that crop holds and it is hoped this work will provide convincing evidence for Government and donors to upscale funding to this crop.
- Shortage of personnel is a big bottleneck to the research of this crop, especially breeding. The author is the only finger millet breeder assigned to the crop in Kenya and may not single handedly substantially unlock the breeding potential of the crop.

- The fact that breeding of finger millet is just beginning, there is limited information on most aspects of breeding. Breeding findings and methodologies successfully applied to other self pollinating cereals need to be applied to finger millet.

CONCLUSION

Looking across the results of the experiments carried out, it is evident that breeding finger millet has potential to result in finger millet yields that match and even surpass "green revolution" cereals – wheat and rice. This work has confirmed the value and potential of the crop in western Kenya farming systems which may be, to a large degree, applicable to other finger millet farming systems in Kenya and sub-Saharan Africa. It has also been confirmed that genetic variability, the foundation of breeding, exists in available finger millet germplasm. Selections from these germplasm alone can lead to substantial yield gains as seen in some accessions yield of over 7,000kg ha^{-1}. To add to direct selection, it has been demonstrated that it is feasible to create more genetic variation by selected parent lines hybridisation using ethrel. With hybridisation, selection for superior traits was possible and genetic studies of important finger millet traits could take place and further enhance breeding gains. The potential of finger millet contribution to community well being and national economies remains high.

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