Genetic studies on head architecture, adaptation and blast resistance of finger millet in Uganda

By

Lawrence Owere

Msc. Crop Science, Bsc. Agriculture (Hons) (Makerere University)

A Thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) in Plant Breeding

African Centre for Crop Improvement

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu Natal

Pietermaritzburg

Republic of South Africa.

December, 2013

Thesis abstract

Finger millet is the second most important cereal in Uganda after maize. The yields however, have remained low due to several constraints, such as finger millet blast disease and limited technology options. Therefore breeding investigations were conducted to determine farmer preferred traits, genetic variation, combining ability and genetic effects for head blast disease and head shapes, and other quantitative traits in finger millet.

Among other traits, farmers preferred high grain yield potential, brown seed colour, compact head shape, tolerance to blast disease, high tillering ability, medium plant height, early maturity, tolerance to shattering and ease of threshing in new finger millet varieties. Path coefficient analysis indicated that the most important traits were grain mass head^{-1}, tillering ability and reaction to head blast disease. Overall, the high heritabilities and genetic advance (GA) as a percentage of mean revealed the existence of variability which can be utilised through selection and/or hybridisation.

The genotype x environment interaction (GEI) and stability analysis showed significant differences due to genotypes (58%), environments (10%) and GEI (32%). Twelve genotypes that combined high yield potential and stability were identified for advancement in the program. Both general (GCA) and specific combining ability (SCA) were significant for most traits, but GCA effects were more important for all the traits except for number of fingers head^{-1}, finger width and panicle width. The Hayman genetic analysis confirmed importance of additive gene action for most of the traits and that additive-dominance model was adequate for explaining genetic variation in finger millet. The results also indicated that yield was controlled by recessive genes whereas blast resistance was controlled by dominant genes.

At least two genes, probably three gene pairs and their interactions seemed to control head shape in finger millet. The interactions observed suggest recessive and dominant epistasis, and probably an inhibitor were involved. Seemingly, the gene for curving of fingers, when present in a dominant form prohibits opening of the heads; whereas the recessive form leads to open head shape irrespective of the gene conditions in the other loci. This study forms the baseline for future investigations and the basis for devising breeding strategy on finger millet head shapes.

Declaration

I, **Lawrence Owere**, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. The thesis does not contain any other persons' data, pictures, photographs or other information unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where written sources have been quoted then:
    a. Their words have been re-written but the general information attributed to them has been referenced.
    b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.
5. This thesis does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the source being detailed in the thesis and in the references sections.

Signed

Lawrence Owere

As the candidate's supervisors, we agree to the submission of this thesis:

Professor Pangirayi Tongoona (Supervisor)

Professor John Derera (Co-Supervisor)

Acknowledgements

I would to express my sincerest gratitude to my supervisors, Professors Pangirayi Tongoona and John Derera of the African Centre for Crop Improvement (ACCI) and my in-country supervisor Dr. Nelson Wanyera of the National Semi – Arid Resources Research Institute Serere, for their guidance, support, supervision and positive criticisms during the entire period of this study which has enabled this endeavour to come to fruition. I also appreciate all the ACCI lecturers for the dedicated training offered which has transformed me from an Agronomist to a Breeder.

I also take this opportunity to extend my gratitude to the Alliance to spur "Green Revolution" in Africa (AGRA) for the sponsorship of this study. To the director of ACCI, Professor Mark Laing, I say thank you very much for admitting me into the programme. This training has enabled me accomplish a milestone in my life. The timely and regular logistical support provided by Ms. Lesley Brown and the administration office is highly appreciated.

My thanks also go to my employers headed by the Director General, National Agricultural Research Organisation (NARO) for granting me study leave during the entire period of this study. Special thanks to the human resource officer and the principal human resource officer at the secretariat, and director Buginyanya Zonal Agricultural Research and Development Institute for facilitating the process of acquiring the study leave, and ensuring that it was a fully paid leave.

To the 2009 cohort and colleagues: Beatrice, Lillian, Rebeka, Netsanet, Murenga, Benjamin, Nathan, Wende and Robooni. Your comradeship, support, and togetherness enabled this to happen. I owe you a lot, but accept my little thank you.

Lastly I would like to thank my family; Karen and the children for being supportive and enduring this entire study period. My dear grandmother, brothers and sisters, I appreciate all you have done to enable me pull through.

Dedication

I dedicate this thesis to my late parents whose efforts enabled me to reach this far, and to those whose love and faith in me has been my inspiration; my wife (Karen), children (Sebastian and Rose) and my grandmother (Lozoria Akello). **Glory be to God whose will and grace has made this possible.**

Table of Contents

List of Tables

List of Figures

General introduction

1.1 Background.

Finger millet (*Eleusine coracana* (L.) Gaertn.) also known as African millet is an annual plant widely grown as a cereal in the semi-arid tropics and sub-tropics of the world under rain-fed conditions. According to Upadhyaya et al. (2007), finger millet ranks fourth in importance among millets in the world after sorghum, pearl millet and foxtail millet. It is a staple food crop in the drought prone areas of the world and is considered an important component of food security which also generates income for millions of poor people (Sreenivasaprasad et al., 2005). Finger millet therefore plays a key role in the livelihoods of smallholder farmers and their families. In Uganda, finger millet is a major staple food crop, rated second only to maize in importance among the cereals (Tenywa et al., 1999). It is a high quality food to millions of smallholder farmers in the country where nearly 80% of the population depend on subsistence agriculture (Ministry of Agriculture Animal Industry and Fisheries (MAAIF), 2008). The crop is grown on an estimated 437,000 ha (Table 1.1) which provides grain harvest of up to 732,000 metric tons (Table 1.2) with the bulk of production in the eastern and northern parts of the country which provide over 65% of the total production (FAOSTAT, 2012).

1.1.1 Importance of Finger millet

Finger millet grain is rich in calcium, iron, methionine, and tryptophan (Newman, 2005; Thatham, 1996) forming an integral part of the diet of the rural populations in developing tropical countries where calcium deficiency and anaemia are widespread (Babu et al., 2013). Besides its importance as a staple food crop in the region, finger millet contributes greatly to the incomes of rural households, particularly to women's income (Okwadi, 2007; Obilana et al., 2002). It is sold directly as grain in local markets where there is a high demand for the crop, and is also brewed into local beer for sale. Moreover it is a fairly resilient crop. It is drought tolerant, and its grain has an extended shelf life of several years without significant damage by storage pests (Parashuram et al., 2011; National Research Council (NRC), 1996). Finger millet, therefore, offers high food security and economic opportunities not only for Uganda, but the whole east African region which is often prone to drought.

Table 1.1: Estimated area planted to selected cereals in Uganda ('000 ha) (2003 - 2007)

Cereal	2003	2004	2005	2006	2007
Finger millet	400	412	420	429	437
Maize	710	750	780	819	839
Sorghum	290	285	294	308	314
Rice	86	93	102	113	119
Wheat	9	9	9	10	11
Total	**1 495**	**1 549**	**1 605**	**1 678**	**1 721**

Source: Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Uganda.

Table 1.2: Estimated production of selected cereals in Uganda ('000 t) (2003 -2007)

Cereal	2003	2004	2005	2006	2007
Finger millet	640	659	672	687	732
Maize	1 300	1 080	1 237	1 258	1 262
Sorghum	421	399	449	440	458
Rice	132	121	153	154	162
Wheat	15	15	15	18	19
Total	**2 508**	**2 274**	**2 526**	**2 557**	**2 362**

Source: Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Uganda.

Despite its importance to a large population in Uganda, its productivity has remained low, with on-farm yields ranging from 400-800 kg ha^{-1} compared to 2,500 kg ha^{-1} on-station where there is higher resource use and improved cultivars. Yield trends over a ten year period show a growing gap between on-farm and on-station productivity (Wanyera, 2007; Kidoido et al., 2002). Although MAAIF data indicates average yields of 1,600 kg ha^{-1}, it however, does not depict a progressive situation. It is therefore erroneous to think that Uganda has land to spare so that increased production can be obtained just by expanding cultivation since there is already increased pressure on land (and other natural resources) due to high population growth. A shift in the right direction to obtaining higher yields and using production methods that conserve the natural resource base must be sought. Breeding higher yielding varieties with adequate levels of tolerance to stresses is one such intervention.

The main constraints to finger millet production include: low research input, finger millet blast disease, and the use of poor, unimproved local finger millet cultivars. Hence, a great need exists in finger millet on improving yield and other attributes if these constraints are to be adequately

mitigated. It has been shown that improvement in research input can lead to evolution of varieties with high yields combined with resistance to disease. This should be the long term and sustainable approach in finger millet which is predominantly grown by poor and marginal farmers who have little means of controlling diseases through chemicals (Bua and Adipala, 1995). This is vital because finger millet farmers in Uganda depend on rain-fed conditions and grow their landraces that have low yield potential resulting in low productivity. The low productivity results in overall low finger millet production in the country. Farmers continue to grow their landraces because of lack of well adapted improved cultivars and probably because of some unique trait preferences that exist in these landraces. There is however, lack of information on the variability, the unique trait preferences and genetic information on the germplasm that exist in Uganda.

1.2 Constraints to finger millet production in Uganda.

Finger millet production constraints can broadly be categorised as socio-economic, biotic, abiotic and policy considerations (low research consideration), some of which cannot be addressed by breeding alone. Finger millet production is labour intensive relative to other crops and this has limited expansion in acreage as it covers only 0.43 ha per household of the average land holding of 7.6 ha in eastern Uganda (Kidoido at al., 2002). The small seed size also contributes to complication in its cultivation (NRC, 1996) as it necessitates planting in well made and fine seed beds at higher plant densities (especially where it is planted by broadcasting). Subsequently weeding becomes a problem further making cultivation of the crop labour intensive. The difficulty in weeding is further complicated by wild relatives of the crop (for instance *Eleusine indica*) that look like finger millet at the time of weeding. In terms of policy, finger millet is grossly neglected both nationally and internationally in terms of research, compared to crops like maize and rice (Oduori, 2005), and this has resulted in use of unimproved, low yielding, disease susceptible cultivars which are also responsible for the low yields observed in finger millet.

Among the biotic factors are weeds, pests and diseases. There is a high weed pressure and the most important ones are *Striga* and wild millets which have been associated with decline in soil fertility. Weeding efforts are challenged further by the prevalence of *Striga,* a weed that parasitises on the crop through root physiological interactions and extracts resources captured or

manufactured by the crop. Consequently the crop becomes stunted, giving poor yields. Means of *Striga* control are still lacking in Uganda and farmers depend on rotational cropping. Wild millets are also highly prevalent and make weeding difficult because of the high level of resemblance with finger millet at the seedling stage and this also greatly reduces yields of finger millet.

A wide range of fungal and bacterial diseases have been reported on finger millet (Ekwamu, 1989), the most important of these diseases in Uganda being blast disease caused by the fungus *Pyricularia grisea* (NRC, 1996). The disease is both economically significant and very destructive, causing over 50% yield loss especially in wet seasons (Esele and Odelle, 1995), but records of over 90% yield loss also exist in Uganda (Ekwamu, 1989). The crop has few insect pests. The principal pest problems in millet production are grasshoppers and army worms. Sometimes shoot fly, stem borers and clinch bugs or false clinch bugs may also cause economic damage but these can be controlled by insecticides. Birds are also important pests, especially, the notorious *Quelea quelea* and other small grain feeding birds. Among the abiotic factors are the unpredictable rainfall patterns and reduced soil fertility. The major focus of the current study with respect to biotic stress is blast disease.

1.2.1 Finger millet blast disease

A major biotic constraint to finger millet production is the wide range of fungal and bacterial diseases which affect the crop (Ekwamu, 1989). The most important of these diseases in Uganda is blast caused by the fungus *Pyricularia grisea* (Sreenivasaprasad et al., 2005; NRC, 1996; Bua and Adipala 1995). *Pyricularia grisea* affects finger millet at all stages of plant development, from seedling to grain formation. The pathogen has a wide host range that includes many *Graminaceous* weeds and therefore initial sources of inoculum comes from nearby weeds or cereal plants which act as collateral hosts (Takan et al., 2004). The fungus may also persist in crop debris which acts as potential inoculum reservoirs. The weeds also act as green bridges for finger millet blast. Bua and Adipala (1995) further elucidated that overall there has been limited progress to produce high yielding disease resistant lines. In view of the importance of finger millet in Uganda, varieties which are high yielding and resistant to blast must urgently be

identified, developed and grown probably in collaboration through a sustainable and concerted efforts both nationally and regionally.

Blast still remains the highest priority constraint to finger millet production in Uganda despite decades of research, and disturbing reports (Wanyera, 2007; Takan et al., 2004; Esele, 1993) indicate an increasing trend as clearly shown by yield loss of only up to 10% in the early 1970s in eastern and northern Uganda. This figure has steadily increased and in some of the highly susceptible materials at Serere, up to 90% loss in yield has been reported indicating that finger millet blast disease is a direct threat to food security in the country. The disease is serious in all the growing areas of Uganda infecting many of the widely grown finger millet landraces and cultivars. Of recent, blast epidemics are a frequent occurrence in all growing areas because it is highly variable in nature and the build-up of inoculum of the new virulent race affecting finger millet varieties despite the great diversity of agro-climatic conditions under which finger millet is cultivated in the country.

Depending on the severity of the infection, the disease may result in total inhibition of grain formation or production of shrivelled grain. Although the disease was first recorded in Uganda in 1933 (Esele, 1993), there is still limited knowledge on its control. In addition, farmers still identified it in 1997 as one of the major constraints to production (Takan et al., 2002), yet information on breeding for resistance and management of this disease is still limited. The cultivars grown therefore need to be improved for resistance to blast disease and this is possible through hybridisation and selection. In the past some options for the management of this disease were developed however, effective management of blast at the farmers' level has not been fully achieved in the country.

The way forward

The use of blast resistant finger millet varieties could be key to an effective blast control programme as it would be compatible with low cost input requirements of small-scale farmers who are the main growers of finger millet. It also poses no technical difficulties to the farmers. The effectiveness of this strategy is enhanced when resistance is available in adapted, productive germplasm (Seetharam and Ravikumar, 1993). In India and to some extent Africa (Uganda, Kenya, Ethiopia and Zimbabwe) efforts have, over the years, been put in breeding for blast

resistance in finger millet (Oduori, 2008). The results, however, have been temporary with varieties currently succumbing to blast. This was probably because the breeding was done without clear and full understanding of the mechanisms of resistance operating in the available finger millet genotypes. There has also been slow breeding progress in recent times due to limited knowledge on genetics (combining ability) of finger millet blast resistance. Another problem has been existence of pathogen variability which probably leads to differences in aggressiveness, therefore presenting a challenge to identifying resistant genotypes in the field due to the interaction between host, parasite and environment. In addition, the challenges are further compounded by some varieties showing adequate resistance but exhibiting poor agronomic traits. Therefore it is necessary to develop varieties that combine blast resistance with high grain yield potential which can be acceptable to farmers and consumers in the country and indeed the region. To conduct the genetic study, the initial step is to understand the available germplasm, the amount of variation existing among the accessions and trait relationships.

1.3 Variability

In order to design breeding programmes that allow development of varieties possessing positive attributes of the Ugandan finger millet, there is need to understand whether genetic variability exists in the germplasm to be improved and whether the variability can be transmitted from parent to off-spring (Falconer, 1996). It is also important to understand what amount of genetic gain can be expected from successive generations of the off-spring. Some studies have been conducted to understand variability, heritability and trait association in finger millet, but no study has been reported in Uganda. There is therefore need to conduct such studies on the Ugandan germplasm in Ugandan conditions especially for traits preferred by farmers.

1.4 Finger millet head shapes and their relevance

Among the yield components of finger millet, head shapes play a vital role in yield improvement and acceptability among farmers (Baniya et al., 2003). Some studies have indicated that open headed or short and/or early maturing genotypes are more susceptible than incurving types. Genotypes with compact head shapes are reported to be reasonably resistant to head infections,

but more susceptible to leaf infections (Esele and Odelle, 1995). Progenies from crosses with disease resistant parents have also been reported to show lower susceptibility followed by crosses from steriles (Esele, 1993). Bua and Adipala (1995) also showed that head shapes may be important in determining resistance to blast disease. There is great variability in finger millet head shapes (de Wet et al., 1984), and based on inflorescence compactness and shape, finger millet is classified into four different races that is, *Elongata, Plana, Compacta and Vulgaries* (Bezaweletaw et al., 2007; Prasada Rao et al., 1993). There are two broad categories of head shapes in finger millet; those in which the digitate spikes of the inflorescence curve in and those in which they are open. Ayyangar (1932) (as cited by Rachie and Peters, 1977) indicated three readily recognized head shapes in finger millet: (1) open, (2) top-curved, and (3) incurved. The incurved was further categorised into incurved and the fisty type with fingers compactly incurved.

Head shapes are also important because farmers have reported preferences for different head shapes for various reasons, yet Oduori (2008) reported a negative correlation between head shape and lodging, stating that open headed genotypes were more prone to lodging than the fist headed genotypes probably due to open heads offering resistance to wind. He further reported higher susceptibility of open headed genotypes to head blast, as head blast increased with tendency to open headedness. Despite these findings however, there seems to be no information on the inheritance of the different head shapes in finger millet. It is therefore important to understand the genetic mechanisms that control this trait so as to, in addition to breeding high yielding and resistant varieties, incorporate head shape as one of the traits influencing farmer preferences.

1.5 Genotype x environment interaction, adaptability and yield stability

Finger millet in Uganda is grown in a wide range of agro-climatic zones which are highly variable resulting in complex genotype x environment interactions. The performance of varieties and identification of blast disease resistance should therefore be evaluated in multi-location trials (if necessary both temporal and spatial) to accurately determine performance (both yield and blast disease resistance), yield stability and to provide a reliable guide for selection of the best genotypes for both yield and adequate yet stable resistance. Sufficient test environments were also advocated by Andrews (1993) in finger millet. Such stable varieties can even perform better

under small-scale farmers' conditions of stress/low inputs (Hanamaratti et al., 2008) and therefore sustainable. Genotype x environment interaction according to Ramagosa and Fox (1993) is the differential genotypic expression across environments which may determine the breeding strategy to be adopted, that is, whether the aim is for specific or broad environment adaptation.

1.6 Farmer perceptions about new varieties and the blast problem

The finger millet breeding programme in Uganda has made some considerable achievements in developing higher yielding finger millet varieties. However, some of these varieties had limited adoption by farmers and of those that were adopted currently have considerable reduction in both yield and blast resistance (cultivar degeneration). The low adoption was probably because farmers' (and even users') perceptions and ideas on the types of the new varieties were not well identified, understood and taken into consideration before varieties were developed (Banziger and Cooper, 2001). Moreover these perceptions also keep evolving with time and a new breed of farmers. For effective breeding therefore, the breeder should take the farmers' perceived constraints and their preferences for varieties into consideration right at the inception of the breeding programme after thorough researcher–farmer interface and collaboration to enhance potential for varietal adoption in finger millet. Participatory approaches are currently preferred as they value the farmers' knowledge, interests, ability to innovate and their active exchange of information (Banziger and Cooper, 2001). In the earlier surveys conducted in finger millet growing areas of Uganda by Okwadi (2007) and Takan et al. (2002), farmers pointed out blast as one of the major constraint to production. They however, did not point out the unique and peculiar farmer preferences in finger millet varieties. This implies an apparent need to develop blast resistant varieties which incorporate additional farmers' preferred traits. This was the basis to farmers' participation through proactive farmers' engagement in discussions in order to understand their current perceptions of the blast problem vis-à-vis their preferences in a resistant finger millet variety. Farmers can provide vital information on plant types, desired traits and insight into trade-offs they are willing to make among traits in designing cultivar types. This initial step will enhance potential for adoption of improved varieties in the respective communities the studies were conducted.

1.7 Research objectives

The specific objectives were:

1 to identify farmer preferred varietal traits and perceptions on constraints to finger millet production in the farming system,

2. to determine the variability that exists in the existing germplasm for blast disease resistance, grain yield and selected agronomic traits, and study relationships among the traits,
3. to evaluate the germplasm for blast resistance, grain yield performance and stability, and select parental materials with stable resistance based on response to differential environment conditions,
4. to estimate the combining ability and genetic effects of selected parental materials for head blast disease, grain yield and other agronomic traits of finger millet, and
5. to study the inheritance mechanisms of head shapes in finger millet.

1.8 Research hypotheses

1. Finger millet farmers are knowledgeable of the major constraints that affect finger millet production and prefer certain peculiar traits and stress tolerance in their varieties.
2. There is high variability in the finger millet germplasm in Uganda plus a few introductions that can be exploited to generate new varieties with high yields, adequate levels of resistance to head blast disease with farmer preferred attributes.
3. Levels of resistance to blast disease and grain yield in finger millet are directly affected by variations in environmental conditions.
4. The selected adapted materials have good general combining ability for ear blast resistance, grain yield and selected agronomic traits.
5. Head shapes in finger millet are simply inherited.

1.9 Thesis outline

The results of the work reported in this thesis were structured following the specific objectives above addressed in seven chapters constituting this thesis as follows:

Introduction to thesis

Chapter 1: Literature review.

Chapter 2: production constraints and farmer preferences for a finger millet variety: implication for breeding.

Chapter 3: Variation and trait relationships among selected finger millet [*Eleusine coracana* (L.) Gaertn] accessions.

Chapter 4: Genotype x Environment interaction, blast disease reaction and adaptability in finger millet.

Chapter 5: Genetic analysis of blast disease resistance and agronomic traits in finger millet.

Chapter 6: Inheritance of head shapes in finger millet.

Chapter 7: General overview.

Each chapter takes the form of a journal article and is quite independent and thus, some overlaps may be observed in content and references as in the other chapters.

References

Andrews, D.J. 1993. Principles for breeding small millets. P. 411 - 423. K.W. Riley, S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York, USA.

Babu, T.K., R.P. Thukar, H.D. Upadhyaya, P.N. Reddy, R. Sharma, A.G. Girish, and N.D.R.K. Sarma. 2013. Resistance to blast (*Magnaporthe grisea*) in a mini-core collection of finger millet germplasm. European Journal of Plant Pathology. Open Access Repository, International Crops Research Institute for Semi-Arid Tropics. http://dx.doi.org/10.1007/s10658-012-0086-2/ (date accessed 10/04/2013).

Baniya, B.K., A. Subedi, R.B. Rana, R.K. Tiwari and P. Chaudhary. 2003. Finger millet seed supply system in Kaski ecosite of Nepal. P. 171-175. Sthapit, B.R., M.P. Upadhyaya, B.K. Baniya, A. Subedi, and B.K. Joshi, (Eds.). On-farm management of agricultural biodiversity in Nepal, Proceedings of a national workshop, 24-26 April 2001, Lumle, Nepal. NARC/LIBIRD/IPGRI, Kathmandu, Nepal/Pokhara, Nepal/Rome, Italy.

Banziger, M. and M. Cooper. 2001. Breeding for low input conditions and consequences for participatory plant breeding: examples from tropical maize and wheat. Euphytica 122: 503-519.

Bezaweletaw, K., P. Sripichitt, W. Wongai, and V. Hongtrakul. 2007. Phenotypic Diversity of Ethiopian Finger Millet [*Eleusine coracana* (L.) Gaertn]. In: relation to Geographic Regions as an Aid to Germplasm Collection and Conservation. Kasetsart Journal of Natural Science, 41:7-14.

Bua, B. and E. Adipala. 1995. Relationship between head blast severity and yield of finger millet. International Journal of Pest Management, 41:55-59.

deWet, J.M.J., K.E. Prasada Rao, D.G. Brink, and M.H. Mengesha. 1984. Systematic evolution of *Eleusine coracana* (Graminea). American Journal of Botany, 7:550-557.

Ekwamu, A. 1989. Host range, morphology and pathogenicity of the genus *Pyricularia* in Uganda. East African Agriculture and Forestry Journal, 54: 101-105.

Esele, J.P. 1993. The current status of research on finger millet blast disease (*Pyricularia grisea*) at Serere research station. P. 467 - 468. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York.

Esele, J.P.N. and S.E. Odelle. 1995. Progress in breeding for resistance to finger millet blast at Serere research station. *In: Proceedings of the 8th EARSAM Regional Workshop on Sorghum and Millets, 30th Oct. – 5th Nov. 1992, Wad Medani, Sudan: 93-99.*

Falconer, D.S. and T.F.C. Mackay. 1996. Introduction to quantitative genetics. 4th Edition. Longman Group Ltd, United Kingdom.

Hanamaratti, N.G., S.K. Prashanthi, P.M. Salimath, R.R. Hanchinal, H.D. Mohankumar, K.G. Parameshwarappa and S.D. Raikar. 2008. Traditional landraces of rice in Karnataka: Reservoirs of valuable traits current Science 94:242-247.

Kidoido, M.M., V. Kasenge, S. Mbowa, J.S. Tenywa, and P. Nyende. 2002. Socio-economic factors associated with finger millet production in eastern Uganda. African Crop Science Journal, 10:111-120.

Ministry of Agriculture Animal Industry and Fisheries (MAAIF). 2008. Facts and Figures for the Agricultural Sector 2008. An Annual Report of Agricultural Planning Department, Entebbe, Uganda. P. 48-49.

National Research Council. 1996. Finger millet. p. 39-57 In Lost crops of Africa: volume I: grains. Board on Science and Technology for International Development. National Academy of Sciences, National Academy Press, Washington D.C.

Newman. 2005. Holding on to finger millet. Plant Microbial, and Insect Genetic Resources, Genomics, and Genetic Improvement (#301), an ARS National Program described on the World Wide Web at www.nps.ars.usda.gov.

Obilana, A.B., E.O. Manyasa, J.G. Kibuka, and S. Ajanga. 2002. Finger millet blast samples collection in Kenya: passport data, analyses of disease incidence and report of activities. ICRISAT, Nairobi, Kenya.

Oduori, C.O.A. 2008. Breeding investigations of finger millet characteristics including blast disease and striga resistance in western Kenya. Unpublished PhD Thesis, University of Kwazulu Natal, Pietermaritzburg, South Africa.

Oduori, C.O.A. 2005. The importance and research status of finger millet in Africa. A paper presented at the McKnight foundation collaborative crop research programme on Tef and Finger millet: comparative genomics of the chloridoid cereals at the biosciences for east Africa (BECA) ILRI, Nairobi, Kenya.

Okwadi, J. 2007. Importance and characteristics of finger millet processing in Uganda. P. 102-111. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi, Kenya.

Parashuram, D.P., J. Gowda, R.G. Satish, and N.M. Mallikarjun. 2011. Heterosis and combining ability studies for yield and yield attributing characters in finger millet (*Eleusine coracana* (L.) Gaertn.). Electronic Journal of Plant Breeding, 2:494-500.

Prasada Rao, K.E., J.M.J. deWet, V. Gopal Reddy, and M.H. Mushonga. 1993. Diversity in small millets collection at ICRISAT. P. 331 – 346. Riley, K.W., S.C. Gupta, A. Seetharam and J.N. Mushonga (Eds). Advances in small millets. International Science Publisher, New York, USA.

Rachie, K.O. and L.V. Peters. 1977. The *Eleusines*: A Review of the World Literature. International Crops Research Institute for the Semi – Arid Tropics. 1 – 11 – 256, Begumpet, Hyderabad, - 500016 (A P) India.

Ramagosa, I. and P.N. Fox. 1993. Genotype x environment interaction and adaptation. Hayward, M.D., N.O. Bosemark, and I. Ramagosa (Eds). In: Plant Breeding: Principles and Prospects. Chapman and Hall, London, 1993, Publication.

Seetharam, A. and R.L. Ravikumar. 1993. Blast resistance in finger millet – its inheritance and biochemical nature. P. 449-465. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York, USA.

Sreenivasaprasad, S., J.P. Takan, M.A. Mgonja, E.O. Manyasa, P. Kaloki, N. Wanyera, J. Okwadi, S. Muthumeenakshi, A.E. Brown, and J.M. Lenne. 2005. Enhancing finger millet production and utilisation in East Africa through improved blast management and stakeholder connectivity. Aspects of Applied Biology, 75:11-22.

Takan, J.P., B. Akello, P. Esele, E.O. Manyasa, A. Obilana, P.O. Audi, J. Kibuka, M. Odendo, C.A. Oduori, S. Ajanga, R. Bandyopadhyaya, S. Muthumeenakshi, R. Coll, A. E. Brown, N.J. Talbot, and S. Sreenivasaprasad. 2004. Finger millet blast pathogen diversity and management in East Africa: a summary of project activities and outputs. International Sorghum and Millets Newsletter, 45:66-69.

Takan, J.P., S. Muthumeenakshi, S. Sreenivasaprasad, B. Akello, R. Bandyopadhyaya, R. Coll, A. E. Brown, and N.J. Talbot. 2002. Characterisation of finger millet blast pathogen populations in East Africa and strategies for disease management. [online] Available: www.bspp.org.uk/archives/bspp2002/bspp02postertitles.htm (date accessed: 21/01/2013).

Tenywa, J.S., P. Nyende, M. Kidoido, V. Kasenge, J. Oryokot, and S. Mbowa. 1999. Prospects and constraints of finger millet production in eastern Uganda. African Crop Science Journal 7:569-583.

Thatham, 1996. Characterisation of the Major Prolamins of Tef (Eragrostis tef) and Finger Millet (*Eleusine coracana*). Journal of cereal Science, 24:65-71.

Upadhyaya, H.D., C.L.L. Gowda, and V. Gopal Reddy. 2007. Morphological diversity in finger millet germplasm introduced from Southern and Eastern Africa. An Open Access Journal Published by ICRISAT., 3.1. Available online: SAT ejournal | ejounal.icrisat.org.

Wanyera, N.M.W. 2007. Facilitating the promotion of improved and blast resistant finger millet varieties to enhance production. P. 66-67. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

1.0 Chapter one

Literature review

1.1 Introduction

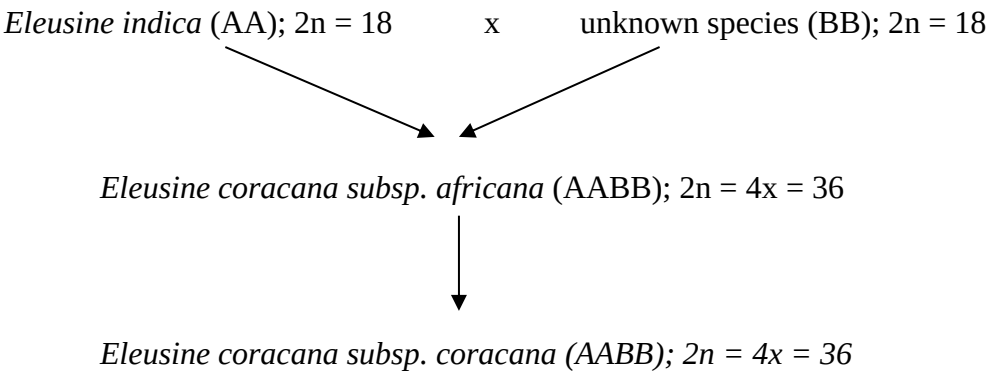
This review of literature provides an insight into the research reported in this thesis covering relevant topics that provide a theoretical basis for conducting the research. The following topics were covered: (1) origin and distribution of finger millet; (2) importance of finger millet blast disease and breeding for blast disease resistance; (3) influence of genotype x environment interaction in finger millet, adaptation and yield stability; (4) relevance of finger millet head shape and mode of its inheritance; (5) finger millet variability and trait association; (6) estimating gene action and mating designs, and (7) the need for farmer participation in finger millet breeding.

1.2 Biology and diversity in finger millet

Finger millet (*Eleusine coracana (L.)* Gaertn.) also known as African millet is an annual plant widely grown as a cereal in the arid areas of Africa and Asia. This species was domesticated in Africa from the wild form *Eleusine africana* more than 5,000 years ago (National Research Council (NRC), 1996), and is believed to have originated from eastern Africa in the area of present day Uganda (Riley et al., 1989) or Ethiopia (de Wet et al., 1984; Vavilov, 1951). Kennedy-O'Byrne (1957) however, suggested Ethiopia or further south as its centre of origin. Finger millet belongs to the family *Poaceae* and subfamily *Chloridoideae* that includes the only other crop, tef (Hilu, 1988). The species has two subspecies, *africana* and *coracana (L) Gaertn.* (Hilu and de Wet, 1976; Kennedy-O'Byrene, 1957). Subspecies *africana* has two races, *africana* and *spontanea*, while subspecies *coracana (L)* Gaertn. has four races: *elongate*, *plana*, *compacta* and *vulgaries* (Prasada Rao et al., 1993). Finger millet 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 from 40 cm to 130 cm tall and matures in 2½ - 6 months (Oduori, 2008).

The genius *Eleusine* to which finger millet (*Eleusine coracana* (L.) Gaertn.) belongs contains a basic chromosome number n = x = 9. Among the reported species, three are tetraploids with 2n =

36 in *E. coracana* and *E. africana,* and 2n = 38 in *E. kageziensis*, while *E. indica*, *E. tristachya*, *E. floccifolia* and *E. intermedia* are diploid species with 2n = 18. Contrary to this, *E. multiflora* and *E. jeageri* are reported to possess 2n = 16 and 2n = 20 chromosomes respectively (Ratnakar et al., 2009). Finger millet is a direct domesticate from *E. coracana subsp. africana*. The species that contributed the genomes of the wild and domesticated are *E. indica* and an unknown species (Dida et al., 2006) and its evolution is summarized below as follows:



Morphological, chloroplast DNA evidence indicates that finger millet evolved directly from the wild tetraploid *E. coracana subsp. africana,* an annual weed common in Africa (Dida et al., 2006). Finger millet and its wild progenitor *E. africana* are allotetraploids derived from hybridization between diploid *E. indica* and an unknown diploid (Dida et al., 2006). It has x = 9 and 4x = 36 chromosomes with genome composition AABB.

Finger millet has the highly efficient C4 photosynthetic pathway in common with maize, sorghum and sugarcane, and very adaptable to a wide range of environmental and climatic conditions. It tolerates salinity better than most cereals (CAB, 2003) and has been reported to contain acid producing, nitrogen fixing bacteria found in roots, rhizosphere and stems (Acetobacter diazotrophicus) (van Wyk and Gericke, 2000).

1.2.1 Finger millet distribution

It is distributed through out the warm temperate regions of the world from Africa to Japan and Australia. Finger millet is grown on over 4 million hectares world wide, it is a primary food for millions in the semi and arid areas of eastern and central Africa and southern India (NRC, 1996;

Werth et al., 1994). Finger millet is the most important small millet grown in eastern and southern Africa where records indicate it has been grown for over 5,000 years (Dida and Devos, 2006). It serves as a subsistence and food security crop that is especially important for its nutritive, storability and cultural values (Oduori et al., 2007). Before maize was introduced, it was also the staple crop of the southern African region. Today it is found in eastern and southern Africa and is the principal cereal grain in Uganda especially in eastern and northern regions (NRC, 1996).

Finger millet was introduced to India from its centre of origin by sea probably in the third millennium B.C., where it became an important cereal and is called "ragi" (Hilu, et al., 1979). The crop is cultivated in a range of agro-ecological areas where it 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 centre 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.

1.3 Finger millet blast pathogen

Finger millet blast disease caused by the fungus *Pyricularia grisea* (Bua and Adipala, 1995) is the highest priority production constraint in Uganda where most cultivars are susceptible (Ekwamu, 1993) resulting in severe head blast. *Pyricularia grisea* is the asexual form of *Magnaporthe grisea* and is the most common spore form of the fungus in Uganda (Ekwamu, 1993). The fungus produces conidia abundantly on lesions and in culture on specialised stalks called conidiophores. The conidia are usually three-celled produced on the apex of a conidiophore and the sporulating colonies are greyish appearance (Babu et al., 2013). Under favourable conditions, the fungus sporulates in the centre of the lesions on both vegetative and reproductive parts of the plant including seed on susceptible cultivars. It rarely sporulates on the

most resistant cultivars (Uddin, 2000).Conidia production is favoured by high humidity and are easily released especially under windy conditions. Infection of finger millet occurs when conidia are deposited on tissues and germinate by producing a germ tube and an appressorium. The appressorium is a melanised structure and from it develops an infection peg which penetrates the tissue. After penetration, the primary infection hypha grows rapidly and ramifies within susceptible tissues. Growth within tissues of resistant cultivars is often inhibited. *Pyricularia grisea* belongs to fungal class of *Deuteromycetes*, order *Moniliaes* and family *Monilaceae* and it has a marked pathogenic variability. The host range of *Pyricularia* is not simple and definite. It affects a wide range of species of the *Graminae* family (Seetharam and Ravikumar, 1993) from wild grasses to cereal crops of which rice and finger millet are the most important. Available literature concerning the taxonomy, nomenclature of the causal organism and host range show contradictions (Takan et al., 2004).

1.3.1 Symptoms of blast disease

Blast disease affects finger millet at all stages of growth and yield losses are due to reduction in the length of spikelets, grain number and grain mass (Takan et al., 2004; Ekwamu, 1989). It affects both total grain yield and grain quality. Increased level of head blast also results in high level of seed infection and low seed viability. This is because the blast fungus causes break down of the parenchymatous, sclerechymatous and vascular tissues of the neck region (Pande et al., 1993), thereby impeding the flow of nutrients into the grains. Consequently, grain formation is partially or totally inhibited. Other 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 (Babu et al., 2013). Seedlings may die under epidemic conditions, and on mature plants, infestation of the head prevents further development resulting in chaffy fingers of varying intensities, depending on the severity of the disease which also depends on the cultivar type and prevailing weather conditions. On the seeds, *Pyricularia grisea* produces profuse growth of whitish grey mycelium. Conidiophores form singly or in groups and cover usually part of the seed and in a few cases the whole seed. Conidiophores are slender, straight and greyish (Pande et al., 1993). The fungus also produces elliptical lesions on leaves, peduncle and ear. On seedlings, the pathogen infects leaves and first appears as minute brown specks.

Under favourable conditions the lesions enlarge and change colour from whitish / greyish or slightly bluish to brown attaining spindle shape with pointed ends and a flattened centre (Babu et al., 2013).

1.3.2 Finger millet blast pathogen epidemiology

Takan et al. (2004) and Sreenivasaprasad et al. (2005) found no distinct genetic and pathogenic differences between blast pathogen isolates from weed hosts and finger millet, indicating the potential of weeds to provide inoculum for blast on finger millet. The virulence pattern of the isolates closely corresponded with their lineage classification. According to Roumen et al. (1997), 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 *Pyricularia 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 finger millet blast in Uganda as there would not be pathogen race diversity in the region to easily break deployed resistances.

All landraces and varieties grown in Uganda show differential susceptibility to finger millet blast disease with neck and head blast being more frequent than foliar blast (Bua and Adipala, 1995; Ekwamu, 1991). Obilana et al. (2002) and Takan et al. (2002) also found this to be the case in western Kenya with compact headed landraces showing less blast incidence relative to the open headed ones. The incidence and severity was higher during the long rain season (February-July) than in short rain (August-December). This is attributed to higher humidity which favours sporulation.

Ekwamu (1991) further reported that seed-borne pathogen also contributes to disease development with high blast levels in susceptible finger millet varieties grown from infected seed, indicating that seed is a significant source of inoculum. Transmission is through seed movement and growing infected seed as finger millet seed is usually farmer saved from season to season (Takan et al., 2004) and according to Pall (1988) one infected seed could cause an epidemic of finger millet blast. In each infection cycle, reproduction occurs through production of millions of conidia when conditions are conducive (Ruiz, 2003; Uddin, 2000). Pande et al.

(1993) further reported that *Pyricularia grisea* sporulated on ungerminated, infected seeds and on rotten or necrotic tissues of seedlings and are able to kill seedlings. Their results showed that the pathogen is confined mostly to the pericarp causing poor germination and seedling mortality. The conidia of the fungus are produced and released during periods of high relative humidity (over 89 %), and optimal temperature of 25-28°C and germinate 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°C, which generates high turgor pressure and physical force, allowing the fungus to break the host cuticle and invade plant tissue (Ekwamu, 1991). In the field the first lesions appear 96 hours after infection and several consecutive infection cycles may follow during a single season, resulting in extensive disease damage in fields (Talbot, 2003). High temperature, high relative humidity and leaf wetness are critical environmental factors that promote disease development. Management would therefore require seed health measures, field sanitation and hygiene and complete weed control (Babu et al., 2013). Disease severity has also been found to be correlated with the amount of infested material (Ruiz, 2003), being more severe in plots receiving the highest amounts of primary inoculum. The number of cycles and number of spores that are produced on each individual lesion are influenced by many factors, including temperature, rainfall, amount of nitrogen used as fertilizer and level of genetic resistance in the cultivar (Prabhu et al., 1996). The amount of disease at the end of the vegetative phase of the growing season also influences the amount of disease during the reproductive phase. Spores produced near the end of growing season may infect the neck and the heads. On the head it can infect the fingers, peduncle and seeds.

1.3. 3 Blast disease control methods

Currently, there is no single method that can completely control blast disease in finger millet. The methods suggested are just preventive measures for instance avoiding seed-borne infections through selection of clean seed, improved weed management and promotion of improved, resistant varieties. Other studies conducted by Bua and Adipala (1995) recommend control of blast disease on finger millet by avoiding both high plant populations and heavy nitrogen fertilizer application and applying chemical fungicides like Mancozeb and Carbofuran. 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. Single gene resistance however, is not durable as it easily breaks down.

1.3.4 Mechanism of resistance to blast disease

According to Robinson (1968) resistance can be physical or biochemical or a combination of the two. Physical mechanisms involve plant structural characteristics like thick cuticles, waxes on leaves, hairy surfaces, thick cell walls and late opening of the stomata that act as physical barriers to pathogens from gaining entrance and spreading through the plant. Chemically, plant cells and tissues produce substances which are either toxic to the pathogen or create conditions that inhibit the growth of the pathogen in the plant (Robinson, 1968). Bvindi (2010) found that resistance of a genotype to rice blast was based on epidermal and mesophyll hypersensitive reaction (HR). No papillae was formed and fungus spread was arrested in the epidermis by epidermal and mesophyll HR in the completely resistant accession. This may as well be the case in finger millet since the pathogens involved are quite similar. Prabhu et al. (1996) indicated that in finger millet the formation of papillae at the sites where penetration failed and the epidermal HR in finger millet–*Pyricularia* interaction does not arrest fungal growth but only slows down its spread into the mesophyll cells.

Some accessions in contrast, the epidermal hypersensitivity reaction could not completely arrest the fungus from spreading into the mesophyll cells. The invaded mesophyll cell collapsed and underwent a HR like cell death (Babu et al., 2013). In this case it can be reasoned that the HR cell death in the mesophyll curtailed the development of the fungus. The accessions which showed complete resistance, partial resistance and susceptible phenotypes to blast pathogen indicated that in the resistant accessions the pathogen growth is curbed in the epidermal and mesophyll HR, in susceptible phenotypes growth of the fungus proceeds to the mesophyll cell with the plant hardly responding to the growth of the fungus and partially resistant phenotypes shows a somewhat intermediate response (Ravikumar, 1988).

Furthermore, Lavanya and Gnanamanickam (2000) working on rice blast reported the mechanism of resistance to be due to: smaller leaf area, narrow leaf angle, fewer stomata, dwarf plants with better conversion efficiency of photosynthates from source to sink, thick epidermis and cuticle on leaf and neck, higher total phenols, and low quantities of total and reducing sugars

contributed towards blast resistance in rice. They further reported that seeds of moderately resistant genotypes had higher total phenol content whereas susceptible genotypes had higher total sugars and reducing sugars. A similar finding was reported by Seetharam and Ravikumar (1993) in finger millet. Path coefficient analysis by Jain and Yadava (2003) also revealed that total phenols at dough stage and total sugars, reducing sugars in dry seed, and 35-day-old seedlings determined blast resistance in finger millet. Results from a study conducted by Bua and Adipala (1995) in Uganda indicated that varieties with dark coloured seeds had more blast resistance than lighter coloured varieties probably pointing to the role of tannins in blast disease reaction. Muthulisi et al. (2007) indicated that grain colour in finger millet varies finger millet type, with pigmented types containing more tannins and higher levels of phenolics than the light coloured types.

1.3.5 Breeding for blast disease resistance

Narayanan et al. (2002) found that the major blast resistance gene Piz5 in finger millet can exclude most *Pyricularia grisea* Sacc. lineages. Madhukeshwara et al. (2001) reported the presence of both major gene and minor genes conferring partial resistance in finger millet because major gene resistance tends to confer immunity as compared to minor genes conferring partial resistance that leads to a gradation of resistance (Fasoula and Fasoula, 1997). This variability for blast resistance can be incorporated in breeding programmes in finger millet. However, host-pathogen relations that are critical to breeding for durable partial resistance have not been studied in finger millet (Seetharam and Ravikumar, 1993). Studies of these relations in finger millet could be inferred from studies conducted in other crops like rice blast host-pathogen relations. It appears both minor and major genes exist for finger millet blast disease resistance that could be bred into desirable varieties.

Attempts have been made in Uganda to screen and select finger millet for resistance against leaf, neck and head blast (Obilana, 2002; Bua and Adipala, 1995). Jain and Yadava (2003) found varieties that showed consistency in resistance against leaf, neck and head blast due to different mechanisms which could be used in the formulation of selection indices in the selection of resistant genotypes for resistance breeding programmes against blast in finger millet. These

attempts however, have frequently pointed to breeding for vertical resistance which often breaks down, compared to durable partial resistance (Robinson, 1968).

1.3.6 Durable resistance

Johnson (1984) defined durable resistance as that which remains effective while a cultivar possessing it is widely cultivated. Durable resistance could be achieved in finger millet by utilization of partial or horizontal resistance and gene pyramiding. Partial resistance is an incomplete quantitative resistance based on minor genes (Robinson, 1968). It is characterized by compatibility between the pathogen and the plant with reduced development of disease compared to plants with no partial resistance. Partial resistance is polygenic and can be affected by the environment. Utami et al. (1999) suggested that there are minor genes that play an important role in maintaining an economically acceptable level of disease under field conditions, these would however, be difficult to identify and characterize in presence of major genes as these have epistatic interactions among themselves. Their presence would also affect the accuracy of classification of lines for complete resistance to blast.

Combinations of resistance genes are thought to provide broader spectra of resistance through both major gene resistance and quantitative complementation would result in durable resistance (Andrews, 1993). Strategic deployment of identified resistances in an integrated manner would therefore be critical to the success of blast control in finger millet. The 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 and use of clean seed is likely to produce durable resistance.

1.4 Genotype x Environment interaction, adaptability and stability

Finger millet is grown in a wide range of agro-climatic conditions in Uganda. Coupled with other stresses there is an inevitable genotype x environment interaction (GEI) that affects performance of genotypes and therefore, effective selection. Presence of significant GEI has been severally reported in finger millet trials (Misra et al., 2009; Joshi et al., 2005; Solanki et al., 2000) in India and Nepal but such information is lacking in Uganda. Genotype x environment interaction is

defined by Ramagosa and Fox (2003) as the differential expression of genotypes across environments. The occurrence of large GEI, is a major challenge for predicting performance since it becomes difficult to decide which genotypes to be selected because selections in one environment may perform poorly in another (Crossa et al., 2002). In finger millet, Misra et al. (2009) reported performance of genotypes to be highly unpredictable due to presence of a significant GEI in finger millet trials because it is statistically impossible to interpret the main effects. There are two types of GEI, that is, the crossover interaction and the non-crossover interaction. The crossover interaction causes changes in genotype ranking across environments while in the non-crossover type, the genotypes behave differently but without changes in the rank order across environments (Crossa et al., 2002). The crossover type is of a particular significance because it slows down progress to selection since this would necessitate breeding for specific adaptation. In addition, the targeting of genotypes to specific locations is difficult when GEI is present, since, according to Samonte et al. (2005) and Solanki et al. (2000) working on finger millet, yield is less predictable and cannot be interpreted based only on genotype and environment means. This would inevitably complicate the process of selecting genotypes with superior performance. Coupled with resource constraints, this slows progress from selection, since different genotypes would have to be chosen in different environments.

Breeders desire superior genotypes with wide adaptation especially for farmers in low resource areas like the case is for finger millet in Uganda. The stable genotypes which perform well under stress and low input conditions are desirable under smallholder farmers' conditions for sustainable crop production. Stability can be categorised as static or dynamic (Becker and Leon, 1988) both of which are useful, but their applications depend on the traits under consideration. Static stability results in unchanged or constant genotypic performance even when environmental conditions improve. Dynamic stability is when the performance of the genotype is affected by the environment but its response is predictable across environments and a stable genotype has no deviation from this response to environment. Stable yields play a major role in developing countries where smallholder farmers, particularly those living in marginal areas, are based. Such farmers are basically interested in constantly superior performance in their farms over time (Ceccarelli, 1994).

1.4.1 Methods used for exploring GEI

Due to the presence of GEI, multi-environment trials (METs) have been severally used and recommended to identify superior varieties with wide adaptation for farmers especially in low resource areas (Yan et al., 2000). The implication is that superior genotypes with high stability (wide adaptation) may not necessarily be the best performers for specific environment (s). Andrews (1993) suggested growing the materials in sufficient test environments to evaluate for superior stable entries of finger millet so as to increase production while Misra et al. (2009) used METs in the identification of stable and productive environments and those that best suit particular finger millet genotypes in India to maximise its production. In addition, METs can also be used to select homogeneous sub-groups of environments and agro-management conditions or mega environments that minimise GEI for recommendations in finger millet (Misra et al., 2009; Samonte et al., 2005). At national levels these could constitute agro-ecological zones. The use of METs in environments which differ in altitude, latitude, photoperiod, temperature, rainfall, soil type and disease incidence allow the expression of high yield potential. Choice of selection sites is therefore particularly relevant in the case of production areas with variable levels of abiotic stress (Ramagosa and Fox, 1993).

To explore the impact of GEI, standard statistical methods have been applied and these include analysis of variance, principal component analysis, linear regression and Additive Main effects and Multiplicative Interaction (AMMI). Each of these methods employs statistical parameters to measure genotypic stability or response to environments according to different concepts of stability. The advantages and disadvantages of each of these methods have severally been dealt with (Balestre et al. 2010; Yan and Kang, 2003; Gauch, 1988; Yan and Hunt, 1988, Zobel et al., 1988). Additive Main effect and Multiplicative Interaction analysis according to Purchase (1997) gives an estimate of total GEI effect of each genotype and also further partitions it into interaction effects due to individual environments. Low GEI of a genotype indicates stability of the genotype over the range of environments. A genotype showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of the specific environment. This analysis permits estimation of interaction effect of a genotype in each environment and it helps to identify genotypes best suited for specific

conditions. Analysis of variance and AMMI were used since these have been used more often and considered better models in finger millet (Misra et al., 2009; Solanki et al., 2000).

1.5 Finger millet head shapes and relevance in finger millet breeding

There is great variability in finger millet head shapes (de Wet et al., 1984), and based on inflorescence compactness and shape, finger millet is classified into four different races that is, *Elongata, Plana, Compacta and Vulgaries* (Bezaweletaw et al., 2007; Prasada Rao et al., 1993). According to Ayyangar (1932) (as cited by Rachie and Peters, 1977), there are two broad categories of head shapes in finger millet: those in which the digitate spikes of the inflorescence curve in and those in which they are open, but indicated there are three readily recognizable head shapes in finger millet: (1) open, (2) top-curved, and (3) incurved. The incurved however, was further categorised by Ayyangar (1933) (as cited by Rachie and Peters, 1977), into incurved and the fisty type with fingers compactly incurved.

There are reports that link finger millet head shapes to blast disease reaction (Baniya et al., 2003). Results have shown that open headed or short and/or early maturing genotypes are more susceptible than genotypes with compact head shapes to head infections, but less susceptible to leaf infections (Esele and Odelle, 1995). Progenies from crosses with disease resistant parents have also been reported to show lower susceptibility followed by crosses from male sterile lines (Esele, 1993). Bua and Adipala (1995) also showed that head shapes may be important in determining resistance to blast disease. Head shapes are also important because farmers have reported preferences for different head shapes for various reasons. Oduori (2008) on the other hand, reported a negative correlation between head shape and lodging, stating that open headed genotypes were more prone to lodging than the fist headed genotypes probably due to open heads offering resistance to wind. He also further reported higher susceptibility of open headed genotypes to head blast disease, as head blast increased with tendency to open headedness. Despite these findings however, there seems to be no information on the gene actions responsible for transmission of the different head shapes in finger millet. It is therefore important to understand the genetic mechanisms that control this trait so as to, in addition to breeding high yielding and resistant varieties, incorporate head shapes as one of the traits influencing grain yield and farmer preferences.

1.5.1 Inheritance studies of finger millet head shapes

There is hardly any information on the inheritance of head shapes in finger millet. The distinct head shapes however, point to mono or oligogenic control (Ayyangar, 1932) (as cited by Rachie and Peters, 1977) indicating probable simple inheritance. Ayyangar (1932) based his conclusions on studies of other qualitative traits of finger millet like pigmentation, seed colour and sterility. He also indicated that there was a possibility of inhibiting factors involved in head shape inheritance whereas Jones (1934) proposed modifying factors. Both however, did not investigate the number of genes involved or their nature of interaction if it existed. But all concluded that head shape is fairly simply inherited. Studies by Ghorpade and Kadam (1980) in sorghum panicles indicated that two or three genes were involved whereas Seetharaman and Srivastava (1972) in rice indicated three genes responsible for head shape inheritance in rice panicles. Gene interactions have also been reported by Santhkumar and Gowda (1998), and Joel et al. (2005) in other qualitative traits of finger millet. Understanding the inheritance of head shapes in finger millet will enhance optimum incorporation of preferred head shapes in improved cultivars to improve adoption and hence production. The aim in a finger millet breeding programme is to improve qualitative and/or quantitative traits, but, to plan an effective breeding strategy breeders need to know the behaviour of genes that control particular traits. The biometric methods are used for quantitative traits whereas probability statistics following Mendellian ratios have been widely used for qualitative traits.

1.6 Variability, correlation and path analysis

1.6.1 Landraces

Landraces, also known as traditional varieties or primitive varieties, have been defined as geographically or ecologically distinctive populations which are conspicuously diverse in their genetic composition both between populations and within them and as a product of local selection by farmers (Cleveland et al., 1994). Landraces can play an important role in agricultural development as they are diverse in terms of yield related traits, tolerant to several stress factors and possess specific trait preferences by farmers (NRC, 1992). Their role in conserving biodiversity in agriculture for agricultural and ecological sustainability has also been publicised (NRC, 1992). Landraces are widespread and popular among farmers, and are important part of agriculture because their diverse array in a crop creates genetic diversity in

agriculture (Modi, 2004) and therefore represent a source of genetic variability (Lule et al., 2012). The genetic variability as reported by Bezaweletaw (2006) in finger millet is key to breeding programs aimed at broadening the gene pool. Landraces are known to be heterogeneous mixtures of genotypes carrying a range of stress tolerance genes (Gomez and Kalami, 2003). Landraces also possess traits that are most preferred by farmers and can be used to produce new cultivars or incorporate desirable traits into varieties (Evans, 1996).

In finger millet and many other crops, landraces have not been bred as varieties but have been adapted to the local conditions of environment and inputs where they are cultivated (Evans, 1996), and have been the mainstay of agricultural systems in many developing countries (Juma, 1989). Several workers have found and reported genetic variability for traits related to high yields and tolerance to various stresses. For instance Oduori (2008) evaluated finger millet landraces in Kenya and found variability for agronomic traits among 310 accessions whereas Bezaweletaw et al. (2006) had similar findings on evaluating 66 accessions of which 64 were landraces from Ethiopia. Apart from genetic variability, breeders can find materials adapted to marginal environments within landraces. Despite the research already done, the role of landraces contributing germplasm to breeding programmes has not been fully appreciated (Hill et al., 1998). This has been due to inadequate testing and lack of genetic information about the landraces. Information on genetic studies could be useful in designing breeding programmes that will best exploit economically important and yield related traits when developing new varieties.

1.6.2 Variability

Studies from other countries indicate existence of high variability in finger millet, though little is known about the Ugandan germplasm in terms of variability of major traits, trait associations and their potential usefulness. Bezaweletaw et al. (2006) indicated that investigating and identifying plants for available variation in the breeding material is the first step of a successful plant breeding and crop improvement programme. These studies were used to measure variability in finger millet collections based on morphological and agronomic traits, and in certain cases molecular studies have also been conducted (Dida and Devos, 2006); even in these studies however, a considerable number of genotypes were not included. High trait variability among finger millet genotypes have been observed in finger millet from previous studies (Oduori, 2008;

Bezaweletaw et al. 2006; Prasada Rao et al. 1993) suggesting broad diversity apparent among finger millet germplasm that were studied in Kenya, Ethiopia and India respectively. This would therefore provide ample opportunities for genetic improvement of the crop through selection directly from the available germplasm or traits recombination through intra-specific hybridisation of desirable traits. Upadhyaya et al. (2007) also observed high variability in most finger millet characteristics in all the four races including number of tillers per plant, maturity period, plant height, panicle length, grains per head, pigmentation and grain yield. The high variations are consistent with reported high heritabilities by Sumathai et al. (2007). Considering the fact that little breeding has been conducted in finger millet, the degree of genetic variation and heritabilities present a greater opportunity for selection and genetic advance than in most of the cereals.

1.6.3 Correlations and path analysis

Grain yield is a complex character and is considered as the ultimate product of its components. Hence selection of superior genotypes based on grain yield is difficult due to the integrated structure of plants in which most of the characters are interrelated and being governed by many genes (Falconer and Mackay, 1996). This necessitates a thorough knowledge on the nature of interrelationships prevalent between contributory characters and grain yield and the extent of genetic variability (Vaithiyalingan et al., 2010; Bezaweletaw et al., 2007). Besides, determination of the interrelationships between various agronomic characters and their direct and indirect effects on grain yield may provide a clue for crop breeders in improving the productivity of the crop and also a pre-requisite to plan a meaningful breeding programme and approach (Singh and Narayanan, 1993).

In the study of trait interrelationships, correlation and path analyses have been conducted in several crops. Correlations indicate the nature and degree of interrelationships among yield and its component characters whereas path analysis indicates direct and indirect contributions of the characters towards yield (Akanda and Mundt, 1996). In path coefficient analysis, grain yield is considered a dependent variable and the remaining traits are considered as independent (causal) variables (Singh and Chaundhary, 1977). A path coefficient is simply a standardised partial regression coefficient and as such estimates the direct influence of one variable upon another and

permits separation of correlation coefficients into components of direct and indirect effects (Dewey and Lu, 1959). The direct contribution of an independent variable to the variation observed in the dependent variable can be determined with reduced confounding influences caused by multicolinearity. Lenka and Mishra (1973) suggested scales for path coefficients in rice with values 0.00 to 0.09 as negligible, 0.10 to 0.19 as low, 0.20 to 0.29 moderate and 0.30 to 0.99 as high path coefficient. This was later used by Lule et al. (2012) in finger millet studies.

Trait association studies in finger millet by Ganapathy et al. (2011) found significant correlation between grain yield in finger millet and productive tillers, finger length and plant height and on decomposing the correlations by path analysis, number of productive tillers was the most important in determining yield although plant height also showed moderate direct effect. Bezaweletaw et al. (2006) reported highly significant positive associations between grain yield with productive tillers, number of grains per spikelet, finger number, and ear length but negatively with days to 50% heading and days to maturity. On decomposing the correlations, their results showed positive direct effects for productive tillers and finger number and negative direct effects for days to maturity and grains per spikelet. Lule et al. (2012) also reported that high and positive direct effects on grain yield per plant were obtained from number of productive tillers, whereas days to heading, days to maturity, lodging index and plant height had negative direct effects on grain yield.

1.7 Estimating gene action and mating designs

Evaluation of finger millet germplasm for blast disease by Seetharam and Ravikumar (1993) showed a continuous variation which indicated that inheritance of resistance is most likely quantitatively controlled by a number of genes, each with individual minor effects and perhaps also largely controlled by the environment. It is an indication that attempt (s) to assess the contribution of individual genes to blast incidence/severity is bound to be ineffective and therefore obtaining estimates of effects averaged over a whole genome is recommended. There are several methods of estimating such quantitative genetic effects through various mating designs. These mating designs include: paired crosses, polycross, Diallel mating designs, North Carolina Designs I, II, and III, Line x Tester mating design, Topcross and Backcross. The advantages and disadvantages of each of these methods have been severally dealt with

(Darbeshwar, 2000; Mather and Jinks, 1982; Griffing, 1956). The most common mating designs that have been used include diallel (Griffing, 1956) and biparental crosses commonly referred to as North Carolina designs I, II, and III (Singh, 1993; Comstock and Robinson, 1948). In this study, the diallel mating design was used as it allows crosses among all possible combinations from a group of parents including themselves (Jinks and Hayman, 1953). The diallel method is commonly used to facilitate identification of superior combiners and specific cross combinations producing best progenies (Kempthorne, 1957). It also permits estimation of the magnitude of additive and non-additive components of heritable variance and provides information on the main effects (GCA) and interactions (SCA) between parental lines. This mating design has been severally used in finger millet to estimate the magnitude of additive and non-additive components of genetic variability on yield and other agronomic traits and found to be appropriate (Parashuram et al., 2011; Shailaja et al., 2010; Krishnappa et al., 2009).

The gene action conditioning resistance to finger millet blast disease and yield in germplasm adapted to the tropical conditions of Uganda, however, is not fully understood. Similarly no information exists on the combining abilities of finger millet under finger millet blast pressure. There however, exists some scanty information especially from India and extensive work on rice. Generation of such information would be useful in selecting parents in a breeding programme and choosing appropriate breeding procedures. Some studies have identified finger millet genotypes with resistance to *Pyricularia grisea* (Cooke) Sacc. (Shailaja, 2010; Krishnappa, 2009; Takan et al., 2004) indicating that breeding for resistance is a realistic option. This can form the basis for initiating studies to determine the genetics of resistance to blast disease pathogen and later be able to incorporate this resistance in new cultivars with appropriate agronomic and farmer preferred attributes.

1.8 Farmers' participation in finger millet breeding

In Uganda over 80% of the population is involved in subsistence agriculture with the most important cereals being maize, finger millet and sorghum in that order (Wanyera, 2007). Production of finger millet is mainly concentrated in the low potential areas which contribute over 65% of finger millet production (MAAIF, 2008) in the country but the devastating effect of blast disease and low yielding varieties have often led to low yields threatening food security (Okwadi, 2007). Therefore, breeding for cultivars with high and stable grain yields tolerant to

blast disease and other stresses is an important priority. Moreover the use of high yielding stress tolerant cultivars may be the only affordable option for many of these resource poor small-scale farmers. For this option to succeed, breeders should take a proactive approach that considers farmers' perceived constraints and preferences in varietal development right from the inception of the breeding programme (Banziger and Cooper, 2001). This is because farmers sometimes have certain specific needs and preferences which breeders might not know (Islam et al., 2008) and might affect adoption. To increase efficiency and effectiveness of classical breeding, Witcombe et al. (2001) recommended a strategy that involves a thorough researcher–farmer interface and collaboration to enhance potential for varietal adoption. Participatory approaches are also currently preferred in breeding as they value the farmers' knowledge, interests, ability to innovate and their active exchange of information (Banziger and Cooper, 2001).

Participatory plant breeding has been suggested as an effective alternative to formal plant breeding as a breeding strategy for achieving productivity gains under low input conditions. In recent years, there has been an increasing shift in paradigm that the farmers' participation in technology development increases the likelihood of technology adoption (Islam et al., 2008). Participatory plant breeding has many advantages, among them increased and more stable productivity, better understanding of farmers' varietal criteria and faster release and adoption of varieties. Formal plant breeding approaches have been ineffective as is evident in both non-adoption of improved varieties by farmers and lack of breeding progress as reflected by performance of adopted varieties under low input conditions (Banziger and Cooper, 2001).

Participatory crop improvement involves farmers directly in the process of variety improvement and testing at an earlier stage than in conventional breeding process. It is designed to better incorporate perspectives of end users than formal plant breeding, reach resource poor farmers, breed for high-stress and diverse conditions and incorporate wide variation in traits for specific farmer preferences (Dorward et al., 2007). There has been success and impact of conventional and centralized plant breeding programmes in high input areas compared to the marginal and variable small-scale farming sector. Thus, for such marginal regions a participatory breeding approach may be more effective (Moris and Bellon, 2004). Participatory approaches have been used and reported to be quite effective in several cases such as in maize in Mexico and Honduras

(Banziger and Cooper, 2001) and in India (Witcombe et al., 2001). Little however, has been devoted to establishing farmers' perceptions and preferences in finger millet breeding in Uganda.

Participatory research allows incorporation of farmers' indigenous technical knowledge, identification of farmers' criteria and priorities and definition of research agenda (Chambers, 1994). Participatory rural appraisal (PRA) tools are usually applied to determine farmers' perceptions and preferences (Kidoido et al, 2002). It involves local people in collecting and analyzing information, allows seeking of insights about their local and actual conditions, and fosters dialogue between scientists and farmers. By integrating farmers' concerns and conditions into agricultural research, research will develop technologies that become widely adopted, resulting in more productive, stable, equitable and sustainable agricultural systems.

References

Akanda, S.I. and C.C. Mundt. 1996. Path coefficient analysis of the effects of stripe rust and cultivar mixtures on yield and yield components of winter wheat. Theoretical and Applied Genetics, 92:666-672.

Andrews, D.J. 1993. Principles for breeding small millets. P. 411 - 423. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York, USA.

Babu, T.K., R.P. Thukar, H.D. Upadhyaya, P.N. Reddy, R. Sharma, A.G. Girish, and N.D.R.K. Sarma. 2013. Resistance to blast (*Magnaporthe grisea*) in a mini-core collection of finger millet germplasm. European Journal of Plant Pathology. Open Access Repository, International Crops Research Institute for Semi-Arid Tropics. Available online **http://dx.doi.org/10.1007/s10658-012-0086-2/** (date accessed 10/04/2013).

Balestre, M., V. B. dos Santos, A.A. Soares, and M.S. Reis. 2010. Stability and adaptability of upland rice genotypes. Crop Breeding and Applied Biotechnology, 10:357-363.

Baniya, B.K., A. Subedi, R.B. Rana, R.K. Tiwari and P. Chaudhary. 2003. Finger millet seed supply system in Kaski ecosite of Nepal. P. 171-175. Sthapit, B.R., M.P. Upadhyaya, B.K. Baniya, A. Subedi, and B.K. Joshi, (Eds.). On-farm management of agricultural biodiversity in Nepal, Proceedings of a national workshop, 24-26 April 2001, Lumle, Nepal. NARC/LIBIRD/IPGRI, Kathmandu, Nepal/Pokhara, Nepal/Rome, Italy.

Banziger, M. and M. Cooper. 2001. Breeding for low input conditions and consequences for participatory plant breeding: examples from tropical maize and wheat. Euphytica, 122:503-519.

Becker, H.C. and J. Leon. 1988. Stability analysis in plant breeding. Plant Breeding, 101:1-23.

Bezaweletaw, K., P. Sripichitt, W. Wongai, and V. Hongtrakul. 2007. Phenotypic Diversity of Ethiopian Finger Millet [*Eleusine coracana* (L.) Gaertn]. In: Relation to Geographic Regions as an Aid to Germplasm Collection and Conservation. Kasetsart Journal of Natural Science, 41:7-14.

Bezaweletaw, K., P. Sripichitt, W. Wongai, and V. Hongtrakul. 2006. Genetic variation, Heritability and Path-Analysis in Ethiopian Finger Millet [*Eleusine coracana* (L.) Gaertn] Landraces. Kasetsart Journal of Natural Science, 40:322-334.

Bua, B., and E. Adipala. 1995. Relationship between head blast severity and yield of finger millet. International Journal of Pest Management, 41:55-59.

Bvindi, C.N. 2010. Host status and genetic analysis of blast (*Magnaporthe oryzae*) resistance in barley. Msc. Thesis Wageningen University and Research Centre, Netherlands.

CAB International. 2003. Crop Protection Compendium. 2005 Edition. Wallingford, UK.

Ceccarelli, S. 1994. Specific adaptation and breeding for marginal conditions. Euphytica, 77:205-219.

Chambers, R. 1994. Participatory Rural Appraisal (PRA): Challenges, potentials and paradigm. World Development, 22:1437-1454. Elsevier Science Ltd. Great Britain.

Cleveland, A.D., D. Soleri, and S.E. Smith. 1994. Do folk varieties have a role in sustainable agriculture? Incorporating folk varieties into the development of locally based agriculture may be the best approach. BioScience, 44:740-751.

Comstock, R.E. and H.F. Robinson. 1948. The components of genetic variance in populations of biparental progenies and their use in estimating the average degree of dominance. Biometrics, 4:254-266.

Crossa, J., P.L. Cornelius, and W. Yan. 2002. Biplots of linear-bilinear models for studying crossover genotype x environment interaction. Crop Science, 42:619-633.

Darbeshwar, R. 2000. Plant Breeding. Analysis and exploitation of variation. Narosa Publishing House, New Delhi, India.

de Wet, J.M.J., K.E. Prasada Rao, D.G. Brink and M.H. Mengesha. 1984. Systematic evolution of *Eleusine coracana* (Graminea). American Journal of Botany, 7:550-557.

Dewey, D.R. and K.H. Lu. 1959. A correlation and path coefficient analysis of crested wheat grass grain production. Agronomy Journal, 51:515-518.

Dida, M. and K.M. Devos. 2006. Genome mapping and molecular breeding in plants. Cereals and Millets, 1:333-343.

Dida, M.M., N. Wanyera, S. Subramanian, J.L. Bennetzen, and K.M. Devos. 2006. Genetic diversity in finger millet (*Eleusine coracana*) and related wild species. Poster at the Fourteenth Plant and Animal Genomes Conference, January 14-18, 2006, Town and Country Convention Centre, San Diego, CA, USA. Abstracts p.148.

Dorward, P., P. Craufurd, K. Marfo, W. Dogbe and R. Bam. 2007. Improving participatory varietal selection process: Participatory varietal selection and the role of informal seed mechanisms for upland rice in Ghana. Euphytica, 155:315-327.

Ekwamu, A. 1993. A review of finger millet blast disease studies at Makerere University. P.467. Riley, K.W., S.C. Gupta, A. Seetharam, and J.N. Mushonga (Eds). Advances in small millets. International Science Publisher, New York, USA.

Ekwamu, A. 1991. Influence of head blast infection on seed germination and yield components of finger millet (*Eleusine coracana* L. Gaertn). Tropical Pest Management, 37:122-123.

Ekwamu, A. 1989. Host range, morphology and pathogenicity of the genus *Pyricularia* in Uganda. East African Agricultural and Forestry Journal, 54:101-105.

Esele, J.P. 1993. The current status of research on finger millet blast disease (*Pyricularia grisea*) at Serere research station. P. 467 - 468. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York.

Esele, J.P.N., and S.E. Odelle. 1995. Progress in breeding for resistance to finger millet blast at Serere research station. Proceedings of the 8th EARSAM Regional Workshop on Sorghum and Millets, 30th Oct. – 5th Nov. 1992, Wad Medani, Sudan: 93-99.

Evans, L.T. 1996. Crop Evolution, Adaptation and Yield. Cambridge University Press, Cambridge, UK.

Falconer, D.S. and T.F.C. Mackay. 1996. Introduction to quantitative genetics. 4th Edition. Longman Group Ltd, United Kingdom.

Fasoula D.A. and V.A. Fasoula, 1997. Gene action and plant breeding. In: J. Janick (Ed.). Plant Breeding Reviews: 315-370. John Wiley and Sons, NY.

Ganapathy, S., A. Nirmalakumari, and A.R. Muthiah. 2011. Genetic variability and interrelationship analyses for economic traits in finger millet germplasm.

Gauch, H.G. 1988. Model selection and validation of yield trials with interactions. Biometrics, 44:705-715.

Ghorpade, D.S. and B.S. Kadam. 1980. Inheritance of Panicle characters in sorghum. Indian Journal of Genetics and Plant Breeding, 40:195-211.

Gomez, S.M. and A. Kalami. 2003. Scope of landraces for future drought tolerance breeding programme in rice (*Oryza sativa* L.). Plant Archives, 3: 77 – 79.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Science, 9:463-493.

Hilu, K.W. 1988. Identification of "A" Genome of finger millet using chloroplast DNA. Genetic Society of America, 118:163-167.

Hill, J., H.C. Becker, and P.M.A. Tigerstedt. 1998. Quantitative and ecological aspects of plant breeding. Chapman and Hall, London.

Hilu, K.W. and J.M.J. de Wet. 1976. Racial evolution of *Eleusine coracana ssp. Coracana* (Finger millet). American Journal of Botany, 63:1311- 1318.

Hilu, K.W., J.M.J. de Wet, and J.R. Harlan. 1979. Archaeobotanical studies of *Eleusine coracana ssp. Coracana* (finger millet). American Journal of Botany, 66:330-333. http://books.nap.edu/openbook.php?record_id=2305&page=39.

Islam, M.R., M.A. Salam, M.A.R. Bhuiyan, M.A. Rahman, and G.B. Gregorio. 2008. Participatory variety selection for salt tolerance. International Journal of BioResources, 4:21-25.

Jain, A.K. and H.S.Yadava. 2003. Mechanism of blast resistance in finger millet (*Eleusine coracana* L. Gaertn.) Available online. http://www.cababstracts.org/abstracts/Abstracts.aspx?AcNo=20053213753

Jinks, J.L. and B.I. Hayman. 1953. The analysis of diallel crosses. Maize Genetics Cooperative Newsletter, 27: 48-54.

Joel, A.J., N. Kumaravadivel, A. Nirmalakumari, N. Senthil, K. Mohanasundaram, T.S. Raveendran, and V. Mallikavangamudi. 2005. A high yielding finger millet variety CO(Ra) 14. Madras Agricultural Journal, 92:375-380.

Johnson, R. 1984. Mechanisms of resistance in plants. Annual Review of Phytopathology, 22:309-330.

Jones, J.W. 1934. Inheritance of characters in rice. Journal of Agricultural Research, 47:771-782.

Joshi, B.K., R.K. Tiwari, R.B. Amgain, P. Shrestha, S. Gyawali, A. Mudwari and B.K. Baniya. Stability and adaptation in finger millet (*Eleusine coracana* (L.) Gaertn.) landraces. 2005. On-farm Conservation of Agricultural Biodiversity in Nepal, 1:73-83.

Juma, C. 1989. The gene hunters: Biotechnology and the Scramble for seeds. Princeton University Press, Princeton, NJ.

Kempthorne, O. 1957. An introduction to Genetic Statistics. John Wiley & Sons Inc., New York.

Kennedy – O'Byrne, J. 1957. Notes on African grasses XXIX. A new species of *Eleusine* from tropical and south Africa. Kew. Bull., 1:65-74.

Kidoido, M.M., V. Kasenge, S. Mbowa, J.S. Tenywa, and P. Nyende. 2002. Socio-economic factors associated with finger millet production in eastern Uganda. African Crop Science Journal, 10:111-120.

Krishnappa, M., S. Ramesh, J. Chandraprakash, J. G. Bharathi, and D.D. Doss. 2009. Genetic analysis of economic traits in finger millet. An Open Access Journal published by ICRISAT. SAT eJournal/ ejounal.icrisat.org., 7:1-5.

Latha, A.M., K.V. Rao, and V.D. Reddy. 2005. Production of transgenic plants resistant to leaf blast disease in finger millet (*Eleusine coracana* (L.) Gaertn.). Plant Science, 169:657-667.

Lavanya, B. and S.S. Gnanamanickam. 2000. Molecular tools for characterization of rice blast pathogen (*Magnaporthe grisea*) population and molecular marker assisted breeding for disease resistance. A review article. In: Current Science, 78:248-257.

Lenka, D. and B. Mishra. 1973. Path coefficient analysis of yield in rice varieties. Indian Journal of Agricultural Science, 43:376-369.

Lule, D., K. Tesfaye, M. Fetene, and S. De Villiers. 2012. Inheritance and Association of Quantitative traits in Finger millet (*Eleusine coracana* Subsp.*coracana*) Landraces collected from Eastern and Southern Africa. International Journal of Genetics, 2:12-21.

Madhukeshwara, S.S., S.G. Mantur, Y.L. Krishnamurthy, and H.N.R. Babu. 2001. Evaluation of finger millet germplasm for resistance to blast disease. Environmental Ecology, 229:832-834.

Mather, K. and J.L. Jinks. 1982. Biometrical Genetics. 3rd Edition. Chapman and Hall, London.

Ministry of Agriculture Animal Industry and Fisheries (MAAIF). 2008. Facts and Figures for the Agricultural Sector 2008. An Annual Report of Agricultural Planning Department, Entebbe, Uganda. P. 48-49.

Misra, R.C., S. Das, and M.C. Patnaik. 2009. AMMI model analysis of stability and adaptability of late duration finger millet (*Eleusine coracana*) genotypes. World Applied Science Journal, 6:1650-1654.

Modi, A.T. 2004. Short-term preservation of maize landrace seed and Taro propagules using indigenous storage methods. South African Journal of Botany, 70:16-23.

Morris, L. and R. Bellon. 2004. Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. Euphytica, 136:21-35.

Muthulisi S., J.R.N. Taylor, W.A.J. de Milliano, and K.G. Duodu. 2007. Occurrence and location of tannins in finger millet grain and antioxidant activity of different grain types. Cereal Chemistry, 84:169-174.

Narayanan, N.N., N. Baisakh, C.M. Cruz, S.S. Gnanamanickam, K. Datta, and S.K. Datta. 2002. Molecular breeding for the development of blast and bacterial blight resistance in rice cv. ir50. Crop Science Journal, 42:2072-2079.

National Research Council (NRC). 1996. Finger millet. p. 39-57 In Lost crops of Africa: volume I: grains. Board on Science and Technology for International Development. National Academy of Sciences, National Academy Press, Washington D.C.

NRC. 1992. Conserving Biodiversity. A Research Agenda for Development Agencies. National Research Council, Washington, DC.

Obilana, A.B., E.O. Manyasa, J.G. Kibuka, and S. Ajanga. 2002. Finger millet blast samples collection in Kenya: passport data, analyses of disease incidence and report of activities. ICRISAT, Nairobi, Kenya.

Oduori, C.O.A. 2008. Breeding investigations of finger millet characteristics including blast disease and striga resistance in western Kenya. Unpublished PhD Thesis, University of Kwazulu Natal, Pietermaritzburg, South Africa.

Oduori, C.O.A., P. Tongoona, W.A.J. de Milliano, M.D. Laing, and O.M. Odongo. 2007. Improvement of finger millet through combination breeding. In: Proceedings of the Third Generation Meeting on Biotechnology, Breeding and Seed Systems for African crops, March 26-29, at Joachim Chissano International Conference Centre, Maputo: p. 182.

Okwadi, J. 2007. Importance and characteristics of finger millet processing Uganda. P. 102-111. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi, Kenya.

Pall, B.S. 1988. Effect of seed-borne inoculum of *Pyricularia setariae* Nishikado on the finger millet blast. Agricultural Science Digest (Karnal), 8:225-226.

Pande, S., S.Z. Makuru, R.O. Odhiambo, and R.I. Karunakar. 1993. Seed-borne infection of *Eleusine coracana* by *Bipolaris nodulosa* and *Pyricularia grisea* in Uganda and Kenya. The American Phytopathology Society, 78:60-63.

Parashuram, D.P., J. Gowda, R.G. Satish, and N.M. Mallikarjun. 2011. Heterosis and combining ability studies for yield and yield attributing characters in finger millet (*Eleusine coracana* (L.) Gaertn.). Electronic Journal of Plant Breeding, 2:494-500.

Prabhu, A.S., M.C. Filippi, and F.P. Zimmermann. 1996. Genetic control of blast in relation to nitrogen fertilization in upland rice. Pesq. agropec. bras., Brasilia, 31:339-347.

Prasada Rao, K.E., J.M.J. de Wet, V. Gopal Reddy, and M.H. Mushonga. 1993. Diversity in small millets collection at ICRISAT. P. 331 – 346. Riley, K.W., S.C. Gupta, A. Seetharam and J.N. Mushonga (Eds). Advances in small millets. International Science Publisher, New York, USA.

Purchase, J.L. 1997. Parametric analysis to describe genotype x environment interaction and yield stability in winter wheat. South African Journal of Plant and Soil, 17:101-107.

Rachie, K.O. and L.V. Peters. 1977. The *Eleusines*: A Review of the World Literature. International Crops Research Institute for the Semi – Arid Tropics. 1 – 11 – 256, Begumpet, Hyderabad, - 500016 (A P) India.

Ramagosa, I. and P.N. Fox. 1993. Genotype x environment interaction and adaptation. In: Plant Breeding: Principles and Prospects. Eds. Hayward, M.D., N.O. Bosemark, and I. Ramagosa. Chapman and Hall, London, 1993, Publication.

Ratnakar, M.S., N.M. Mallikarjuna, K.S. Naveen-Kumar, M.V. Jayarame Gowda, M.V. Mohan Kumar. 2009. Cytomorphological studies in inter-specific hybrids of finger millet. Gregor Mendel Foundation Proceedings, 2009:69-74.

Ravikumar, R.L. 1988. Genetic and biochemical basis of blast resistance in finger millet (*Eleusine coracana* Gaertn.). PhD Thesis, University of Agricultural Sciences, Bangalore, India.

Riley, K.W., A. Seetharam, and G. Harinarayana. 1989. Small Millets in Global Agriculture: Proceedings of the First International Small Millets Workshop, Bangalore, India, 29 Oct. -2 Nov. 1986. Oxford and IBH Publishing, New Delhi, India.

Robinson, R.A. 1968. The concept of vertical and horizontal resistance. Rev. Appl. Mycol., 48:593-606.

Roumen, E., M. Levy, and J.L. Notteghem. 1997. A better knowledge of the population structure in characterization of the European population of the blast pathogen *Magnaporthe grisea*. Cahiers Options Méditerranéennes, 15:120-124.

Ruiz, C.P. 2003. Stratego DC 250 – a new means of control for *Pyricularia oryzae*, *Rhizoctonia solani*, and other important rice-disease pathogens in Colombia. Pflanzenschutz-Nachrichten Bayer, 56:399-416.

Samonte, S.O.P.B., L.T. Wilson, A.M. McClung, and J.C. Medley. 2005. Targeting cultivars onto rice growing environments using AMMI and SREG GGE biplot analysis. Crop Science, 45:2414-2424.

Santhkumar, G. and B.T.S. Gowda. 1998. Inheritance of some qualitative characters in the cross WR 9 x U 6 of *Eleusine coracana* G. Indian Journal of Genetics, 58:381-382.

Seetharam, A. and R.L. Ravikumar. 1993. Blast resistance in finger millet. Its inheritance and biochemical nature. In. P. 449 – 465. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga (Eds), Advances in small millet. New York international science publisher, New York City, New York.

Seetharaman, R. and D.P. Srivastava. 1972. Further investigations in cigar-shaped panicle in rice. Indian Journal of Genetics and Plant Breeding, 33:35-42.

Shailaja, H.B., S.Thirumeni, K. Paramasivam, and T. Ramanadane. 2010. Combining ability analysis in Finger millet *Eleusine coracana* (L.) Gaertn.) under salinity. Electronic Journal of Plant Breeding, 1:129-139.

Singh, B.D. 1993. Plant Breeding. Principles and Methods. Kalyani Publishers, New Dehli.

Singh, P. and F. Narayanan. 1993. Biometrical Techniques in Plant Breeding. Kalyani publishers, New Delhi.

Singh, R.K. and B.D. Chaundhary. 1977. Biometrical Methods in Quantitative Genetics Analysis. Kalyani publishers, New Dehli, p. 304.

Solanki, J.S., S.R. Maloo, and S.P. Sharma. 2000. Stability analysis for seed yield in finger millet. Indian Journal of Agricultural Research, 34:268-270.

Sreenivasaprasad, S., J.P. Takan, M.A. Mgonja, E.O. Manyasa, P. Kaloki, N. Wanyera, J. Okwadi, S. Muthumeenakshi, A.E. Brown, and J.M. Lenne. 2005. Enhancing finger millet production and utilisation in East Africa through improved blast management and stakeholder connectivity. Aspects of Applied Biology, 75:11-22.

Sumathai, P., A.J. Joel, and V. Muralidharan. 2007. Genetic variability in the hybrids of finger millet [*Eleusine coracana* (L.) Gaertn.]. Crop Research, 33:192-194.

Takan, J.P., B. Akello, P. Esele, E.O. Manyasa, A. Obilana, P.O. Audi, J. Kibuka, M. Odendo, C.A. Oduori, S. Ajanga, R. Bandyopadhyaya, S. Muthumeenakshi, R. Coll, A. E. Brown, N.J. Talbot, and S. Sreenivasaprasad. 2004. Finger millet blast pathogen diversity and management in East Africa: a summary of project activities and outputs. International Sorghum and Millets Newsletter, 45:66-69.

Takan, J.P., S. Muthumeenakshi, S. Sreenivasaprasad, B. Akello, R. Bandyopadhyaya, R. Coll, A. E. Brown, and N.J. Talbot. 2002. Characterisation of finger millet blast pathogen populations in East Africa and strategies for disease management. [online] Available: www.bspp.org.uk/archives/bspp2002/bspp02postertitles.htm (date accessed: 21/01/2013).

Talbot, N.J. 2003. On the trail of a cereal killer: exploring the biology of *Magnaporthe grisea*. Annual Review of Microbiology, 57:177-202.

Uddin, W. 2000. Gray leaf spot comes on strong. [online] available: http://groundsmag. com/ar/grounds_maintenance_gray_leaf_spot/ (date accessed 26 December. 2010).

Upadhyaya, H.D., C.L.L. Gowda, and V. Gopal Reddy. 2007. Morphological diversity in finger millet germplasm introduced from Southern and Eastern Africa. An Open Access Journal Published by ICRISAT. 3:1

Utami, D.W., S. Moeljopawiro, E.M. Septiningsih, and S.R. McCouch. 1999. Molecular breeding for blast resistance. In: Proceedings of the International Programme on Rice biotechnology, Phuket, Thailand.

Vaithiyalingan, M., V. Manoharan, and N. Ramamoorthi. 2010. Association analysis among yield and yield attributes of early season drought tolerant groundnut (*Arachis hypogaea* L.). Electronic Journal of Plant Breeding, 1:1347-1350.

Van Wyk, B.E. and N. Gericke. 2000. People's plants: a guide to useful plants of southern Africa. Briza, Arcadia.

Vavilov, N.I. 1951. The origin, variation, immunity and breeding of cultivated plants. The Roland Press Co., New York.

Wanyera, N.M.W. 2007. Facilitating the promotion of improved and blast resistant finger millet varieties to enhance production. P. 66-67. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Werth, C.R., K.W. Hilu, and C.A. Langner. 1994. Isozymes of *Eleusine* (*Gramineae)* and the origin of finger millet. American Journal of Botany, 81:1186-1197.

Witcombe, J.R., K.D. Joshi, R.B. Rana, and D.S. Virk. 2001. Increasing genetic diversity by participatory variety selection in high production systems in Nepal and India. Euphytica, 122:575-588.

Yan, W. and L.A. Hunt. 1988. Genotype x Environment Interaction and Crop Yield. Plant Breeding Reviews, 16:135-228. Ed. Janick, J. In: John Wiley and Sons, inc.

Yan, W., L.A. Hunt, Q. Sheng, and Z. Szlavnics. 2000. Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Science, 40:597-605.

Yan, W. and M.S. Kang. 2003. GGE biplot analysis: a graphical tool for breeders, geneticists, and agronomists. CRC Press LLC. 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431, USA.

Zobel, R.W., J.W. Madison, and H.G. Gauch. 1988. Statistical analysis of a yield trial. Agronomy Journal, 80:388-393.

2.0 Chapter two

Production constraints and farmer preferences for a finger millet variety: Implications for breeding

Abstract

Finger millet is an important food security and cash crop in Uganda but its production is constrained by a number of factors. However, information on the current status of these constraints and farmers' varietal preferences is limited. A study was conducted to: (i) identify the varieties, (ii) identify trait preferences in finger millet, and (iii) assess farmers' constraints to finger millet production and coping mechanisms. The study was divided into two components: (i) a participatory rural appraisal (PRA) and ii) a survey conducted with individual farmers to augment the PRA findings. Farmers identified the major constraint as high labour requirements especially for weeding since over 95% of the farmers used broadcasting as a method of planting. Other constraints that occurred across all the districts were blast disease and low yielding cultivars currently used by farmers. The other constraints reported depended on the farmer groups from the different districts. Farmers also reported to have developed some coping mechanisms/strategies to counter the constraints. In terms of preference for new finger millet cultivars, farmers preferred high grain yield, brown seed colour, compact head shape, tolerance to blast disease, high tillering ability, moderate plant height (1 ± 0.2 m), early maturity, tolerance to shattering and ease of threshing without compromising other preferred attributes. The study further found that a considerable proportion of the farmers had limited or no knowledge on finger millet blast disease, its causes and mechanism of coping. Some of the farmers however, recognised the disease but associated it with other causes. Farmers also reported that blast disease symptoms in all locations were on the increase over the years and pointed out the most susceptible and tolerant cultivars. These findings therefore, present an urgent need for information sharing with farmers and other agricultural development partners, and continuous development of blast resistant cultivars with farmer preferred attributes.

Key words: Blast disease, finger millet, head shapes, participatory rural appraisal, selection criteria, varietal preferences

2.1 Introduction

Finger millet is an important staple food crop in Uganda where it is believed to have originated, but its production is still low. Tenywa et al. (1999) reported farmer grain yield of 400-800 kg ha^{-1} in Uganda which is very low compared to 2,500 kg ha^{-1} attainable in research conditions. The low yields are a manifestation of the low attention and research input accorded the crop (Bedis et al., 2006; Fakrudin et al., 2004). Use of poor unimproved landraces susceptible to finger millet blast disease and drought are the other major contributors to low yields in Uganda. A study by Wanyera (2007b) identified finger millet blast disease as one of the highest priority constraints to finger millet production in Uganda affecting the crop at all stages of growth and affecting most of the landraces and other genotypes. The study also reported that damage by blast in finger millet resulted in major yield losses. The Consultative Group on International Agricultural Research (CGIAR) and the National Research Council (NRC) (1996) believe more research can lead to yields of 'green revolution' cereals of rice and wheat.

In Uganda over 80% of the population is involved in subsistence agriculture with the most important cereals being maize, finger millet and sorghum in that order (Wanyera, 2007a). These farmers contribute over 90% of finger millet production (MAAIF, 2008) in harsh environments that make most of them stick to their landraces and reluctant to adopt improved cultivars (Okwadi, 2007). According to Wanyera (2007a), some improved cultivars have been released but adoption by the small-scale farmers, the main growers of finger millet, is low. Kidoido et al. (2002) suggests a number of reasons for this scenario, principal among them is the failure of breeders to involve and incorporate farmers' concerns in their cultivars development. The outcomes have been new cultivars with limited or no consideration to special preferences of the target farmers in the marginal environments (Banziger and Cooper, 2001; Thiele et al., 1997). To enhance adoption, breeding will have to be based on clear understanding of farmers' preferential trait attributes in new cultivars and appropriate solutions to their specific and unique constraints. One of the options suggested by Banziger et al. (2000) is participatory variety development to capture perspectives and ensure ownership of the new cultivars. This therefore makes the participatory breeding approach a way of knowing these farmers' experiences so as to include them in the breeding objectives (Islam et al., 2008).

2.1.1 Participatory plant breeding

Participatory plant breeding has been suggested as an effective alternative to formal plant breeding as a strategy for achieving productivity gains under low input conditions. In recent years, there has been an increasing shift in paradigm that the farmers' participation in technology development increases the likelihood of technology adoption (Islam et al., 2008). Participatory plant breeding has many advantages, among them increased and more stable productivity, better understanding of farmers' varietal criteria and faster release and adoption of varieties. Formal plant breeding approaches have been ineffective as is evident in both non-adoption of improved varieties by farmers and lack of breeding progress as reflected by performance of adopted varieties under low input conditions (Banziger and Cooper, 2001). Farmers have an extensive and well adapted knowledge based on their environments, crops and cropping patterns built up over many seasons and generations (Banziger et al., 2000). Participatory crop improvement involves farmers directly in the process of variety improvement and testing at an earlier stage than in a conventional breeding process. It is designed to better incorporate perspectives of end users than formal plant breeding, reach resource poor farmers, breed for high-stress and diverse conditions and incorporate wide variation in traits for specific farmer preferences (Dorward et al., 2007). There has been success and impact of conventional and centralized plant breeding programmes in high-input areas compared to the marginal and variable small-scale farming sector. Thus, for such marginal regions a participatory breeding approach may be more effective (Morris and Bellon, 2004). Participatory approach has been used and reported to be quite effective in several cases such as in maize in Mexico and Honduras (Banziger et al., 2000) and in India (Witcombe et al., 2001).

In order to estimate the potential adoption of the new varieties and facilitate overall evaluation of potential benefits of developing new varieties, an assessment of attributes of finger millet varieties preferred by farmers and the socio-economic environment under which the farmers operate is an important starting point. Acceptability of agricultural technologies by farmers depends on how well researchers have identified farmers' objectives and constraints (Upton, 1987). As breeders involve farmers as participants, they will learn more about the most important criteria of farmers' preferences in cultivars; this encourages the use of locally adapted cultivars and makes the breeders less dependent of foreign materials (Daniel et al., 2007). Farmer

evaluations help scientists to design, test and recommend new technologies in light of information about farmers' preferences. In this context, participation is crucial. Participatory research also allows incorporation of farmers' indigenous technical knowledge, identification of farmers' criteria and priorities and definition of research agenda (Chambers, 1994). Participatory rural appraisal (PRA) tools are usually applied to determine farmers' perceptions and preferences (Kidoido et al., 2002), it involves local people in collecting and analyzing information, allows seeking of insights about their local and actual conditions and fosters dialogue between scientists and farmers. By integrating farmers' concerns and conditions into agricultural research, research will develop technologies that become widely adopted, resulting in more productive, stable, equitable and sustainable agricultural systems.

2.1.2 Participatory rural appraisal

Participatory rural appraisal in Uganda has gained popularity since its inception and some have been conducted in the semi-arid areas of eastern Uganda (Okwadi, 2007). Kidoido et al. (2002) conducted a PRA in Soroti district and identified constraints limiting agricultural production as mainly low income, lack of markets, drought, poor infrastructure, pests and diseases; the report also indicated that farmers in the districts of study were interested in early maturing varieties tolerant to drought and resistant to major pests and diseases. Another PRA conducted by Tenywa et al. (1999) in the districts of Kumi, Pallisa and Kamuli found that drought and soil fertility were the major constraints limiting finger millet production in these districts. Wanyera (2007a) also reported that the farmers in eastern Uganda planted mainly the local landraces leading to low yields. In the districts of Kaberamaido, Amuria and Soroti; blast disease, drought and poor soils were identified as the other major constraints limiting finger millet production. Whereas, Takan et al. (2004) found blast the most important disease to finger millet production in Uganda with incidences of up to 50% and severity of up to 68% in the major growing areas. Most farmers were however, not aware of the cause of blast disease, modes of transmission and control measures of this disease. None of the reports however pointed to specific farmer preferences in a blast resistant, high yielding finger millet variety.

The use of blast resistant finger millet cultivars therefore might be the most effective blast control measure for small-scale farmers in marginal areas since it is compatible with their low-input farming practices. This suggests a need to urgently develop blast resistant cultivars with

farmer preferred attributes to overcome this major production constraint as this would enhance acceptance and adoption of such varieties by farmers. To achieve this, the first step was to carry out a participatory rural appraisal and a survey among selected farmers and farmers' groups in some of the major growing districts with the following objectives: (i) to identify the finger millet varieties farmers grow, (ii) to identify trait preferences in finger millet, and (iii) to assess farmers' constraints to finger millet production and coping mechanisms.

2.2 Materials and Methods

The study was divided into two components: i) a participatory rural appraisal was conducted to reveal the varieties farmers were growing, preferences in finger millet cultivars, production constraints and knowledge on blast disease and management, and ii) a survey was also conducted with individual farmers to confirm and supplement the PRA findings.

2.2.1 Sampling procedure and Data collection

A multi-stage sampling procedure was used to select the sites for the study that represent diverse ecological and socio-economic environments in the finger millet growing areas of Uganda. Selection was based on relative importance of finger millet in the agro-ecological zone, major constraints and severity of finger millet blast disease. A preparatory survey was conducted before the PRA in all the study areas, in which a team visited each of the selected district agricultural officers, and from these meetings, sub-counties that produce the most finger millet were identified and selected. The extension officers from the sub-counties were requested to identify farmer groups to participate in the PRA exercise and select individual farmers for the survey. Additional relevant data were also collected from other partners in the agricultural sector with specific interest on finger millet.

The participatory rural appraisal (PRA) and survey were conducted in three selected districts of eastern Uganda, namely: Kumi, Bukedea and Kaberamaido. Focus group discussions were held with four farmer groups, one each for Kumi and Bukedea and two in Kaberamaido. These districts were selected because finger millet is one of the most important cereals and a staple crop. The discussions were to determine the major crops grown, finger millet varieties, main constraints to finger millet production and identify preferences for new finger millet varieties.

The focus group discussion was conducted using a checklist (appendix 2.1) and the major crops and constraints were subsequently ranked using pair-wise ranking method. The current varieties and trait preference were also ranked but according to frequencies of respondents. A semi-structures questionnaire (appendix 2.2) was used for the survey to supplement the findings from the focus group discussions. The survey was conducted with 15 individual farmers each from both Kumi and Bukedea, and 30 from Kaberamaido. The survey focused particularly on finger millet farmers who grow the crop every year. A total of 149 farmers participated in the focus group discussions and the numbers ranged from 30 – 46 in each group. There were 33 farmers in Kumi, 40 in Bukedea and 76 in Kaberamaido groups. For the individual household survey, there were sixty farmers involved of whom 27 where female and 33 were males or 45% and 55% respectively. The districts are shown in Figure 2.1. The coordinates for the districts are as follows: Kumi (1° 30N, 33° 57E), Bukedea (1° 21N, 34° 04E) and Kaberamaido (1° 47N, 33° 09E).

2.2.2 Data analysis

The data generated were analysed using descriptive statistics to characterize and summarise the farmers' responses from all the study sites in Statistical Package for Social Scientists (SPSS) version 20 (SPSS, 2011).

2.3 Results

2.3.1 Major crops grown

The major crops grown in the three districts are indicated in Table 2.1. In Kumi and Bukedea, finger millet was grown mainly during the long rains (March – July), whereas in Kaberamaido many farmers grew it in both seasons since both rain seasons were said to be stable and finger millet is the major food crop. Finger millet also ranked higher in Kaberamaido and Bukedea than Kumi, as these areas received reliable rainfall in both seasons and the yields were considerably higher in both seasons. In Kaberamaido, during the first rains both groups reported finger millet as the most important crop and was their main food crop, however, in the second rains maize seemed to be the major cereal probably because of the higher labour requirements associated with finger millet production.

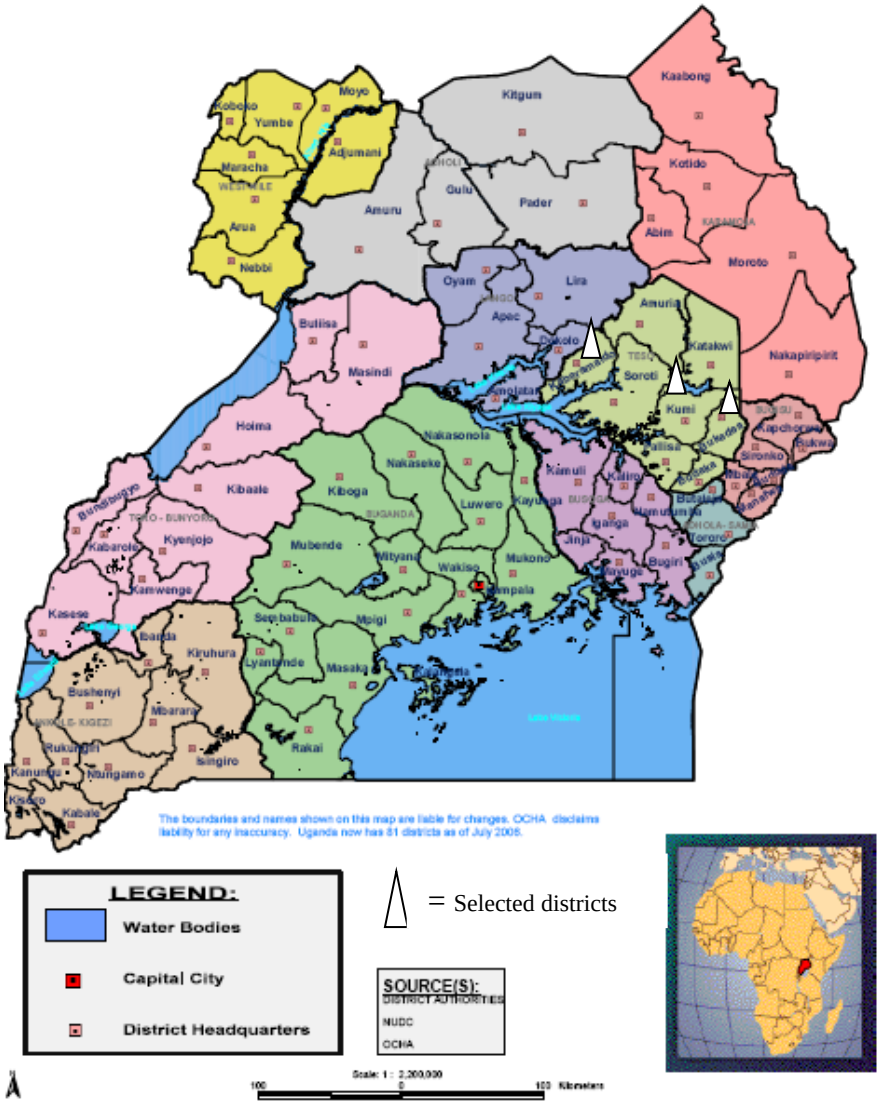


Figure 2.1 Map of Uganda showing the selected districts for the study. *Map adapted from*: United Nations Office for the Coordination of Humanitarian Affairs.

In Kumi, farmers' preference to grow finger millet in the first rains was due to adequate moisture/precipitation during the season, ease of land preparation after the dry season (December – March), and higher yields obtained during the first rains compared to the second rains. Tradition was also noted to account for non-growing of finger millet during the second rains and high labour requirements. It was also established that during the first rains the crops escaped damage by grass hoppers, web worms, shoot fly and aphids which are highly prevalent during

the second rains. Farmers in Kaberamaido also indicated higher rains during the March – July season, but rainfall was equally adequate during the second season. Ease of working used fields from the preceding seasons prior to the dry season and well filled grains for the first rains were also reported.

Table 2.1: Major crops grown in different districts and seasons ranked in order of importance

Crop	Kumi		Bukedea		Kaberamaido			
	Akukurantu farmers' group		Nyakoi farmers' group		Ajuko farmers' group		Awasi farmers' group	
Season 1								
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Groundnuts	07	1	09	2	01	8	01	8
Cassava	05	2	06	4	05	4	05	3
Sweet potatoes	05	3	04	7	-	-	04	5
Green grams	04	4	05	5	-	-	-	-
Cowpeas	03	5	02	10	-	-	-	-
Sorghum	02	6	03	8	02	7	02	7
Finger millet	02	7	08	3	08	1	08	1
Maize	00	8	10	1	06	3	05	4
Beans	-	-	04	6	03	6	-	-
Paddy rice	-	-	03	9	-	-	-	-
Bambara nuts	-	-	01	11	-	-	-	-
Sesame	-	-	-	-	07	2	07	2
Sunflower	-	-	-	-	04	5	03	6
Soybeans	-	-	-	-	00	9	01	9
Season 2								
Groundnuts	05	3	-	-	-	-	-	-
Cassava	07	1	05	2	-	-	03	7
Sweet potatoes	05	2	02	7	-	-	-	-
Green grams	02	6	03	5	-	-	-	-
Cowpeas	03	5	04	4	-	-	03	5
Sorghum	04	4	05	3	-	-	06	3
Finger millet			00	8	03	2	03	6
Maize	01	8	06	1	03	1	06	2
Pearl millet	01	7	-	-	-	-	-	-
Beans	-	-	03	6	01	5	07	1
Sesame	-	-	-	-	01	4	-	-
Sunflower	-	-	-	-	02	3	05	4
Soybeans	-	-	-	-	-	-	01	9
Cotton	-	-	-	-	-	-	02	8

The scores were obtained from pair-wise ranking and is equivalent to the frequency of the crop in column and row representing the crop. Low score = high ranking indicating crop is less preferred. In case of a tied score, voting was carried out to rank the respective crops.

In Bukedea district, adequate rains, ease of land preparation, low weed prevalence, early maturity due to adequate moisture and low pest risk were the reasons for preference of growing finger millet during the first rains. Some farmers also reported less *striga* severity during the first rainy season.

2.3.2 Finger millet use

The various uses of finger millet are indicated in Table 2.2. In Kumi and Bukedea, it is mainly grown for its high nutritious value where it is used for porridge for children and food, and food security requirements as it stores well for long periods and high quality bread as reported across all the three districts. High quality beer was reported across all districts but ranked higher in Kaberamaido. In Kaberamaido however, porridge was ranked lowest by both groups.

Table 2.2: Finger millet use ranked across districts

Finger millet use	Kumi	Bukedea	Kaberamaido	
	Nyakoi farmers' group	Ajuko farmers' group	Ajuko farmers' group	Awasi farmers' group
Finger millet bread	√ 1st	√ 3rd	√ 1st	√ 1st
Porridge / *Uji*	√ 2nd	√ 2nd	√ 4th	√ 4th
For sale / cash as grain	√ 3rd	√ 1st	√ 3rd	√ 3rd
Local brew	√ 4th	√ 4th	√ 2nd	√ 2nd
Exchange for labour	√ 5th	√ 7th	-	-
Loan security	√ 6th	-	-	-
Poultry feed	√ 7th	√ 6th	-	-
Exchange for other crops	√ 8th	-	-	-
Seed source	√ 9th	√ 5th	-	-

-, *denotes use not considered as major or even mentioned.*

2.3.3 Farmers' preference for improvement

Table 2.3 shows a list of farmers' preferences in a finger millet variety as ranked by the farmer groups. Some few farmers indicated that some of the improved varieties did not have good taste and aroma in food and/or could not make quality brew. It was however, agreed in all the groups that there was need for improvement in the current varieties grown by most of the farmers. The major areas of improvement included: high grain yield, tolerance to blast disease, high tillering ability, plant height, early maturity, tolerance to shattering and ease of threshing without compromising the attributes preferred in their landraces.

2.3.4 Major finger millet varieties grown and associated attributes

Preferred finger millet varieties by district are indicated in Table 2.4. The varieties most preferred were Eserait and Etiyo in Kumi, Etiyo and Pese 1 in Bukedea, and Otunduru in Kaberamaido. Farmer groups also listed important advantages and disadvantages of the various

varieties grown (Table 2.5). It was found that the varieties differed from the different districts, and this mainly depended on distance from one district to another. Bukedea being close to Kumi had similar varieties, that is, Etiyo and Omududu, where as Kaberamaido which is far from these two districts had completely different varieties. For the two groups in Kaberamaido, most of the varieties grown were also similar. This observation could be an indication that the varieties in far off areas have been evolving independently with no or limited mixes, and limited movement of the varieties. Among the farmers' groups, improved varieties: Pese 1 and Seremi 2 were prevalent in Bukedea and Kumi only, whereas no improved material was reported in Kaberamaido. This could be due to close proximity of the two districts to Serere Research Institute compared to Kaberamaido and need for up-scaling dissemination activities to all finger millet growing areas.

Table2.3: Farmers preferences for improvement - ranked by percentage

Variety characteristic	**Kumi Akukurantu farmers' group (n = 33)**		**Bukedea Nyakoi farmers' group (n = 40)**		**Kaberamaido Ajuko farmers' group (n = 30)**		**Awasi farmers' group (n = 46)**	
	Frequency (%)	Rank	Frequency (%)	Rank	Frequency (%)	Rank	Frequency (%)	Rank
Large head size	100	1	100	1	-	-	80.4	4
High grain yield	100	1	100	1	100	1	100	1
Large grain size	84.9	3	-	-	-	-	-	-
Brown – reddish brown grain colour	66.6	4	47.5	6	-	-	30.4	7
Higher grain mass	63.6	5	-	-	-	-		-
Disease tolerance	60.6	6	62.5	3	40	8	80.4	4
Compact head shape	54.6	7	27.5	8	83.3	3	80.4	4
Ease of harvest and threshing	51.5	8	40	7	43.3	7	-	-
Early maturity	48.5	9	-	-	93.3	2	-	-
Tolerance to lodging	39.4	10	-	-	-	-	-	-
Tolerance to shattering	36.4	11	50	5	-	-	47.8	5
Drought and heat tolerance	30.3	12	70	2	-	-	89.1	2
Good aroma and taste	27.3	13	-	-	63.3	4	-	-
Pest resistance	-	-	57.5	4	-	-	-	-
High tillering ability	-	-	27.5	8	-	-	87	3
Quality brew	-	-	27.5	8	83.3	3	30.4	7
Medium plant height (1 ± 1.2 m)	-	-	-	-	60	5	-	-
High marketability	-	-	-	-	50	6	-	-
Deep green colour of leaves	-	-	-	-	-	-	37	6

– *denotes characteristic not reported.*

The farmer groups were asked to rate the importance of finger millet traits on a scale of 1-5 and these are summarised in Table 2.5. High yields, brown seed colour and medium height were preferred across all the three districts by all the farmer groups. For the main varieties in the different districts; Eserait was liked mainly for large grain size, reddish-brown colour, early maturity, compact head shape and medium plant height. Etiyo was liked for large head size, reddish brown colour, high marketability, compact head shape, early maturity, and good aroma and taste in food. While Otunduru was preferred for large head size, high grain yield, large grain size, brown seed colour, blast disease tolerance, compact head shape, tolerance to shattering, long storage life, brewing quality, and good taste and aroma. Otunduru was however, noted to be late maturing and with high plant height which made harvesting more difficult especially for women who mainly harvest the crop, meanwhile for Etiyo the grains were reported to be of small size and the plants were shorter making harvesting difficult.

Table 2.4: Finger millet cultivars grown by district

Variety	**Kumi**	**Bukedea**	**Kaberamaido**	
	Akukuruantu farmers' group	**Nyakoi farmers' group**	**Ajuko farmers' group**	**Awasi farmers' group**
Eserait	√ 1st			
Etiyo	√ 2nd	√ 1st		
Omududu	√ 4th	√ 3rd		
Seremi 2	√ 3rd			
Pese 1		√ 2nd		
Obeet		√ 4th		
Otunduru			√ 1st	√ 1st
Oturolwete			√ 2nd	√ 3rd
Ekama			√ 3rd	√ 2nd
Emiroit			√ 4th	√ 4th
Ebaati			√ 5th	√ 6th
Omunga				√ 5th
Ongomi				√ 7th
Okurowiye				√ 8th

Table 2.5: Major attributes of finger millet cultivars grown in the districts of Kumi, Bukedea and Kaberamaido of eastern Uganda

Positive trait attribute	Variety and ranking of the varieties for the different trait attributes													
	Eserait	**Etiyo**	**Omududu**	**Seremi 2**	**Pese 1**	**Obeet**	**Otunduru**	**Oturolwete**	**Ekama**	**Emiroit**	**Ebaati**	**Omunga**	**Ongomi**	**Okurowiye**
Large head size	-	1	2	3	1	-	1	2	-	-	-	-	-	-
High grain yield	2	2	3	3	2	2	1	2	3	2	4	3	3	1
Large grain size	1	5	1	2	1	1	1	3	4	3	1	-	1	1
Brown – reddish brown seed colour	1	1	5	1	2	5	1	4	4	5	1	4	2	2
Higher grain mass	-	-	-	2	-	-	1	-	-	-	-	-	-	-
Disease tolerance	-	-	-	2	3	-	1	-	-	-	-	-	-	-
Compact head shape	2	2	5	2	4	5	1	3	4	5	1	2	2	1
Ease of harvest and threshing	-	-	-	1	-	-	-	4	-	-	-	-	-	4
Early maturity	2	2	3	1	¾	4	5	2	1	4	3	1	2	3
Tolerance to lodging	-	-	-	1	3	-	-	-	-	-	-	-	-	-
Tolerance to shattering	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Drought and heat tolerance	-	-	-	(1)	-	-	1	-	-	5	4	-	-	-
Good aroma and taste	-	2	-	2	-	-	1	4	-	-	-	3	-	-
Pest resistance	-	-	-	-	-	-	-	-	-	-	-	--	-	-
Plant height	2	3	5	1	2	2	4	1	4	1	1	4	3	4
Quality brew	-	-	-	-	4	-	1	3	3	-	-	-	4	1
High marketability	-	1	4	1	-	-	-	1	-	-	-	-	-	-
High tillering ability	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Greenness		-	-	-	-	-	-	-	-	-	-	-	-	-
Long storage life	-	-	-	-	-	-	1	-	-	-	-	-	-	1

Ranking used is 1 – 5; with 1 most desirable attribute of the trait and 5 least desirable attribute of the trait. Whereas – denotes attributes not reported.

2.3.5 Constraints to finger millet production in Eastern Uganda and coping mechanisms

The major constraint reported across the three districts (Table 2.6) was the high labour requirements especially for weeding since 95% of all the farmers involved used broadcasting as a means of planting.

Table 2.6: Major production constraints ranked in order of importance across districts

Constraint	Kumi		Bukedea		Kaberamaido			
	Akukuruantu farmers' group		Nyakoi farmers' group		Ajuko farmers' group		Awasi farmers' group	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
High labour cost	05	1	04	1	06	1	02	1
Insect pests	04	2	-	-	00	7	-	3
Birds	04	3	-	-	-	-	01	-
Blast disease	03	4	03	4	02	5	02	2
Striga	02	5	01	6	-	-	-	-
Declining soil fertility	02	6	-	-	05	2	-	-
Low yielding varieties	01	7	03	3	04	3	01	4
Drought	-	-	03	2	03	4	-	-
Land shortage	-	-	01	5	-	-	-	-
Striga	-	-	-	-	-	-	-	-
Thefts	-	-	-	-	01	6	-	-

The scores were obtained from pair-wise ranking and is equivalent to the frequency of the crop in column and row representing the crop. Low score = high ranking indicating crop is less preferred. In case of a tied score, voting was carried out to rank the respective crops.

Other constraints that occurred across all the districts were blast disease and low yielding cultivars currently used by farmers. The other constraints depended on the farmer groups from the different districts, for instance, insect pests were reported in Kumi and Kaberamaido groups but not in Bukedea, drought was reported in Bukedea and one of the groups in Kaberamaido, and declining soil fertility was also reported in Kumi and one of the groups of Kaberamaido but not in Bukedea. Farmers reported to have developed some coping mechanisms/strategies (Table 2.7) against bird damage, declining soil fertility, drought and land shortage but none for blast disease management and lack of improved seed. For bird damage farmers reported scarring, use of scare crows and planting when birds seemed to be in their breeding seasons somewhere else. This was particularly reported for the voracious *Quelea quelea* whose absence was presumed to coincide with their breeding seasons probably in the swamps, rivers and lake shores. This was based on

personal experiences of the farmers. For fertility, most farmers reported use of manure and rotation; whereas, to mitigate land shortage most farmers practiced intercropping and land hire.

Table 2.7: Coping mechanisms for major production constraints

Problem	Coping mechanism	Percentage of responses
High labour costs	-Hire of casual labour	91
	-Reduction in acreage	65
	-Row planting	5
	-Use of previously used field	56
Insect pests	-None	100
Bird damage	-Scarring birds	44
	-Planting to escape peak population	62
Blast disease	-None	100
Low yielding varieties	-Use of improved varieties	8
Drought	-Planting short duration varieties	43
	-Early planting	62
Striga weed	-Growing sweet potatoes and legumes	43
	-Use of crop rotation	54
	-Use of intercropping	34
Land shortage	-Use of intercropping	86
	-Land hire	15
Declining fertility	-Use of organic manures	73
	-Crop rotation	68
	-Use of inorganic fertilizers	6
Thefts	-Early harvest	38
	-Storage in the house	64

2.3.6 Farmers knowledge on blast disease

After a comprehensive description of blast disease and its effects on finger millet by the team, majority of the farmers recognised the disease but associated it to other causes like witch-craft and drought and had no local name for it, only a very small fraction were aware of the disease and had a name for it. In Kumi and Bukedea it was called *ejetele* (chaffy or dry heads) whereas there was no name given to it in Kaberamaido. On the occurrence of blast disease symptoms farmers in all locations reported that symptoms were on the increase over the years and pointed out the most susceptible and tolerant cultivars. Farmers in Kumi pointed out that only Seremi 2 was tolerant while in Kaberamaido, Otunduru was the most tolerant cultivar. It was noted in Kumi and Bukedea that Pese 1 which was very tolerant before is currently showing more symptoms of the disease than previously. Farmers also reported that susceptibility was higher in open headed cultivars compared to fisted/compact headed cultivars**.** Cause and spread of the disease was not known among the farmers/farmers' groups creating a serious lack of awareness of the pathogen, pathogen development and spread and therefore control mechanism.

2.3.7 Cropping practices: Field operations

Improvement of a production system would require as a first step identification of major constraints and therefore potential interventions that should recognise the current production practices by the farmers. Most farmers surveyed used ox-plough and hand hoe for seed-bed preparation (98.3%) and only a small faction (1.7%) used tractors, while the major method of planting was broadcasting which was predominant in all the districts with only a small proportion 2 to 5% employing row planting. This scenario probably explains the high labour requirements as the main constraint to finger millet production coming especially from weeding. It was also noted that most farmers planted cultivar mixtures, and even where pure varieties were grown there was still a high degree of physical mixtures. Although most mixtures seemed to be accidental, some were intended by the farmers for a number of reasons namely yield stability, obtaining higher yields, determining suitable cultivars, lack of labour and land to grow separately the different cultivars, and to maintain some old but desirable landraces.

From the survey, inorganic fertilizers were used by a small number of farmers (16.7%), coupled with declining fertility this can also be seen as a major contributor to the low finger millet yields. The few who used inorganic fertilizer used DAP and Urea, whereas a considerable number

reportedly used organic fertilizers in the forms of farm yard and compost manure for amendment and improvement.

2.3.8 Finger millet yield and household production

The majority of the farmers growing finger millet in the three districts grew between 0.5 to 2.0 acres (Table 2.8) although more farmers in Kaberamaido had larger fields than other areas with some farmers growing up to 2.5 hectares. Kaberamaido had relatively higher yields compared to the other district probably due to ownership of larger plots of land which allowed for adequate rotation, maintaining relatively higher fertility compared to the other districts.

Table 2.8: Area under finger millet

Area (hectares)	**Percentage of respondents**	
	Season 1 (n = 60)	**Season 2 (n = 60)**
0.00	0	51.7
0.20	15	16.6
0.40	48.3	30
0.50	1.7	0
0.60	6.7	0
0.80	18.3	0
1.20	5	0
1.60	0	1.7
2.00	3.3	0
2.40	1.7	0
Total	**100.0**	**100.0**

2.3.9 Sources of information

The farmers who participated in the PRA reported several sources of information including: community/neighbours, Non-Governmental Organisations (NGOs), research organisations, government extension and universities as shown in Table 2.9. Community and farmer-to-farmer information dissemination was the most commonly used and therefore needed to be strengthened and integrated with the other sources reported by the different groups. The NGOs tended to operate in localised areas, and in their respective areas of operation they were reported as one of the main sources of information. For instance; FAO, TPO, AFRICARE and CCF operated in Kaberamaido but not in Kumi and Bukedea, whereas CIP operated only in Kumi as UNDP and P'KWII operated only in Bukedea among the PRA districts. The government agencies NARO and NAADS were reported in all the districts though not by all farmers, an indication that these are important source of agricultural information that can be strengthened by integrating with other sources.

2.3.10 Finger millet seed sources

The sources mentioned were; own saved seeds, local markets, relatives, neighbours/friends and research; local market being the main source with a number of farmers also obtaining seed from more than one source as indicated in Table 2.10.

Table 2.9: Organisation/information sources reported by farmers

Information source	Percentage of farmers reporting from each farmer group			
	Akukuruantu farmers' group (total n = 33)	Nyakoi farmers' group (total n = 40)	Ajuko farmers' group (total n = 30)	Awasi farmers' group (total n = 46)
Community/neighbours	100	87.5	100	97.8
Makerere University	100	0	0	0
NARO	100	37.5	23.3	4.5
LEAD USAID	69.7	0	16.7	23.9
NAADS/Government extension	100	5.0	40	39.1
CIP	100	0	0	0
NUSAF	100	100	43.3	0
UNDP	0	100	0	0
P'KWII	0	55.0	0	0
FAO	0	0	100	73.9
TPO	0	0	20	100
AFRICARE	0	0	30	100
CCF	0	0	46.7	0

NARO; National Agricultural Research Organisation, NAADS; National Agricultural Advisory Services, CIP International potato centre (Centre international de la Papa), NUSAF: Northern Uganda Social Action Fund, UNDP: United Nations Development Programme, P'KWII: Popular knowledge women's' initiative, FAO Food and Agricultural Organisation, TPO Trans-cultural Psychosocial Organisation, AFRICARE, and CCF: Christian Children Fund

Table 2.10: Sources of finger millet seed used by the Surveyed farmers

Seed source	Percentage of respondents using source (n = 60)
Local markets	46.7
Own saved seed	13.3
Relatives	11.7
Neighbours/friends	8.3
Research	5.0
Local markets + research	3.3
Local markets + neighbours	5.0
Local markets + research + neighbours	3.3
Relatives + neighbours	1.7
Relatives + neighbours + research	1.7
Total	**100.0**

n = number of farmers surveyed

2.4 Discussion

2.4.1 Finger millet production constraints in selected districts of eastern Uganda

In the current study, farmers identified high labour costs as the leading constraint to finger millet production. This finding is consistent with earlier studies carried out by Okwadi (2007), Kidoido et al. (2002), and Tenywa et al. (1999), in which farmers had earlier on pointed out labour costs as a major constraint to finger millet production. This mainly occurred because of the finger millet seed size which required a very fine seedbed, and with over 95% of the farmers planting through broadcasting, it makes weeding and harvesting difficult.

The major biotic stress reported across all the districts was finger millet blast disease, with some reports of insect pests as reported in Kumi district, and occasionally the notorious and voracious *Quelea quelea* birds. This study revealed the persistence of the blast disease problem in finger millet production which was showing signs of increase, both in terms of incidence and severity over the years. The evidence of the increase was shown by a high proportion of farmers from their responses, including those who had observed it on the originally resistant cultivars. In Bukedea and Kumi, the prevalence was reported to be exceptionally higher compared to Kaberamaido. The increase in prevalence over the years could be due to emergence of new races, recycling of infested seed and accumulation of inoculum through crop debris, volunteer crops and weeds. Whilst the reported low prevalence in Kaberamaido compared to the other two districts could point to longer fallow periods in rotations affordable in Kaberamaido since the household land holdings were higher, a difference in pathogen races and probably early selection and seed treatment by the Kaberamaido farmers.

2.4.2 Farmers' varietal preference in finger millet

In terms of preference for new finger millet cultivars, farmers who participated in this study preferred high grain yield, brown seed colour, compact head shape, tolerance to blast disease, high tillering ability, moderate plant height (1 ± 0.2 m), early maturity, tolerance to shattering and ease of threshing without compromising the attributes preferred in their landraces. The major preferred varieties were Eserait and Etiyo in Kumi, Etiyo and Pese 1 in Bukedea, and Otunduru

in Kaberamaido (Table 2.4). Brown seed colour was preferred because it mixes well with dry cassava chips to produce flour that is used for making local bread (*Kwon* or *Atap*) and has high malting quality for local brew as also reported by Salasya et al. (2009). This probably indicates that the main use of finger millet in the study areas is for food (both *Atap* and porridge). It was also pointed out that reddish – brown grain colour was more preferred in the market and fetched higher prices compared to other grain colours. In addition, bird damage was reported to be less on the brown and dark coloured grains than the whitish coloured grains. In these communities therefore, brown-grained finger millet cultivars are important as a food and nutrition security crop and for cash as well. Grain colour therefore is associated with its utility value as was also pointed out by Oduori and Kanyenji (2007), and hence has influence on the market value of the crop. Darker grain colours were also associated with low blast incidence and/or severity and less bird damage probably due to association with tannins. White and light-grained genotypes were reported by Seetharam and Ravikumar (1993) to have highly significant higher protein and lower phenols and tannins while brown-grained genotypes had relatively less protein with high phenols and tannins. Muthulisi et al. (2007) also reported pigmented grain types to contain higher levels of tannins and phenolics than light coloured grain types. Their findings suggested that in general, white-grained genotypes were more susceptible than brown and dark-grained types to blast disease.

Compact or fisted head shape was associated with higher grain yield, less shattering, blast disease tolerance and limited bird damage making it a highly preferred trait. Cultivars with compact head shape ensured the farmer of yield in situations of high blast occurrence and serious bird damage. The high yield still ensured that there was enough food at the farmers' household and surplus for sale. Early maturing cultivars on the other hand were associated with drought escape, early relief for hunger, and minimizing crop loss through disease escape especially if sowing was done early (Wanyera, 2007b). This was particularly observed in Kumi with shorter rainy periods compared to Kaberamaido where drought seemed not to be important and their most preferred variety was a long duration cultivar. Another factor for the seemed preference of a longer duration cultivar was because of lack of short duration cultivars available in

Kaberamaido. There has been an effort (after the survey) to introduce Seremi 2, a short duration cultivar with relatively high yield to Kaberamaido district.

On plant height; farmers preferred medium plants because of ease of harvest as also observed by Wanyera (2007a), and reduced lodging which occurs in taller plants. The other reason as pointed out by Kimani et al. (2011) on rice was that short varieties are near the ground and would increase damage due to rodents, water splash, ground walking birds and termite damage on grains. They also observed that birds found it easy to perch on the shorter varieties because they were relatively stronger.

2.4.3 Farmers' knowledge on finger millet blast disease

Based on this study, a considerable proportion of the farmers had limited or no idea about the disease, its causes and mechanism of coping. The majority of the farmers however, recognised the disease but associated it with other causes like witch-craft and drought and had no name for it; only a very small fraction were aware of the disease and had a name for it. In Kumi and Bukedea it was called *ejetele* whereas there was no name given to it in Kaberamaido. On the occurrence of blast disease symptoms farmers in all locations reported that symptoms were on the increase over the years and pointed out the most susceptible and tolerant cultivars. Farmers in Kumi pointed out that only Seremi 2 was tolerant while in Kaberamaido, Otunduru was the most tolerant cultivar. It was noted in Kumi and Bukedea that Pese 1, which was very tolerant, was now showing more symptoms of the disease than in earlier years. Farmers also reported that susceptibility was higher in open headed cultivars compared to fisted/compact headed cultivars similar to findings of Takan et al. (2004). The cause and spread of the disease was not known among the farmers/farmers' groups; creating a serious lack of awareness of the pathogen, pathogen development and spread, and therefore no control mechanisms were reported. This is an indication of the need for more and vigorous research and adequate extension services to manage the disease. In the short term, a number of genotypes are to be evaluated in different environments of the finger millet growing areas to: a) study the pathogen, b) identify sources of resistance and c) increase the resistant materials with farmer preferred attributes and channel them to the farmers through different seed uptake pathways. This approach of resistance

breeding is more applicable to the small-scale resource poor farmers who grow finger millet with low inputs who are the majority of finger millet growers in the country.

2.4.4 Sources of agricultural information

Major access to information was through farmer to farmer contrary to what Mhike et al. (2012) found for drought tolerant maize varieties in Zimbabwe. Information access through farmer to farmer ranged from 87.5% of the farmers surveyed to 100% for the different farmer groups. This means that involvement of lead farmers or groups in breeding and dissemination activities may be a successful option. Government agencies were reported across all the other groups as sources of information. These were the government extension system and the national research organisation but at varying levels (Table 2.9). NGOs were also identified, but they tended to be localised in particular areas of operation though with high levels of coverage in those particular areas than the government agencies. Inspite of the visible information exchange among the farmers, lack of information was still apparent on finger millet improved varieties, blast disease and other associated finger millet production technologies. This has resulted in farmers growing their old varieties with low yields due to lack of options. Strengthening information dissemination or flow would therefore involve breeding in partnership with farmers, government extension and the private sector.

2.5 Conclusion and implications for breeding

This study demonstrated and revealed the importance of finger millet in Uganda as a food, food and nutrition security, and income crop. The major constraints included among others: high labour requirements, biotic stress factors chief among them finger millet blast disease; declining soil fertility, drought and land shortage in some areas. Farmers in the study area showed preference for high grain yield, brown seed colour, compact ear shape, tolerance to blast disease, high tillering ability, medium plant height of 1 ± 0.2 m, early maturity, tolerance to shattering and ease of threshing without compromising the attributes preferred in their landraces. The study also revealed that a considerable proportion of the farmers had limited or no idea on finger millet blast disease, its causes and control strategies. The majority of the farmers recognised the disease

but associated it with other causes; this therefore calls for more research and adequate extension services to manage the disease. As a short term management strategy, a number of genotypes with considerable resistance are to be evaluated in the different environments of the finger millet growing areas to: a) study the pathogen, b) identify sources of resistance and c) increase the resistant materials with farmer preferred attributes and channel them to the farmers through different seed uptake pathways. In the long term, development of blast disease resistant varieties through breeding is to be pursued. This approach has been proved more applicable to the small-scale resource poor farmers, the majority of whom are finger millet growers in Uganda. There is also limited involvement of the private sector in the finger millet improvement and seed system, a revelation that requires the strengthening and support of current players, that is, the private sector, NGOs and government extension system coordinated by the public sector breeding program for efficient development and delivery of clean seed and associated technologies to the finger millet farmers.

References

Banziger, M. and M. Cooper. 2001. Breeding for low input conditions and consequences for participatory plant breeding: examples from tropical maize and wheat. Euphytica, 122: 503-519.

Banziger, M., G.O. Edmeades, D. Beck, and M. Bellon. 2000. Breeding for drought and nitrogen stress tolerance in maize: From theory to practice. Mexico, D.F.: CIMMYT.

Bedis, M.R., B.N. Ganvir, and P.P. Patil. 2006. Genetic variability in finger millet. Journal of Maharashtra Agricultural University, 31:369-370.

Chambers, R. 1994. Participatory Rural Appraisal (PRA): Challenges, potentials and paradigm. World Development, 22:1437-1454. Elsevier Science Ltd. Great Britain.

Daniel D., J. Parveviet, C. Almekinders, and G. Thiele. 2007. Farmers' participation and breeding for durable disease resistance in the Andean region. Euphytica, 153:385 – 396.

Dorward, P., P. Craufurd, K. Marfo, W. Dogbe, and R. Bam. 2007. Improving participatory varietal selection process: Participatory varietal selection and the role of informal seed mechanisms for upland rice in Ghana. Euphytica, 155:315–327.

Fakrudin, B., R.S. Kulkani, H.E. Shashidhar, and S. Hittalmani. 2004. Genetic diversity assessment of finger millet, *Eleusine coracana* (Gaertn), germplasm through RAPD analysis. Biodiversity International Newsletter, 138:50-54.

Islam, M.R., M.A. Salam, M.A.R. Bhuiyan, M.A. Rahman, and G.B. Gregorio. 2008. Participatory variety selection for salt tolerance. International Journal of BioResources, 4:21-25.

Kidoido, M.M., V. Kasenge, S. Mbowa, J.S. Tenywa, and P. Nyende. 2002. Socio-economic factors associated with finger millet production in eastern Uganda. African Crop Science Journal, 10:111-120.

Kimani, J.M., P. Tongoona, J. Derera, and A.B. Nyende. 2011. Upland rice varieties development through participatory plant breeding. Asian Research Publishing Journal, 6:39-49.

Mhike, X., P. Okori, G.T. Kassie, C. Magorokosho, and S. Chikobvo. 2012. An appraisal of farmer variety selection in drought prone areas and its implication to breeding for drought tolerance. Journal of Agricultural Sciences, 4:27-43.

Ministry of Agriculture Animal Industry and Fisheries (MAAIF). 2008. P. 48-49. Facts and Figures for the Agricultural Sector 2008. An Annual Report of Agricultural Planning Department, Entebbe, Uganda.

Morris, L. and R. Bellon. 2004. Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. Euphytica, 136:21-35.

National Research Council, USA. 1996. Finger millet. P. 39-57. In: Lost crops of Africa: volume I: Grains. Board on Science and Technology for International Development. National Academy of Sciences, National Academy Press, Washington D.C.

Oduori, C.O.A. and B. Kanyenji. 2007. Finger millet in Kenya: Importance, Advances in R & D, Challenges and opportunities for improved production and profitability. Facilitating the promotion of improved and blast resistant finger millet varieties to enhance production. P. 10-22. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Okwadi, J. 2007. Importance and characteristics of finger millet processing Uganda. P. 102-111. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Salasya, B., C. Oduori, N. Ambitsi, E. Onyango, P. Oucho, and J. Lumuli. 2009. The status of finger millet production in western Kenya. African Crop Science Conference Proceedings, 9:719-723.

Seetharam, A. and R.L. Ravikumar. 1993. Blast resistance in finger millet. Its inheritance and biochemical nature. In. P. 449 – 465. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga (Eds), Advances in small millet. New York international science publisher, New York City, New York.

SPSS 20.0, (2011). SPSS Inc. 2011. Headquarters, 233 S. Wacker Drive, 11th floor Chicago, Illinois, USA.

Takan, J.P., B. Akello, P. Esele, E.O. Manyasa, A. Obilana, P.O. Audi, J. Kibuka, M. Odendo, C.A. Oduori, S. Ajanga, R. Bandyopadhyaya, S. Muthumeenakshi, R. Coll, A. E. Brown, N.J. Talbot, and S. Sreenivasaprasad. 2004. Finger millet blast pathogen diversity and management in East Africa: a summary of project activities and outputs. International Sorghum and Millets Newsletter, 45:66-69.

Tenywa, J.S., P. Nyende, M. Kidoido, V. Kasenge, J. Oryokot, and S. Mbowa. 1999. Prospects and constraints of finger millet production in eastern Uganda. African Crop Science Journal, 7:569-583.

Thiele, G., G. Gardner, R. Torrez, and J. Gabriel. 1997. Farmer involvement in selecting new varieties: Potatoes in Bolivia. Experimental Agriculture, 33: 275-290.

Upton, M. 1987. African Farm Management. New York. Cambridge University Press. U.S.A.

Wanyera, N.M.W. 2007a. Finger millet (*Eleusine coracana* (L) *Gaertn*) in Uganda. P. 1-9. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Wanyera, N.M.W. 2007b. Facilitating the promotion of improved and blast resistant finger millet varieties to enhance production. P. 66-67. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Witcombe, J.R., K.D. Joshi, R.B. Rana, and D.S. Virk. 2001. Increasing genetic diversity by participatory variety selection in high production systems in Nepal and India. Euphytica, 122:575-588.

3.0 Chapter three

Genetic variability and path coefficient analysis of secondary traits on yield in finger millet

Abstract.

There is currently no information on variability, heritability and trait association on finger millet in Uganda. Therefore the objectives of this study were to assess the variability, heritability and association of traits of the Ugandan germplasm. A total of 100 finger millet accessions consisting mainly of landraces from Uganda were evaluated for morpho-agronomic characters in a 10 x 10 lattice design with three replications at NaSARRI and Ikulwe during the long and short rains of 2011. Analysis of variance was conducted and mean squares of the genotypes were significant for all the traits studied with days to 50% flowering showing the least coefficient of variation and leaf blast severity the highest. The mean performance of 15 top yielding accessions at both sites ranged from 3.23 – 4.56 tons ha^{-1}, with seven common accessions. High resistance to both leaf and head blast at both sites was recorded from a few accessions. Heritability estimates ranged from 7.39% for threshing percentage to 68.4% head blast severity whereas values of expected genetic advance varied from 2.00 to 79.9% for threshing percentage and head blast severity, respectively. High heritability and genetic advance estimates were exhibited for head blast severity, head blast incidence, productive tillers $plant^{-1}$ and grain yield. Correlation analysis revealed high positive association between grain yield ha^{-1} with panicle width, finger number, number of productive tillers and grain mass per head, but highly negative with leaf blast incidence, head blast severity and days to 50% flowering. When the significant correlations were decomposed by path analysis, it further revealed that in determining yield the most important traits were grain mass per head, tillering ability and reaction to head blast disease. These showed high significant direct effects compared to the other traits. Overall the result revealed existence of high variability for the traits studied in the finger millet accessions which can be utilised in genetic improvement through selection and/or hybridisation.

Key words: *Eleusine coracana,* genetic advance, germplasm, finger millet, heritability, landrace, variability

3.1 Introduction

Finger millet (*Eleusine coracana* (L.) Gaertn) is a member of the *Chloriroidea* family and sub-family *Poaceae* believed to have originated from eastern Africa (National Research Council (NRC), 1996), its centre of origin and diversification (Oduori, 2008; Bezaweletaw et al., 2006 and NRC, 1996). It is an important allo-tetraploid cereal crop widely cultivated in the arid and semi arid regions of the world. Being rich in protein, iron and calcium, finger millet serves as an important staple food for rural populations in developing tropical countries where calcium deficiency and anaemia are widespread (Babu et al., 2013). In Uganda, finger millet is the second most important cereal after maize cultivated in over 470,000 ha, producing over 850,000 metric tons $year^{-1}$ (FAOSTAT, 2012) in several ecological zones with heterogeneous climatic conditions. The cultivars grown include mostly landraces adapted to the various local conditions and a few improved and introduced materials.

In terms of research however, this important nutri-cereal has been largely neglected and often categorised as an orphan crop (Kumar and Pande, 2010; Wanyera, 2007) mainly grown by subsistence farmers who employ their own methods of selection to preserve and try to improve their germplasm. These farmers grow mainly landraces, and compounded with other production constraints the yields are often low, in most cases less than one metric ton ha^{-1} (Okwadi, 2007; Kidoido et al., 2002). A few new varieties have been released through the years (Wanyera, 2007) and disseminated in some parts of the country with varying degrees of success. Replacement of landraces by modern pure-line cultivars may however, reduce the genetic variation in the cropping system. Nonetheless, some germplasm collection and maintenance has been carried out by the National Semi Arid Resources Research Institute (NaSARRI) though not fully complete and with some challenges a number of accessions are being preserved at the institute.

Reports indicate that there is existence of high variability, but despite the high range of availability of materials and urgent need to improve finger millet productivity through genetic manipulation little is known about the Ugandan germplasm in terms of variability, major traits, trait associations and the potential usefulness of the individual accessions being maintained. Bezaweletaw et al. (2006) indicated that investigating and identifying plants for available variation in the breeding material is the first step of a successful plant breeding and crop improvement programme. Studies have been conducted elsewhere but not in Uganda to measure

variability in finger millet collections based on morphological and agronomic traits and in certain cases molecular studies have also been conducted; even in these studies however, a considerable number of accessions were left out. High trait variability among finger millet traits have been observed in finger millet from previous studies (Oduori 2008; Bezaweletaw et al. 2006; Prasad Rao et al., 1994) suggesting broad diversity apparent among finger millet germplasm that were studied in Kenya, Ethiopia and India, respectively. This would therefore provide ample opportunities for genetic improvement of the crop through selection directly from the available germplasm or traits recombination through intra-specific hybridisation of desirable traits. Lamo (2010) and Oduori (2008) in their studies of rice and finger millet respectively, used mean comparisons and frequency distribution methods to characterise their germplasm. This could be equally applicable in the current study to characterise the finger millet accessions at NaSARRI which if evaluated for trait variability and association would serve as a foundation for the breeding programme.

Grain yield is a complex character and is considered as the ultimate product of its components. Hence selection of superior genotypes based on grain yield is difficult due to the integrated structure of plants in which most of the characters are interrelated and being governed by many genes (Falconer and Mackay, 1996). This necessitates a thorough knowledge on the nature of relationships prevalent between contributory characters and grain yield and the extent of genetic variability (Bezaweletaw et al., 2007). Besides, determination of the interrelationships between various agronomic characters and their direct and indirect effects on grain yield may provide a clue for crop breeders in improving the productivity of the crop and also a pre-requisite to plan a meaningful breeding programme and approach (Singh and Narayanan, 1993).

In the study of trait inter-relationships, correlation and path analyses have been conducted in several crops; correlations indicating the nature and degree of inter-relationship among yield and its component characters whereas path analysis indicates direct and indirect contributions of the characters towards yield (Akanda and Mundt, 1996). In path coefficient analysis, grain yield is considered a dependent variable and the remaining traits are considered as independent (causal) variables (Singh and Chaundhary, 1977). A path coefficient is simply a standardised partial regression coefficient and, as such estimates the direct influence of one variable upon another and permits separation of correlation coefficients into components of direct and indirect effects

(Dewey and Lu, 1959). The direct contribution of an independent variable to the variation observed in the dependent variable can be determined with reduced confounding influences caused by multicolinearity. The purposes of conducting path analysis in this study were to determine both effects of blast disease on yield components of finger millet and the relative importance of the disease and yield components on yield and to unravel the opposing effects between variables along the different paths of influence.

3.1.1 Objectives

The purpose of the investigations carried out in this study was to determine the variability and trait interrelationships in Ugandan finger millet germplasm for selected agronomic traits and blast disease reaction. This was based on the premise that there is high heritable genetic variation which could be exploited to develop high yielding varieties with adequate levels of blast resistance that farmers would accept and adopt. The specific objectives were to:

I. assess the variability and performance of the different accessions in terms of yield and reaction to blast disease,
II. assess the amount of variability which is heritable in order to design appropriate breeding and selection strategies that will best exploit any found variability, and
III. assess the trait association among finger millet accessions for future use in the breeding programme.

3.2 Materials and Methods

The experiments were conducted at NaSARRI (Latitude 1° 29' 39N Longitude 33° 27' 19E 1085 m.a.s.l,) and Ikulwe (0° 27' 3N; 33° 28' 16E; 1157 m.a.s.l,) satellite station during the 2011 main cropping season using 100 different cultivars and landraces collected from different regions of the country. The 100 accessions were collected from all the finger millet producing regions of Uganda which included; Lango, Westnile, and Acholi in the North; Ankole and Bunyoro in the west; and Bukedi, Bugisu and Teso in the east. Some introductions from the International Crops Research Institute for Semi and Arid Tropics (ICRISAT) Nairobi were also sown along side five improved cultivars from NaSARRI at both stations. A lattice design with three replications and plot size of six rows of 3 m long and 1.5 m wide with row spacing of 30 cm and plant to plant spacing of 10 cm was used. Data was collected on the following traits: leaf blast incidence, leaf blast severity, head blast incidence and head blast severity under natural infestation, days to 50%

flowering, number of productive tillers, flag leaf length, flag leaf width, finger number per head, grain mass per head, threshing percentage, single plant yield and yield ha^{-1}. At NaSARRI additional data was taken on finger length, finger width, peduncle length, panicle length and width and plant height. Data were taken from 40 randomly selected plants from two mid rows for each of the accessions following finger millet descriptors (IBPGR, 1985). Some of the descriptors are as follows:

1. Plant height (cm) from ground level to the tip of inflorescence (head) at dough stage,
2. Productive tillers: number of basal tillers which bear mature heads,
3. Days to 50% flowering from sowing to stage when heads emerge from 50% of main tillers,
4. Finger length (cm) from base to the tip of longest spike (finger) on main tiller at dough stage,
5. Finger number on main head at dough stage, and
6. Grain yield per plant: mean was taken from ten plants, post-harvest.

    a. Grain yield (tons ha^{-1}): measured as grain mass was taken from the fourty plants, post-harvest and converted to tons ha^{-1}. Using the formula:

    b. $$\text{Grain yield}(\text{tons ha}^{-1}) = \frac{333{,}333 \text{ x Yield of the 40 plants (Kg)}}{40 \text{ x } 1000}$$

Leaf blast (LB) incidence and severity were recorded at booting stage approximately 45 to 50 days after emergence as recommended by Babu et al. (2013) and head blast (HB) observations were recorded at the time of grain maturity. The disease incidence was calculated as the number of diseased plants divided by the total number of plants sampled per plot. Leaf blast severity was estimated on the basis of leaf area covered by lesions using 1 – 5 rating scale of Mackill and Bonman (1992). The percent disease index (PDI) for determining leaf blast severity (LBS) was calculated using the formula given by Wheeler (1969) as follows:

$$\text{LBS} = \frac{n_1 \text{ x } 1 + n_2 \text{ x } 2 + n_3 \text{ x } 3 + n_4 \text{ x } 4 + n_5 \text{ x } 5}{\text{Total number of leaves observed x maximum grade}}$$

n_1 to n_5 represent the total number of leaves falling under 1 – 5 scale, respectively.

The resultant percentages were categorized as follows: immune – 0.0%, highly resistant 0.1 -5%, resistant 5.1 – 10%, moderately susceptible 10.1 – 25% and susceptible >25%.

For head blast severity, all heads from the 10 plants were used to determine blast severity at maturity. For each head, proportions of spikelets affected by the disease were estimated and a Standard Evaluation System (SES, IRRI, 1996) was adopted. This is based on the number of heads, and head blast severity computed as follows:

$$\text{HBS} = \frac{(10 \text{ x } N1) + (20 \text{ x } N2) + (40 \text{ x } N5) + (70 \text{ x } N7) + (100 \text{ x } N9)}{\text{Total number of panicles}}$$

N1 – N9 are number of panicles infected with the disease, multiplied with the corresponding portion infected. From the resultant percentages, the genotypes were categorised as follows: 0%; no incidence or immune, less than 5% as highly resistant, 5-10% resistant, 11 -25% moderately resistant, 26 – 50% susceptible and more than 50% highly susceptible.

Meteorological data for year 2011

Site	Month	Rain fall (mm)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)
Ikulwe	Jan	31.7	32.5	19.0	62
	Feb	2.3	33.9	19.6	67
	March	121.2	32.2	19.9	71
	April	89.5	31.8	19.4	79
	May	142.4	29.4	19.3	85
	June	82.6	28.7	19.2	83
	July	50.3	29.1	18.5	82
	August	184.7	28.0	18.3	84
	September	116.5	28.3	18.5	83
	October	177.4	28.9	18.8	79
	November	162.2	28.4	18.7	83
	December	37.1	30.3	18.9	70
NaSARRI	Jan	60.0	30.0	15.1	78
	Feb	27.2	29.9	15.4	80
	March	201.2	28.7	16.3	78
	April	132.8	28.3	16.7	80
	May	130.6	27.3	16.4	84
	June	92.5	27.7	15.5	87
	July	59.8	27.9	15.0	86
	August	159.6	26.8	15.3	89
	September	191.6	27.2	16.2	88
	October	331.4	27.6	17.8	80
	November	177.3	27.4	17.7	88
	December	55.3	27.6	17.6	82

3.2.1 Data analysis

Analysis of variance

All data collected were subjected to the analysis of variance (ANOVA) to obtain mean squares for genotypes, and the residual using GenStat (edition 12) (Payne et al., 2009). The genotypic (σ^2_g), phenotypic (σ^2_p), interaction (σ^2_{ge}) and error (σ^2_e) variances were computed using the formulae of Burton and De Vane (1953) (as cited by Bezaweletaw et al., 2006) as σ^2_g = (MSg-MSge)/re; $\sigma^2_p = \sigma^2_g + \sigma^2$ge)/e + σ^2e/re, where MSg = genotypic mean square, MSge = mean square due to genotype x environmental interaction, e = number of environments and r = the number of replications. σ^2ge = (MSge – Mse)/r, where MSe = combined error mean square. The phenotypic (PCV), genotypic (GCV), environmental (ECV), and genotype x environment (GECV) coefficients of variability were estimated following the procedures of Kumar et al. (1985); PCV = 100(σ_p)/ $\bar{x}$; GCV = 100(σ_g)/ $\bar{x}$; ECV = 100(σ_e)/ $\bar{x}$; and GECV = 100(σ_{ge})/ $\bar{x}$ where σ_p = phenotypic standard deviation, σ_g = genetic standard deviation, σ_e = environmental standard deviation, σ_{ge} = genotypic x environmental standard deviation and $\bar{x}$ = trait mean.

Heritability (H^2) in the broad-sense was estimated by the formulae of Allard (1960); $H^2 = \sigma^2_g / \sigma^2_p$. Expected genetic advance (GA), assuming selection intensity of 5% was estimated according to the method of Johnson et al. (1955); GA = K H^2 σ_p, where K was the selection intensity constant at 5% (K = 2.056), H^2 the broad sense heritability and σ_p the phenotypic standard deviation. The genetic advance as a percent of mean was obtained as: GA (% of mean) = 100 (GA/ $\bar{x}$), where GA = genetic advance, and $\bar{x}$ = population mean for the trait considered. The heritability estimates were classified according to Robinson et al. (1949) into three classes, that is 0 – 30% low, 31 – 60% as medium, and > 60% as high. On the other hand, Johnson et al. (1955) categorised genetic advance as a percentage of mean into 0 – 10% low, 10 – 20% moderate and > 20 % as high. These categorisations were used in this study.

3.2.2 Correlation and path analysis

The Pearson's correlation coefficients between all possible pairs of quantitative traits and path analysis were carried out and tested for their significance in SAS programme version 9.2 (SAS, Cramer et al., 1997) using PATHSAS software. The path coefficient analysis was used to

decompose the correlation coefficients into direct and indirect effects and to clarify the relationships between different traits with grain yield. The direct and indirect effects of yield related to quantitative traits on grain yield were calculated following the formula suggested by Dewey and Lu (1959) (as cited by Lule et al., 2012) as $r_{ij} = P_{ij} + r_{ik}P_{kj}$ where; r_{ij} is mutual association between the independent character (i) and dependent character (j) as measured by the correlation coefficient; P_{ij} is the component of direct effects of the independent character (i) and dependent character (j) as measured by the path coefficient and ; $\sum r_{ik}P_{kj}$ is the summation of indirect effect of a given dependent character (j) via all other independent characters (k). Residual effects, which determine how best the causal factor accounts for the variability of the dependent character was estimated by the formula $\sqrt{1-R^2}$; Where $R^2 = P_{ij}r_{ij,}$ P_{ij} = component of direct effects of the independent character (i) and dependent character (j) as measured by the path coefficient; r_{ij} = mutual association between the independent character (i) and dependent character (j) as measured by the correlation coefficient.

Scales suggested by Lenka and Mishra (1973) in rice studies and used by Lule et al. (2012) of path coefficients values 0.00 to 0.09 as negligible, 0.10 to 0.19 as low, 0.20 to 0.29 moderate and 0.30 to 0.99 as high path coefficient were used in this study. This scale was supplemented by the significance test of the direct effects using PATHSAS software in SAS computer package.

3.3 Results

3.3.1 Variation among the accessions used

The analysis of variance results (Table 3.1) showed highly significant ($p \leq 0.001$) differences between the genotypes for all the traits studied, an indication that the accessions tested were highly variable. The coefficient of variations ranged from 5.3% for days to 50% flowering to 28.1% for leaf blast severity. The top yielding 15 genotypes are also presented in Table 3.2 for both NaSARRI and Ikulwe.

3.3.2 Mean performances of finger millet accessions for yield and reactions to blast disease

The mean performance of 15 top yielders and blast resistant genotypes at both NaSARRI and Ikulwe are indicated in Table 3.2. The highest yields of the top 15 accessions ranged from 3.83 – 4.56 tons ha^{-1} at NaSARRI, meanwhile, at Ikulwe it ranged from 3.23 – 3.84 tons ha^{-1}. Seven

accessions among the top 15 yielders that appeared at both sites were: Achaki acc # 84, Okwangapel acc # 19, Otunduru acc # 23, Emumware acc # 86, Bulo acc # 77, Ekama acc # 95 and Kali acc # 38. Of the 15 top yield performers at both sites, Bulo # 77 had low leaf blast scores at both sites while Achaki, Ekama # 95 and Kali # 38 showed least scores only at Ikulwe. Additionally, among these seven top yielders at both sites, Otunduru # 23 showed least head blast at Ikulwe while Achaki # 84 and Emumware # 86 had least scores at NaSARRI. At NaSARRI eight accessions among the top 15 yield performers had least leaf blast scores whereas at Ikulwe there were five. For head blast scores, of the top 15 yield performers at NaSARRI, four were among the least diseased genotypes, while two had low scores at Ikulwe.

Based on head shapes, among the top 15 yield performers at NaSARRI, six were fist shaped, three open head types, two top-curved and incurved head shaped types, while at Ikulwe, three were fisted, one open, seven-top curved and four incurved. Least head blast scores were recorded from six fisted, one open, one top-curved and eight incurved genotypes at NaSARRI while at Ikulwe there were four fisted, none open, four incurved and seven top curved head shaped genotypes indicating incurved and fisted had more head blast resistant genotypes while open had the least.

The mean leaf blast scores for the 15 least affected accessions were: 3.86 – 7.41% and 1.78 – 4.87% for NaSARRI and Ikulwe respectively, while the mean head blast scores for the 15 least affected accessions varied from 9.52 – 13.61% and 1.7 – 8.45% at NaSARRI and Ikulwe respectively. However, apart from the top 15 accessions, 51% of the accessions altogether had leaf blast scores of less than 10% at Ikulwe. At NaSARRI; 17 accessions had leaf blast scores of less than 5%. Twenty four accessions had head blast scores of less than 10% at Ikulwe whereas at NaSARRI there were only two accessions. Among the 15 top yield performers at NaSARRI, Aringo acc. # 26, exhibited high head blast scores, while among the top yield performers at Ikulwe, three accessions; Etiyo-D acc. # 64 and Okwangapel acc. # 19 and Engenyi acc. # 90 exhibited high leaf blast scores.

Table 3.1: Analysis of variance for yield and yield related traits, and blast disease in 100 genotypes at four environments

SOV	DF	Mean squares												
		DTF	HBS	LBS	HBI	LBI	FN	FLL	FLW	PTP	GWH	TP	SPY	GYH
Envt	3	0.15	0.268***	1.64***	4.081***	4.286***	207.51**	2199.57***	157.68***	17.9**	25.05***	0.255***	128.09***	14.13***
Rep (Envt)	8	39.61***	0.002	0.006***	0.052***	0.018	3.44***	248.13***	17.23***	0.99	3.37***	0.022***	6.066***	0.67**
Genotype	99	31.41***	0.092***	0.013***	0.228***	0.072***	2.522***	28.8**	2.75***	1.806**	4.17**	0.009*	22.184**	2.46***
Genotype x Envt	297	18.34***	0.016***	0.007***	0.041***	0.029***	0.55***	24.54***	1.93*	0.48*	1.27**	0.009*	4.136***	0.46**
Error	792	11.94	0.003	0.002	0.009	0.01	0.34	11.5	1.649	0.12	0.435	0.007	0.747	0.083
CV		5.3	26.4	28.1	16.5	23	9.6	10.6	10.2	10.8	10.4	11.3	10.3	10.3

DTF = days to 50% flowering, HBS = head blast severity, LBS = leaf blast severity, HBI = head blast incidence, LBI = leaf blast incidence, FN = Finger number, FLL = flag leaf length (cm), FLW = flag leaf width (cm), PTP = Productive tillers per plant, GWH = grain mass head^{-1} (g), TP = Threshing percentage, SPY = Single plant yield (g), GYH = Grain yield per hectare (tons ha^{-1})

Table 3.2: Mean performances in yield, leaf blast scores and head blast scores of the top accessions at NaSARRI and Ikulwe during 2011, season, 1

Yield in tons ha^{-1}				Leaf blast scores (%)				Head blast scores (%)			
Top performing accessions											
NaSARRI		Ikulwe		NaSARRI		Ikulwe		NaSARRI		Ikulwe	
Accession (†)	**Yield**	**Accession (†)**	**Yield**	**Accession (†)**	**Score**	**Accession (†)**	**Score**	**Accession (†)**	**Scores**	**Accession (†)**	**Score**
Achaki Acc # 84 (F)	4.56	Etiyo – D Acc # 64 (TC)	3.84	Angoromi Acc # 91 (F)	3.86	IE 812 Acc # 49 (IC)	1.78	IE 2244 Acc # 46 (F)	9.52	Etiyo – B Acc # 05 (F)	1.70
Bulo Acc # 77 (TC)	4.55	Achaki Acc # 84 (F)	3.84	Bulo Acc # 77 (TC)	4.87	IE 2790 Acc # 20 (TC)	2.29	Obongiti Obokiriti) Acc # 72 (IC)	9.56	Kali Atar – A Acc # 62 (IC)	3.24
Ebule kasabale Acc # 29 (F)	4.42	Okwangapel Acc # 19 (IC)	3.81	Aringo Acc # 26 (IC)	4.81	Bulo Acc # 77 (TC)	2.64	Omunga Acc # 35 (IC)	10.83	UK – Ogoloi Acc # 02 (TC)	4.38
Emumware Acc # 86 (IC)	4.37	Engenyi Acc # 90 (TC)	3.64	Bulo – B Acc # 74 (IC)	4.90	Lira market Acc # 41 (F)	2.99	IE 2663 Acc # 60 (IC)	11.44	Kali – B Acc # 58 (IC)	6.15
Angoromi Acc # 91 (F)	4.33	SEC 915 Acc # 51 (TC)	3.61	IE 812 Acc # 49 (IC)	6.05	Ekama Acc # 95 (F)	3.03	Achaki Acc # 84 (F)	11.99	Ebule kasabale Acc # 29 (F)	6.31
Lira market Acc # 41 (F)	4.30	Seremi 1 Acc # 61 (TC)	3.61	IE 2244 Acc # 46 (F)	6.13	Kalialer Acc # 79 (TC)	3.15	Angorom Acc # 91 (F)	12.01	Namata Acc # 24 (IC)	6.90
Okwangapel Acc # 19 (IC)	4.19	Kali Acc # 38 (O)	3.49	Enyamuret Acc # 30	6.14	Obeet Acc # 09 (IC)	3.38	Emiroit Acc # 36 (O)	12.01	Otunduru Acc # 23 (IC)	7.18
Eteke Acc # 21 (O)	4.14	Ebaati Acc # 22 (F)	3.47	IE 7 Acc # 48 (TC)	6.44	Amumwari fisted Acc # 89 (O)	3.58	Kali Atar – A Acc # 62 (IC)	12.36	Ebaati Acc # 22 (F)	7.20
Ekama Acc # 95 (F)	4.05	Ekama Acc # 95 (F)	3.34	Namata Acc # 24 (IC)	6.49	Enyamuret Acc # 30 (TC)	4.09	IE 2367 Acc # 45 (IC)	12.63	Emoru Acc # 10 (TC)	7.62
Aringo Acc # 26 (IC)	4.05	Tunduru Acc # 37 (TC)	3.29	IE 2640 Acc # 42 (O)	6.62	Kali Acc # 38 (O)	4.09	Engenyi – B Acc # 16 (IC)	12.76	Enyamuret Acc # 30 (TC)	7.66
Ex meru black Acc # 06 (TC)	3.98	Bulo Acc # 77 (TC)	3.29	Oturolwete Acc # 47 (TC)	6.71	IE 2640 Acc # 42 (O)	4.13	Ebule kasabale Acc # 29 (F)	12.90	Obungiti Acc # 69 (IC)	7.74
Abao Acc # 04 (F)	3.98	Emumware Acc # 86 (IC)	3.28	Seremi 2 Acc # 99 (IC)	7.20	Banyolo / Alur Acc # 71 (IC)	4.31	Ojune Acc # 34 (F)	13.09	UK – Omaditok Acc # 03 (F)	7.79
Otunduru Acc # 23 (IC)	3.91	Bweyale market Acc # 87 (IC)	3.25	Engenyi-B Acc # 16 (IC)	7.27	Achaki Acc # 84 (F)	4.51	Enyamuret Acc # 30 (TC)	13.49	UK – Iyolwa Acc # 65 (IC)	8.21
Kali Acc # 38 (O)	3.83	Otunduru Acc # 23 (IC)	3.24	Ebule kasabale Acc # 29 (F)	7.40	UK Asuret Centre Acc # 18 (TC)	4.79	Emumware Acc # 86 (IC)	13.52	Kaliatari – B Acc # 63 (IC)	8.35
Amumwari Acc # 89 (O)	3.83	IE 2035 Acc # 52 (TC)	3.23	Kaliatari B Acc # 63 (IC)	7.41	Eserait Acc # 94 (IC)	4.87	Etiyo - B Acc # 05 (F)	13.61	IE 2790 Acc # 20 (TC)	8.45
Mean	3.12		2.64		8.04		11.52		21.58		15.89
SE ±	0.20		0.15		2.14		2.04		2.55		3.26
Lsd (0.05)	0.09		0.07		0.97		0.93		1.16		1.48
C.V (%)	10.38		9.42		30.13		41.23		19.21		33.39
Minimum	1.07		1.11		0.00		0.00		6.40		0.00
Maximum	4.92		4.57		47.00		38.00		66.90		96.70

† Type of head shape: O = open, TC = top-curved, IC =incurved and F = fisted types of head shapes.

3.3.3 Estimates of variability, heritability and genetic advance among the accessions

As shown in Table 3.3, highest genotypic and phenotypic variances were exhibited by days to 50% flowering, single plant yield, grain mass head^{-1}, number of tillers plant^{-1}, flag leaf length and finger number whereas the lowest were observed in threshing percentage and leaf blast severity. Traits such as head blast severity, head blast incidence, productive tillers plant^{-1}, grain mass head^{-1} and grain yield ha^{-1} had H^2 values above 60% hence exhibiting high heritability (Robinson et al., 1949). These traits depict a large proportion of the phenotypic variance was accounted for by the genetic component. The phenotypic (PCV) and genotypic (GCV) coefficient of variations of the different traits computed based on analysis of variance ranged from 3.17 to 57.0 for days to 50% flowering and head blast severity, and 0.89 to 39.2 for threshing percentage and head blast severity respectively. High GA as a percentage of means according to classification of Johnson et al. (1955) were obtained for head blast severity, leaf blast severity, head blast incidence, leaf blast incidence, number of productive tillers plant^{-1} and grain yield, whilst lowest values were obtained with days to 50% flowering, threshing percentage, flag leaf width and flag leaf length.

3.3.4 Frequency distributions for mean yields, percentage leaf and head blast scores

Frequency distribution graphs are presented in Figures 3.1 – 3.3. Yield distribution at both NaSARRI and Ikulwe are presented in Figure 3.1, indicating near normal distribution at both sites. At Ikulwe, however, there was a slight skewness towards low yield values. The genotypes were categorised into eight classes at NaSARRI, with 1% of the genotypes falling below 1.5 tons ha^{-1}, 6% between 1.51 -2.0, 8% between 2.01 – 2.5, 28% between 2.51 – 3.0, 28% between 3.01-3.5, 19% between 3.51-4.0, 8% between 4.01 – 4.5 and 2% above 4.5 tons ha^{-1}. At Ikulwe, they were categorised into six classes; 2% below 1.5 tons ha^{-1}, 9% between 1.51–2.0, 27% between 2.01 – 2.5, 37% between 2.51-3.0, 19% 3.01 – 3.5 and 6% between 3.51-4.5 tons ha^{-1}. There were no accessions in the yield categories of 4.0 and above at Ikulwe, an indication of better yields at NaSARRI than Ikulwe.

Table 3.3: Population mean, variance, coefficient of variations and genetic advance in 100 genotypes

Trait	Mean	GV	PV	GEV	EV	GCV	PCV	GECV	ECV	H^2	GA	GA as % of mean
Days to 50% flowering	64.74	1.089	4.214	2.130	0.995	1.62	3.17	2.25	1.54	51.10	4.430	6.84
Head blast severity	0.20	0.006	0.014	0.004	0.003	39.20	57.00	32.00	26.00	68.40	0.163	79.90
Leaf blast severity	0.15	0.001	0.004	0.002	0.002	16.20	42.00	27.00	28.00	38.10	0.050	33.30
Leaf blast incidence	0.43	0.004	0.020	0.006	0.010	14.00	33.00	19.00	23.00	42.40	0.120	27.90
Head blast incidence	0.57	0.017	0.037	0.011	0.009	22.90	33.80	18.40	16.60	67.80	0.270	47.40
Finger number	6.85	0.164	0.574	0.070	0.340	5.91	11.06	3.86	8.51	53.40	0.830	12.14
Fag leaf length (cm)	40.58	0.355	16.310	4.350	11.600	1.47	9.95	5.14	8.39	14.80	1.230	3.03
Flag leaf width (mm)	12.65	0.067	1.905	0.028	1.810	2.05	10.91	1.32	10.64	18.80	0.533	4.20
Productive tillers $plant^{-1}$	2.34	0.111	0.284	0.053	0.120	14.21	22.77	9.84	14.89	62.41	0.684	29.20
Threshing percentage	0.71	0.001	0.007	0.001	0.007	0.89	12.04	3.73	11.44	7.39	0.014	2.00
Grain mass $head^{-1}$	4.21	0.408	1.121	0.278	0.435	15.17	25.15	12.52	15.67	60.4	1.320	31.23
Grain yield ha^{-1} (tons)	2.81	0.167	0.379	0.123	0.089	14.54	21.91	12.48	10.62	66.4	0.840	29.90
Single plant yield (grams)	8.43	1.504	3.416	1.112	0.800	14.55	21.92	12.51	10.61	66.4	2.520	29.90

GV = genetic variance, PV = phenotypic variance, GEV = genotype x environment variance, EV = environmental variance, GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation, GECV = genotype x environment coefficient of variability, ECV = environmental coefficient of variation, H^2 = broad-sense heritability, GA = genetic advance.

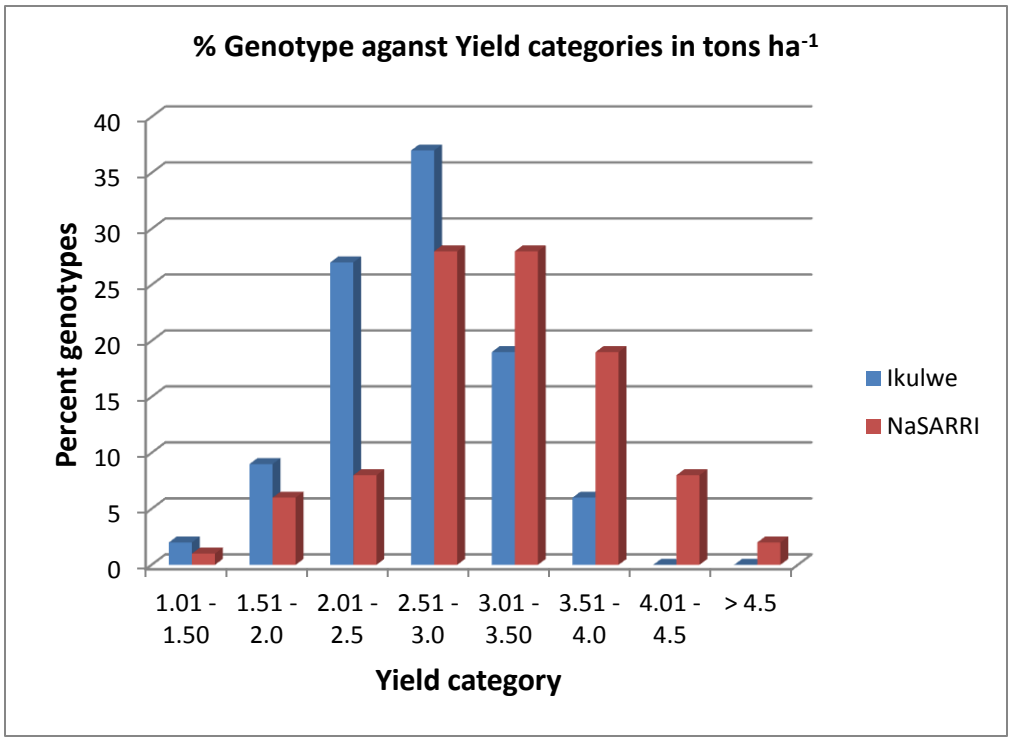


Figure 3.1 Distribution of genotypes by yield category at both NaSARRI and Ikulwe

Considering the accessions under investigation, leaf blast score distribution (Fig. 3.2) was normally distributed at Ikulwe with slight skewness towards resistance. Seventeen percent of the accessions were categorised as highly resistant while 62% were categorised as resistant and 21% were moderately susceptible. At NaSARRI, there was a slight skewness towards susceptibility compared to Ikulwe. Head blast scores distribution (Figure 3.3) also showed that no genotype was completely immune at both sites, 3% were highly resistant at Ikulwe with none at NaSARRI. Genotypes categorised as resistant at Ikulwe and NaSARRI were 27 and 3% respectively, moderately resistant were 57 and 70% at Ikulwe and NaSARRI respectively. Susceptible genotypes were 12 and 25% at Ikulwe and NaSARRI respectively and genotypes categorised as completely or highly susceptible were 1 and 2% at Ikulwe and NaSARRI respectively.

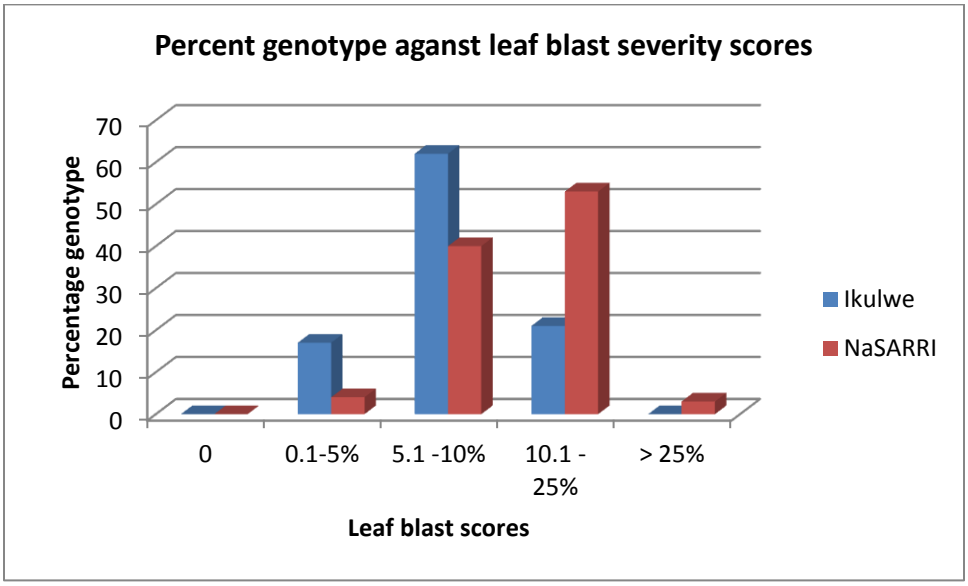


Figure 3.2: Distribution of genotypes according to leaf blast scores at Ikulwe and NaSARRI

At both sites, the most susceptible genotypes were E 11 (a susceptible check) and ACF 15 (an introduction), with near normal distribution, although the genotypes showed more resistance at Ikulwe than at NaSARRI where the distribution curve was slightly skewed towards susceptibility.

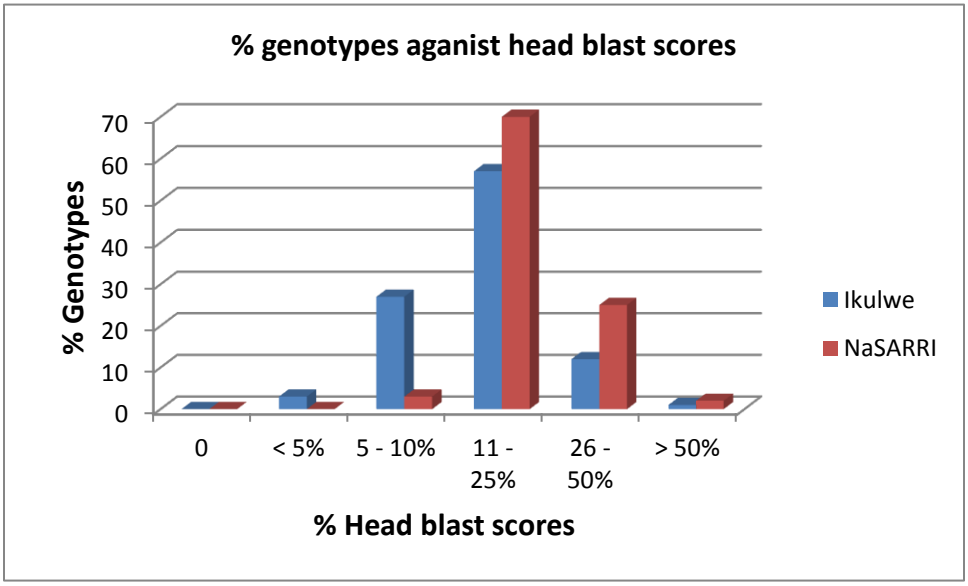


Figure 3.3: Distribution of genotypes according to head blast scores at Ikulwe and NaSARRI

3.3.5 Pearson's correlation coefficients

The correlations among the traits are presented in Table 3.4. There was a high positive correlation between grain yield ha^{-1} and panicle width, finger number, plant height, number of productive tillers, grain mass per head, threshing percentage and single plant yield; but negatively with leaf blast incidence, head blast incidence, head blast severity and days to 50% flowering. Head blast severity meanwhile, had significant positive correlation with leaf blast incidence and head blast incidence but negatively correlated with panicle width, flag leaf length, days to 50% flowering, grain mass per head and single plant yield. Plant height on the other hand had positive significant correlation with panicle length, finger length, peduncle length, flag leaf length, days to 50% flowering.

3.3.6 Path coefficient analysis

In the current study, the correlation coefficients were further divided into direct and indirect effects using path coefficient analysis (Table 3.5). Of the 11 independent variables, six had positive direct effect values, namely finger length (0.014), finger width (0.044), finger number (0.001), number of productive tillers (0.527), grain mass per head (0.625) and threshing percentage (0.056). On the other hand, leaf blast severity (-0.062), head blast incidence (-0.09), head blast severity (-0.103), days to 50% flowering (-0.012) and plant height (-0.043) showed negative direct effects.

Grain mass per head exerted the highest positive direct effect on grain yield (0.625) and it also exhibited a negative low indirect effect (-0.114) via number of productive tillers. Productive tillers exerted the second highest positive direct effect (0.527) on grain yield ha^{-1}. It also exhibited low negative indirect effect (-0.136) via grain mass per head. All the remaining independent variables exhibited negligible direct effects on grain yield ha^{-1} with the exception of head blast severity which showed a low negative direct effect (-0.103) with a high indirect effect (0.298) via grain mass per head. Of the variables with negligible indirect effects however, finger length exhibited a low negative indirect effect (-0.137) via number of productive tillers. Days to 50% flowering showed a high positive indirect effect (0.302) via grain mass per head; finger number and threshing percentage showed moderate positive indirect effects (0.264, 0.257 respectively) via grain mass per head while plant height exhibited low positive indirect effect (0.197) via grain mass per head.

Table 3.4: Pearson's correlation coefficients in selected finger millet traits

	LBI	LBS	HBI	HBS	PANL	PANW	LFL	LFW	PEDL	FLL	FLW	DTF	FN	PHT	PTP	GWH	TP	SPY	GYH[1]
LBI	1.00																		
LBS	0.444**	1.00																	
HBI	0.071	-0.012	1.00																
HBS	0.271**	0.046	0.518**	1.00															
PANL	0.100	-0.154	0.409**	0.177	1.00														
PANW	-0.073	0.013	-0.133	-0.293**	-0.110	1.00													
LFL	0.062	-0.205*	0.332**	0.119	0.969**	-0.096	1.00												
LFW	0.072	0.017	0.151	-0.015	0.160	0.354**	0.144	1.00											
PEDL	0.050	-0.013	0.033	0.033	0.101	-0.009	0.137	-0.039	1.00										
FLL	-0.168	-0.164	-0.238*	-0.342**	0.162	-0.006	0.218*	0.136	-0.240*	1.00									
FLW	0.057	-0.025	0.002	-0.121	0.253*	0.112	0.271**	0.286**	0.044	0.396**	1.00								
DTF	-0.279**	-0.119	-0.442**	-0.427**	-0.111	0.047	-0.017	-0.079	-0.087	0.630**	0.064	1.00							
FN	-0.144	-0.156	-0.033	-0.195	0.031	0.253*	0.059	0.050	0.267**	0.184	0.387**	0.109	1.00						
PHT	-0.270**	-0.365**	-0.098	-0.204*	0.253*	0.059	0.303**	0.024	0.267**	0.292**	-0.006	0.356**	0.286**	1.00					
PTP	-0.183	0.002	-0.022	-0.029	-0.243*	0.117	-0.260**	-0.036	0.274**	-0.235*	-0.364**	0.004	-0.063	-0.006	1.00				
GWT	-0.205*	-0.135	-0.287**	-0.476**	0.035	0.173	0.127	0.071	-0.079	0.448**	0.393**	0.483**	0.423**	0.315**	-0.217*	1.00			
TP	-0.107	-0.174	0.005	-0.219*	0.03	0.100	0.060	-0.076	0.111	-0.006	0.039	0.018	0.180	0.162	0.026	0.411**	1.00		
SPY	-0.334**	-0.144	-0.314**	-0.463**	-0.147	0.354**	-0.77	0.053	0.066	0.153	0.079	-0.366**	0.265**	0.212*	0.393**	0.603**	0.350**	1.00	
GYH[1]	-0.334**	-0.144	-0.313*	-0.463**	-0.146	0.354**	-0.076	0.053	0.067	0.153	0.079	0.366**	0.265**	0.214*	0.393**	0.603**	0.350**	1.00**	1.00

*, ** *Significant at 5% and 1% probability levels respectively;* LBI = leaf blast incidence, LBS = leaf blast severity, HBI = head blast incidence, HBS = head blast severity, PANL = panicle length (cm), PANW = panicle width (cm), LFL = longest finger length (cm), LFW = longest finger width (mm), PEDL = peduncle length (cm), FLL = flag leaf length (cm), FLW = flag leaf width (cm), DTF = days to 50% flowering, FN = Finger number, PHT = Plant height (cm), PTP = Productive tillers per plant, GWT = Grain weight per head, TP = Threshing percentage, SPY = Single plant yield, GYH = Grain yield per hectare (tons ha^{-1}).

Table 3.5: Path coefficient analysis: Showing direct and indirect effects via 11 characters on grain yield ha^{-1}

Trait	Direct effect	Indirect effect via											Total correlation with grain yield
		Leaf blast severity	head blast incidence	head blast severity	Finger length	Finger width	Days to 50% flowering	Finger number	Plant height	Productive tillers	Grain mass/head	Threshing %	
Leaf blast severity	**-0.062^{ns}**	-	0.0011	-0.0047	-0.0029	0.0008	0.0014	-0.0002	0.0157	0.0011	-0.0844	-0.0097	-0.144
Head blast incidence	**-0.090^{ns}**	0.0007	-	-0.0534	0.0047	0.0066	0.0053	-0.0004	0.0042	-0.0116	-0.1794	0.0003	-0.313
Head blast severity	**-0.103^{ns}**	-0.0029	-0.0466	-	-0.0017	-0.0007	0.0051	-0.0002	0.0088	-0.0153	-0.2975	-0.0123	-0.463
Finger length	**0.014^{ns}**	0.0127	-0.0299	-0.0123	-	0.0063	0.0002	0.0001	-0.013	-0.1370	0.0794	0.0034	-0.076
Finger width	**0.044^{ns}**	-0.0011	-0.0136	0.0016	0.002	-	0.001	0.0001	-0.001	-0.019	0.0444	-0.0043	0.053
Days to 50% flowering	**-0.012^{ns}**	0.0074	0.0398	0.044	-0.0002	-0.0035	-	0.0001	-0.0153	0.0021	0.3019	0.0010	0.366
Finger number	**0.001^{ns}**	0.0097	0.003	0.0201	0.0008	0.0022	-0.0013	-	-0.0123	-0.0332	0.2644	0.0101	0.265
Plant height	**-0.043^{ns}**	0.0226	0.0088	0.021	0.0042	0.0011	-0.0043	0.0003	-	-0.0032	0.1969	0.0091	0.214
Productive tillers	**0.527*****	-0.0001	0.002	0.003	-0.0036	-0.0016	-0.0001	-0.0001	0.0003	-	-0.1356	0.0015	0.393
Grain mass head^{-1}	**0.625*****	0.0084	0.0258	0.049	0.0018	0.0031	-0.0058	0.0004	-0.0136	-0.1144	-	0.023	0.603
Threshing %	**0.056^{ns}**	0.0108	-0.0005	0.0226	0.0008	-0.0033	-0.0002	0.0002	-0.007	0.0137	0.2569	-	0.350

Residual effects (h) = 0.417; R^2 Value = 0.71; $^{*, **, ***, ns;}$ are significant at P levels 0.05, 0.01, 0.001 and non-significant respectively.

3.4 Discussion

3.4.1 Variability, heritability and genetic gain

Wide range of variation was observed in all the traits studied indicating existence of broad variability which would provide a genuine opportunity for genetic improvement through selection and hybridisation. Similar findings were reported in finger millet by Lule et al. (2012) and Bezaweletaw et al. (2006) on Ethiopian germplasm. Since there were significant differences, mostly contributed by genotypes as compared to environment, it is a further indication that the collection had high variability in terms of these traits to be exploited for improvement as a large portion of the phenotypic variance was directly contributed by the genetic component and unaltered by the environment as indicated by Falconer and Mackay (1996).

It has also been suggested that heritability estimates, genetic advance as a percentage of mean and their combination could be useful in predicting the performance of the best selected individuals in a population (Johnson et al., 1955). Based on the current study, traits exhibiting high broad-sense heritability estimates depicted a large proportion of the phenotypic variance accounted for by the genetic component. This indicated the existence of reasonable inherent variability that remained unaltered by environmental conditions among the genotypes, which in turn can be more useful for exploitation in hybridisation and/or selection. Overall the phenotypic coefficients of variation (PCV) estimates were higher than the genotypic coefficients of variation (GCV) which showed that the apparent variation was not only due to genotypes but also to the influence of the environment. In the majority of the traits however, the environmental coefficients of variation (ECV) estimates were lower than both genotypic and phenotypic coefficient of variation which implied that the environmental role was less for expression of such traits. In these cases, the traits may be employed to select for superior genotypes among the progeny that may be generated from their crosses since the traits would be transmitted to the progenies.

High heritability estimates and high genetic advance as a percentage of mean observed in certain traits was probably indicative of additive gene action and therefore these traits could be improved through selection, whereas moderate heritability and low genetic advance might imply non-additive gene effects. Improvement in such traits could be achieved by crossing the landraces to genotypes with higher values for such traits followed by selecting progenies

segregating positively for such traits. On the other hand, low heritability traits and low genetic advance could probably suggest gene interactions making selecting in the early generation of progenies ineffective.

3.4.2 Mean performance and distribution of grain yield, leaf and head blast scores

The highest yields of the top 15 accessions revealed higher values at NaSARRI (3.83 – 4.56 tons ha^{-1}) compared to Ikulwe (3.23 – 3.84 tons ha^{-1}). The performance probably indicated that the conditions at NaSARRI were more favourable for finger millet production compared to Ikulwe and higher adaptation of the genotypes to NaSARRI than Ikulwe**.** Such a yield variation was also reported by Verma (1989). The near normal distribution exhibited is probably an indication that for most of the accessions under investigation, little or no deliberate effort has been made in yield improvement of these populations as most were landraces, for the respective conditions. It may therefore present an opportunity since those at the high yield range can be used in breeding for higher finger millet yields. The slight skewness to low yield values at Ikulwe could probably be an indication that the environment was not very favourable for finger millet production since most of the accessions were located to the lower scores of the distribution curve, or most of the accessions were not adapted to the site since most of the materials were collected from other parts of the country.

The slight negative and positive skewness of the accessions under investigation for both leaf and head blast scores at both sites slightly differed from the findings of Oduori (2008) who found a normal distribution among the Kenyan germplasm probably due to differences in the germplasm used and environmental conditions. The results also revealed that most of the materials had low blast scores among the accessions at Ikulwe whereas slightly higher scores at NaSARRI were recorded. It probably confirmed NaSARRI as a 'hot spot' for the disease (high disease pressure). The near normal distributions at both sites may also indicate little effort so far carried out to deliberately address this disease; and availability of resistance genes which provides an opportunity for improvement as was suggested by Ravikumar et al. (1990).

The differences at the two sites could be due to differences in environmental conditions since Babu et al. (2013) indicated that blast pathogen depends on climatic conditions of temperature and relative humidity for establishment and spread. The results therefore showed that conditions at Ikulwe were not probably congenial for disease development. The availability of accessions

with low scores in the ranges of highly resistant and resistant among the germplasm against both leaf and head blast also revealed availability of resistance genes which can be exploited in the breeding programme to generate high yielding cultivars with adequate resistance to both leaf and head blast. The near normal distribution may suggest presence of several genes with quantitative effects (Seetharam and Ravikumar, 1993; Ravikumar, 1988) and is further supported by the fact that no accessions were completely immune at both sites. Sreenivasaprasad et al. (2007) reported no distinct compatibility and incompatibility reactions from a set of isolates and finger millet accessions expected in a gene-for-gene interaction system involving major genes and hence concluded that polygenic quantitative resistance was more common in the finger millet blast interaction.

3.4.3 Correlations analysis

High positive association between grain yield ha^{-1} and panicle width (0.354), finger number (0.265), number of productive tillers (0.393), grain mass $head^{-1}$ (0.603), single plant yield (1.00) and threshing percentage (0.350) showed that yield is a result of both growth and yield components and therefore a complex trait. Grain yield, however, was highly negatively associated with leaf blast incidence (0.334), head blast incidence (0.313), head blast severity (0.463) and days to 50% flowering (0.366). The negative association with blast disease indicates that both leaf blast and head blast reduced yield, but head blast was probably more important in yield reduction compared to leaf blast since both incidence and severity were significantly associated with grain yield. This is probably because head blast can be particularly more destructive (Takan et al. 2004) as it directly reduces final yield through reduction in grain number and grain mass. Babu et al. (2013) also suggested a build-up of adult plant resistance to leaf blast which seemed to reduce the impact of leaf blast as the current study seemed to suggest.

These results further revealed that besides selection for grain yield *per se*, indirect selection for panicle width, finger number, number of productive tillers, grain mass per head, threshing percentage and plant height (in case of non-lodging materials or conditions) can lead to improvement in grain yield since they exhibited significantly positive correlation with grain yield. However, there should be a balance among characters in selection particularly between number of productive tillers and grain mass per head which had a significant negative correlation between themselves; and plant height which could lead to lodging (Oduori, 2008).

Leaf blast incidence was highly positively correlated with leaf blast severity (0.444) and head blast severity (0.271). These results revealed that highly susceptible cultivars to leaf blast were also susceptible to head blast similar to results of Quynh and Bong (1999) who discovered that varieties with high and moderate resistance to leaf blast normally maintained the resistance to panicle blast in rice, and most varieties with unstable resistance to leaf blast were found to be susceptible to panicle blast**.** The findings seem to suggest an interaction between leaf blast incidence with both leaf blast severity and head blast severity, an indication that accessions with high incidences of leaf blast also showed high leaf and head blast severity. Lenne et al. (2007) and Takan et al. (2004) clearly proved that isolates causing leaf and panicle blast on millet were genetically similar, indicating that the same strains were capable of causing different expressions of blast under suitable agro-ecological conditions. Similarly, there was a very high positive association between head blast incidence and severity, an indication that accessions with high incidence also tended to have high severity.

3.4.4 Path coefficient analysis

Scales suggested by Lenka and Mishra (1973) to categorise path coefficients was used in the current study. The path coefficients values 0.00 to 0.09 was categorised as negligible, 0.10 to 0.19 as low, 0.20 to 0.29 moderate and 0.30 to 0.99 as high path coefficients.

The current study revealed high positive and significant direct effects of grain mass head^{-1} and number of productive tillers and their positive association to grain yield ha^{-1} is an indication that these were the most important traits (contributors) alongside head blast severity which showed a negative direct effect. Among the selected variables, it is evident that these are the variables with high value to selection. However, caution is required since, for instance, number of productive tillers exhibited low negative indirect effect via grain mass head^{-1} and likewise grain mass head^{-1} also exhibited a low negative indirect effect via number of productive tillers. Head blast severity, which showed a low negative direct effect with a high indirect effect via grain mass head^{-1} revealed that efforts must be made to ensure only heads free from, or with very low levels of head blast disease are selected as it is a more important biotic factor compared to leaf blast. This is probably because the disease occurs at the time of determination of yield components directly and indirectly through grain mass per head (Torres and Teng, 1993). Further, Takan et al. (2004) observed that seed borne inoculum contributed to initial blast development in the field where

high disease incidence was observed in plantings with seeds containing a high proportion of inoculum.

The role of head blast to yield is well documented and is mainly attributed to reduction in the number of seeds head^{-1} or grain mass therefore the number and mass are expected to be greater in the absence than in presence of the disease, as a result increased number of seeds head^{-1} and/or mass would result in increased total yield. The negative effect of disease on yield was also reported by Akanda and Mundt (1996) who found that path analysis showed all yield components to be negatively affected by rust on wheat. Plots with higher tiller densities would have expected higher yield but might also provide a more favourable microclimate or micro-environment for blast disease. This effect was found in the rice pathosystem, where leaf blast was positively correlated with number of effective tillers by Torres and Teng (1993).

Considering variables with negligible direct effects (< 0.09), however, finger length exhibited a low negative indirect effect via number of productive tillers (0.137); days to 50% flowering showed a high positive indirect effect through grain mass per head (0.302). Finger number contrary to findings of Oduori (2008) but consistent with findings of Lule et al. (2012) and Bezaweletaw (2006), and threshing percentage showed moderate positive indirect effects through grain mass head^{-1} (0.264 and 0.257 respectively); while plant height exhibited low positive indirect effect through grain mass per head. This showed these traits could be used for indirect selection. From this study, it is also possible to simultaneously select early maturing, tall cultivars with high finger numbers for high yields due to their high indirect effects through head grain mass. Therefore it can be inferred that genetic and environmental factors that delay flowering of the crop and increase height and the other characters may also require attention in improvement programmes as these indirectly contribute to yield via grain yield per head.

Conclusion

The study has provided crucial information on variability in finger millet accessions in terms of selected traits and reaction to leaf and head blast disease. It revealed that:

1 both genetic and phenotypic variability exist within the Uganda germplasm in all traits that were studied,

2 head blast severity, head blast incidence, grain mass head^{-1}, grain yield ha^{-1}, and productive tillers plant^{-1} were found to have high heritability values depicting large proportion of phenotypic variance was accounted for by the genetic component in these traits

3 high genetic advance as a percentage of means were obtained for head blast severity, leaf blast severity, head blast incidence, leaf blast incidence, number of productive tillers plant^{-1} and grain yield. Traits with both high heritability and genetic advance as a percentage of mean would be transmitted to their progeny from crosses involving the 100 genotypes used in this study. These included blast disease resistance and grain yield.

4 finger millet accessions Achaki # 84, Bulo # 77, Otunduru # 23, and Emumware # 86 showed both high grain yields and high levels of resistance to blast disease at both Ikulwe and NaSARRI, and therefore could be used as sources of genes for both blast disease resistance and high grain yield, and

5 productive tillers per plant and grain mass per head had positive significant correlation to yield and high positive directs effects, therefore, selecting for these traits would probably result in high yielding genotypes.

References

Akanda, S.I. and C.C. Mundt. 1996. Path coefficient analysis of the effects of stripe rust and cultivar mixtures on yield and yield components of winter wheat. Theoretical and Applied Genetics, 92:666-672.

Allard, R.W. 1960. Principles of Plant Breeding. John Wiley and Sons Inc., New York, USA.

Babu, T.K., R.P. Thukar, H.D. Upadhyaya, P.N. Reddy, R. Sharma, A.G. Girish, and N.D.R.K. Sarma. 2013. Resistance to blast (*Magnaporthe grisea*) in a mini-core collection of finger millet germplasm. European Journal of Plant Pathology. Open Access Repository, International Crops Research Institute for Semi-Arid Tropics. Available online http://dx.doi.org/10.1007/s10658-012-0086-2/ (date accessed: 10/04/2013).

Bezaweletaw, K., P. Sripichitt, W. Wongai, and V. Hongtrakul. 2007. Phenotypic Diversity of Ethiopian Finger Millet [*Eleusine coracana* (L.) Gaertn]. In: relation to Geographic Regions as an Aid to Germplasm Collection and Conservation. Kasetsart Journal of Natural Science, 41:7-14.

Bezaweletaw, K., P. Sripichitt, W. Wongai, and V. Hongtrakul. 2006. Genetic variation, Heritability and Path-Analysis in Ethiopian Finger Millet [*Eleusine coracana* (L.) Gaertn] Landraces. Kasetsart Journal of Natural Science, 40:322-334.

Cramer, C.S., T.C. Wehne, and S.B. Donaghy. 1997. PATHSAS 1.0. Programme for analysis of path coefficients using SAS. SAS Institute Inc., Cary, NC, USA.

Dewey, D.R. and K.H. Lu. 1959. A correlation and path coefficient analysis of crested wheat grass grain production. Agronomy Journal, 51:515-518.

Falconer, D.S. and T.F.C. Mackay. 1996. Introduction to quantitative genetics. 4th Edition. Longman Group Ltd, United Kingdom.

FAOSTAT. 2012. Production of finger millet in Uganda during 1999- 2010. Statistic database of Food and Agricultural Organisation Publications, Rome, Italy.

IBPGR. (International Board for Plant Genetic Resources) 1985. Descriptors of finger millet (*Eleusine coracana (L.)* Gaertn). IBPGR Secretariat, Rome, Italy: P. 20

IRRI; Standard Evaluation System for rice 4th Edition; IRRI, INGER Genetic Resources Center, Manila, Philippines, 1996.

Johnson, H.W., H.F. Robinson and R.E. Comstock. 1955. Genotypic and phenotypic correlations in soybean and their implication in selection. Agronomy Journal, 47:477-483.

Kidoido, M.M., V. Kasenge, S. Mbowa, J.S. Tenywa, and P. Nyende. 2002. Socio-economic factors associated with finger millet production in eastern Uganda. African Crop Science Journal, 10:111-120.

Kumar, A., S.C. Misra, Y.P. and B.P.S. Singh. 1985. Variability and correlation studies in triticale. Journal of Maharashtra Agricultural University, 10:273-275.

Kumar, K. and A. Pande. 2010. Study of genetic diversity in finger millet (*Eleusine coracana* L. Gaertn) Using RAPD markers. African Journal of Biotechnology, 9:4549-4549. Available online: http://www.academicjounals.org/AJB (date accessed: 23/11/2011).

Lamo, J. 2010. Genetic studies on drought tolerance and grain chattering in rice. PhD Thesis, University of Kwazulu Natal, Pietermaritzburg, South Africa.

Lenka, D. and B. Mishra. 1973. Path coefficient analysis of yield in rice varieties. Indian Journal of Agricultural Science, 43:376-369.

Lenne, J.M., J.P. Takan, M.A. Mgonja, E.O. Manyasa, P. Kaloki, N. Wanyera, J. Okwadi, S. Muthumeenakshi, A.E. Brown, M. Tamale, and S. Sreenivasaprasad. 2007. Finger millet blast management: a key entry point for fighting malnutrition and poverty in East Africa. Outlook on Agriculture, 36:101-108.

Lule, D., K. Tesfaye, M. Fetene, and S De Villiers. 2012. Inheritance and Association of Quantitative traits in Finger millet (*Eleusine coracana* Subsp.*coracana*) Landraces collected from Eastern and Southern Africa. International Journal of Genetics, 2:12-21.

Mackill, D.J. and J.M. Bonman. 1992. Inheritance of blast resistance in near-isogenic lines of rice. Phytopathology, 82:746-749.

Muthulisi S., J.R.N. Taylor, W.A.J. de Milliano, and K.G. Duodu. 2007. Occurrence and location of tannins in finger millet grain and antioxidant activity of different grain types. Cereal Chemistry, 84:169-174.

National Research Council, USA. 1996. Finger millet. P. 39-57. In: Lost crops of Africa: volume I: Grains. Board on Science and Technology for International Development. National Academy of Sciences, National Academy Press, Washington D.C.

Oduori, C.O.A. 2008. Breeding investigations of finger millet characteristics including blast disease and striga resistance in western Kenya. Unpublished PhD Thesis, University of Kwazulu Natal, Pietermaritzburg, South Africa.

Okwadi, J. 2007. Importance and characteristics of finger millet processing Uganda. P. 102-111. In: Mgonja, M.A., J.M. Lenne, E. Manyasa and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445,

UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Payne, R.W., D.A. Murray, S.A. Harding, D.B. Baird, and D.M. Soutar. 2009. An introduction to GenStat for Windows (12th edition). VSN International, 5 The Waterhouse, Waterhouse Street, Hemel Hemstead, UK.

Prasad Rao, K.E., J.M.J. de Wet, V. Gopal Reddy and M.H. Mengesha. 1994. P. 331-345. In: Riley, K.W., S.C. Gupta, A. Seetharam and J.N. Mushonga (Eds). Diversity in the small millets collections at ICRISAT, Advances in Small Millets, International Science Publisher, New York.

Quynh, L.V. and B.B. Bong. 1999. Study of durable resistance of rice varieties to blast disease in the Mekong delta of Vietnam. Omonrice, 7:9-14.

Ravikumar, R.L. 1988. Genetic and biochemical basis of blast resistance in finger millet (*Eleusine coracana* Gaertn.). PhD Thesis, University of Agricultural Sciences, Bangalore, India.

Ravikumar, R.L., A. Seetharam, and B.T.S. Gowda. 1990. Identification of sources of stable resistance to finger millet (*Eleusine coracana* (L) *Gaertn*) blast. SABRAO Journal, 22:117-121.

Robinson, H.F., R.E. Comstock, and P.H. Harvey. 1949. Estimates of heritability and degree of dominance in corn. Agronomy Journal, 41:353-359.

Seetharam, A. and R.L. Ravikumar. 1993. Blast resistance in finger millet - Its inheritance and biochemical nature. P. 449-465. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York.

Singh, P. and F. Narayanan. 1993. Biometrical Techniques in Plant Breeding. Kalyani publishers, New Delhi.

Singh, R.K. and B.D. Chaundhary. 1977. Biometrical Methods in Quantitative Genetics Analysis. Kalyani publishers, New Dehli, p. 304.

Sreenivasaprasad, S., J.P. Takan, S. Muthumeenakshi, A.B. Obilana, E.O. Manyasa, P.O. Audi, C.A. Oduori, R. Coll, A.E. Brown, N.J. Talbot, and R. Bandyopadhyaya. 2007. Finger millet blast in east Africa: Pathogen diversity and disease management. P. 34 – 48. In: Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stakeholders' workshop, projects R8030 & 8445, UK

Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Takan, J.P., B. Akello, P. Esele, E.O. Manyasa, A. Obilana, P.O. Audi, J. Kibuka, M. Odendo, C.A. Oduori, S. Ajanga, R. Bandyopadhyaya, S. Muthumeenakshi, R. Coll, A. E. Brown, N.J. Talbot, and S. Sreenivasaprasad. 2004. Finger millet blast pathogen diversity and management in East Africa: a summary of project activities and outputs. International Sorghum and Millets Newsletter, 45:66-69.

Torres, C.O., and P.S. Teng. 1993. Path coefficient and regression analysis of the effect of leaf and panicle blast on tropical rice yield. Crop Protection 12:296-302

Vaithiyalingan, M., V. Manoharan, and N. Ramamoorthi. 2010. Association analysis among yield and yield attributes of early season drought tolerant groundnut (*Arachis hypogaea* L.). Electronic Journal of Plant Breeding, 1:1347-1350.

Verma, V.S. 1989. Variability pattern in quantitative traits of ragi (*Eleusine coracana* (L) *Gaertn*). Madras Agricultural Journal, 76:626-629.

Wanyera, N.M.W. 2007. Finger millet (*Eleusine coracana* (L) *Gaertn*) in Uganda. P. 1-9. In: Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Wheeler, B.E.J., 1969. An introduction to plant disease. John Wiley and Sons Ltd., London, p. 301

4.0 Chapter four

Genotype x Environment interaction, blast disease reaction and adaptability of finger millet genotypes in Uganda

Abstract

Finger millet is grown in a wide range of agro-climatic conditions in Uganda and thus affected by an inevitable genotype x environment interaction (GEI) that affects performance of genotypes and therefore, effective selection. The objectives of the study were to: i) identify the best performing genotypes in terms of grain yield and blast disease resistance across environments, and in specific environments, and ii) evaluate the influence of genotype, environment, and genotype-environment interaction on grain yield. To achieve these objectives, 100 genotypes were evaluated in four environments with three replications in each environment. Analysis of variance and AMMI analyses were used to identify superior and stable genotypes, sources of stable resistance to blast disease, and least segregating environments. The grain yield results indicated highly significant ($p \leq 0.01$) differences between environments, genotypes and genotype x environment interaction. On partitioning the GEI, genotype x location, genotype x season and genotype x location x season were all highly significant ($p \leq 0.01$). From the AMMI analysis, genotype had the greatest effect accounting for 57.69%, GEI 32.27%, with environment main effects accounting for only 10%. This showed a higher variability among the genotypes and lower variability in the test environments. The highly significant ($p \leq 0.01$) effect of environment from AMMI II analysis showed high differential genotypic responses across environments. Twelve genotypes were high yielding and stable, whereas thirteen were high yielding but unstable. Eleven genotypes exhibited stable performance with regard to blast resistance. Overall the study revealed that six genotypes, that is, G84, G4, G60, G95, G23, and G29 combined both stable high grain yield and stable resistance to blast disease.

Key words: adaptability, AMMI analysis, finger millet, G x E interaction, stability

4.1 Introduction

Finger millet is the second most important cereal in Uganda (FAOSTAT, 2012), grown in a wide range of environments by small-scale resource poor farmers both as a food security and cash crop. Data from FAOSTAT (2012) indicates increasing acreage over the years. This however, is not matched by corresponding increase in yield and in certain cases declining yield trends have been reported (Wanyera, 2007; Kidoido et al., 2002). There are many factors for this trend which include: the ever increasing unpredictability of agro-climatic conditions, lack of appropriate adapted varieties and finger millet blast disease. The decline in yield per unit area may also explain the increase in acreage to compensate for the yield gap. The lack of appropriate adapted varieties, declining yield trend and expansion to new crop areas will require basic understanding of performance of varieties in relation to the environment, and to determine whether genotype by environment interaction (GEI) is important. Such information is currently limited on finger millet which is mainly associated with subsistence small-scale farming. Reports from elsewhere on finger millet, however, indicate that finger millet is affected by GEI (Misra et al., 2009; Joshi et al, 2005; Solanki et al., 2000). The occurrence of large GEI poses a major problem for predicting performance which makes it difficult to decide which genotypes to be selected. It is therefore important to understand the nature of GEI to make testing and ultimately selection of genotypes more efficient.

According to Crossa et al. (2002), a significant GEI means that a selection from one environment may perform poorly in another. This would necessitate breeding for specific adaptation, which is not possible under limited resource conditions like the case is for Uganda on finger millet. In addition, the targeting of genotypes to specific locations is difficult when GEI is present, since yield is less predictable and cannot be interpreted based only on Genotype and Environment means (Samonte et al., 2005; Solanki et al., 2000). This would inevitably complicate the process of selecting genotypes with superior performance. Coupled with resource constraints, this slows progress from selection, since different genotypes would have to be chosen in different environments. As a result, multi-environment trials (METs) have been severally used and recommended to identify superior varieties with wide adaptation for farmers especially in low resource areas. The stable genotypes which perform well under stress and low-input conditions are desirable under farmers' conditions for sustainable finger millet and indeed crop production.

Multi-environment trials also assist in the identification of production environments that best suit certain genotypes (Crossa et al., 2002; Yan et al., 2000). It is therefore important to identify the causes of GEI in order to set up appropriate finger millet breeding objectives since Solanki et al. (2000) inferred that grain yield in finger millet is highly influenced by agro-climatic conditions, in order to achieve the best and maximum expression of genotypes. Andrew (1993) also suggested growing the materials in sufficient test environments to evaluate for superior stable entries of finger millet so as to increase production. Evaluation of interaction of genotypes with environments and other agro-management conditions would thus help in obtaining information on adaptability and stability of performance of genotypes and consequently improve productivity.

This study is on the premise of lack of information on finger millet genotypes adapted to diverse agro-ecological conditions in Uganda often results in low productivity of finger millet. Obtaining such information would lead to identification of cultivars that perform well across environments. To explore the impact of GEI, standard statistical methods have been applied and these include analysis of variance, principal component analysis, linear regression and Additive Main effects and Multiplicative Interaction (AMMI). Each of these methods employs statistical parameters to measure genotypic stability or response to environments according to different concepts of stability. The advantages and disadvantages of each of these methods have severally been dealt with (Balestre et al., 2010; Yan and Kang, 2003; Gauch, 1988; Yan and Hunt, 1988; Zobel, 1988). However, for this study, analysis of variance and AMMI were used since these have successfully been used more often and are considered better models in finger millet (Misra, 2009; Solanki et al., 2000).

Additive Main effects and Multiplicative Interaction analysis according to Purchase (1997) gives estimate of total GEI effects of each genotype and also further partitions it into interaction effects due to individual environments. Low GEI of a genotype indicates stability of the genotype over the range of environments. A genotype showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of that specific environment. The AMMI analysis permits estimation of interaction effect of a genotype in each environment and it helps to identify genotypes best suited for specific conditions. Though analysis of GEI interaction of multi-location data has been reported severally in other

crops, for finger millet little is available and particularly for Uganda it is not available. All these workers however, stressed the usefulness of AMMI analysis for selection of promising genotypes for specific locations or environmental conditions. In general therefore, by examining AMMI biplot, the following questions can be answered for a MET according to Crossa et al. (2002):

1. What are the genotypes that give the highest average yields across environments?
2. What are the environments that gave the highest average yields across the genotypes?
3. Is there a significant GE interaction in this MET?
4. What are the positive and negative GE combinations?
5. Which genotype(s) are most (least) responsive to the environments?
6. Which are the environment(s) that best (least) differentiate the genotypes?.

4.1.1 Objectives

The objectives of this study were to: i) identify the best performing genotypes in terms of grain yield and blast disease resistance across and in specific environments, and ii) evaluate the influence of genotype, environment, and genotype-environment interaction on grain yield.

4.2 Materials and Methods

The experimental material consisted of 100 diverse genotypes of finger millet planted at NaSARRI (Latitude 1° 29' 39N Longitude 33° 27' 19E 1085 m.a.s.l,) and Ikulwe (0° 27' 3N; 33° 28' 16E; 1157 m.a.s.l,) satellite station for two seasons (making four environments, Table 4.1). The 100 genotypes consisted of different cultivars and landraces collected from different regions of the country from which data were collected for this study (Appendix 4.1). The crops were grown under rain-fed conditions in a 10 x 10 lattice design replicated three times in all the locations and seasons. Cultivars E 11 and Seremi 2 were checks for susceptibility and resistance respectively.

Table 4.1: Environments used for evaluation of the 100 genotypes during the 2011 seasons

Environment	Location	Year/season	Code	Rainfall (mm)‡
1	NaSARRI	2011 (LR)	NaS 11LR	616.9
2	NaSARRI	2011 (SR)	NaS 11SR	915.2
3	Ikulwe	2011 (LR)	NaS 11LR	485.9
4	Ikulwe	2011 (SR)	NaS 11SR	677.9

‡ = amount of rain fall during the growing periods, LR and SR are long and short rainy seasons respectively.

Each genotype was directly sown in six rows of three metres long and 1.5 m wide with row spacing of 30 cm and plant to plant spacing of 10 cm. Measurements were recorded from ten randomly selected plants in each season for leaf blast, head blast and grain yield. The grain yield was obtained on a per plant basis and then converted to yield ha^{-1}. Leaf blast (LB) incidence and severity were assessed at booting stage approximately 45 to 50 days after emergence as recommended by Babu et al. (2013). Head blast (HB) ratings were recorded at the time of grain maturity. The disease incidence was calculated as the number of diseased plants divided by the total number of plants sampled per plot, whereas for severity, different approaches were used for leaf and ear blast respectively. Percent disease index (PDI) on LB was calculated using the formula given by Wheeler (1969) to determine leaf blast severity with the resultant percentages expressed as proportions of 1.00 and categorized as follows: immune – 0.0%, highly resistant 0.1 -5%, resistant 5.1 – 10%, moderately susceptible 10.1 – 25% and susceptible >25%. For head blast severity, 40 heads from two mid row plants in a plot were randomly selected to determine head blast severity at maturity. For each head a proportion of the spikelets affected by the disease were estimated using the Standard Evaluation System (SES, IRRI, 1996). Based on the number of heads, then head blast severity was computed as follows:

$$\text{HBS} = \frac{(10\text{xN1}) + (20\text{xN3}) + (40\text{xN5}) + (70\text{xN7}) + (100\text{xN9})}{\text{Total number of panicles observed}}$$

N1 – N9 are number of panicles infected with disease, multiplied with the corresponding portion infected. The plants were then categorised as: 0 = no disease or immune, less than 5% = highly resistant, 5-10% = resistant, 11 -25% = moderately resistant, 26 – 50% = susceptible and more than 50% = highly susceptible.

4.3 Data analysis

The components of variance, the GEI and residual were estimated by the method of general analysis of variance using GenStat (edition 12.1, Payne et al., 2009) software package. Genotype x environment interaction was further analysed using AMMI model as described by Zobel et al. (1988) and Gauch (1992) to identify finger millet accessions adapted to the different environments.

The approach based on analysis of variance and use of phenotypic means considered the effects of genotype, environment and interaction as fixed in the model. Then a combined analysis of

variance was performed considering genotypes as fixed effects in GenStat version 12.1 (Payne et al., 2009). Significance of all effects was tested against mean square of error and also genotype-environment interactions. Genotype means were ranked and compared using t-test ($p \leq 0.05$) for both yield and blast reaction scores.

Meteorological data during the experimentation period are presented in Table 4.2 showing higher rainfall and lower temperatures at NaSARRI compared to Ikulwe. The relative humidity was more or less the same but slightly higher at NaSARRI compared to Ikulwe during the experimentation periods.

Table 4.2: Meteorological data for year 2011

Site	Month	Rain fall (mm)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)
Ikulwe	Jan	31.7	32.5	19.0	62
	Feb	2.3	33.9	19.6	67
	March	121.2	32.2	19.9	71
	April	89.5	31.8	19.4	79
	May	142.4	29.4	19.3	85
	June	82.6	28.7	19.2	83
	July	50.3	29.1	18.5	82
	August	184.7	28.0	18.3	84
	September	116.5	28.3	18.5	83
	October	177.4	28.9	18.8	79
	November	162.2	28.4	18.7	83
	December	37.1	30.3	18.9	70
NaSARRI	Jan	60.0	30.0	15.1	78
	Feb	27.2	29.9	15.4	80
	March	201.2	28.7	16.3	78
	April	132.8	28.3	16.7	80
	May	130.6	27.3	16.4	84
	June	92.5	27.7	15.5	87
	July	59.8	27.9	15.0	86
	August	159.6	26.8	15.3	89
	September	191.6	27.2	16.2	88
	October	331.4	27.6	17.8	80
	November	177.3	27.4	17.7	88
	December	55.3	27.6	17.6	82

The following model was used for the combined data:

$Y_{ij} = \mu + G_i + E_j + GE_{ij} + e_{ij}$ where; μ, is the general mean, G_i, E_j, and GE_{ij} represent the effects of genotype, environment and GEI respectively, and e_{ij} is the average of random errors associated with r^{th} plot that receives the i^{th} genotype in the j^{th} environment (Crossa, 1990).

Additive main effects and multiplicative interactions analysis method which integrates analysis of variance and principle components into a unified approach (Gauch, 1988) was also performed. The AMMI model for *t* genotypes and *S* environments may be written as:

$Y_{ij} = \mu + g_i + e_j + \sum e_n \acute{a}_{in} \tilde{a}_{jn} + \mathring{a}_{ij}$

I = 1, 2, 3, ……., t; j = 1, 2, 3, ….., S

Where Y_{ij} is the yield of the i^{th} cultivar in j^{th} location, μ is the overall mean, g_i is the i^{th} cultivar effect, e_j is the j^{th} environment effect, $\sqrt{e_n}\, \acute{a}_{in}$ and $\sqrt{e_n}\, \tilde{a}_{jn}$ are the principal component scores for i^{th} genotype and j^{th} environment respectively. Error åij N (0, σ2); with $\sum_i \acute{a}^2_{in} = \sum_i \tilde{a}_{jn} = 1$ and the multiplicative interaction term satisfy the constraints, $\ddot{e}_1\ \ddot{e}_{2>\ldots\ldots>}\ \ddot{e}_n > 0$. Biplots derived by plotting the genotypes and environments markers (scores) of the first two multiplicative terms summarizing interaction patterns. The biplot analyses permits visualisation of differences in interaction effects (Misra et al., 2009) since the two axes use the same physical scale.

Cultivar superiority index for yield and blast disease resistance across the four environments was determined by calculating the superiority index (Lin and Binns, 1994) using the model:

$P_i = \sum (X_{ij} - M_j)/2n$. Where; P_i = superiority of the ith genotype in the jth environment, M_j = maximum yield for all the genotypes in the jth environment, n = number of environments (n = 1, 2, 3, 4). Genotypes with the lowest P_i values are regarded as the most superior and stable across the test environments. For blast disease however, the highest Pi values were regarded as the most superior and stable across test environments since in disease, lower score values are desired unlike yield.

4.4 Results

4.4.1 Analysis of Variance

The pooled analysis of variance for grain yield and reaction to blast disease across the four environments showed the main effects of environment, genotypes and their interactions to be highly significant ($p \leq 0.01$, Table 4.3). Yield performance therefore revealed wide variation in cultivars between environments. Some cultivars produced significantly greater grain yield in one environment. Likewise genotype reaction to disease was also variable according to environment. On partitioning the GEI component, genotype x location, genotype x season and genotype x season x location effects were highly significant ($p \leq 0.05$) for both blast reaction traits and grain yield. Single environment analysis showed genotypes to be significantly different in all the environments and single location analysis revealed no seasonal effect on head blast severity at NaSARRI and head blast incidence at Ikulwe.

Table 4.3: Pooled analysis of variance for finger millet blast disease and grain yield ha-1 of 100 finger millet accessions grown in two locations and two seasons during 2011

S.O.V	DF	Mean squares				
		LBI	LBS	HBI	HBS	Grain yield
Environment	**3**	**4.286****	**1.64****	**4.081****	**0.268****	**14.131****
Rep (Environment)	**8**	**0.018**	**0.006****	**0.052****	**0.0016**	**0.674****
Genotype	**99**	**0.072****	**0.013****	**0.228****	**0.092****	**2.462****
G x E	**297**	**0.029****	**0.007****	**0.041****	**0.0155****	**0.459****
• G x Location	99	0.032**	0.005**	0.038**	0.013**	0.602**
• G x Season	99	0.033**	0.01**	0.061**	0.021**	0.535**
• G x Location x season	99	0.022**	0.005**	0.024**	0.012**	0.24**
Residual	**792**	**0.01**	**0.002**	**0.009**	**0.003**	**0.09**
C.V.		23.0%	28.1%	16.5	26.4%	10.3%

**, ** significant (p≤ 0.05 and 0.01 respectively),* S.O.V, Df, LBI, LBS, HBI, HBS and G.yield are source of variation, degrees of freedom, leaf blast incidence, leaf blast severity, head blast incidence, head blast severity and grain yield ha^{-1} respectively.

4.4.2 Top ranked genotypes

Table 4.4, shows 20 top ranked genotypes by environment. The highest mean grain yield was obtained in NaS 11SR whereas the lowest was in IKU 11SR. The maximum yield ranged from 4.01 to 4.92 in IKU 11LR and NaS 11SR respectively. The minimum yield on the other hand, ranged from 1.07 to 1.47 t ha^{-1} in NaS 11SR and IKU 11LR respectively. Among the top yielding 20 genotypes, three were open head shaped, six top-curved, five incurved and six fist head shaped in NaS 11LR. At NaS 11SR; two were open head shaped, four top-curved, nine

incurved and seven fist head shaped. Environment IKU 11LR had three genotypes with open head shape, eight top-curved, five incurved and three fist head shaped; whilst one was open head shaped, eight top-curved, seven incurved and four fist head shaped in IKU 11SR. The pooled genotypic means across all the four environments had three open shaped genotypes, six top-curved, six incurved and five fist head shaped genotypes.

4.4.3 Ranking top 20 genotypes on resistance to head blast severity

The means, minimum and maximum head blast severity scores for the top 20 most resistant genotypes in each environment, and pooled for all environments is presented in Table. 4.5. The means ranged from 0.159 to 0.221 in IKU 11SR and NaS 11LR respectively. The maximum head blast scores ranged from 0.669 to 0.97 in NaS 11SR and IKU 11SR respectively; while the minimum scores were between 0.00 in NaS 11LR and IKU 11SR to 0.064 in NaS 11SR.

Table 4.4: Ranking top 20 genotypes in terms of grain yield (tons ha^{-1}) based on ANOVA across environments and pooled for all four environments

Rank	Environments								Pooled	
	NaS 11LR		NaS 11SR		IKU 11LR		IKU 11SR			
	‡genotype	Mean	‡genotype	Mean	‡genotype	Mean	‡genotype	Mean	‡Genotype	GM
1	^{4}G84	3.80	^{3}G86	4.36	^{4}G84	3.66	^{4}G22	3.82	^{4}G84	3.80
2	^{3}G86	3.57	^{2}G77	4.35	^{4}G22	3.56	^{2}G61	3.67	^{3}G86	3.56
3	^{4}G4	3.53	^{4}G84	4.34	^{2}G51	3.54	^{2}G64	3.66	^{2}G51	3.54
4	^{2}G77	3.52	^{4}G29	4.31	^{2}G64	3.45	^{2}G51	3.60	^{4}G4	3.53
5	^{1}G89	3.49	^{4}G4	4.35	^{2}G61	3.41	^{4}G84	3.51	^{2}G77	3.52
6	^{2}G51	3.48	^{1}G89	4.21	^{1}G38	3.39	^{3}G67	3.49	^{4}G95	3.51
7	^{4}G95	3.47	^{4}G91	4.20	^{4}G95	3.38	^{2}G37	3.40	^{3}G60	3.50
8	^{3}G60	3.47	^{3}G60	4.18	^{2}G37	3.38	^{1}G38	3.39	^{1}G89	3.49
9	^{1}G38	3.39	^{2}G6	4.15	^{2}G100	3.33	^{2}G100	3.32	^{1}G38	3.44
10	^{2}G37	3.35	^{3}G66	4.10	^{3}G86	3.32	^{4}G95	3.29	^{2}G37	3.43
11	^{3}G19	3.35	^{1}G21	4.02	^{4}G4	3.31	^{2}G90	3.24	^{4}G22	3.39
12	^{2}G100	3.34	^{4}G41	3.95	^{1}G67	3.20	^{3}G94	3.21	^{2}G100	3.39
13	^{3}G49	3.31	^{3}G26	3.90	^{1}G89	3.27	^{3}G49	3.20	^{3}G19	3.38
14	^{4}G22	3.30	^{4}G95	3.90	^{3}G60	3.26	^{2}G68	3.17	^{3}G49	3.34
15	^{3}G23	3.28	^{3}G19	3.79	^{3}G19	3.26	^{3}G19	3.18	^{3}G23	3.34
16	^{4}G29	3.28	^{3}G65	3.76	^{3}G49	3.26	^{3}G3	3.16	^{2}G64	3.32
17	^{1}G21	3.28	^{3}G23	3.74	^{2}G77	3.25	^{4}G4	3.09	^{1}G21	3.31
18	^{2}G64	3.25	^{3}G80	3.68	^{3}G23	3.18	^{2}G31	3.07	^{2}G61	3.27
19	^{4}G91	3.20	^{2}G55	3.66	^{2}G68	3.15	^{3}G23	3.07	^{4}G29	3.25
20	^{2}G61	3.15	^{3}G49	3.66	^{2}G90	3.14	^{3}G86	3.06	^{3}G87	3.21
Mean		2.76		3.12		2.70		2.64		2.81
Min		1.09		1.07		1.47		1.11		1.07
Max		4.24		4.92		4.01		4.57		4.92
C.V.		11.7		10.7		7.8		10.0		0.23
Lsd (0.05)		0.52		0.54		0.34		0.42		10.3
P value		< 0.001		< 0.001		< 0.001		< 0.001		< 0.001

NaS 11LR, = NaSARRI long rains of 2011, NaS 11 SR, = NaSARRI short rains of 2011, IKU 11LR Ikulwe long rains of 2011, IKU 11SR, Ikulwe short rains of 2011, ‡ Type of head shape: ^{1} = open, ^{2} = top-curved, ^{3} =incurved and ^{4} = fisted types of head shapes. GM = Genotypic pooled means.

Of the genotypes that exhibited the least head blast scores among the top 20, head shapes varied as follows: at NaS 11LR; three, three, ten and four genotypes had open, top-curved, incurved and fist type head shapes respectively, at NaS 11SR; two, two, eight and seven genotypes had open, top-curved, incurved and fist shaped head types respectively. At IKU 11LR, three genotypes were open head shaped, five top-curved, eight incurved and four fist head shaped whereas at IKU 11SR, one was open head shaped, three top-curved, eight incurved and fist head shaped.

Table 4.5: Ranking top 20 genotypes with least head blast scores based on ANOVA across environments and pooled for all four environments

Rank	Environments								Pooled	
	NaS 11LR		NaS 11SR		IKU 11LR		IKU 11SR			
	‡genotype	Mean	‡genotype	Mean	‡genotype	Mean	‡genotype	Mean	‡Genotype	GM
1	[3]G45	0.008	[3]G86	0.110	[4]G84	0.042	[4]G5	0.031	[4]G84	0.068
2	[4]G84	0.030	[3]G35	0.110	[4]G4	0.071	[4]G84	0.048	[3]G23	0.094
3	[3]G23	0.031	[3]G72	0.122	[2]G97	0.084	[3]G62	0.053	[4]G46	0.094
4	[4]G4	0.049	[4]G91	0.129	[3]G63	0.085	[3]G60	0.059	[4]G4	0.095
5	[3]G32	0.061	[4]G41	0.126	[3]G23	0.087	[4]G46	0.062	[1]G36	0.099
6	[1]G36	0.065	[3]G62	0.127	[3]G32	0.095	[1]G36	0.074	[3]G32	0.105
7	[1]G83	0.082	[4]G46	0.130	[4]G46	0.101	[2]G2	0.075	[2]G30	0.113
8	[2]G48	0.082	[3]G60	0.134	[3]G65	0.106	[4]G95	0.075	[3]G63	0.116
9	[4]G46	0.083	[4]G95	0.135	[1]G36	0.108	[2]G30	0.076	[3]G65	0.125
10	[1]G85	0.093	[4]G5	0.137	[3]G60	0.110	[3]G63	0.077	[1]G85	0.125
11	[3]G53	0.095	[2]G77	0.138	[1]G85	0.114	[4]G29	0.078	[4]G95	0.127
12	[4]G41	0.096	[4]G29	0.139	[2]G30	0.116	[4]G4	0.078	[3]G56	0.128
13	[3]G82	0.103	[1]G36	0.140	[1]G50	0.118	[4]G91	0.079	[2]G2	0.129
14	[2]G76	0.107	[1]G21	0.142	[3]G56	0.121	[3]G99	0.081	[3]G62	0.131
15	[3]G86	0.106	[3]G99	0.143	[2]G10	0.122	[3]G35	0.084	[3]G99	0.131
16	[3]G87	0.109	[2]G13	0.144	[3]G62	0.123	[3]G65	0.084	[4]G29	0.134
17	[3]G67	0.110	[2]G2	0.145	[4]G28	0.125	[3]G23	0.084	[1]G50	0.136
18	[2]G30	0.113	[3]G33	0.145	[2]G39	0.125	[3]G32	0.088	[3]G72	0.137
19	[3]G56	0.113	[3]G16	0.145	[3]G45	0.129	[4]G34	0.088	[2]G10	0.143
20	[3]G63	0.118	[4]G34	0.147	[2]G2	0.130	[2]G20	0.089	[3]G81	0.144
Mean		0.221		0.215		0.219		0.159		0.204
Min		0.00		0.064		0.011		0.00		0.00
Max		0.82		0.669		0.84		0.97		0.967
C.V.		25.8		19.6		25.6		36.7		26.4
Lsd (0.05)		0.092		0.068		0.09		0.094		0.043
P value		< 0.001		< 0.001		< 0.001		< 0.001		< 0.001

NaS 11LR, = NaSARRI long rains of 2011, NaS 11 SR, = NaSARRI short rains of 2011, IKU 11LR Ikulwe long rains of 2011, IKU 11SR, Ikulwe short rains of 2011, ‡ Type of head shape: [1] = open, [2] = top-curved, [3] =incurved and [4] = fisted types of head shapes. GM = genotypic pooled means

4.4.4 Cultivar superiority index and mean rank

Cultivar superiority index P_i for grain yield ha^{-1} of the to 20 cultivars showed G84 had the lowest superiority index of 0.004 which implied the genotype is superior in terms of yield to all the other genotypes in this study (Table 4.6). The second most superior cultivar was G86. For

blast disease, the cultivar with highest superiority index was still G84 and second most superior was G 46. This showed that G 84 was the most superior in terms of blast disease resistance.

Table 4.6: Superiority index (P_i) and mean rank for grain yield and blast disease resistance for 20 genotypes

Grain yield ha^{-1}				Blast disease			
Genotype	P_i	Genotype	Mean rank	Genotype	P_i	Genotype	Mean rank
G84	0.004	G84	7	G84	0.87	G84	95
G86	0.006	G51	11.25	G4	0.81	G46	91
G95	0.007	G86	11.25	G23	0.80	G36	87.8
G4	0.007	G95	12	G46	0.80	G4	85.1
G77	0.009	G4	13	G36	0.79	G60	85.1
G51	0.009	G37	13.75	G45	0.78	G30	84.8
G38	0.010	G38	14.25	G32	0.78	G23	83.8
G60	0.011	G77	15.5	G63	0.76	G32	81.8
G37	0.011	G100	16.25	G30	0.75	G95	81.6
G89	0.011	G49	17.25	G60	0.75	G63	80.3
G49	0.012	G60	17.5	G65	0.74	G45	79.8
G100	0.012	G89	17.5	G62	0.73	G2	79.3
G23	0.012	G23	19.25	G85	0.72	G65	78.8
G21	0.013	G21	21.5	G95	0.72	G29	78.4
G29	0.016	G22	22.5	G2	0.72	G62	78.3
G19	0.017	G64	25.5	G56	0.72	G99	78.3
G87	0.017	G29	25.25	G99	0.71	G91	73.8
G8	0.018	G19	26.5	G29	0.71	G50	73.5
G68	0.018	G68	26.5	G50	0.71	G56	73
G64	0.019	G87	26.75	G10	0.70	G85	71.8

The cultivars among the top 20 that combined superiority for both grain yield and blast disease resistance were: G84, G4, G60, G95, G23 and G29. These showed both high and stable grain yield and stable resistance to blast disease.

4.4.5 Stability and adaptability analysis

The ANOVA table of the AMMI II model analysis of yield data presented in Table 4.7 showed that all the three components were highly significant ($p \leq 0.01$). The genotype, environment, and GE interaction explained 57.69, 10.04 and 32.27% of the total treatment variation, respectively. The G x E interaction was further partitioned into IPCA1 and IPCA2. The IPCA1 component explained 17.33% of the total variation, which was 53.71% of the GE interaction whereas ICPA2

component explained 14.94% of total variation, which was 46.29% of the GE, with residual effects explaining 0% of both total variation and GE interactions. Therefore, the genotypic and GE components explained 89.96 of the total treatment variation whereas environment only explained 10.04%

Table 4.7: AMMI ANOVA of 100 finger millet accessions for yield (tons ha^{-1}) in four environments

Source of variation	Df	SS	% G-E SS	MS	F	% of GXE Interaction SS
Treatment	399	422.4	100.00	1.059	12.78**	
Genotypes	99	243.7	57.69	2.462	29.71**	
Environments	3	42.4	10.04	14.131	20.97**	
Interactions	297	136.3	32.27	0.459	5.54**	
IPCA 1	101	73.2	(17.33)	0.724	8.74**	53.71
IPCA 2	99	63.1	(14.94)	0.638	7.70**	46.29
Residual	97	0.0	0.00	0.000	0.00	0.00
Error	792	65.6		0.083		

Df = degrees of freedom, SS = sums of squares, % G-E SS = percentage genotype/environment sum of squares, MS = mean square.

4.4.6 The four genotype selection from AMMI

AMMI generated best four selections from each environment as presented in Table 4.8. The genotypes which appeared among the top four yielders in at least two environments were G22, G51, G64, G84 and G86; G84 appearing three times. The least IPCA 1 score in terms of magnitude was obtained at NaSARRI during the long rainy season whereas the highest was at NaSARRI during the short rainy season.

Table 4.8: First four AMMI selections per environment

Environment	Mean grain yield (tons ha^{-1})	IPCA score	Rank			
			1	2	3	4
NaS 11LR	2.77	0.136	G84	G86	G4	G88
NaS 11SR	3.12	1.718	G86	G77	G84	G29
IKU 11LR	2.70	-0.573	G84	G22	G51	G64
IKU 11SR	2.64	-1.281	G22	G61	G64	G51

NaS 11LR, = NaSARRI long rains of 2011, NaS 11 SR, = NaSARRI short rains of 2011, IKU 11LR Ikulwe long rains of 2011, IKU 11SR, Ikulwe short rains of 2011.

4.4.7 AMMI – Biplots for classification of genotypes and environments

The most powerful interpretive tool in analysis of G x E interaction in AMMI model according to Crossa et al. (1991) is the biplot analyses since the biplots permit visualisation of differences in interaction effects (Misra et al., 2009). In the AMMI II biplot (Fig 4.1), the IPCA1 scores of genotypes and environments are plotted against their respective means. The results revealed that the main effects (Genotypes and environments) accounted for 67.73% and IPCA1 accounted for 17.33% of the total variation in the data and the rest accounted for by residual, therefore AMMI I biplot gave a model fit of 85.06%. The scatter of the genotype points in the AMMI I biplot showed three environmental clusters that is NaS 11SR with very high positive interaction, IKU 11SR with high negative interaction and NaS 11LR and IKU 11LR with low to moderate levels of interactions but in opposite directions. Genotypes close to IPCA1 value of zero indicate minimal interaction with the environment and among them with above mean yields were: G5, G9, G10, G19, G23, G49, G50, G59, G84, G86, G87, G96 and G100.

The results also showed that environments NaS 11SR and IKU 11SR were the highest and lowest yielding environments respectively as they produced the highest and least means, whereas NaS 11LR and IKU 11LR were close to each other and the origin with values above the mean. Since NaS 11LR and IKU 11LR were the long rainy season for NaSARRI and Ikulwe respectively, it is an indication that during the long rainy season the yields were stable, the differences observed being due to location. On the other hand, the great disparity observed in short rainy season, showed high variance in conditions during the season at the two locations. Environment NaS 11SR had the highest mean yield (3.12 t ha^{-1}) whilst IKU 11SR had the least mean yield (2.64 t ha^{-1}). Genotypes exhibiting high interactions were G52, G48, G67, G61, G64, G22 (negative) and G6 (positive) otherwise the other genotypes may be categorised as having moderate interaction. Environment NaS 11SR showed positive moderate interactions with G6, G66, G91, G29, G21, G41, G55, and G56 whilst IKU 11LR and IKU 11SR showed positive interactions with G52, G48, G42, G71, G44, G7, G15, G68, G13 and G85.

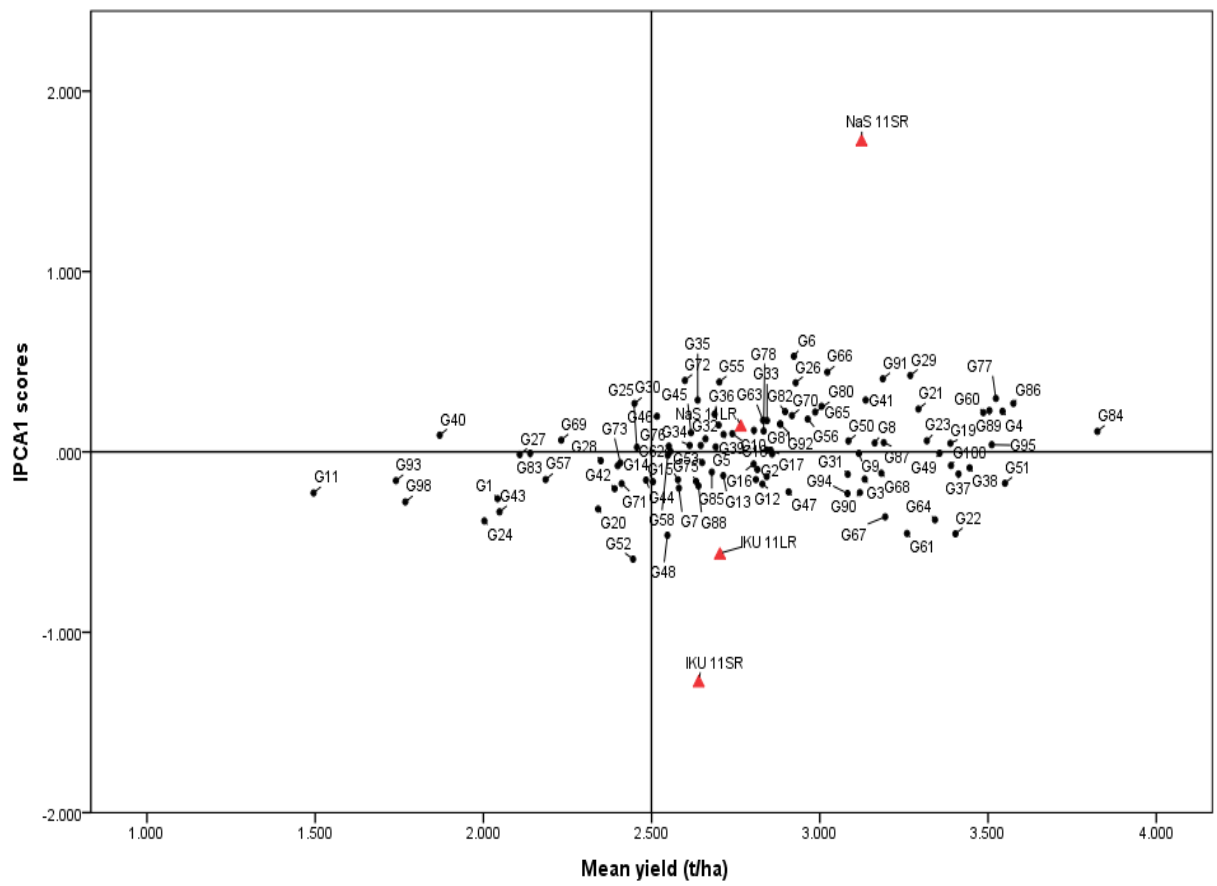


Figure 4.1: Plot of Genotype and environmental IPCA1 VS Means for the four environments. the environments; NaS 11LR, NaS 11SR, IKU 11LR and IKU 11 SR are NaSARRI long rainy season 2011, NaSARRI short rainy season 2011, Ikulwe long rainy season 2011 and Ikulwe short rainy season 2011 respectively.

▲ = Environments; ● = genotypes

4.5 Discussion

The significant environment, genotype main effects and GEI for grain yield indicated that the genotypes were different, environments diverse and the performance of a genotype was affected by environmental conditions. From the AMMI analysis, genotype had the greatest effect accounting for 57.69%, GEI 32.27%, with environment accounting for only 10%. This showed a higher variability among the genotypes and lower variability in the test environments. The first two IPCA scores explained 100% of the interaction sum of squares. The highly ($p \leq 0.01$) significant effect of environment showed high differential genotypic responses across environments. Variations in rainfall amounts, temperatures, relative humidity and blast disease

could have contributed to the observed differences. Verma (1989) reported high mean daily temperature followed by frequent rainfall with low light intensity reduced grain filling in finger millet and thus limited yield.

4.5.1 Yield performance based on analysis of variance

Significant differences for yield across environments suggested genotypes performed differently under diverse environments and their performances were unpredictable across environments as was also reported by (Rasyad et al., 2012). Since GEI was also significant ($p \leq 0.01$) in the current study, it is an indication that selecting superior finger millet varieties in particular areas and seasons may not necessarily result in superior performance in other areas and/or seasons. It must therefore be decided whether to plant widely adapted varieties or locally adapted varieties. To choose a widely adapted variety, breeders and farmers need to choose varieties which are stable across locations and/or seasons. Edaphic and climatic conditions tend to vary across locations and seasons which are highly likely to cause yield variation (Verma, 1989).

The significant genotype x location interaction observed in the current study indicated that genotypes performed differently in the different locations and therefore performance was less stable. From the results, there was expression of crossover (qualitative) interaction since there were genotypic changes in ranking from one environment to another. However, there were genotypes which were quite consistent in the top 20 best performers as they occurred in all environments indicating relative stability.

Genotype x season interaction was also significant, a reflection of inconsistency in performance of genotypes in different seasons. The genotype x location component of G x E, may be indicative of specific adaptation by subdividing target areas in homogeneous regions that minimise G x E within locations. Since the genotype x season and genotype x location x season were also significant, it makes spatial subdivision of the locations difficult for finger millet production. Therefore testing of genotypes in such a scenario would require a representative range of conditions as a reliable strategy since it would cover a representative sample of spatial and temporal variations, and according to Crossa et al. (1991), a selection environment in one year may have little relation to those experienced in the next. The observations made in the current study, therefore, would suggest testing finger millet genotypes for many crop cycles. To save time however, several workers have suggested substituting temporal variation with spatial

variation assuming that testing over wide locations can ensure a parallel degree of temporal buffering capacity in their germplasm (Romagosa and Fox, 1993). It has also been statistically elucidated by Barah et al. (1981) that both spatial and temporal buffering rely on the same mechanism in experiments with sorghum, and Flinn and Garrity (1989) working with rice.

4.5.2 Genotypic blast disease reaction across environments

The main effects of environment and genotype and genotype x environment interaction on blast disease were highly significant ($p \leq 0.01$), similar to findings of Takan et al. (2004) and Lenne et al. (2007) who demonstrated that there is a considerable variation in aggressiveness of *Magnaporthe grisea* isolates on different finger millet varieties. They also observed that aggressiveness varied according to source of isolates, a hint that isolates from different locations were different. They however inferred that there was no gene-for-gene relationship between finger millet pathogen as in rice implying no major genes for resistance were involved in these interactions. *Pyricularia grisea*, the *Eleusine* pathotype is defined by its specific pathogenicity to *Eleusine* species such as *Eleusine coracana*, *Eleusine indica* and *Eleusine africana* (Tanaka et al., 2009). He further reported that though the pathogen seems to be uniform, its members are however not cultivar-specific. Dobinson et al. (1993) divided *Eleusine* isolates into at least two genetically distinct sub-groups, which were further divided by Tanaka et al. (2009) according to origin indicating variability of the *Pyricularia Eleusine* pathogen.

The significant effect of environment and genotype x season effect on blast disease was also reported by Takan et al. (2004) indicating differential reaction based on environments and seasons. The report indicated that during the short rainy season, the disease incidence and percentage severity were significantly low compared to the long rainy season. This could be attributed to low precipitation, low humidity and high temperature; factors which do not encourage blast pathogen development (Babu et al., 2013). So the seasonal differences in blast occurrence could explain the significant differences during the seasons. The higher levels of disease at NaSARRI compared to Ikulwe could also be due to the fact that the conditions were probably more favourable for disease development and multiplication at NaSARRI where there has been continuous cultivation of finger millet compared to Ikulwe. This could have led to accumulation of the pathogen making NaSARRI a hot spot area. The somewhat low yields

obtained at Ikulwe compared to NaSARRI despite low pathogen levels may be explained by other unfavourable agro-climatic conditions that could have led to poor agronomic performance.

4.5.3 Top ranking of genotypes based on blast disease reaction and grain yield

From the results, genotypes that showed blast resistance irrespective of environment among the farmer varieties were: G23, G36 and G84; ICRISAT introductions G45 and G46 also showed resistance across environments, and an improved and released variety G99 was also resistant. These results showed that within the 100 accessions, there were genotypes with high levels of blast resistance across the test environments; therefore sources of genes for stable and/or durable resistance against blast disease could be identified. There were also varieties that showed consistently higher yields across environments; among them were: G4, G21, G23, G37, G38, G77, G84 and G95 among the farmers' varieties, G49 an introduction from ICRISAT, G51 and G100, improved cultivars from NaSARRI. These identified varieties can be utilised further in the breeding programme to improve varieties with good agronomic traits but with high levels of disease resistance. The stable resistance was a further indication of availability of genotypes that could be used as sources of genes for resistance against several races of the pathogen. The significance of GEI would also imply screening for both resistance to blast disease and yield must be conducted in target environments or a representative target environment where finger millet cultivars will be grown. Cultivar superiority index also identified high yielding genotypes across environments with stable resistance against blast disease. Six genotypes: G84, G4, G60, G23 and G29 combined both high grain yield potential and stable blast resistance.

4.5.4 AMMI Model analysis to classify genotypes and environments

From the AMMI biplot the environments fall into three groups: NaS 11SR with large positive IPCA 1 scores, which interact strongly with genotypes that have positive IPCA 1 scores and negatively with genotypes with negative scores; IKU 11SR with large negative IPCA 1 scores thus strongly interact with the genotypes but in the opposite direction to NaS 11SR; NaS 11LR and IKU 11LR with small IPCA 1 scores (between 0 and ± 0.5), suggesting that they had little interaction with the genotypes and therefore least differentiated genotypes unlike NaS 11SR and IKU 11SR. Environments can be sub grouped according to their average yield over the genotypes. Within the genotypes, G6, G19, G21, G22, G23, G26, G29, G41, G49, G64, G66, G84, G87, G91, G100 had higher average yields; of which G6, G26, G29, G41, G66, G91 were

especially suitable to NaS 11SR, while G22, G61, G64 and G67 were specifically adapted to IKU 11SR.

The genotypes and environments of axis 1 showing values close to zero contributed little to the sum of squares of the genotype x environment interaction; they were therefore the most stable. Genotypes G9, G19, G23, G25, G49, G50, G59, G62, G87, and G99, were among those that contributed least to the genotype x environment interaction, in other words were less responsive to environmental changes. Genotypes G10, G19, G17, G37, G53, G96 and G100, had relatively high yields and showed intermediate IPCA1 values. These genotypes were moderately stable, showing wide adaptation to the test environments. The genotypes with high average yields making the highest contribution to this interaction were G6, G22, G52, G61, G64, and G67 clearly indicating specific adaptation and low stability (Yan and Kang, 2003), whereas genotypes; G1, G11, G24, G43, G93 and G98 were lowest yielding and least stable showing non-adaptation to any of the test environments. The environments making the greatest contribution were NaS 11SR and IKU 11SR; the smallest contributions were made by NaS 11LR and IKU 11LR, that is, the long rainy season at both NaSARRI and Ikulwe. The most productive environment was NaS 11SR followed by NaS 11LR (NaSARRI short and long rainy seasons respectively) a further confirmation of NaSARRI being more favourable compared to Ikulwe probably due to the differences in agro-climatic conditions and better adaptation of the genotypes to NaSARRI.

Analysis of the genotype x environment interaction thus detected variability of environments for both grain yield and head blast disease reaction, with groups of some genotypes showing specific adaptability and others showing stability. Differential performances of genotypes due to the environmental variability was observed and explained by Broccoli and Burak (2004) who associated the variability with soil and water conditions as these are paramount to grain filling, and prevailing temperatures also affecting effective photosynthesis and photosynthates translocation. Pajic and Babic (1991) working with maize also reported that the size and weight of grain depended exclusively on environment although other workers like Broccoli and Burak (2004) found that genotype also had influence on these traits.

Displacement along the x-axis of the AMMI biplots reflected differences in main effects, whereas displacement along the y-axis exhibited differences in interaction effects. Genotypes

with IPCA1 scores near zero had little interaction with environments. Genotypes or environments on the same parallel line relative to the y-axis had similar mean values for yield, and genotype or environment on the right hand side of the guidelines had yields above the mean. The impact of environment was highly significant on yield justifying MET to identify good performers in particular environments and/or across environments. Significant variation due to locations and seasons is a further pointer to the need of multi-locational performance trials for more than one season for reliability of performance to be made and therefore reliable decisions in finger millet breeding.

Partitioning the variance components revealed that Location and Genotype x Season were the main sources of G x E interaction for yield suggesting the possibility of identifying varieties with specific adaptation. Seasonal effect was the main source of GEI for both leaf blast severity and head blast severity. For yield the impact of environment is expected since yield is a polygenic trait (Lin and Binns, 1994), and therefore subject to influence from the environment. The environmental impact complicates potential genetic gain and advance in yield and resistance to blast disease and thus requires testing of genotypes in multi-environments to identify those with specific adaptation and/or stability.

Conclusion

The combination of ANOVA and AMMI analyses were sufficient to explain the effects of environments, genotypes and the GEI observed in the study and resulted in identification of genotypes with stable high yields and field resistance to blast disease across environments. Both ANOVA and AMMI analyses revealed the best genotypes, but AMMI further identified the best genotypes that had wide adaptation. The genotypes identified as stable and high yielding were: G9, G19, G23, G49, G50, G59, G62, G84, G87, G95, G99, and G100, whereas genotypes identified as high yielding but unstable and probably suitable for specific adaptation were: G4, G6, G22, G29, G51, G61, G64, G66, G77, G86, G88, G91 and G94.

Analysis of variance also revealed genotypes with the least blast scores, and those that exhibited both least blast scores and high yields. These included: G4, G23, G84 and G95. Additive Main effects and Multiplicative Interaction analysis also identified NaS 11SR as a high yielding

environment but most segregating, whereas NaS 11LR and IKU 11LR were relatively high yielding and least differentiated genotypes. Cultivar stability index identified genotypes for both stable high grain yield and stable blast disease resistance. These were: G84, G4, G60, G23 and G29.

References

Andrew, D.J. 1993. P. 411 – 423. Riley, K.W., S.C. Gupta, A. Seetharam, and J.N. Mushonga. (Eds.). Advances in small millets. Oxford and IBH Publication Co. Pvt. Ltd. New Delhi.

Babu, T.K., R.P. Thukar, H.D. Upadhyaya, P.N. Reddy, R. Sharma, A.G. Girish, and N.D.R.K. Sarma. 2013. Resistance to blast (*Magnaporthe grisea*) in a mini-core collection of finger millet germplasm. European Journal of Plant Pathology. Open Access Repository, International Crops Research Institute for Semi-Arid Tropics. Available online http://dx.doi.org/10.1007/s10658-012-0086-2/ (date accessed: 10/04/2013).

Balestre, M., V. B. dos Santos, A.A. Soares, and M.S. Reis. 2010. Stability and adaptability of upland rice genotypes. Crop Breeding and Applied Biotechnology, 10:357-363.

Barah, B.C., H.P. Binswanger, B.S. Rana, and N.G.P. Rao. 1981. The use of risk aversion in plant breeding; concepts and application. Euphytica, 30:451-458.

Broccoli, A.M. and R. Burak. 2004. Effect of genotype x environment interactions in popcorn maize yield and grain quality. Spanish Journal of Agricultural Research, 2:85-91.

Crossa, J. 1990. Statistical analysis of multi-location trials. Advances in Agronomy, 44:55-85.

Crossa, J., P.L. Cornelius, and W. Yan. 2002. Biplots of linear-bilinear models for studying crossover genotype x environment interaction. Crop Science, 42:619-633.

Crossa, J., P.N. Fox, W.H. Pfeiffer, S. Rajaram, and H.G. Gauch. 1991. AMMI adjustment for statistical analysis of an international wheat yield trial. Theoretical and Applied Genetics, 81:27-37.

Dobinson, K.F., R.E. Harris, and J.E. Hamer. 1993. Grasshopper, a long terminal repeat (LTR) retroelement in the phytopathogenic fungus *Magnaporthe grisea*. Mol Plant Microbe Interaction, 6:114-126.

FAOSTAT. 2012. Production of finger millet in Uganda during 1999- 2010. Statistic database of Food and Agricultural Organisation Publications, Rome, Italy.

Flinn, J.C. and D.P. Garrity. 1989. Yield stability and modern rice technology. P. 250 – 264. Anderson, J.R. and P.B.R. Hazell (Eds). In: Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries, John Hopkins University Press, Baltimore.

Gauch, H.G. 1992. Statistical analysis of regional yield data: AMMI analysis of factorial designs. Amsterdam, Elsevier.

Gauch, H.G. 1988. Model selection and validation of yield trials with interactions. Biometrics, 44:705-715.

IRRI; Standard Evaluation System for rice 4th Edition; IRRI, INGER Genetic Resources Center, Manila, Philippines, 1996.

Joshi, B.K., R.K. Tiwari, R.B. Amgain, P. Shrestha, S. Gyawali, A. Mudwari and B.K. Baniya. Stability and adaptation in finger millet (*Eleusine coracana* (L.) Gaertn.) landraces. 2005. On-farm Conservation of Agricultural Biodiversity in Nepal, 1:73-83.

Kidoido, M.M., V. Kasenge, S. Mbowa, J.S. Tenywa, and P. Nyende. 2002. Socio-economic factors associated with finger millet production in eastern Uganda. African Crop Science Journal, 10:111-120

Lenne, J.M., J.P. Takan, M.A. Mgonja, E.O. Manyasa, P. Kaloki, N. Wanyera, J. Okwadi, S. Muthumeenakshi, A.E. Brown, M. Tamale, and S. Sreenivasaprasad. 2007. Finger millet blast management: a key entry point for fighting malnutrition and poverty in East Africa. Outlook on Agriculture, 36:101-108.

Lin, C.S. and M.R. Binns. 1994. Concepts and methods for analyzing of regional trial data for cultivar and location selection. Plant Breeding Review, 12:271-297.

Misra, R.C., S. Das, and M.C. Patnaik. 2009. AMMI Model Analysis of Stability and Adaptability of late duration finger millet (*Eleusine coracana*) Genotypes. World Applied Science Journal, 6:1650-1654.

Pajic, Z. and M. Babic. 1991. Interaction of popping volume and some agronomic characteristics in popcorn hybrids. Genetika, 2:137-144.

Payne, R.W., D.A. Murray, S.A. Harding, D.B. Baird, and D.M. Soutar. 2009. An introduction to GenStat for Windows (12th edition). VSN International, 5 The Waterhouse, Waterhouse Street, Hemel Hemstead, UK.

Purchase J.L. 1997. Parametric analysis to describe genotype x environment interaction and yield stability in winter wheat. South African Journal of Plant and soil, 17:101-107.

Ramagosa, I. and P.N. Fox. 1993. Genotype x environment interaction and adaptation. In: Hayward, M.D., N.O. Bosemark, and I. Ramagosa (Eds.). Plant Breeding: Principles and Prospects. Chapman and Hall, London, 1993, Publication.

Rasyad, A., G. M. E. Manurung, D. A. Van Sanford. 2012. Genotype x Environment interaction and stability of yield components among rice genotypes in Riau province, Indonesia. SABRAO Journal of Breeding and Genetics, 44:102-111.

Samonte, S.O.P.B., L.T. Wilson, A.M. McClung and J.C. Medley. 2005. Targeting cultivars onto rice growing environments using AMMI and SREG GGE biplot analysis. Crop Science, 45:2414-2424.

Solanki, J.S., S.R. Maloo, and S.P. Sharma. 2000. Stability analysis for seed yield in finger millet. Indian Journal of Agricultural Research, 34:268-270.

Takan, J.P., B. Akello, P. Esele, E.O. Manyasa, A. Obilana, P.O. Audi, J. Kibuka, M. Odendo, C.A. Oduori, S. Ajanga, R. Bandyopadhyaya, S. Muthumeenakshi, R. Coll, A. E. Brown, N.J. Talbot, and S. Sreenivasaprasad. 2004. Finger millet blast pathogen diversity and management in East Africa: a summary of project activities and outputs. International Sorghum and Millets Newsletter, 45:66-69.

Tanaka, M., H. Nakayashiki, and Y. Tosa. 2009. Population structure of *Eleusine* isolates of *Pyricularia oryzae* and its evolutionary implications. Journal of General Plant Pathology, 75:173-180.

Yan, W. and L.A. Hunt. 1988. Genotype x Environment Interaction and Crop Yield. Plant Breeding Reviews, 16:135-228.

Yan, W. and L.A. Hunt, Q. Sheng, and Z. Szlavnics. 2000. Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Science, 40:597-605.

Yan, W., and M.S. Kang. 2003. GGE biplot analysis: a graphical tool for breeders, geneticists, and agronomists. CRC Press LLC. 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431, USA.

Verma, V.S. 1989. Variability pattern in quantitative traits of ragi (*Eleusine coracana* (L) *Gaertn*). Madras Agricultural Journal, 76:626-629.

Wanyera, N.M.W. 2007. Finger millet (*Eleusine coracana* (L) *Gaertn*) in Uganda. P. 1-9. In: Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Wheeler, B.E.J., 1969. An introduction to plant disease. John Wiley and Sons Ltd., London.

Zobel, R.W., J.W. Madison, and H.G. Gauch. 1988. Statistical analysis of a yield trial. Agronomy Journal, 80:388-393.

5.0 Chapter five

Genetic analysis of blast disease resistance and agronomic traits in finger millet

Abstract

Head blast disease is the most important biotic constraint to finger millet production. Therefore disease resistant varieties are required. However, there is limited information on combining ability for resistance and indeed other agronomic traits of the germplasm in Uganda. This study was carried out to estimate the combining ability and gene effects controlling blast disease resistance and selected agronomic traits in finger millet. Thirty six crosses were generated from a 9 x 9 half diallel mating design. The seed from the 36 F_1 crosses were advanced by selfing and the F_2 families and their parents were evaluated at NaSARRI in three replications. General combining ability (GCA) for head blast resistance and the other agronomic traits were all highly significant ($p \leq 0.01$), whereas specific combining ability (SCA) was highly significant for all traits except grain yield and grain mass head^{-1}. On partitioning the sum of squares, the GCA values ranged from 31.65% to 53.05% for head blast incidence and severity respectively, and 36.18% to 77.22% for the other agronomic traits measured. Additive gene effects were found to be predominant for head blast severity, days to 50% flowering, grain yield, number of productive tillers plant^{-1}, grain mass head^{-1}, plant height and panicle length. Non-additive gene action was predominant for number of fingers head^{-1}, finger width and panicle width. The parents which contributed towards high yield were *Seremi 2, Achaki*, *Otunduru*, *Bulo* and *Amumwari*. Generally, highly significant additive gene action implied that progress would be made through selection whereas non-additive gene action could slow selection progress and indicated selection in the later generations. The Hayman genetic analysis confirmed importance of additive gene action in most of the traits and indicated the additive-dominance model was effective and adequate for genetic studies in finger millet. Parents *E11, ACF 19, Abao* contributed most dominant genes for yield, whereas *Achaki* contributed recessive genes for blast disease resistance; *Achaki, Amumwari*, *Otunduru*, *Seremi 2* and *Bulo* contributed most dominant genes an indication that resistance to blast was controlled by dominant genes whereas yield by recessive genes.

Key words: Combining ability, finger millet, grain yield, gene action, head blast disease.

5.1 Introduction

Finger millet production is faced with many biotic challenges, the most important of them being blast disease caused by *Pyricularia grisea* (Cooke) Sacc. There have been attempts to address this challenge resulting in some ephemeral solutions. *Pyricularia grisea* can cause yield losses as high as 50% on finger millet (Lenne et al., 2007; Ekwamu, 1993) and in favourable seasons the losses can be as high as 90% (Esele, 1993). In Uganda, finger millet blast is endemic to all growing areas although some cultivars are more susceptible than others (Takan et al., 2004) and more severe in some areas than others depending on weather conditions. Despite its wide prevalence very little is actually known about host plant resistance and its inheritance compared to rice for instance. Blast appears on all plant parts damaging leaves, stems, peduncle and heads, with head blast the most destructive as it directly reduces yield (Prabhu et al., 1996). Although chemical control has been shown to be effective (Bua and Adipala, 1995; Seetharam and Ravikumar, 1993), its use on a field scale is not practical because of resource constraints of the farmers growing finger millet making exploitation of host plant resistance an extremely important option in preventing yield loss and enhancing yields.

Pyricularia grisea belongs to fungal class of *Deuteromycetes,* order *Moniliaes* and family *Monilaceae* and it has a marked pathogenic variability (Takan et al., 2004). The host range of *Pyricularia* is quite wide affecting many species of the *Graminae* family (Seetharam and Ravikumar, 1993) from wild grasses to cereal crops of which rice and finger millet are the most important. The fungus produces elliptical lesions on leaves, peduncle and panicles. On seedlings, the pathogen infects leaves and first appears as minute brown specks. Under favourable conditions the lesions enlarge and change colour from whitish/grayish or slightly bluish to brown attaining spindle shape with pointed ends and flattened in the centre (Babu et al., 2013). Severe infection may result in the death of the seedling. During the vegetative stage of the plant, the disease is not as serious as when it occurs in the reproductive stage (Bvindi, 2010; Takan et al., 2004). The infestation of the head prevents further development resulting in chaffy fingers of varying intensities, depending on the severity of the disease which also depends on the cultivar type and prevailing weather conditions.

To address the blast disease problem, host resistance is advocated because it is cheap and poses no technical difficulties to the farmer provided that resistance genes are readily available

(Ekwamu, 1989). To attain resistant cultivars however, Esele and Odelle (1995) pointed out that pedigree breeding without selecting for blast resistance may likely result in highly susceptible and intolerant crop varieties, which could be very costly in any kind of production system, yet most of the finger millet breeding work has been focused on yield *per se* with little regard to this devastating disease probably because yield is easy to select for. To effectively breed for plant host resistance it is therefore imperative to identify sources of resistance, understand the nature of host plant resistance and the gene action conditioning resistance to finger millet blast disease.

The gene action conditioning resistance to finger millet blast disease is not fully understood and similarly no information exists on the combining abilities of finger millet lines adapted to tropical conditions in Uganda under finger millet blast pressure. There however, exists some scanty information especially from India and extensive work on rice. Generation of such information would be useful in selecting parents in a breeding programme and choosing appropriate breeding procedures. Studies elsewhere have identified finger millet genotypes with resistance to *Pyricularia grisea* (Cooke) Sacc. (Shailaja et al., 2010; Krishnappa et al., 2009; Takan et al., 2004) indicating that breeding for resistance is a realistic option. This can form the basis for initiating studies to determine the genetics of resistance to blast disease pathogen and later be able to incorporate this resistance in new cultivars with appropriate agronomic and farmer preferred attributes.

Earlier results from the evaluation of a world collection of finger millet germplasm for blast disease showed a continuous variation which indicated that inheritance of resistance is most likely quantitatively controlled by a number of genes each with individual minor effects and perhaps also largely controlled by environment (Seetharam and Ravikumar, 1993). It is an indication that attempt(s) to assess the contribution of individual genes to blast incidence/severity is bound to be ineffective and therefore obtaining estimates of effects averaged over a whole genome is recommended (Seetharam and Ravikumar, 1993). There are several methods of estimating such quantitative genetic effects through various mating designs and one such mating design is the diallel mating design which has been severally used in finger millet to estimate the magnitude of additive and non-additive components of genetic variability. In addition, combining ability analysis in finger millet has also been previously carried out by Parashuram et

al. (2011); Shailaja et al. (2010); and Krishnappa et al. (2009), based on Griffings (1956) methods and found to be appropriate in explaining the components of genetic variation.

The main objectives of the current study were to assess the nature and magnitude of gene action controlling blast disease inheritance and other agronomic traits important to yield determination and to suggest breeding strategies for finger millet improvement. The specific objectives were to: (i) estimate the general combining ability (GCA) of selected parents and the specific combining ability (SCA) of a parent in a cross with another parent, and (ii) determine the genetic effects which control the inheritance of blast disease resistance and selected agronomic traits in finger millet.

5.2 Materials and Methods

5.2.1 Selection of parental materials

The experimental material consisted of nine finger millet varieties (Table 5.1) as parents. The varieties selected were adapted landraces, bred and released varieties and introductions from ICRISAT. The landraces and released cultivars used are highly popular among the farmers and are being used in various production systems. Owing to their already high adaptability, acceptability, resistance to blast disease (in some cases) and yielding ability, these were chosen for hybridization to exploit the existing variation for finger millet improvement in Uganda. Among the nine varieties, five had green pigmentation whereas four had purple pigmentation at the nodes and leaf margin (Table 5.1). These were deliberately selected so that the F_{1S} could easily be identified as the purple pigmentation is known to be dominant over the green pigmentation (Shailaja et al., 2010; Krishnappa et al., 2009) which served as a useful marker in identifying true crosses at the seedling stage where the parents had different nodal and head pigmentation. Other added markers were plant height, head shapes and seedling vigour.

5.2.2 Crossing procedures

Finger millet is predominantly a self-pollinated crop with bisexual flowers (florets) which are small in size making artificial hybridization a difficult process. Emasculation without injury to floral parts is extremely difficult hence two methods were adopted for this study to improve chances of success.

Table 5.1: Parental lines with entry numbers, reaction to head blast disease, nodal pigmentation, head shapes and germplasm source

Entry	Type of disease reaction†	Nodal pigmentation	Head shapes	Source
01 (E11)	S	Purple	Open	ICRISAT
02 (ACF 5)	S	Green	Incurved	Introduction – world collection
03 (Seremi 2)	R	Purple	Semi compact	Released cultivar
04 (ACF 19)	R	Green	Tips curved	Introduction – world collection
05 (Achaki)	R	Green	Compact	Landrace – Tororo
06 (Abao)	MR	Purple	Compact	Landrace – Lira
07 (Otunduru)	MR	Purple	Compact	Landrace – Kaberamaido
08 (Bulo)	MR	Green	Tip curved	Landrace – West
09 (Amumwari)	R	Green	Open	Landrace – Busia

† S = resistant, R = resistant, MR = moderately resistant

Top-curved head shape

incurved head shape

Fisted head shape

Open head shape

incurved head shape

Fisted head shape

Figure 5.1: Showing various head shapes observed and used in the study

The two methods were; 1) the polythene bag method (in which emasculation was obtained using a 7.5 cm x 10 cm polythene bag lined with moist filter paper inverted over the flower and plugged with absorbent cotton wool. This creates high humidity inside the bag. Under such

humidity, the florets open, the anthers emerge but shed no pollen. Pollen was collected from the designated male parents by tapping the bag before dehiscence of anthers. The pollen collected from the bag was dusted on the emasculated head and again covered with a pollination bag and labeled. 2) the contact method of crossing as described by Ravikumar (1988) and successfully used by Ratnakar et al. (2009) were adopted to obtain F_1 seed. In this second method the heads of the male and female parents were brought together and finger to finger contacts were made by tying them together with a thread at anthesis or before anthesis. Anthesis is known to take place from 1 am to 4 am and ends by 11 am (Ratnakar et al., 2009). After pollination, ear heads were separated and seeds collected only from the female parent. This method is known to enhance the frequency of out-crossing by providing an opportunity for the pollen of male parents to come in close contact with the stigmatic surface of female parents. This has been one of the widely practiced methods in grasses including finger millet where floret size is too small for emasculation prior to crossing.

The parents were grown in a green house at the National Semi Arid Resources Research Institute Serere, Uganda during the second season of 2011. The sowing was staggered to achieve synchrony in flowering to facilitate crossing as the different genotypes had different flowering periods.

5.2.3 Diallel crosses and evaluation of the parents and progenies

The nine selected parents were crossed in a green house at NaSARRI (Latitude 1° 29' 39N Longitude 33° 27' 19E 1085 m.a.s.l) using the 9 x 9 half diallel mating design. The successful F_{1S} were identified in the field during the following season by comparing the crosses with the maternal parents. This was done by sowing the F_1 seed between rows of both parents and among the crosses, plants similar to female parents were identified and removed based on the morphological markers. The true F_1 plants were then advanced to obtain F_2 seed. The F_2 seed was sown under natural infestation in the field alongside the parents in an alpha-lattice design of 5 x 9 by adopting a spacing of 30 cm x 10 cm between rows and plants in a single row. Basal application of diammonium phosphate fertilizer and top-dressing with urea was used to boost the nitrogen levels to facilitate disease development (Prabhu, 1996; Seetharam and Ravikumar,

1993; Russell, 1978). Fourty competitive plants were labelled per plot from which data were recorded.

Data collection

Data was collected on the following traits: head blast incidence and head blast severity under natural infestation, days to 50% flowering, number of productive tillers per plant, finger number per head, grain mass per head, plant height, finger length, finger width, panicle length, panicle width and grain yield ha^{-1}. Data on these traits were collected using finger millet descriptors (IBPGR, 1985) as a guide. Some of the descriptors are as follows:

- Plant height (cm) from ground level to the tip of inflorescence (head) at dough stage,
- Productive tillers: number of basal tillers which bear mature heads,
- Days to 50% flowering from sowing to stage when heads emerge from 50% of main tillers,
- Finger length (cm) from base to the tip of longest spike (finger) on main tiller at dough stage,
- Finger number on main head at dough stage, and
- Single plant yield: mean was taken from fourty plants, post-harvest.

Grain yield (tons ha^{-1}): measured as grain mass was taken from the fourty plants, post-harvest and converted to tons ha^{-1}. Using the formula:

$$\text{Grain yield}\,(\text{tons ha}^{-1}) = \frac{333{,}333 \text{ x Yield of the 40 plants (Kg)}}{40 \text{ x } 1000}$$

Head blast incidence and severity were recorded at the time of grain maturity. The disease incidence was calculated as the number of diseased plants divided by the total number of plants sampled per plot, whereas for severity, all heads from the fourty plants were used to determine blast severity at maturity. For each head, proportions of spikelets affected by the disease were estimated and a Standard Evaluation System (SES) (IRRI, 1996) was adopted. This is based on the number of heads, and head blast severity computed as follows:

$$\text{HBS} = \frac{(10 \text{ x N1}) + (20 \text{ x N2}) + (40 \text{ x N5}) + (70 \text{ x N7}) + (100 \text{ x N9})}{\text{Total number of panicles}}$$

N1 – N9 are number of panicles infected with the disease, multiplied with the corresponding portion infected. The plants were then categorised as: 0 = no disease or immune, less than 10% = highly resistant, 11 - 20% = resistant, 20 - 30% = moderately resistant, 30 – 50% = susceptible and more than 50% highly susceptible.

5.3 Analysis

Data were analysed as a randomized complete block design (RCBD) since preliminary Lattice analysis resulted in no gain in accuracy due to blocking over RCBD analysis. Genetic analysis for blast disease resistance and other agronomic traits were performed as fixed effects model for the 45 entries (36 crosses and nine parents) in three replications. Diallel SAS05 programme was used to perform Griffings method 2, model I diallel analysis (Zhang et al., 2005). This model was most suitable for the present study where only parents and one set of F_1s (without reciprocals) were included and treated as fixed effects in the analysis. From the mean sums of squares, estimates of GCA effects (g_i) for each parent and SCA effect (s_{ij}) for each cross combination were also determined. The statistical model for the mean value of a cross (i x j) is as follows: $Y_{ij} = \mu + g_i + g_j + s_{ij} + 1/b\ \Sigma_k\Sigma_l e_{ijkl}$,

Where:

Y_{ij} = Mean of (i x j)th cross over replications k (k = 1, 2, …, b)

μ = The population (general) mean,

g_i and g_j = General combining ability (*g.c.a.*) effects of ith and jth parents, respectively,

s_{ij} = Specific combining ability (*s.c.a*) effect of *ij*th cross such that $s_{ij} = s_{ji}$

e_{ijkl} = Environmental effect associated with *ijkl*th observation in kth replication

Restrictions are imposed on combining ability effects, such that $\Sigma_i g_i = 0$ and $\Sigma_i s_{ij} = 0$ (for each j) therefore,

$1/b\ \Sigma_k\Sigma_l e_{ijkl}$ = Mean error effect.

The relative importance of general and specific combing ability in determining progeny performance was assessed by calculating the proportion of GCA : GCA + SCA sum of squares. The GCA : GCA + SCA sum of square ratio was proposed by Sprague and Tatum (1942), (cited and used by Simmonds and Smartt, 1999).

Further genetic studies were conducted following the model proposed by Hayman-Jinks (Hayman, 1954; Jinks and Hayman, 1953) including the graphical methods to test: (i) the adequacy of the additive – dominance model, (ii) the degree of dominance, and (iii) the direction

of dominance, in regard to prevalence of dominant and recessive genes. The model equation is as follows: $Y = \mu + a + b + a*block + b*block$; where:

Y_{ij} = mean of $(i \times j)^{th}$ cross over replications k (k = 1, 2, …, b)

μ = the population (general) mean,

a = additive effects

b = dominance effects

a*block = interaction of the replications with additive gene component

b*block = interaction of the replications with the dominance gene component

The dominance effects were further partitioned into: b1, direction of dominance. This term tested the mean deviation of the progeny from their mid-parent values. Significance indicate dominance deviations of the genes in the various genotypes used were predominantly in one direction; b2, test asymmetry of alleles. This term tests whether the dominance deviation of the progeny from their mid-parent values within each array differs over arrays. It will do so if some parents contain considerably more dominant alleles than others; b3, tests whether some dominance is peculiar to some progenies.

Regression coefficient (b) analysis was further used to test the adequacy of the model to describe the data set. The regression coefficient was generated from a plot of covariance (Wr) on the variance of the family means. Departure of b from zero was tested using $(b - 1)/s.e_b$, whereas, departure of b from 1 was tested using $(1 - b)/s.e._b$, where s.e. is standard error. Testing for the presence of epistasis was also carried out using the formula $(1 - b)/s.e.$ A value of > 2.0 indicated presence of epistasis. The genetic model was considered adequate if the regression coefficient deviated significantly ($p \leq 0.05$) from zero but not unity. The assumptions in the model were observed despite finger millet being an allo-tetraploid, it is assumed to behave as a diploid since their chromosomes pair and form bivalents at meiosis (Sleper and Poehlman, 2006)

5.4 Results

The mean of the parental lines for blast disease incidence, severity and grain yield per plant are presented in Table 5.2. The nine parental lines in this study showed significant differences in the reaction to head blast disease indicated by both incidence and severity, and grain yield. There was a whole range of reaction from resistance based on classification used here to susceptible

being exhibited by parental lines *E 11* and *ACF 5* both of which were introductions from ICRISAT and collections at University of KwaZulu Natal respectively.

Table 5.2: Means of parental lines for head blast incidence, severity and grain yield (tons ha^{-1})

Entry	Head blast incidence (%)	Head blast severity (%)	Type of disease reaction‡	Grain yield (tons ha^{-1})
01 (E11)	68.7	34.0	S	1.36
02 (ACF 5)	52.6	57.0	HS	1.41
03 (Seremi 2)	31.0	16.7	R	2.61
04 (ACF 19)	30.7	18.0	R	2.94
05 (Achaki)	25.3	12.7	R	4.17
06 (Abao)	38.7	26.0	MR	2.30
07 (Otunduru)	24.3	26.7	MR	2.89
08 (Bulo)	27.0	28.7	MR	3.46
09 (Amumwari)	30.0	19.7	R	3.40
Mean	36.5	26.9		2.73
Minimum	18.00	11.00		1.11
Maximum	93.00	50.90		4.49
LSD (0.05)	8.58	5.71		0.26
C.V. (%)	31.7	28.2		10.8

‡ type of disease reaction: S = Susceptible, HS = Highly susceptible, R = Resistant and MR = Moderately resistant.

5.4.1 Combining ability estimates

Results of mean squares for blast disease incidence, severity and agronomic traits are presented in Table 5.3. The mean square for entry, GCA effects and SCA effects for head blast incidence and severity were highly significant ($p \leq 0.01$) and partitioning the cross sum of squares the GCA effects of head blast incidence and severity accounted for 31.65% and 53.05% respectively.

Mean squares for the other agronomic traits were all highly significant ($p \leq 0.01$) for entry and GCA effects, whereas SCA effects were highly significant for all traits except panicle width which was just significant ($p \leq 0.05$). Specific combining ability effects were non-significant (0.05) for grain mass head^{-1} and grain yield ha^{-1}. On partitioning the sums of squares, the GCA effects ranged from 36.18% – 77.22%, whereas SCA effects contributed 22.78 – 63.82% of the total variance among the crosses. The contribution of GCA effects was highest for days to 50% flowering and lowest in panicle width, contrary to SCA effects. Considering all the agronomic traits; SCA effects were predominant for: number of fingers head^{-1}, finger width and panicle width, whereas GCA effects were predominant for grain yield ha^{-1}, days to 50% flowering, number of productive tillers plant^{-1}, grain mass head^{-1}, plant height and panicle length.

Table 5.3: Mean squares for blast disease incidence, severity and other agronomic traits of finger millet in half diallel cross evaluated at NaSARRI

Source of variation	DF	FBI	FBS	Grain yield (tons ha^{-1})	Days to 50% flowering	Tillers $plant^{-1}$	Finger number $head^{-1}$	Grain mass $head^{-1}$	Plant height	FL	FW	PANW	PANL
Rep	**2**	112.13^{ns}	45.97^{ns}	0.83^{ns}	11.34^{*}	0.92^{*}	0.39^{ns}	0.30^{ns}	173.41^{**}	0.10^{ns}	0.02^{**}	1.32^{**}	0.26^{ns}
Entry	**44**	382.53^{***}	345.54^{***}	1.93^{***}	53.67^{**}	1.20^{***}	1.15^{**}	0.70^{***}	161.94^{**}	1.20^{**}	0.02^{**}	0.12^{**}	1.46^{**}
GCA	8	665.97^{**}	1008.08^{***}	6.85^{***}	227.94^{**}	3.57^{**}	2.74^{**}	2.50^{**}	653.37^{**}	3.23^{**}	0.03^{**}	0.25^{**}	4.41^{***}
SCA	36	319.54^{***}	198.31^{**}	0.82^{ns}	14.95^{**}	0.67^{**}	0.79^{**}	0.29^{ns}	52.73^{**}	0.75^{**}	0.01^{**}	0.10^{*}	0.80^{**}
Error	**88**	85.50	37.97	0.61	2.65	0.09	0.13	0.22	9.52	0.11	0.002	0.06	0.11
CV		27.47	22.83	11.25	2.22	11.49	5.41	24.33	4.07	5.57	5.22	11.99	5.25
R^2		0.69	0.82	0.73	0.91	0.87	0.82	0.62	0.90	0.84	0.82	0.61	0.87
Corrected total	**134**												
Contribution of GCA		31.65	53.05	65.53	77.22	54.14	43.47	65.40	73.36	49.03	36.46	36.18	54.98
Contribution of SCA		68.35	46.95	34.57	22.78	45.86	56.53	34.60	26.64	50.97	63.54	63.82	45.02

*, ** and *** indicates the term is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ respectively; ns – not significant ($p > 0.05$), FBI = finger blast incidence, FBS = finger blast severity, FL = finger length, FW = finger width, PANW = panicle width, PANL = panicle length.

5.4.2 General combining ability effects of the parental materials

The GCA effects for the nine parental lines for head blast disease and other agronomic traits are presented in Table 5.4. For head blast disease the desirable GCA effect for the parents should be negative. The GCA effects for head blast disease incidence were significantly positive for *E 11* ($p \leq 0.01$), *ACF 5*, ($p \leq 0.001$) and *ACF 19* ($p \leq 0.05$), while negative, significant effects were shown for *Achaki* ($p \leq 0.001$) and *Otunduru* ($p \leq 0.01$), whereas, *Seremi 2*, *Abao*, *Bulo* and *Amumwari* were negative though non-significant ($p \leq 0.05$). For blast severity, positive significant effects were recorded for parents: *E 11* ($p \leq 0.001$), *ACF 5* ($p \leq 0.001$) and ($P \leq 0.05$). The parental materials produced similar effects (in terms of sign) for both incidence and severity. Negative significant effects were observed for *Seremi 2* ($p \leq 0.001$), *Achaki* ($p \leq 0.001$), and *Amumwari* ($p \leq 0.001$) while *Otunduru* and *Bulo* showed non-significant ($p \leq 0.05$), negative effect and *Abao* a positive, non-significant ($p \leq 0.05$) effect. The results therefore indicated that the desirable parents were *Seremi 2*, *Achaki*, *Amumwari* and to some extent *Otunduru* and *Bulo*.

For grain yield ha^{-1}, grain mass $head^{-1}$, tillers $plant^{-1}$, number of fingers $head^{-1}$, finger length, finger width, panicle length and panicle width the desirable GCA effect was positive. Whereas desirable GCA effects for days to 50% flowering and plant height is negative. Parents with significant, positive GCA effects for grain yield ha^{-1} were *Seremi 2*, *Achaki*, *Otunduru*, *Bulo* and *Amumwari*, whereas, for grain mass $head^{-1}$ were *Seremi 2*, *Achaki*, *Otunduru* and *Bulo*. Desirable combiners for productive tillers $plant^{-1}$ were *E 11*, *Achaki* and *Amumwari*; for number of fingers $head^{-1}$, *Seremi 2*, *ACF 19*, *Achaki*, *Abao* and *Bulo*; while finger length had *E 11*, *Seremi 2*, *Achaki* and *Bulo*. Parents that showed negative, significant GCA effects for days to 50% flowering and therefore desirable were *E 11* and *Seremi*, whilst negative, high significant GCA effects ($p \leq 0.01$) on plant height were recorded for *E 11*, *ACF 5*, *Seremi 2*, and *Abao*, while *Bulo* had no significant ($p \leq 0.05$) GCA effect.

Table 5.4: General combining ability effects for blast disease and other agronomic traits

Parent	FBI	FBS	Grain yield (tons ha^{-1})	Days to 50% flowering	Tillers $plant^{-1}$	Finger number $head^{-1}$	Grain mass $head^{-1}$	Plant height	FL	LFW	PANW	PANL
1	4.21^{**}	$3,67^{***}$	-0.72^{***}	-5.57^{***}	0.37^{***}	-0.60^{***}	-0.43^{***}	-4.01^{***}	0.22^{***}	-0.06^{***}	0.13^{**}	0.57^{***}
2	7.91^{***}	11.02^{***}	-0.53^{***}	0.67^{*}	-0.42^{***}	0.11	-0.32^{***}	-4.58^{***}	-0.20^{**}	-0.03^{***}	0.05	-0.35^{***}
3	-2.99	-5.70^{***}	0.29^{*}	-3.05^{***}	-0.32^{***}	0.21^{**}	0.17^{*}	-6.44^{***}	0.28^{***}	0.01	-0.04	-0.07
4	3.15^{*}	2.20^{*}	-0.26^{*}	1.19^{***}	-0.19^{**}	0.16^{*}	-0.15	2.09^{***}	-0.15^{**}	0.01	-0.07	-0.04
5	-6.15^{***}	-7.05^{***}	0.54^{***}	0.86^{**}	0.48^{***}	0.16^{**}	0.33^{***}	4.79^{***}	0.47^{***}	0.02^{*}	0.16^{**}	0.57^{***}
6	0.91	1.80	-0.31	-0.02	-0.09	0.16^{**}	-0.19^{*}	-1.85^{**}	-0.53^{***}	-0.02^{**}	-0.06	-0.37^{***}
7	-4.45^{**}	-1.23	0.35^{**}	1.91^{***}	-0.05	-0.33^{***}	0.21^{**}	5.19^{***}	-0.12^{*}	0.01	-0.03	-0.28^{**}
8	-1.73	-0.54	0.42^{**}	1.46^{***}	-0.17^{**}	0.23^{***}	0.25^{**}	0.11	0.20^{**}	0.04^{***}	0.07	0.19^{**}
9	-0.87	-4.18^{***}	0.21	2.55^{***}	0.39^{***}	-0.09	0.13	4.71^{***}	-0.17^{**}	0.03^{**}	0.05	-0.21^{**}
SE	9.24	6.15	0.28	1.63	0.30	0.36	0.47	3.08	0.34	0.04	0.24	0.33

*, ** and *** indicates the term is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ respectively; FBI = finger blast incidence, FBS = finger blast severity, FL = finger length, LFW = longest finger width, PANW = panicle width, PANL = panicle length. Parents 1, 2, 3, 4, 5, 6 and 7 are: E 11, ACF 5, Seremi 2, ACF 19, Achaki, Abao, Otunduru, Bulo and Amumwari respectively.

5.4.3 Genetic effects for blast disease resistance and grain yield associated traits

Analysis of variance for the Hayman diallel analysis (Table 5.5) indicated highly significant ($p \leq 0.01$) additive effects (a) controlling all the traits, but just significant ($p \leq 0.05$) for panicle width. Dominance effects (b) were highly significant for most of traits considered but non-significant ($p \leq 0.05$) for finger number, grain mass head^{-1} and plant height. On partitioning the dominance effects, direction of dominance (b1) was non-significant ($p \leq 0.05$) for head blast incidence, head blast severity, number of productive tillers plant^{-1} and panicle length. Asymmetry of alleles (b2) showed significance for all the traits considered except head blast incidence, grain mass head^{-1} and panicle width. Residual effects (b3) were also significant for all traits except grain mass head^{-1}.

The graphs of regression of the covariance (Wr) on the variance (Vr) of the progeny families for all the traits considered are presented in Figures 5.2 to 5.7. The regression gives a measure of the adequacy of the model, average dominance and the distribution of dominant and recessive genes (Hayman, 1954). For traits grain mass head^{-1}, single plant yield and finger length Wr/Vr regression was significantly different from zero with a regression coefficient not different from unity. The intercepts of the regression slope were significant ($p \leq 0.05$) and above zero for single plant yield, head blast severity, productive tillers per plant, and finger number, whilst significant and negative for finger length.

For grain mass head^{-1}, genotypes *E 11* and *Otunduru* were close to the origin whereas *Achaki* and *Bulo* were at the furthest positions with the rest intermediate from the origin (Fig. 5.2). Single plant yield had *E 11*, *ACF 19* and *Abao* close to the origin while *Achaki* was the furthest (Fig. 5.3). Head blast severity had *Bulo*, *Seremi 2*, *Achaki* and *Amumwari* being close to the origin but E 11, ACF 5, *ACF 19* and *Abao* were furthest from the origin. Productive tillers per plant, finger number per head and finger length are shown in figures 5.5, 5.6 and 5.7 respectively.

Table 5.5: Mean squares for blast disease incidence, severity and other agronomic traits of finger millet in half diallel cross evaluated at NaSARRI

Source of variation	DF	FBI	FBS	SPY	Days to 50% flowering	Tillers plant^{-1}	Finger number head^{-1}	Grain mass head^{-1}	Plant height	FL	FW	PANL	PANW
Additive (a)	**8**	0.07***	0.10***	58.50***	221.89***	3.57***	2.80***	2.44***	653.37***	3.23***	0.03***	4.41*	0.25***
Dominance (b)	**36**	0.03***	0.02***	8.78***	15.35***	0.67***	0.80	0.29	52.73	0.75***	0.01***	0.80**	0.10***
b1	1	0.08	0.00	15.78**	104.02**	1.30	3.48	0.00	44.93	1.00**	0.03*	0.14*	0.21
b2	8	0.03	0.02***	6.59***	5.44**	0.45*	0.73	0.27	102.71	0.88***	0.01**	0.50	0.08***
b3	27	0.03***	0.02***	9.16***	14.00***	0.71***	0.72	0.31	38.21	0.70***	0.01***	0.92**	0.10***
Wr/Vr		0.039	0.17	0.59	0.73	0.17	0.42	0.87	0.87	0.91	0.32	0.41	0.27
Total	**44**												

*, ** and *** indicates the term is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ respectively; FBI = finger blast incidence, FBS = finger blast severity, SPY = single plant yield, FL = finger length, FW = flag leaf width, PANL = panicle length, PANW = panicle width. b1= direction of dominance, b2 = asymmetry of alleles and b3 = residual dominance effects, Wr = covariance, Vr = variance.

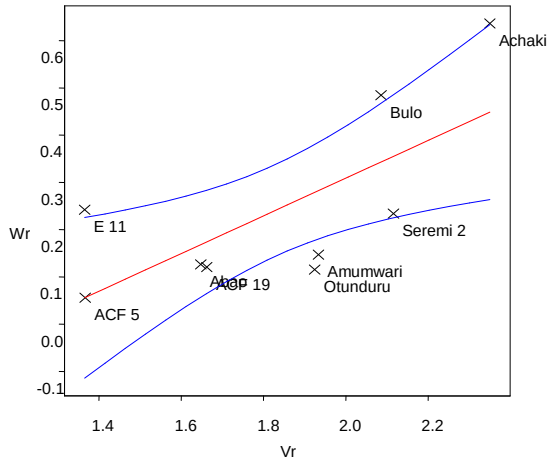


Figure 5.2: Linear regression of covariance (Wr)/variance (Vr) for grain mass per head

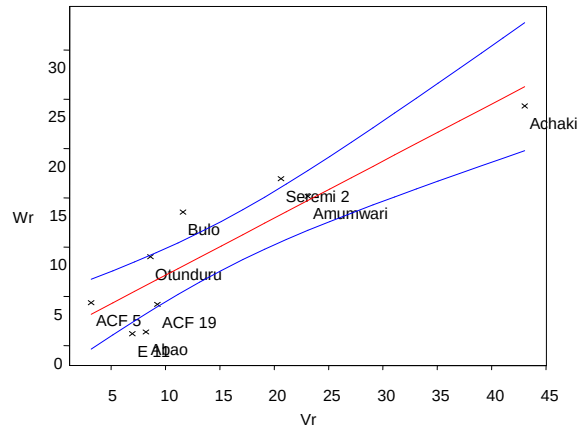


Figure 5.3: Linear regression of covariance (Wr)/variance (Vr) for single plant yield

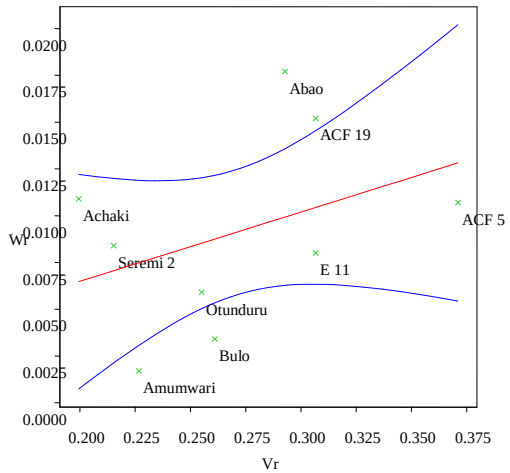


Figure 5.4: Linear regression of covariance (Wr)/variance (Vr) for head blast severity

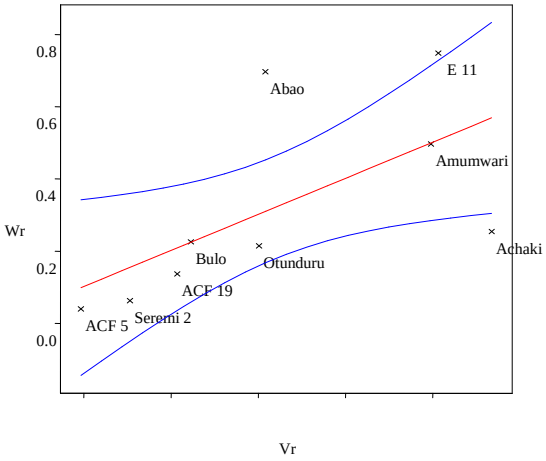


Figure 5.5: Linear regression of covariance (Wr)/variance (Vr) for productive tillers per plant

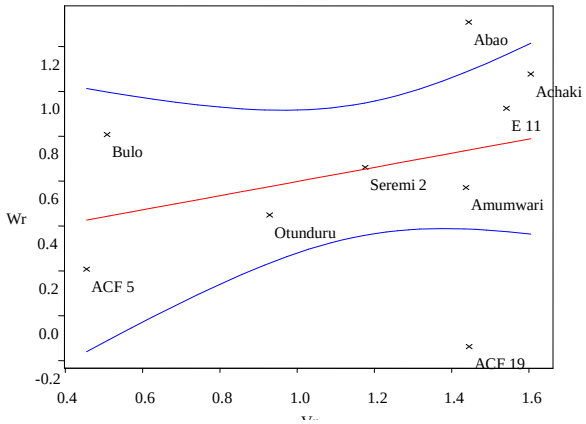


Figure 5. 6: Linear regression covariance (Wr)/variance (Vr) for finger number per head

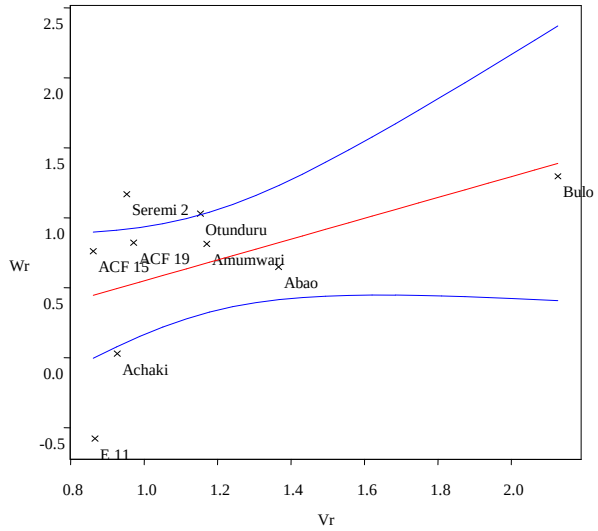


Figure 5.7: Linear regression of covariance (Wr)/variance (Vr) for finger length

5.5 Discussion

The results indicated a high range for both blast disease incidence and severity which probably implied continuous variation exhibited by the genotypes in terms of head blast resistance. This may point to polygenic control, coupled with the fact that no cultivar showed or approached immunity. Some of the varieties showed high levels of resistance which may provide economically acceptable control of the disease and therefore could be used as sources of resistance in combination with other analysis results.

5.5.1 Combining ability effects and gene action

The significant GCA and SCA effects observed for both head blast severity and incidence showed that both additive and non-additive gene effects were important to head blast resistance. The GCA effects accounted for most of the head blast severity variance whereas the SCA effects contributed most of the head blast incidence variance based on cross sums of squares, an indication that selection of parents can contribute to progress for blast severity. Similar findings were reported by Seetharam and Ravikumar (1993) on severity, but completely in contrast to that of Selvaraj et al. (2011) on rice panicle blast. The variance to the results of Seetharam and Ravikumar (1993) on incidence, and Selvaraj et al. (2011) on both incidence and severity may point to the fact that the mechanisms of resistance depend on the germplasm used and environment where investigations are carried out as was also reported by Ravikumar (1988). The current results showed that additive gene action was more predominant for head blast severity while non-additive gene action was more predominant for head blast incidence, an indication of severity being fairly heritable whereas incidence is less heritable and making progress would be slow. The presence of greater additive genetic variance for severity would also suggest that disease reaction for progeny families is predictable based on the GCA estimates of its parents (Falconer and Mackay, 1996; Dhillon, 1975). In contrast, the presence of greater non- additive genetic variance as exhibited in incidence makes it less predictable and would slow progress to selection for incidence.

General combining ability effects were significant for all the other traits, whereas SCA effects were also significant for all except grain mass head^{-1} and grain yield ha^{-1}. The contribution of GCA effects were higher for grain yield, days to 50% flowering, number of productive tillers

plant^{-1}, grain mass head^{-1}, plant height and panicle length, whilst SCA effects contribution was higher for finger number head^{-1}, finger width and panicle width. These results therefore showed the preponderance of additive gene action for grain yield, days to 50% flowering, tillering ability, grain mass head^{-1}, plant height and panicle length except for finger number head^{-1}, finger width and panicle width; a suggestion that both additive and non-additive gene actions and/or variations are important. Similar results were obtained by Parashuram et al. (2011) for number of fingers head^{-1}, finger width, and panicle width but contrary for the other agronomic traits in the current study, and completely contrary to report by Shailaja et al. (2010) whose report indicated non-significance for these traits under salinity conditions further augmenting the importance of environmental conditions on expression of these traits in finger millet. Krishnappa et al. (2009) on the other hand, also working on finger millet obtained similar results as in the present study for number of productive tillers plant^{-1}, number of fingers head^{-1} and grain yield, but non-additive effects for days to 50% flowering and plant height. Lamo (2010) also reported higher preponderance of additive gene effect in rice for grain yield, plant height and tiller numbers than non-additive gene effects.

Based on the results of these investigations, additive gene effects were more important in transmission of blast resistance, number of productive tillers, days to 50% flowering, grain mass per head, plant height and panicle length. This implies that breeding progress can be achieved through selection for these traits. Selection for these traits therefore would involve breeding methods that entail selection in the early generations such as single seed descent, pedigree selection and modified pedigree as suggested in rice by Hammoud et al. (2012). In finger millet specifically, Andrews (1993) suggested a method that involves bulking before evaluation as an appropriate method. In situations where non-additive gene effects are more important, selection should be delayed until later generations as the case was for finger and panicle width**.** For these traits repeated crossing in the segregating populations may be useful to pool all the desirable genes in one genotype as proposed by Selvaraj et al. (2011) and Sleeper and Poehlman (2006).

5.5.2 General combining ability effects of parents for blast reaction and yield traits

The selection of parents based on *per se* performance may not always result in producing superior crosses (Simmonds and Smartt, 1999; Falconer and Mackay, 1996), and they pointed

out that combining ability of parents gives useful information on the choice of parents in terms of expected performance of their progenies. This was clearly shown in cases where the magnitude and sign of the effect of each parent was not in agreement with individual performance. In the current investigations, most resistant parents to blast disease infection included *Achaki*, *Seremi 2*, *ACF 19*, and *Amumwari*. Of these parental materials, *Achaki*, *Seremi 2*, and *Amumwari* had negative, significant GCA effects which were desirable for blast resistance (general good combiners for head blast resistance) showing their capacity to transmit resistance for head blast disease. However, *ACF 19* in spite of being resistant, showed positive, significant ($p \leq 0.05$) GCA effects for both head blast incidence and severity implying it would contribute towards susceptibility in most of the progeny families for which it is involved unlike the other three parental lines, therefore, it is not appropriate for incorporation for blast resistance breeding. Furthermore, in the current study, *Otunduru*, which exhibited moderate resistance had a negative, highly significant ($p \leq 0.01$) GCA effect for head blast incidence and significant, negative SCA effect for blast disease in its progeny families with *E 11* a susceptible material, *Seremi 2* and *Amumwari* whilst positive, significant SCA effect in crosses with *ACF 5*, and *Abao*. It is suffice to suggest that *Otunduru*, unlike *ACF 19* is appropriate for incorporation in blast resistance breeding.

Overall, some resistant crosses involved a susceptible and a resistant or a moderately resistant parent similar to findings of Seetharam and Ravikumar (1993), whereby at least one of the parents had a negative GCA effect which could further confirm the influence of non-additive gene action in head blast resistance in finger millet and probably existence of dominance for head blast resistance genes. Parents *E 11*, *ACF 5* and *ACF 19* were poor general combiners as they exhibited significant, positive GCA effects for blast resistance. Exceptions were, however, observed for crosses *E 11* x *ACF 5* and *ACF 5* x *Abao* which showed negative SCA effects in their progeny families.

Among the parental lines, *E 11* was found to be a good general combiner for days to 50% flowering, tillering ability, plant height, finger length, panicle width and length; *ACF 5* and *ACF 19* were only good general combiners for plant height and finger number $head^{-1}$ respectively. *Seremi 2* was good general combiner for grain yield ha^{-1}, days to 50% flowering, finger number $head^{-1}$, grain mass $head^{-1}$, plant height and finger length; *Achaki* was good general combiner for

grain yield ha^{-1}, productive tillers plant^{-1}, finger number head^{-1}, grain mass head^{-1}, finger length, finger width, panicle width and panicle length, whereas *Abao* was only good for finger number head^{-1} and plant height. *Otunduru* on the other hand, was a good general combiner for grain mass plant^{-1} and grain mass head^{-1}; *Bulo* for grain mass plant^{-1}, finger number head^{-1}, grain mass head^{-1}, finger length, finger width and panicle length, as *Amumwari* was good for grain yield ha^{-1}, number of productive tillers plant^{-1} and finger width.

Parents that had positive significant GCA effects for grain yield contributed towards higher yields in most of the progenies in which they were part. For days to 50% flowering, negative, significant GCA effects indicated early maturity and these were observed for *E 11* and *Seremi 2*. Likewise desirable height was depicted by significant, negative GCA effects as was observed with *E 11*, *ACF 5*, *Seremi 2* and *Abao*. Positive, significant GCA effects for days to 50% flowering indicated late maturity; however, overall these results are indications that parents with good combing ability for grain yield per plant but were late maturing as depicted by positive, significant GCA effects for days to 50% flowering may be suited for high resource (potential) areas. It is also possible to select lines with positive GCA effects for yield and negative GCA effects for days to 50% flowering for limited resource (low potential) areas as they may also escape drought. Moreover they could also be used to generate early maturing cultivars suitable for increasing cropping intensity for the high potential areas. Meanwhile desirability of negative effects for height is to avoid lodging, which would even further be enhanced in high potential areas.

Parents with high GCA effects can be utilized in the hybridization programme for selection of recombinants in segregating progenies as suggested by Falconer and Mackay (1996). Knowledge of combining ability with mean performance of parents is therefore of great value in selecting suitable parents for hybridization programme (Selvaraj et al., 2011; Simmonds and Smartt, 1999). In the current study, high values for mean performance (in terms of grain yield) and GCA effects observed in some parental lines is clearly evident and this was also observed by Parashuram et al. (2011). Parents *Seremi 2*, *Achaki*, *Otunduru* and *Amumwari* recorded high mean performance and GCA effects for yield contributing traits studied and blast disease resistance and, therefore, will be pertinent in the hybridization programme for selection of

superior recombinants. Parashuram et al. (2011); Tamilcovane and Jayaraman (1994); and Ravikumar et al. (1986) also identified good general combiners in finger millet in India.

5.5.3 Genetic effects

The regression line will intercept the Wr axis above the origin if additive genetic effect is larger than the non-additive component of variance. If additive effect is equal to non-additive effect the regression line passes through the origin hence complete dominance. From the current study, significant negative intercept was only observed for finger length indicating over dominance effect for this trait in finger millet. From the graphs, parents closer to the regression line indicate the absence of epistasis. The results showed that grain mass head^{-1}, days to 50% flowering, finger number head^{-1}, plant height, finger length and panicle length exhibited no epistasis. On the contribution of dominance genes, parents which clustered close to the origin of the regression line contributed most dominant genes, whilst those furthest from the origin contributed most recessive genes and intermediate for those in-between. For instance, for single plant yield, parents *E 11, ACF 19* and *Abao* contributed most dominant genes whilst *Achaki* contributed most recessive genes (Fig. 5.3). This implied that high grain yield was contributed by recessive genes since Achaki was the highest yielding parent. For blast disease reaction, parents *Bulo* and *Amumwari, Achaki, and Seremi 2,* contributed most of the dominant genes, whereas *E 11, ACF 5*, and *ACF 19,* were furthest from the origin showing their contributions were mostly recessive genes. The implication is that resistance to blast disease is by dominant genes because the parents that contributed most dominant genes were also more resistant.

Based on the results from the current study, a regression of a unit slope ($b_{wr} > 0.5$), a regression coefficient of approximately 50% or more indicated that the additive-dominance model was adequate to describe the data (Dabholkar, 1992). These results also revealed that both additive and dominant genes were important in the inheritance of most of the traits but additive genes were more important than dominant genes based on the magnitude of the respective mean squares. The implication is that selection of parents can contribute to the progress in accumulating genes for increased grain yield and blast resistance in finger millet. On partitioning the dominance component of variance, asymmetry in gene distribution was significant for head blast severity, single plant yield, days to 50% flowering, number of productive tillers plant^{-1},

finger length, finger width and panicle width. This implied that some parents contained more dominant traits for these traits than others. This was clearly shown by the graphs for each of the traits. Residual dominance effects were also significant for some traits which revealed that epistasis contributed in the inheritance of head blast incidence, head blast severity, number of productive tillers plant^{-1}, finger width and panicle width. It could also be due to failure of some of the assumptions.

Conclusion

In conclusion parental materials that were resistant to head blast disease observed in the study included *Achaki*, *Seremi 2*, *ACF 19*, *Otunduru* and *Amumwari*, the parents *Achaki*, *Seremi 2*, and *Amumwari* had negative GCA effects and contributed negative SCA effects in most of the crosses involving them indicating that they are potential parents for head blast resistance breeding. Parental materials *Achaki*, *Seremi 2*, *Otunduru, Bulo* and *Amumwari* contributed towards high grain yield and with exception of *Seremi 2* were late in maturity. General combining ability contributed 31.65% and 53.05% of the crosses sums of squares for blast incidence and severity respectively while SCA effects contributed 68.35% and 46.95% respectively. The GCA effects for grain yield, days to 50% flowering and plant height accounted for 65.5%, 77.22% and 73.36% respectively of the crosses sums of squares. This indicated the predominance of genes with additive gene effects for grain yield ha^{-1}, days to 50% flowering and plant height in the parental lines and by extension high heritability for these traits in finger millet. Overall, highly significant additive effects implied that progress in high grain yield and blast disease resistance would be made through methods such as pedigree breeding and modified pedigree.

The analysis of genetic effects further confirmed the importance of additive gene action in most of the traits and indicated that the additive-dominance model was effective and adequate for genetic studies in finger millet. Partitioning the dominance component also revealed asymmetry for head blast severity, single plant yield, days to 50% flowering, number of productive tillers per plant, finger length, finger width and panicle width. These are traits associated with blast disease resistance, grain yield and head size therefore parents with dominant alleles could be identified. Parents contributing dominant genes for grain yield were *E 11*, *ACF 19*, and *Abao*,

whereas *Achaki*, which was also the highest yielding, contributed recessive genes. On the other hand, parents that contributed most dominant genes for blast resistance were *Achaki*, *Seremi 2*, *Amumwari*, *Otunduru*, and *Bulo*, which implied that resistance to finger millet blast disease is controlled by dominant genes.

References

Andrews, D.J. 1993. Principles for breeding small millets. P. 411 - 423. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York, USA.

Babu, T.K., R.P. Thukar, H.D. Upadhyaya, P.N. Reddy, R. Sharma, A.G. Girish, and N.D.R.K. Sarma. 2013. Resistance to blast (*Magnaporthe grisea*) in a mini-core collection of finger millet germplasm. European Journal of Plant Pathology. Open Access Repository, International Crops Research Institute for Semi-Arid Tropics. Available online http://dx.doi.org/10.1007/s10658-012-0086-2/ (date accessed: 10/04/2013).

Bua, B. and E. Adipala. 1995. Relationship between head blast severity and yield of finger millet. International Journal of Pest Management, 41:55-59.

Bvindi, C.N. 2010. Host status and genetic analysis of blast (*Magnaporthe oryzae*) resistance in barley. Msc. Thesis Wageningen University and Research Centre, Netherlands.

Dabholkar, A.R. 1992. The diallel mating design: Graphical and numerical approach. Concept Publishing Company, New Dehli, India.

Dhillon, B.S. 1975. The application of partial-diallel crosses in plant breeding: A review. Crop Improvement, 2:1-8.

Ekwamu, A. 1993. A review of finger millet studies at Makerere University. P. 467. Riley, K.W., S.C. Gupta, A. Seetharam, and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York, USA.

Ekwamu, A. 1989. Host range, morphology and pathogenicity of the genus *Pyricularia* in Uganda. East African Agriculture and Forestry Journal, 54: 101-105.

Esele, J.P. 1993. The current status of research on finger millet blast disease (*Pyricularia grisea*) at Serere research station. P. 467 - 468. Riley, K.W., S.C. Gupta, A. Seetharam, and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York.

Esele, J.P. and S.E. Odelle. 1995. Progress in breeding for resistance to finger millet blast at Serere research station. P. 93-99. In: Proceedings of the 8th EARSAM Regional Workshop on Sorghum and Millets, 30th Oct. – 5th Nov. 1992, Wad Medani, Sudan.

Falconer, D.S. and T.F.C. Mackay. 1996. Introduction to quantitative genetics. 4th Edition Longman Group Ltd, United Kingdom.

Griffings, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Sciences, 9:463-493.

Hammoud, S.A.A., S.E.M. Sedeek, I.O.M.. El-Rewainy and R.A. El-Namaky. 2012. Genetic behaviour of some agronomic traits, blast disease and stem borer resistance in two rice crosses under two nitrogen levels. Journal of Agricultural Research of Kafer El-Sheik University, 38:83-105.

Hayman, B.I. 1954. The theory and analysis of diallel crosses. Genetics, 39:789-809.

IBPGR. (International Board for Plant Genetic Resources) 1985. Descriptors of finger millet (*Eleusine coracana (L.)* Gaertn). IBPGR Secretariat, Rome, Italy: P. 20

IRRI; Standard Evaluation System for rice 4th Edition; IRRI, INGER Genetic Resources Center, Manila, Philippines, 1996.

Jinks, J.L. and B.I. Hayman. 1953. The analysis of diallel crosses. Maize Genetics Cooperative Newsletter, 27:48-54.

Krishnappa, M., S. Ramesh, J. Chandraprakash, J. G. Bharathi, and D.D. Doss. 2009. Genetic analysis of economic traits in finger millet. An Open Access Journal published by ICRISAT. SAT eJournal/ ejounal.icrisat.org, 7:1-5.

Lamo, J. 2010. Genetic studies on drought tolerance and grain chattering in rice. PhD Thesis, University of Kwazulu Natal, Pietermaritzburg, South Africa.

Lenne, J.M., J.P. Takan, M.A. Mgonja, E.O. Manyasa, P. Kaloki, N. Wanyera, J. Okwadi, S. Muthumeenakshi, A.E. Brown, M. Tamale, and S. Sreenivasaprasad. 2007. Finger millet blast disease management. A key entry point for fighting malnutrition and poverty in East Africa. Outlook on Agriculture, 36:101-108.

Parashuram, D.P., J. Gowda, R.G. Satish, and N.M. Mallikarjun. 2011. Heterosis and combining ability studies for yield and yield attributing characters in finger millet (*Eleusine coracana* (L.) Gaertn.). Electronic Journal of Plant Breeding. 2:494-500.

Prabhu, A.S., M.C. Filippi, and F.P. Zimmermann. 1996. Genetic control of blast in relation to nitrogen fertilization in upland rice. Pesq. agropec. bras., Brasilia, 31:339-347.

Ratnakar, M.S., N.M. Mallikarjuna, K.S. Naveen-Kumar, Jayarame Gowda, M.V. 2009. Mohan Kumar. Cytomorphological studies in inter-specific hybrids of finger millet. Gregor Mendel Foundation Proceedings, 2009:69-74.

Ravikumar, R.L. 1988. Genetic and biochemical basis of blast resistance in finger millet (*Eleusine coracana* Gaertn.). PhD Thesis, University of Agricultural Sciences, Bangalore, India.

Ravikumar, R.L., B.T. Shankare-Gowda, and A. Seetharam. 1986. Studies on Heterosis in finger millet. Millets Newsletter, 5:26-27.

Russell, G.E. 1978. Plant breeding for pest and disease resistance. Butterworth and company Publisher, Ltd. London, UK.

Seetharam, A. and R.L. Ravikumar. 1993. Blast resistance in finger millet – its inheritance and biochemical nature. P. 449-465. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York, USA.

Selvaraj, C.I., P. Nagarajan, K. Thiyagarajan, M. Bharathi, and R. Rabinddran. 2011. Studies on heterosis and combining ability of well known blast resistant rice genotypes with high yielding varieties of rice (*Oryza sativa* L.). International Journal of Plant Breeding and Genetic, 5:111-129.

Shailaja, H.B., S.Thirumeni, K. Paramasivam, and T. Ramanadane. 2010. Combining ability analysis in Finger millet *Eleusine coracana* (L.) Gaertn.) under salinity. Electronic Journal of Plant Breeding. 1:129-139.

Simmonds, N.W. and J. Smartt. 1999. Principles of Crop Improvement. 2nd Edition. Blackwell science Ltd. Oxford, UK.

Sleper, D.A. and J.M. Poehlman. 2006. Breeding field crops, 5th Edition. Blackwell Publishing, Iowa, USA.

Takan, J.P., B. Akello, P. Esele, E.O. Manyasa, A. Obilana, P.O. Audi, J. Kibuka, M. Odendo, C.A. Oduori, S. Ajanga, R. Bandyopadhyaya, S. Muthumeenakshi, R. Coll, A. E. Brown, N.J. Talbot, and S. Sreenivasaprasad. 2004. Finger millet blast pathogen diversity and

management in East Africa: a summary of project activities and outputs. International Sorghum and Millets Newsletter, 45:66-69.

Tamilcovane, S. and N. Jayaraman. 1994. Association between yield components in ragi. Journal of Phytological Research, 7:194-194.

Zhang, Y., M.S. Kang, and K.R. Lamkey. 2005. DAILLEL-SAS05. A Comprehensive programme for Griffings and Gardner-Eberhart analyses. Agronomy Journal, 97:1097-1106.

6.0 Chapter six

Inheritance of head shapes in finger millet

Abstract

Finger millet is highly variable in terms of head shapes and farmers in Uganda have indicated preference for varieties with fingers that curve in. Unfortunately no information exists on the inheritance and mode of gene action on this trait. The objective of this study therefore was to determine the inheritance of head shapes in Ugandan finger millet landraces. Crosses were made between genotypes of four different head shapes as follows: open x fisted, open x incurved, top-curved x incurved, top-curved x fisted, open x top-curved and incurved x fisted types in a green house. Both F_1 and F_2 generations were evaluated phenotypically for head shapes. In the cross between open x fisted head shape genotypes, a modified Mendellian ratio of 9:3:4 was obtained for phenotypes: top-curved, fisted and open; for top-curved x fisted the ratio was 12:3:1 top-curved, incurved, and fisted respectively, whilst top-curved x incurved the F_2 population also showed a modified segregation ratio of 12:3:1 for top-curved, incurved and fisted. These results indicated two genes controlling the inheritance of head shape and there were inter-allelic interactions which were: recessive epistasis and dominant epistasis respectively controlling this trait in the different crosses. However, the open x incurved cross generated an F_2 segregation ratio of approximately 36:16:9:3 indicating trihybrid segregation and therefore involvement of a third gene in the inheritance of head shapes in finger millet. By implication therefore, these findings suggest that three gene pairs expressing recessive epistasis and dominant epistasis, and probably an inhibitor, are involved in the inheritance of finger millet head shapes and therefore selection for this trait may be delayed to later generations from products of hybridisation. This was an initial study on finger millet head shapes and may not be sufficient to reveal and explain comprehensively the inheritance mechanism of head shapes. Further investigations should be carried out to validate these findings since head shapes are important in varietal adoption because they are associated with blast disease reaction, lodging, shattering by rain water, and bird damage.

Key words: Finger millet, head shapes, inheritance, landraces

6.1 Introduction

Finger millet (*Eleusine coracana* (L.) Gaertn.) is the second most important cereal in Uganda and first among millets (Ministry of Agriculture, Animal Industry and Fisheries, MAAIF, 2008). It ranks top in the list of nutri-cereals with wider adaptability than maize and rice among the cereals especially under low resource conditions. Among yield components, head shapes play a vital role in yield improvement and acceptability among farmers (Baniya et al., 2003). Wide variability in head shape has been noticed in finger millet, starting from open long types to compact fisty types, yet there is no information on the inheritance and therefore appropriate selection procedure for this trait. There are two broad groups of panicle shapes in finger millet: those in which the digitate spikes of the inflorescence curve in and those in which they are open. Ayyangar (1932) (as cited by Rachie and Peters, 1977) indicated three readily recognised head shapes in finger millet: (1) open, (2) top-curved, and (3) incurved. The incurved have short fingers, curve in and practically close up the central hollow giving the head an obovate shape (Kennedy-O'Byrne, 1957). The top-curved have intermediate fingers in length and tend to curve in at the tips only, thereby retaining the central hollow. The open types have the longest fingers and present a characteristic funnel shaped appearance which on drying tends to curve out slightly. The incurved can further be categorised into incurved and the fisty type (fist-like) with fingers compactly incurved (Rachie and Peters, 1977). For this study therefore, finger millet head shapes are considered in four distinct classes in terms of head shapes, that is; open, top-curved, incurved and fisty head shape types.

The wide variation based on inflorescence compactness and shape has also been adequately described by other workers (Amgain et al., 2007; de Wet et al., 1984) and based on this trait, finger millet is classified into four different races; *Elongata*, *Plana*, *Compacta and Vulgaries* (Reddy et al., 2009; Bezaweletaw et al., 2007; Prasada Rao et al.,1993). *Elongata* and *Plana* comprise the different sub-races categorised as open, *Compacta* combines fisted and incurved whilst *Vulgaries* consist of the top-curved head shapes. Head shapes are thus distinct, grouped into discrete classes and important, but the nature of its inheritance has not been investigated. Baniya et al. (2003) further reported that among the traits farmers look for - in addition to big head size, large grain size and freedom from finger millet blast disease are head shape and non-

lodging plants and high yielding varieties with these features in their local varieties. Therefore, head shape as a trait is important and ought to be integrated in breeding programmes.

Despite the relevance of head shape in finger millet production, very few studies have so far been conducted on them and their relevance to finger millet production. Oduori (2008) for instance, reported a negative correlation between head shape and lodging, pointing out that open headed genotypes were more prone to lodging than the fist headed genotypes probably due to open heads offering resistance to wind and also the susceptibility of open headed genotypes to finger millet blast disease increased with tendency to open headedness. Bua and Adipala (1995) also found significant relationships between head shape and blast disease damage and hence yield in disease conditions. Ekwamu (1991) further reported a significant relationship between head components and grain yield in a study of blast severity on different finger millet genotypes and concluded that these head components are therefore important in determining yield in finger millet including shape. Head shapes also have a direct implication to bird damage and grain shattering by rain as damage is often on the top side of the curved panicle where it is easier for birds to feed leaving the inside intact unlike the open headed types.

Selection of parents based on traits with good farmer preferences and acceptability will undoubtedly enhance adoption of improved cultivars. In development of improved varieties however, recombination breeding occupies a predominant position. Information on relative importance of inheritance studies is therefore of immense use in the development of an efficient breeding programme in finger millet (as well as other crops). It does not only help to identify the parents and crosses, which are likely to give the maximum improvements for the character under consideration, but also provides means of understanding the nature of gene action involved in it (Krishnappa et al., 2009). Finger millet head shape is such an important trait as already pointed out, yet there appears to be no report to date on the inheritance of head shapes in finger millet. However, inheritance of some qualitative traits by Ayyangar (1932) (as cited by Rachie and Peters, 1977) and Ravikumar and Seetharam (1990) on pigmentation exist indicating mono or oligogenic inheritance for these traits. However, this is not related to head shape. It is therefore imperative to investigate the mode of inheritance of head shape in finger millet. The knowledge on the inheritance of head shapes will enhance optimum incorporation of preferred head shapes in improved cultivars required by the farmers.

6.1.1 Objective of the study

The objective of the study was to determine the inheritance of head shapes in finger millet landraces through genetic analysis of the F_2 segregating populations from crosses of finger millet varieties showing four distinct head shapes.

6.2 Materials and Methods

The crosses were made between the different finger millet varieties with different head shapes as follows: top-curved x open, open x incurved, fisted x open, top-curved x incurved, top-curved x fisted and fisted x incurved to cover all the four head shape types (Table 6.1). The crosses were all carried out using potted plants in a greenhouse at the National Semi Arid Resources Research Institute Serere (NaSARRI) in 2011. All the F_1s were raised in the first season of 2012 and phenotyped for head shape and F_2 seed harvested. The F_2 generation was raised during the second rainy season of 2012 and screened phenotypically for head shapes.

Table 6.1: Crosses, female and male parents with nodal pigmentation

Crosses	♀ **parent**	♂ **parent**
Top-curved x Open	ACF 19	E 11
Open x incurved	E 11	Otunduru
Fisted x Open	Achaki	E 11
Top-curved x Incurved	ACF 19	Otunduru
Top-curved x fisted	Bulo	Achaki
Fisted x Incurved	Achaki	Otunduru

♀ female parents, ♂ male parents

6.2.1 Crossing techniques

Finger millet is very highly self-pollinating and estimates of natural crossing generally have not exceeded 1% (Rachie and Peters, 1977). Moreover, the flowers are very small and extremely

difficult to manipulate. Two methods were adopted for this study to improve chances of success, that the contact method first used by Ayyangar (1932) (as cited by Rachie and Peters, 1977) and the plastic bag method. The contact method involved removal of all except a single finger or portion of a finger of the designated female parents and pollinating the flowers by contact with the designated male head. The two fingers were then tied together using a thread as suggested by Ravikumar (1988) and then enclosed by bagging to prevent unwanted pollen. In the plastic bag method, emasculation was achieved using a 7.5 cm x 10cm polythene bag lined with moist filter paper inverted over the flower and plugged with absorbent cotton wool. This creates high humidity inside the bag. Under such humidity, the anthers emerge but do not dehisce to shed pollen. Pollen was then collected from the designated male parent which was shedding pollen. The pollen collected from the bag was dusted on the emasculated head and again covered with a pollination bag and labeled. After pollination, seeds were collected only from the female parent. These procedures were carried out at anthesis during the morning hours between 7 am to 9 am as anthesis in finger millet is known to take place beginning 1 am and 4 am and ends by 11.00 am (Ratnakar et al., 2009). The planting was staggered to achieve synchrony in flowering to facilitate crossing since the different genotypes had different flowering periods.

6.2.2 Identification of true F1s

Identification of the true F_1 crosses was done during the first rainy season of 2012 at NaSARRI. All the potential crosses from the pollinated heads were planted in two rows of 10 m long in between rows of the female and male varieties. The first row was that of the female parent, followed by two rows of the potential crosses and fourth row was that of the male parent. The female and male parent rows were planted to facilitate identification of the true F_1s. True F1s were identified by use of certain morphological markers where ever applicable. The parents were selected on the basis of nodal colours since the purple colour is known to be dominant over green (Ratnakar et al., 2009; Santhkumar and Gowda, 1998, Ravikumar and Seetharam, 1990; Ravikumar, 1988). Other morphological characters used were: plant height, head shape, flowering periods and plant vigour. Any plants that looked like the female parents were rejected as they were considered to be selfed progenies.

6.2.3 Experimental lay-out

The six F_2 populations were planted in the field under natural conditions between parental rows (for head shape comparison) using a randomised complete block design adopting a spacing of 30 cm x 10 cm between rows and plants in a single row at NaSARRI (Latitude 1° 29' 39N Longitude 33° 27' 19E 1085 m.a.s.l). Basal application of diammonium phosphate fertilizer and topdressing with urea was used to boost the nitrogen levels to achieve optimal growth. Ninety competitive plants were labelled for each F_2 population from which head shape phenotyping was done. Head shapes were classified according to descriptions of Ayyangar (1932) (cited by Ratchie and Peters, 1977) and Kennedy-O'Byrne (1957); recently used by Lule et al. (2012) and Upadhyaya et al. (2007) at the dough stage.

6.2.4 The observed segregation

The observed segregation patterns from the six F_2 populations were individually tested by chi-square analysis against expected ratios for Mendelian monohybrid, dihybrid and trihybrid inheritance. The six data sets were tested individually for goodness-of-fit to the expected ratios of 3:1, 9:3:3:1 and 27:9:9:9:3:3:3:1 for monohybrid, dihybrid and trihybrid segregation ratios respectively.

6.3 Chi-square analysis

Chi-square tests which are normally done when sample subjects are distributed among discrete categories (Klug and Cummings, 1999) were used to evaluate the data. The formula for converting categorical experimental data to a chi-square is as follows:

$$\chi^2 = \frac{\Sigma(O-E)^2}{E}$$

Where:

χ^2 = the Greek letter Chi

O = Observed number for the category

E = Expected number for the category

$\sum$ = Sum of the calculations for all categories

6.3.1 Estimating minimum number of genes

The minimum number of genes controlling head shape in finger millet was estimated using the formula by Wright (1968) as follows: $N = (\overline{x}_1 - \overline{x}_2)^2/8*(\sigma^2F_2 - \sigma^2F_e)$, where:

N = Number of genes

$\overline{x}_1$ = Mean head shape score of parent 1

$\overline{x}_2$ = Mean head shape score of parent 2

$\sigma^2F_2 - \sigma^2F_e = \sigma^2_g$

σ^2F_2 = Variance of F_2 generation

σ^2F_e = Environmental variance within each representative F_2 family.

σ^2_g = The genetic variance stemming from differences in gene frequencies of the parental populations in the F_2 population from a cross of the two parental populations. This formula is used with the assumptions that all genes controlling the traits are unlinked, affect the trait in equal magnitude and direction, and there are no dominance and/or epistasis effects involved.

The head shapes were scored as follows: open = 1, top-curved = 2, incurved =3, fisted = 4. This was based on the degree of curving of the fingers. The higher the value, the higher the degree of curving. These figures were then used to estimate the variances and means used in the estimation of the minimum number of genes.

6.4 Results

6.4.1 Chi-square test for inheritance of head shape

Of the six F_2 populations resulting from the six crosses, four F_2 populations (fisted x open, open x incurved, top-curved x fisted and top-curved x incurved head shape crosses) produced more than two phenotypes and were therefore tested for Mendellian dihybrid segregation ratios. Two crosses on the other hand, that is, open x top-curved and incurved x fisted generated two phenotypes each and were tested for the monohybrid segregation ratio. Three of the four crosses that generated more than two phenotypes, that is, fisted x open, top-curved x fisted, and top-curved x incurved departed significantly from the Mendelian dihybrid segregation ratio, each population generating three phenotypic classes (Table 6.2). Open x incurved F_2 family segregation on the other hand generated four phenotypes and was tested for both Mendellian dihybrid and trihybrid segregation ratios because of the behaviour in the other crosses and the

observed ratio. This cross did not depart significantly from the dihybrid segregation ratio of 9:3:3:1, but departed significantly from the trihybrid segregation ratio (Table 6.2). The phenotypes produced were 21, 46, 14, and 09 for open, top-curved, incurved and fisted respectively. This result approximated the trihybrid segregation ratio of 36:16:9:3 in presence of epistasis for top-curved, open, incurved and fisted head shape types respectively and was therefore used as such for explaining the results.

The result of fisted x open showed that when the F_1s were advanced to the F_2, phenotypic screening of the F_2 generation for head shape, the χ^2 value was greater than the critical value (at $p \leq 0.05$) indicating departure from the 9:3:3:1 expected segregation ratio. The observed value however, revealed an estimated segregation ratio of 9:3:4 for top-curved, fisted and open, respectively. This indicated presence of recessive epistasis and therefore inter-allelic interaction in this cross.

For the top-curved x fisted cross; 58, 25 and 07 plants respectively, produced top curved, incurved and fisted head shaped plants from the F_2 family segregation. This observed ratio also departed significantly (χ^2 at $p \leq 0.05$) from the expected 9:3:3:1 Mendellian segregation ratio but was approximate to the two gene interaction segregation ratio of 12:3:1. Similarly, the top-curved x incurved head shape cross generated three phenotypes at the F_2 generation as follows: 70 were top-curved, 18 incurved and 2 fisty head shaped types. The chi-square test as well indicated a significant χ^2 departure from the 9:3:3:1 dihybrid segregation ratio, but approximated the 12:3:1 modified dihybrid ratio for top-curved: incurved : fisty head shape types. These two crosses therefore, seemed to exhibit dominant epistasis from the segregation of their F_2 families. The two crosses tested for the monohybrid segregation ratio, that is, top-curved x open and fisted x incurved generated phenotypic ratios in conformity with Mendellian monohybrid segregation ratio of 3:1.

6.4.2 Estimated number of genes

The estimated number of genes ranged from 0.41 to 2.63 for the crosses fisted (F) x incurved (IC) and fisted (F) x open (Op) respectively (Table 6.3). In the crosses involving the open head shape types there were more than two genes responsible for determining head shape in finger millet whereas, in the F x IC only one gene seemed to contribute to head shape.

Table 6.2: Breeding behaviour in F_1 and F_2 progenies from crosses of four different finger millet head shapes

Cross	F_1	F_2 observed and expected phenotypic frequencies					ER	Total χ^2	χ^2 at ($p \leq 0.05$)	OR
			Op	TC	IC	F				
Achaki (F) x E 11 (Op)	TC	Ob	22	54	-	14	3:9:3:1	31.06	5.991	4:9:3
		Ex	16.88	50.63	16.88	5.63				
†E 11 (Op) x Otunduru (IC)	TC	Ob	21	46	14	09	3:9:3:1	3.94	5.991	3:9:3:1
							27:9:9:9:3:3:3:1	49.59	14.07	16:36:9:3
		Ex	16.88	50.63	16.88	5.63				
ACF 19 (TC) x E 11 (Op)	TC	Ob	23	67	-	-	3:1	0.5	3.841	3:1
		Ex	22.5	67.5	-	-				
Bulo (TC) x Achaki (F)	TC	Ob	-	58	25	07	3:9:3:1	22.19	5.991	12:3:1
		Ex	16.88	50.63	16.88	5.63				
ACF 19 (TC) x Otunduru (IC)	TC	Ob	-	70	18	02	3:9:3:1	26.7	5.991	12:3:1
		Ex	16.88	50.63	16.88	5.63				
Achaki (F) x Otunduru (IC)	IC	Ob	-	-	65	25	3:1	0.33	3.841	3:1
		Ex	-	-	67.5	22.5				

Op = open head shape, TC = top-curved head shape, IC = incurved head shape, F = fisted, ER = expected phenotypic ratio, OR = observed ratio, Ob = observed frequency, and Ex = expected frequency. † the cross was tested for both dihybrid and Trihybrid segregation ratios.

Table 6.3: **Estimates of minimum number of genes from six different finger millet crosses in the F_2 families**

Crosses	Op x F	Op x IC	Op x TC	TC x F	TC x IC	IC x F
σ^2F_2	2.33	4.57	2.24	1.94	2.77	3.28
MNG	2.63	2.38	2.19	2.28	1.12	0.41

σ^2F_2 = variance of F_2 generation, MNG = minimum number of genes, Op = open head shape, TC = top-curved head shape, IC = incurved head shape, and F = fisted.

6.5 Discussion

From the results, it appears three major independent genes were involved in the inheritance of finger millet head shapes. The minimum number of genes ranged from 0.41 to 2.63; however, these are most likely to be on the lower side because epistasis and dominance seemed apparent from the results. Biased estimates due to epistasis and/or dominance were observed by Wright (1968). It is therefore possible that the number of genes could be more than what was observed in this study but were biased since the analysis did not meet the preconditions. These assumptions are that all involved genes are unlinked and active in a strictly semi-dominant manner with an equivalent contribution to the phenotype (Zeng, 1992).

The results from four of the six crosses expressed phenotypes indicative of two or more genes involvement in the inheritance of finger millet head shapes as opposed to a single gene. These results also indicated gene interactions which have also been reported to occur in some qualitative traits in sorghum, finger millet and rice. In sorghum, Ghorpade and Kadam (1980) reported it in panicle shape and colour; in finger millet Rachie and Peters (1977) reported it in nodal colour, panicle colour and seed characteristics, while Jones (1934) reported it in rice for panicle shape, presence or absence of awns, and colour of lemma and palea furrows. Otherwise there has been no detailed and comparable work in head shape inheritance in finger millet, setting this study as a base line. The expression of intermediate phenotypes, that is top-curved, in the F_1 crosses for fisted x open and open x incurved head shape types also indicated that none of the two parental phenotypes showed complete dominance over the other, probably subtly pointing to epistasis or partial dominance. This has also been observed in studies in rice and sorghum.

Interpretation of results

Considering a three gene scenario which seems to be most likely, two different genes seem to determine head shape in finger millet. A third gene appears to be present and determines whether curving in the fingers occurred or not. A dominant gene of this pair (C for this study) is needed for curving to occur irrespective of A and B. The dominant C gene therefore inhibits openness of heads in finger millet. The dominant A gene in this study is responsible for open head shape, and

dominant B for incurved. The recessive condition in both A and B results in fisted head shapes whilst dominant condition in both A and B resulted in top-curved head shapes. This can be illustrated as follows:

A- B- results in top-curved head shapes

A- bb results in open head shapes

aa B- results in incurved head shapes

aabb results in fisted head shapes.

The C gene however, seemed to affect the expression of these phenotypes when present in either recessive or dominant condition and the following seemed to be the probable genotypes involving all the three gene pairs. A-B-C- and A-bbC-, resulted in top-curved head shapes, A-B-cc, A-bbcc, aaBBcc, and aabbcc resulted in open head shape, aaB-C-, resulted in incurved head shape and aabbC- resulted in fisted head shape. The C gene in dominant form inhibits the expression of A, whereas in the recessive form both A- and aa behave in the same way. The recessive form of C produces open head shape irrespective of conditions at the A and B loci, and A is epistatic to B. In this case however, it appears to be dominant epistasis. The B locus is responsible for both incurved and fisted head shapes when A is recessive and C dominant, the incurved condition is however dominant to the fisted head shape type. The detailed analysis and deductions for each cross and subsequent F_2 families are indicated below, and probable genotypes are summarised in Table 6.4.

6.5.1 Open head shaped variety x fisty head shaped variety

The F_2 progeny segregation ratio of 9:3:4 observed from the open head shape variety x fisted head shape varietal cross is consistent with recessive epistasis which occurs when a homozygous recessive gene masks the expression of another gene or gene pair (Klug and Cummings, 1999). In the current study however, there seemed to be three genes controlling head shapes and interacting with each other. The genes involved controlled the expression of the same general phenotypic characteristic in an antagonistic manner, which leads to masking the effect of another gene. The result could also be pointing to a possibility of an inhibitor which was reported by Ayyangar (1932) (as cited by Rachie and Peters, 1977) in millets and grasses. This seems to be

the most likely explanation for this cross. The inhibitor in this case is the C gene which when present in dominant form, the A gene for openness is suppressed. A homozygous recessive condition in both A and B loci seem to be responsible for fisted head shape and preventing formation of open head shapes in presence of the dominant form of the C gene.

This finding is in conformity with the finding of Ayyangar (1932) in millets and grasses (as cited by Rachie and Peters, 1977) who suggested that there is a factor for finger curving that masks or inhibits the expression of the open head shape in finger millet. This probably explains the approximate modified dihybrid ratio of 9:3:4 in the open x fisted cross. Seetharaman and Srivasta (1972) also reported similar findings in rice. Jones (1934) working on rice, suggested a possibility of modifying factors.

By way of illustration, if the genotype A- causes openness in the absence of the dominant form of C, and aa for fisty head shape in presence of dominant form of C, the presence of dominant forms of C gene result in top-curved head shape if A- is present but fisty in absence of A. In the current case, the genotype AA bb C- produced top-curved head shape, both A- bb cc and aabbcc produced open head shape whereas aa bb C- produce fisty head shape. The probable parental genotypes were: AAbbcc for open (E 11) x aabbCC for fisted head shaped (Achaki) types resulting in AabbCc F_1 progeny which were all top-curved. This behaved like a dihybrid in which the third gene (b) is homozygous in the F_1 resulting in a 9:3:4 recessive epistatic ratio because both A- and aa are affected by the c allele which leads to openness.

6.5.2 Open x Incurved head shapes

All the F_1 progeny in this cross were top-curved and the F_2 progeny segregation ratio did not depart significantly ($p \leq 0.05$) from the dihybrid ratio of 9:3:3:1. However, this was not consistent with the findings from the other crosses, but on testing for a trihybrid segregation ratio it significantly departed. The observed ratio was approximate to 36:16:9:3 trihybrid segregation involving allelic interactions for top-curved, open, incurved and fisty head shapes. This ratio was consistent with findings from the other crosses and therefore used in this study to explain the inheritance of head shapes. This result indicated that, presence of dominant alleles at both the A and C loci resulted in top-curved head shapes irrespective of the alleles at the B locus, all

homozygous recessive forms of C resulted in open head shapes irrespective of the gene conditions at A and B, a dominant allele at the B and C loci when A was recessive resulted in the incurved head shape. The recessive conditions at both A and B resulted in fisted head types when C was dominant. The C gene seems to be determining the ability to form the curving head shape types whereas the A gene seems to exhibit partial dominance over the B gene. The probable parental genotypes were: AAbbcc for the open head type (E 11) and aaBBCC for the incurved head shape (Otunduru) parent. The F_1 genotype would probably be AaBbCc. Selfing the F_1 generated an approximate 36:16:9:3 ratio. This result indicated presence of gene interactions which probably involved epistasis, modifier genes and probably other forms of interactions.

6.5.3 Top-curved x fisted head shapes

The 12:3:1 ratio observed suggest two segregating gene pairs (Klug and Cummings, 1999), in this case, the A and B loci only. This result also seemed to suggest the presence of a homozygous dominant gene at the C locus for both parents. The presence of a dominant allele at the A locus resulted in the top-curved head shape, whereas a homozygous recessive condition at the A locus and a dominant allele at the B locus resulted in incurved head shape. The homozygous recessive gene at both A and B genes resulted in the fisted head shape type. The dominant A gene appears to be epistatic to the B gene which is responsible for the in-curving head shape type. The result also revealed an intermediate phenotype (incurved) generated resulting in a ratio of 12:3:1 for top-curved : incurved : fisted in the F_2 generation.

This can be illustrated as: in absence of dominant gene at the A and B loci that is, aa bb C-, the head shape was fisty, if there is a dominant gene at either locus A or both A and B loci the head shape was top-curved thus A-B-C- and A- bb C-, genotype aa B- C- resulted in the incurved head shape type. The probable parental genotypes were therefore: AA BB CC for top curved (Bulo) x aa bb CC for the fisted head shaped (Achaki) parent, with AaBbCC as the probable F_1 genotype. This behaved as a dihybrid segregation involving the A and B loci expressing dominant epistasis. In the presence of dominant A gene, the B gene is not expressed.

6.5.4 Incurved x top-curved (all F_1s top-curved)

The observed segregation ratio departed significantly (χ^2 at $p \leq 0.05$) from the 9:3:3:1 expected from the Mendellian dihybrid segregation ratio. However, it did not deviate significantly from the 12:3:1 modified dihybrid segregation ratio for top-curved : incurved : fisted head types. This pointed to presence dominant epistasis involving A and B genes only. The result revealed that presence of a dominant allele in at least the A and C loci resulted in the top curved head shape, homozygous recessive at both A and B loci, and at least a dominant allele at the C locus resulted in the fisted head shape and a dominant allele at the B and C loci resulted in incurved head shape. A dominant allele at the A locus suppressed the expression of the incurved head shape (the B locus). The 12:3:1 phenotypic ratio was also reported in rice by Seetharaman and Srivastava (1972) who attributed it to presence of two independent genes for panicle shape inheritance one being present in each parent. They however, reported that there was an epistatic gene to one of the genes resulting in cigar shaped panicles in rice. There is however, no report in finger millet.

This can be illustrated as: A- B- C- and A- bb C- produced top-curved head types, aa B-C- produced incurved type and aa bb C- produces the fisty type. The dominant gene A masked the effect of B. This is a case of dominant epistasis since in presence of A both B- and bb behaved in a similar way. The probable genotypes of the parents were as follows: AAbbCC for top-curved (ACF 19) x aaBBCC for incurved (Otunduru).

6.5.5 Open head shape x top-curved head shape

This cross resulted in top-curved F_1 crosses. However, the F_2 family segregation resulted in a 3:1 monohybrid ratio for top-curved : open head shape types. This result pointed to the presence of a dominant gene at the C locus which masked the effect of a dominant gene at the A locus (dominant epistasis) irrespective of the B locus. So by implication, the dominant allele at the C locus is epistatic to the A locus responsible for openness of the head shapes. The result also indicated that the parental materials had similar allelic compositions in two of the three genes responsible for head shape inheritance. The segregation indicated that C- resulted in the top-curved head shape types whereas cc resulted in the open head shape type.

By illustration: A- B- C- and A-bb C- resulted in top-curved head shape and A-B-cc, A- bb cc resulted in open head shape type. This result indicated that there was segregation only at the C locus and therefore the probable genotypes of the parental materials were AAbbCC for the top-curved head shape type and AAbbcc for the open head shape type. This behaved as a monohybrid in which the other two genes (A and B) were homozygous in the F_1, segregation occurring only at the C gene.

6.5.6 Incurved x fisted

The 3:1 segregation ratio observed for incurved x fisted head shapes was also indicative of one segregating gene pair in the F_2 population from a cross involving these two head shape types therefore controlled from one locus (basic gene) in this cross. The segregation appears to be at the B gene with B- genotypes resulting in incurved head shapes and bb genotypes resulting in fisted head shapes. This segregation ratio indicates that the incurved condition is dominant over the fisted head shape condition. The finding seems to be consistent with findings from other crosses in this study where the observation seemed to indicate that the incurved is conditioned by a dominant gene at one locus whereas, fisted head shape is conditioned by homozygous recessive alleles at both A and B loci. This result is in conformity to the findings of Seetharaman and Srivastava (1972) who indicated that inheritance of some panicle shapes in rice may be conditioned by a basic recessive condition in one locus. The result also revealed that for these two head shapes there is no interaction between the three loci responsible for head shape inheritance probably because there were similar alleles at both the A and C loci. The probable genotypes of the F_2 progeny were: aa B- C- for incurved and aa bb C- for fisted head shape types; and suggested parental genotypes were: aabbCC for the fisted head shape type and aaBBCC for the incurved head shape type. The probable genotype for the F_1 was aaBbCC.

Conclusion

The segregation patterns observed from this study showed that more than a single gene, probably three genes are responsible for inheritance of head shapes in finger millet and there is an interaction between these genes. The minimum number of genes also appeared to support these findings since in four crosses the observation was above two. These figures on number of genes

though appeared to be on the lower side because the conditions for estimation of minimum number of genes were not strictly adhered to since factors like epistasis and dominance which are known to bias the estimates of effective genes downwards seemed apparent. It is possible that the number of genes was more than what was observed in this study but three genes seemed to be adequate to explain the inheritance patterns in the different head shapes. The model of Wright, although it did not fit the current study, was used because this was an initiative to bench mark inheritance studies in finger millet head shapes due to its importance. More studies are therefore required to validate this initial study. The results may not also exhaustively reveal and explain the gene action in finger millet head shapes because if there were more than two genes as seemed the case, the sample size of 90 per family (adequate for two genes) was inadequate. Therefore, a more comprehensive study with a sample size of about 400 plants may be required. The results also revealed that the fisted head shape is obtained by homozygous recessive condition in A and B gene whereas top-curved requires presence of a dominant allele at the A and C loci. Without the influence of C, A results in open head shapes and B in incurved head shapes. In summary, the probable genotypes for the parents used in this study were as follows: E 11 – Aabbcc, Achaki – aabbCC, Otunduru – aaBBCC, ACF 19 – AabbCC and Bulo – AABBCC.

Table 6.4: **Summary table showing phenotypes and proposed genotypes for the parents, F1 and F2 generations**

	Parent 1	Parent 1	F_1	F_2 family phenotypic ratios and proposed genotypes				Comments
Cross	Achaki	E 11		TC	Op	IC	F	Homozygous recessive condition at A and B loci results in fisty head shapes,
Phenotypes	F	Op	TC	9	4	-	3	
Genotypes	aabbCC	AAbbcc	AabbCc	1AAbbCC 2AAbbCc 2AabbCC 4AabbCc	1AAbbcc 2Aabbcc 1aabbcc	-	1aabbCC 2aabbCc	There is recessive epistasis, Dominant C gene suppresses expression of A gene. This is a case of dihybrid segregation involving A and C loci.
Cross	E 11	Otunduru						Trihybrid segregation with epistasis,
Phenotypes	Open	Incurved	TC	36	16	9	3	
Genotypes	AAbbcc	aaBBCC	AaBbCc	27A-B-C- 9A-bbC-	9A-B-cc 3A-bbcc 3aaBbcc 1aabbcc	9aaB-C-	3aabbCC	dominant alleles at A and C loci resulted in top-curved head shapes irrespective of alleles at B locus, Homozygous recessive forms of C resulted in open head shapes irrespective of A and B loci.
Cross	ACF 19	E 11						Presence of dominant C gene masked the expression of the A gene,
Phenotypes	TC	Op	TC	3	1	-	-	
Genotypes	AAbbCC	AAbbcc	AAbbCc	1AAbbCC 2AAbbCc	1AAbbcc	-	-	only C gene is segregating resulting in the 3:1 phenotypic ratio. It is therefore monohybrid segregation.
Cross	Bulo	Achaki						Presence of dominant gene at the A locus suppresses the expression of the B gene when C is homozygous dominant in both parents,
Phenotypes	TC	F	TC	12	-	3	1	
Genotypes	AABBCC	aabbCC	AaBbCC	1AABBCC 2AaBBCC 2AABbCC 4AaBbCC 1AAbbCC 2AabbCC	-	1aaBBCC 2aaBbCC	aabbCC	this is dominant epistasis with A epistatic to B, this is a dihybrid segregation involving A and B loci, In presence of a dominant allele in the A locus both B- and bb behaved in a similar way.
Cross	ACF 19	Otunduru						This observed segregation ratio is typical of dominant epistasis, in this case involving the A and B loci,
Phenotypes	TC	IC	TC	12	-	3	1	
Genotypes	AAbbCC	aaBBCC	AaBbCC	1AABBCC 2AaBBCC 2AABbCC 4AaBbCC 1AAbbCC 2AabbCC		1aaBBCC 2aaBbCC	aabbCC	dominant A gene suppresses expression of B, that is in the presence of A, both B- and bb behaved in a similar way.
Cross	Achaki	Otunduru						Only one gene pair (in this case B) is segregating and presence of B results in incurved head shape whereas bb results in fisted head shape.
Phenotypes	F	IC	IC	-	-	3	1	
Genotypes	aabbCC	aaBBCC	aaBbCC	-	-	1aaBBCC 2aaBbCC	aabbCC	

Op = open head shape, TC = top-curved head shape, IC = incurved head shape, F = fisted, ER = expected phenotypic ratio, OR = observed ratio, Ob = observed frequency, and Ex = expected frequency.

References

Amgain, R.B., B.K. Joshi, P. Shrestha, B. Chaudhary, N.P. Adhikari, and B.K. Baniya, 2007. Intra- and inter-population variation in finger millet (*Eleusine coracana* (L.) Gaertn) landraces grown in Kachorwa, Bara, Nepal. On-farm Conservation of Agricultural Biodiversity in Nepal 1:84-95. Assessing the amount and distribution of genetic diversity on-farm.

Baniya, B.K., A. Subedi, R.B. Rana, R.K. Tiwari and P. Chaudhary. 2003. Finger millet seed supply system in Kaski ecosite of Nepal. P. 171-175. Sthapit,B.R., M.P. Upadhyaya, B.K. Baniya, A. Subedi, and B.K. Joshi, (Eds.). On-farm management of agricultural biodiversity in Nepal, Proceedings of a national workshop, 24-26 April 2001, Lumle, Nepal. NARC/LIBIRD/IPGRI, Kathmandu, Nepal/Pokhara, Nepal/Rome, Italy.

Bezaweletaw, K., P. Sripichitt, W. Wongai, and V. Hongtrakul. 2007. Phenotypic Diversity of Ethiopian Finger Millet [*Eleusine coracana* (L.) Gaertn]. In: relation to Geographic Regions as an Aid to Germplasm Collection and Conservation. Kasetsart Journal of Natural Science, 41:7-14.

Bua, B. and E. Adipala. 1995. Relationship between head blast severity and yield of finger millet. International Journal of Pest Management, 41:55-59.

deWet, J.M.J., K.E. Prasada Rao, D.G. Brink and M.H. Mengesha. 1984. Systematic evolution of *Eleusine coracana* (Graminea). American Journal of Botany, 7:550-557.

Ekwamu, A. 1991. Influence of head blast infection on seed germination and yield components of finger millet (*Eleusine coracana* L. *Gaertn*). Tropical Pest Management, 37:122-123.

Ghorpade, D.S. and B.S. Kadam. 1980. Inheritance of Panicle characters in sorghum. Indian Journal of Genetics and Plant Breeding, 40:195-211.

Jones, J.W. 1934. Inheritance of characters in rice. Journal of Agricultural Research, 47:771-782.

Kennedy – O'Byrne, J. 1957. Notes on African grasses XXIX. A new species of *Eleusine* from tropical and South Africa. Kew. Bull., 1:65-74.

Klug, W.S. and M.R. Cummings. 1999. 3rd Edition. Essentials of genetics. Prentice Hall, Upper Saddle River, New Jersey.

Krishnappa, M., S. Ramesh, J. Chandraprakash, J. G. Bharathi, and D.D. Doss. 2009. Genetic analysis of economic traits in finger millet. An Open Access Journal published by ICRISAT. SAT eJournal/ ejounal.icrisat.org. vol. 7:1-5.

Lule, D., K. Tesfaye, M. Fetene, and S De Villiers. 2012. Inheritance and Association of Quantitative traits in Finger millet (*Eleusine coracana* Subsp.*coracana*) Landraces collected from Eastern and Southern Africa. International Journal of Genetics, 2:12-21.

Ministry of Agriculture Animal Industry and Fisheries (MAAIF). 2008. Facts and Figures for the Agricultural Sector 2008. An Annual Report of Agricultural Planning Department, Entebbe, Uganda. P. 48-49.

Oduori, C.O.A. 2008. Breeding investigations of finger millet characteristics including blast disease and striga resistance in western Kenya. Unpublished PhD Thesis, University of Kwazulu Natal, Pietermaritzburg, South Africa.

Prasada Rao, K.E., J.M.J. deWet, V. Gopal Reddy, and M.H. Mushonga. 1993. Diversity in small millets collection at ICRISAT. P. 331 – 346. K.W. Riley, S.C. Gupta, A. Seetharam and J.N. Mushonga (Eds). Advances in small millets. International Science Publisher, New York, USA.

Rachie, K.O. and L.V. Peters. 1977. The *Eleusines*: A Review of the World Literature. International Crops Research, Institute for the Semi–Arid Tropics. 1 – 11 – 256, Begumpet, Hyderabad, - 500016 (A P) India.

Ratnakar, M.S., N.M. Mallikarjuna, K.S. Naveen-Kumar, Jayarame Gowda, M.V. 2009. Mohan Kumar. Cytomorphological studies in inter-specific hybrids of finger millet. Gregor Mendel Foundation Proceedings, 2009:69-74.

Ravikumar, R.L. 1988. Genetic and biochemical basis of blast resistance in finger millet (*Eleusine coracana* Gaertn.). PhD Thesis, University of Agricultural Sciences, Bangalore, India.

Ravikumar, R.L. and A. Seetharam. 1990. Inheritance of plant pigmentation in finger millet. Crop Improvement, 17:141-143.

Reddy, V.G., H.D. Upadhyaya, C.C.L. Gowder, and S. Singh. 2009. Characterisation of east African finger millet germplasm for qualitative and quantitative characters at ICRISAT.

Journal of SAT Agricultural Research 7. Available online. SAT ejournal|ejournal.icrisat.org (date accessed: 2/8/2010).

Santhkumar, G. and B.T.S. Gowda. 1998. Inheritance of some qualitative characters in the cross WR 9 x U 6 of *Eleusine coracana* G. Indian Journal of Genetics, 58:381-382.

Seetharaman, R. and D.P. Srivastava. 1972. Further investigations in cigar-shaped panicle in rice. Indian Journal of Genetics and Plant Breeding, 33:35-42.

Upadhyaya, H.D., C.L.L. Gowda, and V. Gopal Reddy. 2007. Morphological diversity in finger millet germplasm introduced from Southern and Eastern Africa. An Open Access Journal Published by ICRISAT. 3.1. Available online: SAT ejournal | ejounal.icrisat.org.

Wright, S. 1968. Evolution of the genetics of populations. Vol. 1. Genetics and Biometrical Foundations. University of Chicago press, Chicago.

Zeng, Z.-B. 1992. Correcting the bias of Wright's estimates of the number of genes affecting a quantitative character: A further improvement method. Genetics Society of America, 131:987-1001.

7.0 Chapter seven

General Overview

7.1 Introduction

This chapter provides an overview with a recap of objectives and hypotheses, and presents major findings from the literature review and the accomplished research. The implications and suggestions for future research are also presented.

The specific objectives were:

1. to identify farmer preferred varietal traits and perceptions on constraints to finger millet production in the farming system,
2. to determine the variability that exists in the existing germplasm for blast disease resistance, grain yield and selected agronomic traits, and study relationships among the traits,
3. to evaluate the germplasm for blast resistance, grain yield performance and stability, and select parental materials with stable resistance based on response to differential environment conditions,
4. to estimate the combining ability and genetic effects of selected parental materials for head blast disease, grain yield and other agronomic traits of finger millet, and
5. to study inheritance mechanisms of head shapes in finger millet.

The research hypotheses tested in this study were:

1. Finger millet farmers are knowledgeable of the major constraints that affect finger millet production and prefer certain peculiar traits and stress tolerance in their varieties.
2. There is high variability in the finger millet germplasm in Uganda plus a few introductions that can be exploited to generate new varieties with high yields, adequate levels of resistance to head blast disease with farmer preferred attributes.
3. Levels of resistance to blast disease and grain yield in finger millet are directly affected by variations in environmental conditions.
4. The selected adapted materials have good general combining ability for ear blast resistance, grain yield and selected agronomic traits.

5. Head shapes in finger millet are simply inherited.

7.2 Summary of major findings and implications

7.2.1 Literature review

Literature review established that:

1. There has been little breeding and research work in finger millet leading to limited literature though the crop is important to many smallholder farmers in east, central and southern Africa. Finger millet has a great diversity which presents a potential for improvements with prospects of exploiting both conventional breeding methods and biotechnology.
2. In Uganda, it is a very important cereal second only to maize, containing amino acids and minerals lacking in other cereals. The production of finger millet in Uganda however, is still low due to a number of constraints and farmers mainly grow their landraces despite the advantages of improved varieties.
3. One of the traits of particular interest among farmers affecting preference is head shape. There are several head shapes but limited or no information exists on the mechanism of its inheritance though studies in sorghum and rice have indicated oligogenic inheritance, none is reported on finger millet therefore the need for its investigation.
4. Among the constraints, blast disease was the most important constraint to finger millet production in Uganda. Despite past efforts, it is a revelation that the disease still deserves attention from scientists. The literature also indicates that there are limited resistance sources which is worsened by high variability of the pathogen and agro-climatic and/or agro-management conditions in the country. It is therefore important to identify sources of durable and stable resistance. There have been studies on finger millet blast resistance conducted in other countries with different germplasm. The applicability of such genetic information is therefore limited to the specific environments and germplasm since genotypes were fixed. This presents and justifies the need to investigate the nature of gene action for the Ugandan germplasm.
5. The review on response of genotype (s) to environmental variability indicated that significant GEI affects performance of genotypes and therefore effective selection as selections from one environment can perform poorly in another.

6. Methods of analysing GEI were explored and adaptation and stability pointed out as important factors in the variable agro-ecological and management in finger millet growing environments of Uganda. The significance of GEI justified the need to investigate the nature of GEI and yield stability in the adapted germplasm.

7.2.2 Production constraints and farmer preferences for a finger millet variety

1. The participatory rural appraisal and survey conducted in Bukedea, Kumi and Kaberamaido districts of eastern Uganda established that finger millet was a main food crop in all the three districts; being the principal crop in Kaberamaido and second most important cereal in both Kumi and Bukedea districts. The study also revealed that landraces were the most prevalently grown by farmers in all the districts. Eserait was the most popular in Kumi, Etiyo in Bukedea and Otunduru in Kaberamaido.
2. Farmers in all the study districts preferred finger millet varieties with high grain yields, brown seed colour, compact head shape, tolerance to blast disease, high tillering ability, moderate plant height (1 to 1.5 m), early maturity (of about three months), and ease of threshing. Ability in a cultivar to make local brew (excellent brewing ability), in other places referred to as 'opaque beer', was also highly rated among all the farmers and farmer groups. This indicates that varieties with high diastatic power and malting qualities are preferred. The implication of these results are a clear indication that breeding with focus on only grain yield with less attention to grain colour or brewing quality may result in poor adoption. It therefore shows the importance of initially interacting with farmers to understand their varietal preferences as a first step in a breeding programme. Only then can farmers' views be comprehensively incorporated. Oduori and Kanyenji (2007) indicated that white grained varieties, though high yielding, were rejected by farmers in Kenya, whereas in Uganda, Pese 1, an improved high yielding cultivar was also rejected by some farmers because it could not make 'quality' local brew.
3. There was a myriad of constraints encountered by the farmers some not necessarily of breeding nature. The main constraints considered for this study were blast disease and low yielding cultivars currently grown by farmers.

This work provides critical information required to improve finger millet breeding in Uganda and recommends breeding for resistance to key biotic stresses. Preferably the farmers' varieties

could be improved on using intra-specific hybridisation. Farmers need to be involved in the variety selection process so that they can get a sense of value for their knowledge, interests, and ownership of the new varieties. This shall facilitate the breeding process leading to faster release and improved adoption of developed materials. For this study, farmers will be involved in selections from preliminary yield trials to provide them an opportunity to select materials that are high yielding, tolerant to blast disease and incorporates their unique trait preferences to improve adoption and facilitate cultivar development.

7.2.3 Variability and trait association in finger millet germplasm for blast resistance and agronomic traits

On evaluation of the Ugandan germplasm consisting of landraces, introductions and some improved varieties, the results revealed that:

1. Both phenotypic and genotypic factors contributed significantly to the variability observed among the accessions for blast resistance, yield and other agronomic traits.
2. High heritability estimates and genetic advance (GA) were exhibited by head blast severity, head blast incidence, number of productive tillers plant^{-1} and grain yield. This is an implication that these traits would be transmitted to their progenies and selection shall lead to genetic advance in population mean. Johnson et al. (1955) suggested heritability to be used together with GA as percent of mean could be useful in predicting the performance of the best selected individuals.
3. Phenotypic coefficients of variability (PCV) were generally higher than genotypic coefficients of variability (GCV) which showed that apparent variation was not only due to the genotypes but also to the influence of the environment. To improve heritability therefore techniques that reduce environmental influence are required. The ECV were however, lower than both phenotypic and genotypic coefficients of variability, implying the environmental role was less for expression of traits.
4. Correlation analysis revealed high positive association between grain yield ha^{-1} with panicle width, finger number, number of productive tillers and grain mass head^{-1} but negatively with leaf blast incidence, head blast severity, and days to 50% flowering. Path analysis indicated grain mass head^{-1}, tillering ability, and reaction to head blast disease as the most important traits in yield determination. Therefore, indirect selection for grain yield can be achieved through these traits.

5. The availability of genotypes with low scores in the range of highly resistant and resistant within the germplasm against both leaf and head blast also revealed availability of resistance genes which can be exploited in the breeding programme to generate high yielding cultivars with high levels of resistance to both leaf and head blast in finger millet.
6. The near normal distribution for reaction to blast disease probably suggested presence of several genes with quantitative effects (Seetharam and Ravikumar, 1993) and is further supported by the fact that no accessions were completely immune at both sites. The mean grain yield score values were also close to normal distribution. This implied that suitable parents for improvement for the two traits could be indentified within the germplasm since most of these materials had not been selected before.

It is proposed that use be made of the identified genotypes with tolerance to blast disease and high grain yield in the finger millet breeding programme in Uganda. It is also important that more characterisation studies be conducted on more landraces and more traits. Additional sources of resistance should also be identified and made available to the breeding programme.

7.2.4 Genotype x environment interaction, adaptability and stability analysis

This study was to identify the best performing genotypes in terms of grain yield and blast disease resistance, and evaluate the influence of genotype (G), environment (E), and genotype x environment interaction (GEI) on grain yield.

1. The significant environment, genotype main effects and GEI for grain yield indicated that the genotypes were different, environments diverse and the performance of a genotype was affected by environmental conditions.
2. From AMMI, the first two IPCAs explained 100% of the interaction sums of squares, genotype had the greatest effect, accounting for 57.69%, GEI 32.2%, and environment accounting for only 10%. This result revealed higher variability among the genotypes and lower variability in the test environments.
3. Common genotypes selected by both ANOVA and AMMI as high yielding and stable were: G9, G19, G23, G49, G50, G59, G62, G84, G87, G95, G99, and G100, whereas high yielding but unstable genotypes were: G4, G6, G22, G29, G51, G61, G64, G66,

G77, G86, G88, G91 and G94. It therefore implied that the two methods were able to identify genotypes for both wide and specific adaptation

Since the genotype x season component of GEI was also significant, it makes spatial subdivision of the locations difficult for finger millet production. Therefore testing of genotypes in such a situation would require a representative range of conditions as a reliable strategy since it would cover a representative sample of spatial and temporal variations. From this study, the recommendation is to test finger millet genotypes for many crop cycles, but to save time several workers have suggested substituting temporal variation with spatial variation (Crossa et al., 1991).

7.2.5 Combining ability and genetic effects analysis in finger millet

The thirty six F_1 crosses generated using a 9 x 9 half diallel mating design were advanced to the F_2 generation. The F_2 evaluation revealed that:

Combining ability effects

1. Additive gene action was more important in controlling blast disease resistance, an indication that resistance to blast disease can be effectively improved through selection.
2. Significant genetic control of grain yield, days to 50% flowering, tillering ability, grain mass head^{-1}, plant height and panicle length with preponderance of additive gene effects also indicated that improvement can be made in these traits through selection. These were also some of the traits which farmers indicated preference for in selection of a cultivar such as: head size, plant height, grain yield, tillering ability, early maturity and blast resistance. This is an indication that these traits can be manipulated through breeding to generate superior cultivars incorporating farmer preferred attributes.
3. The following genotypes: *Achaki, Seremi 2, Amumwari,* and *Otunduru* which were used as parents, had desirable GCA effects for blast disease resistance and therefore can be used as sources of genes for transferring blast resistance into their progenies.
4. Parental varieties; *Achaki, Seremi 2, Bulo, Otunduru* and *Amumwari* also had desirable GCA effects for grain yield, these could be used as sources of genes for grain yield increase as they contributed towards higher grain yield.

Combining ability effects studies for both grain yield and blast disease resistance identified some genotypes that had desirable GCA for resistance and high grain yield. These materials are recommended for inclusion in the finger millet breeding programme. Genotypes which displayed early maturity and significant favourable GCA effects can be used in a breeding programme for generating early maturing varieties, which is specifically important in low potential areas.

Genetic effects

1. The Hayman genetic analysis confirmed importance of additive gene action in most of the traits and indicated the additive-dominance model was effective and adequate for genetic studies in finger millet,
2. Parents: *E11*, *ACF 19*, *Abao* contributed most dominant genes for yield, whereas, *Achaki* contributed recessive genes,
3. Parents: *Achaki*, *Amumwari*, *Otunduru*, *Seremi 2* and *Bulo* contributed most dominant genes for blast disease resistance, an indication that resistance to blast was controlled by dominant genes whereas yield was controlled by recessive genes.

7.2.6 Inheritance of head shapes in finger millet

1. From the results, it appears three major independent genes were involved in the inheritance of finger millet head shapes.
2. They also indicated epistatic gene interactions were involved in the inheritance of head shapes in finger millet.
3. The third gene appears to be an inhibitor gene, whose presence inhibits the expression of open head shape.
4. Fisty shape head type is recessive without the dominant inhibitor gene.

Implication for breeding is that since there seems to gene interactions involved in the inheritance of finger millet head shapes, selection for this trait would be delayed to later generations. Also from this study, caution is required because this was an initial study on finger millet head shapes and may not be sufficient to reveal and explain comprehensively the seemingly complex inheritance mechanism of head shapes. Further investigations should be carried out to validate these findings since head shapes are important in varietal adoption and preference by the farmers because certain shapes are associated with less blast disease damage, lodging, shattering by rain

water, and bird damage. The further investigations should include more than 400 plants for the evaluations to exhaustively and conclusively reveal and explain the gene action in finger millet head shapes since the number of genes involved appear to be more than two.

7.3 Conclusions and way forward

The findings from this study have shown that there is wide genetic variability for blast resistance, grain yield and other selected agro-morphological traits studied among the 100 finger millet accessions from Uganda. There is need to collect more germplasm to conduct similar investigations on the Ugandan and international germplasm. There is also need to characterise the germplasm using both morphological and molecular methods. It would also be important to study genetic variability for additional traits such as drought and S*triga* tolerance, tolerance to shattering, and ease of threshing since the PRA identified these as some of the preferred traits in finger millet varieties by the farmers in the Ugandan conditions. Traits that were found to be predominantly controlled by additive gene action implied selection progress can be achieved from early generation selection for such traits. These included among others; grain yield, head blast severity and days to 50% flowering.

The seed harvested from the F_2 populations generated in this study was planted as F_3 families in April, 2013 and selections initiated both within and between families. Breeding lines with desirable traits will be advanced up to F_7 then further study of the various traits utilising additional sites and seasons in order to capture more GEI as a process towards developing varieties for both wide and specific adaptation. Further development shall also emphasise developing varieties carrying multiple mechanisms of resistance. Such resistance is expected be more durable than single mechanism resistance (Robinson, 1968). Other stress factors shall also be looked into in the breeding programme and consideration of farmers' preferences to enhance adoption of improved materials. The resistant varieties should then be used in an integrated manner with other control options such as appropriate rotation and use of clean seed to effectively minimise the effects of blast on finger millet production and productivity. This will also call for collaborative efforts which will integrate seed uptake pathways and the extension system.

The study has clearly shown that adapted varieties with high levels of resistance can be bred and characteristics preferred by farmers incorporated in them. The study also revealed that farmers

predominantly used their landraces, but these could be improved and adoption of the improved cultivars could be enhanced by incorporation of both formal and non-formal seed systems. This however, requires support to avail seed to appropriate uptake pathways in an efficient and effective manner so that seed is available to the farmers. For head shapes, since this was an initial study, further studies will be conducted to comprehensively understand the mode of inheritance with more crosses and bigger sample size of at least 400 plants. This will facilitate incorporation of head shapes in the breeding programme. The current materials at the F_3 family level shall also be used in the subsequent studies of head shapes besides varietal development.

References

Crossa, J., P.N. Fox, W.H. Pfeiffer, S. Rajaram, and H.G. Gauch. 1991. AMMI adjustment for statistical analysis of an international wheat yield trial. Theoretical and Applied Genetics, 81:27- 37.

Johnson, H.W., H.F. Robinson and R.E. Comstock. 1955. Genotypic and phenotypic correlations in soybean and their implication in selection. Agronomy Journal, 47: 477 – 483.

Oduori, C.O.A. and B. Kanyenji. 2007. Finger millet in Kenya: Importance, Advances in R & D, Challenges and opportunities for improved production and profitability. Facilitating the promotion of improved and blast resistant finger millet varieties to enhance production. P. 10-22. Mgonja, M.A., J.M. Lenne, E. Manyasa, and S. Sreenivasaprasad (Eds). Proceedings of the first international finger millet stake-holders workshop, projects R8030 & 8445, UK Department for international development – crop protection programme held on 13th -14th September 2005 at Nairobi.

Robinson, R.A. 1968. The concept of vertical and horizontal resistance. Rev. Appl. Mycol., 48:593-606.

Seetharam, A. and R.L. Ravikumar. 1993. Blast resistance in finger millet – its inheritance and biochemical nature. P. 449-465. Riley, K.W., S.C. Gupta, A. Seetharam and J. Mushonga. (Eds.). Advances in small millets. International Science Publisher, New York, USA.

Appendix 2.1

PRA CHECKLIST FORMAT FOR FINGER MILLET STUDY IN EASTERN UGANDA

Interview details

1. Name of discussion leader ……..
2. Name of discussion recorder …….
3. Name of group …….
4. Venue of PRA: District,……., Sub-county,……., Village,…….
5. Date of discussion ……..

A Factors in farming

1. How many cropping seasons do you have in this area
2. Which is the most promising of the seasons in crop production
3. List crops grown in each of the seasons

No.	Season 1	How many crops grown	No.	Season 2	How many crops grown
1			1		
2			2		
3, …., n			3, …, n		

4. In which season is finger millet most grown ……..
5. What makes finger millet most suited for this season than other seasons? Give reasons

(a) ……..

(b) …….

(c) ……., ----, n.

6. How many are for reason (a) …….. (b) …… (c) …… (d) ……. (e) ……. (f) ……. (g) ……. (h) …… (i) ……. (j) ……

7. How do you use finger millet in this area? List

No.	Uses of finger millet	Rank by numbers
1		
2		
3, …, n		

8. Rank the crop in order of importance. (pair wise ranking)

Crops season 1									
	A	B	C	D	E	F	G	H	I
A									
B									
C									
D									
E									
F									
G									
H									
I									

Crops season 2									
	A	B	C	D	E	F	G	H	I
A									
B									
C									
D									
E									
F									
G									
H									
I									

9. Is there need to improve finger millet grown in this area?, How many say yes…… no…….

10. For those who say yes, why? (list the reasons)

(i)……
(ii)……..
(iii), …n.

13. For those who say yes, how many support reason (i) ….., (ii) ……, (iii) ……., (iv) ……., (v) ……, (vi) ……, (vii) ……., (viii) ……., (ix) ……., (x)……..

14. for those who say No in 11, why? (list their reasons)

(i)……
(ii)……..
(iii), …n.

15. For those who say No, how many support reason (i) ….., (ii) ……, (iii) ……., (iv) ……., (v) ……, (vi) ……, (vii) ……., (viii) ……., (ix) ……., (x)……..

16. What aspects of finger millet should be improved? (list them)

No.	Aspect for improvement	Increase / decrease	To what level
1			
2			
3, …, n			

SOCIO-ECONOMIC ACTIVITIES AND LIVELIHOOD

1. How do you earn income in this area?

No.	Ways of earning income	Rank by numbers
1		
2		
3, .., n		

2. Finger millet products sold and market outlets (list) in the last two seasons

No.	Product	How many farmers	Market outlet	How many farmers
1				
2				
3, …, n				

3. List all the prices you have ever received in each of the market outlet for finger millet in the last two seasons for each of the products

Product	Outlet 1 price	Outlet 2 price	Outlet 3 price	Outlet 4 price	Outlet 5 price
1					
2					
3, …, n					

4. Importance of outlets, ranked by numbers

VARIETIES OF FINGER MILLET GROWN

5. Varieties of finger millet grown and list prices of the different varieties sold regardless of market outlet in the last two seasons

Variety	Short rains of 2009		Long rains of 2010		Comments
	Minimum price	Maximum price	Minimum price	Maximum price	
1					
2					
3, …, n					

6. Rank the varieties according to market value. No. 1……..., 2……., 3……, 4……, 5……..., 6……, 7……..., 8……..., 9……., 10……..
7. In which of the seasons do you receive a better price for finger millet? Long rains ……, short rains ……..
8. List factors that influence the price of your finger millet in the market

   (i)……
   (ii)……
   (iii)……
   (iv)…….
   (v)……

9. List ways of improving the price of your finger millet in the market

(i)……

(ii)……

(iii)……

10. What would be the ideal price for a unit weight of finger millet grain in the market? (list the suggestions and reason).

Suggestion	Reason	Number of farmers

11. What would be a fair price per unit of finger millet used as shown in table below (participants indicate in cards)

Use	Price

Certified seed	
Farmers' preserved seed	
Consumption (grain)	

12. Classification of finger millet growers by variety

No.	Variety	How many grow	Why do they grow this variety
1			
2			
3, …, n			

13. Which of these varieties is most preferred in the market **(use scores and ranking)**

14. Which of the varieties do you prefer for your use **(pair wise ranking)**

15. Give characteristics of all the varieties grown

Variety	Height	earliness	Grain yield	Grain colour	Grain size	Head structure
1						
2						
3, …, n						

16. For each of the traits, what would be your preference in a variety? **(use cards)**

17. What would be ideal traits in a variety of finger millet?

CONSTRAINTS TO FINGER MILLET PRODUCTION, PROCESSING, UTILISATION AND MARKETING

1. List production constraints to finger millet production in this area? **(use cards)**

2. Rank the constraints according to seriousness **(use pair-wise ranking)**

3. What is the role of finger millet in the farming system?
4. What is the role of finger millet in the diet of the people in this area?
5. What is the role of finger millet in livestock production in this area?
6. What is the role of finger millet in trade and commerce in this area?
7. What are the market outlets of finger millet in this area? (list in order of importance)

8. What would happen if finger millet production was greatly increased in this farming system
9. What if it was removed in the farming system?
10. In an improvement programme, what would be an ideal finger millet you would want to see? List by trait. (head compactness, grain size, grain colour, peduncle length, leaf numbers, stem characteristics, tiller numbers, plant height, maturity, root characteristics).

ORGANISATIONS AND INSTITUTIONS BASED IN THE AREA

1. List organisations, government ministries and institutions that operate in your area and the problems they address

No.	Organisation	Core activities	Participants involved with organisation	Cost sharing
1				
2				
3, …, n				

2. How do these organisations choose the people they work with (state their criteria)
   ……
   ……
   ……
   ……..
3. What is your view on cost sharing? …….
4. Which of the organisations would help expand finger millet production in this area?
   ……
   …….
5. How do organisations / government ministries / government institutes affect you or your family or community? List

No.	Organisation	Effect on family	Effect on community
1			
2			
3, …, n			

6. Do you believe farmers affiliated to organisations / government ministries / government institutes are agriculturally more productive than non affiliate farmers? Give your feelings.……
7. Are affiliate farmers the way they are because of influence of the organisations or because organisations choose farmers in that condition? ……
   ……
   …….
8. How many say organisational influence……., how many say they choose farmers in that condition……..

Appendix 2.2

PART II OF PRA GUIDE: INDIVIDUAL FARMER PERCEPTIONS ON FINGER MILLET PRODUCTION, RESOURCE ENDOWMENT AND UTILISATION IN EASTERN UGANDA.

A. HOUSEHOLD COMPOSITION

1. Name: Mr./Mrs./Ms./Rev./Dr./Prof. …….
2. Gender (M/F) ……
3. Date of discussion…… Cluster …….
4. Level of education ……
5. Please give the following information about members of your household;

Family member	Relationship to head of Household	Gender	Age	Education level	Dependent (Y/N)	Independent (Y/N)

6. Who makes decisions on the farm? ……..
7. Residence/location particulars: village:……., sub-county:……, District:……..
8. How many of the members listed in 5 are involved in farming activities: (1) directly: …….. (2) Indirectly: ……..

9. What finger millet varieties did you grow during the long and short rain seasons (list in the table provided)

Finger millet varieties (long rains)	Finger millet varieties (short rains)

9. Why did you choose these varieties among others? …….
   ……
   ……

10. List reasons for choice of varieties during the long and short rain seasons

Why varieties in LRs	Why varieties in SRs

11. Source of seed: ……..
12. Which of these varieties do you like most? ……
13. Name the attributes/traits that make you like (prefer) the variety more than others that you grow. (1)……,(2) ……, (3) ……
    (4)……,(5)……..(6)…….
    .

14. Why did you choose to grow many varieties instead of only the variety you like most? (Provide reasons) .....

15. Describe all the varieties you grow (use the table provided)

Variety name	Height	Earliness	Head shape	Grain yield	Tillering	Grain colour	Grain size
1							
2							
3, …, n							

16. Continuation

Variety name	Flour quality	Flour colour	Cooking quality	Taste	Other	
1						
2						
3, …, n						

17. What products / foods do you make out of your finger millet? (1) …….
(2) ……, (3) ……. (4)
…….. (5) …… (6)
……., (7)…….. (8) ……

18. Name your best variety: …….

19. What do you like about it? ……

20. List the biotic and abiotic constraints and rank them

21. Which of the varieties is most tolerant to drought?

22. Which of the varieties is most tolerant to finger millet blast disease?

23. In your view, which tolerance do you consider more important?

24. List the attributes you would like improved in your finger millet varieties?

FARM INFORMATION:

1. What is the total size of your farm? (fill in the table below)

Land owned	Cultivated area (acres)	Uncultivated area (acres)	Total land (acres)
Parcel 1			
Parcel 2			
Parcel 3			
Parcel 4			
Parcel 5			

2. How much of the land was under cultivation during the long rains and during the short rains?

Land owned	Area under crops LR	Area under crops SR

Parcel 1		
Parcel 2		
Parcel 3		
Parcel 4		
Parcel 5		

3. Give details of finger millet production in your farm

Variety	Long rain season		Short rain season	
	Area planted (acres)	Harvest (Kgs)	Area planted (acres)	Harvest (Kgs)
1				
2				
3, …, n				

4. Give details of price by finger millet varieties

Variety	Prices received LRs	Prices received SRs

5. Did you grow improved finger millet variety and what was the source?

Variety	Source during LRs	Source during SRs
1		
2		
3, …, n		

6. How many of the total cultivated area was occupied by finger millet in the long and short rain seasons (use table below)

Land owned	Area under finger millet in LRs	Area under finger millet in SRs
Parcel 1		
Parcel 2		
Parcel 3		
Parcel 4		
Parcel 5		

7. What was the market price of finger millet; (1) during the long rains ……. (2) during the short rain season……..
8. Last year, what other crops did you grow, and what was the acreage, and harvest (use table below)

Crops	Area occupied	Quantity harvested	Prices

grown						
	LRs	SRs	LRs	SRs	LRs	SRs
1						
2						
3, …, n						

9. Do you use fertilizers in your crops? Yes: ……, No: ……..
10. What types of fertilizers? ……
11. Which crops do you fertilize? ……
12. How much of the finger millet land was fertilised? (1) During the long rains ……
    (2) During the short rain season ……
13. Do use pesticides in production of your crops? Yes: ……., No: …….
14. Indicate the types used……
15. Did you spray your finger millet crop during the long rains? Yes/No ……, with which pesticide? ……..
16. Did you spray your finger millet crop during the short rains? Yes/No ……, with which pesticide? …….
17. Do practice any form of soil conservation? Yes/No …….
18. What methods of soil conservation do use? List: …….
18. How do you open up new land?
19. What method(s) do use to plant finger millet?
20. How do you weed your finger millet crop?
21. Please provide the following information for the typical long and short rain seasons:

Crops grown	Output consumed		Output sold		Unit price		Remarks

22. Please provide the following information for a typical long and short rain seasons:

Crops grown	Long rains		Short rains		Remarks
	Area fertilised	Area not fertilised	Area fertilised	Area not fertilised	

LIVESTOCK

1. Do you own livestock? Yes/No. …., if yes fill table below

Type of livestock owned	**Number of livestock owned**	**Remarks**
Cattle		
Goats		
Sheep		
Donkeys		
Chicken		
Oxen		
Pigs		

2. Do you use manure? Yes/No ……..
3. How much manure from the entire livestock kept in the farm (estimated in wheel burrows etc.

   ……

   ……
4. How do you use manure? (1) sell …….. (2) apply to crops…… (3) burn ……. (4) none ……..

   (5) combination of any two, ……..

5. do you sometimes sell your livestock? Yes/No: ……., what do you do with the proceeds?

……

…….

6. what is the wage rate for casual labour in this area? …….

7. for what activities do you hire labour for? List ……

……

…….

9. Did you hire labour for finger millet production activities? Y/N, If yes, for which particular activities? ……..
10. For how many days do hire labour in a year?…….. long rains ……..

Short rains, …….

11. How do you pay for hired labour
12. Estimate labour costs (separately for long rains and short rains)
13. How do you earn livelihood in this community? (Farming, self employed, non self employment within community, employment out side the area, government employment etc).

Appendix 4.1: Finger millet accessions, numbers and sources

Genotype No.	Genotype name (if known)	Source	Ear shape type
G1	Asana	Adoku, Ogoloi S/C, Serere	Open
G2	unknown	Seed obtained from market in Omaditok, Ogoloi S/C, Serere)	Top-curved
G3	unknown	Seed obtained from market, in Omaditok, Ogoloi S/C, Serere)	Incurved
G4	Abao	From Ngora district	Fisted
G5	Etiyo - B	From Atiari, Nyero S/C, Ngora district	Fisted
G6	EX-meru Black	ICRISAT	Top-curved
G7	IE 2312	ICRISAT	Incurved
G8	unknown	from Katiangole, Kelim, Ngora district	Top-curved
G9	Obeet	From Katiangole, Kelim, Ngora)	Incurved
G10	Emoru	Kumi district	Top-curved
G11	E 11	Susceptible check, ICRISAT	Open
G12	unknown	From Orapada, Okuoba parish, Kumi district	Open
G13	Emorumoru	From Orapada, Okuoba parish, Kumi district	Top-curved
G14	IE 027	ICRISAT	Fisted
G15	Ekimaite	From Asilang-Obit, Atiira, Serere district	Top-curved
G16	Engeny – B	From Omukunyu-Opida, Asuret S/C, Soroti district	Incurved

G17	unknown	From Asuret centre, Asuret S/C, Soroti district	Incurved
G18	unknown	From Asuret centre, Asuret S/C, Soroti district	Top-curved
G19	Okwangapel	From Obutei, Arapai S/C, Soroti district	Incurved
G20	IE 2790	ICRISAT	Top-curved
G21	Eteke	Soroti district	Open
G22	Ebaati	From Ojele village, Kalaki S/C, Kaberamaido district	Fisted
G23	Otunduru	From Kalaki S/C, Kaberamaido)	Incurved
G24	Namata	Mbale district	Incurved
G25	Busiu market	Busiu, Manafa	Open
G26	Aringo	From Nngetta, Iyolwa S/C, Tororo district	Incurved
G27	Tansakira - A	Manafa district	Incurved
G28	Tansakira - B	Manafa district	Fisted
G29	Ebule kasabale	From Ajuket, Busitema S/C, Busia district	Fisted
G30	Enyamuret	Buteba S/C, Busia district	Top-curved
G31	Arani	From Amonikakinei, Buteba S/C, Busia district	Top-curved
G32	unknown	From Lwala, Mulanda S/C, Tororo district	Incurved
G33	Obokoriti	From Abochet, Buteba D/C, Busia district	Incurved
G34	Ojune	From Abochet, Buteba, Busia district	Fisted
G35	Omunga	Buteba S/C, Busia district	Incurved
G36	Emiroit	Bukedea district	Open
G37	Tunduru	Kaberamaido district	Top-curved
G38	Kali	Dokolo district	Open
G39	Lira market - A	Lira district	Top-curved
G40	ACF 21	From ACCI – KwaZulu Natal	Open
G41	Lira market	Lira district	Fisted
G42	IE 2640	ICRISAT	Open
G43	Apaala	Mulanda, Tororo district	Open
G44	Otim cherigar / kali langо	Lira district	Top-curved
G45	IE 2367	ICRISAT	Incurved
G46	IE 2244	ICRISAT	Fisted
G47	Oturolwete	Alwa S/C, Kaberamaido	Top-curved
G48	IE 7	ICRISAT	Top-curved
G49	IE 812	ICRISAT	Incurved
G50	SEREMI 3	NaSARRI – Improved pending release	Open
G51	SEC 915	NaSARRI – Improved pending release	Top-curved
G52	IE 2035	ICRISAT	Top-curved
G53	Omukowie market	Sironko district	Incurved
G54	IE 1010	ICRISAT	Incurved
G55	Famaatari	Gulu district	Top-curved
G56	IE42	ICRISAT	Incurved
G57	Kali – A	Gulu district	Open
G58	Kali – B	Lira district	Incurved
G59	Kali – C	Apach district	Open
G60	IE 2663	ICRISAT	Incurved
G61	SEREMI 1	NaSARRI – Improved and released	Top-curved
G62	kali atari – A	Lira district	Incurved
G63	Kali atari – B	Dokolo district	Incurved
G64	Etiyo - D	Kumi district	Top-curved
G65	unknown	From Nngetta village, Iyolwa, Tororo district	Incurved
G66	Etiyo	Serere district	Incurved
G67	Anyanva Anyadri, A	Arua district	Incurved
G68	Anyanva Anyadri, B	Arua district	Top-curved

G69	ObungIti	Soroti district	Top-curved
G70	Ekama brown	Kaberamaido district	Incurved
G71	Banyolo / Alur	Masindi district	Incurved
G72	Obongiti (Obokoriti)	From Kayoro, Buteba, Busia district	Incurved
G73	ACF 15	ACCI – KwaZulu Natal	Top-curved
G74	Bulo – B	Masindi district	Incurved
G75	ACF 17	ACCI – KwaZulu Natal	Open
G76	ACF 19	ACCI – KwaZulu Natal	Top-curved
G77	Bulo	Mbarara district	Top-curved
G78	Kisalisi mkt A	Bweyale district	Incurved
G79	KALALER	Dokolo	Top-curved
G80	Kisalisi mkt – B	Masindi district	Incurved
G81	IE 2355	ICRISAT	Incurved
G82	Ayiro	From Pubwok, Mulanda, Tororo district	Incurved
G83	Kisalisi market	Bweyale district	Open
G84	Achaki	From Mairo-aboro, Iyolwa, Tororo	Fisted
G85	Bweyale mkt A	Bweyale district	Open
G86	Emumware	From Abochet, Buteba, Busia district	Incurved
G87	Bweyale mkt B	Bweyale district	Incurved
G88	Otala chilingal	Lira district	Top-curved
G89	Amumwari	Buteba S/C, Busia district	Open
G90	Engeny	NaSARRI - improved released variety	Top-curved
G91	Angoromi	Busia district	Fisted
G92	Green N susceptible	NaSARRI	Incurved
G93	ACF 5	ACCI – KwaZulu Natal	Incurved
G94	Eserait	From Katiangole, Kelim parish, Ngora district	Incurved
G95	Ekama	From Mugaane, Arapai S/C, Soroti district	Fisted
G96	Adwoki market	Lira district	Incurved
G97	Etiyo	From Orapada, Okuoba parish, Kumi district	Top-curved
G98	Katongole Emorut	NaSARRI collection	Open
G99	SEREMI 2	NaSARRI – Improved and released variety	Incurved
G100	PESE 1	NaSARRI – Improved and released variety	Top-curved