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Farmer identification of production constraints: An assessment of farmer participation in Uganda

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Abstract

Permitting farmers' needs constraints to define the demand structure for technological research and development is now considered to be essential if African National Agricultural Research and Extension systems (NARES) are to develop client-relevant technologies. Contemporary approaches advocate direct participation by farmers in these assessments. An important assumption made by those who advocate integrating farmer knowledge into research agenda planning is that farmers will identify and prioritise constraints differently from research scientists. If the assumption is accurate, then differences in constraint perceptions need to be identified and explored in order to improve the capacity for interpreting and utilising farmer knowledge to advance research agenda planning. This assumption is analysed using information from a survey conduced in 1994 of 543 farmers in 5 districts of Uganda, and a research review and prioritisation exercise conducted in 1994 with research scientist from the Ugandan National Agricultural Research Organisation (NARO). Constraint categories derived from the literature are used to compare and contrast commodity specific production constraints. Results indicate that farmer prioritisation of commodity specific constraints only partially differ from those provided by scientists. Also, farmers are more likely to specify visible biological constraints such as insects and vertebrate pests, and economic constraints such as labour and markets. Researchers on the other hand are more likely to specify varietal deficiencies and plant diseases. Reconciling perceptual differences can best be done by including farmers in priority setting exercises at the time when they occur.

Key words: Farmers, researchers, research planning, needs assessment , Uganda

Introduction

A priori assessments of farmer constraints are now considered essential in order for African National Agricultural Research and Extension Systems (NARES) to develop client-relevant technologies (Spencer, 1991; World Bank, 1998). Contemporary approaches advocate direct participation by farmers in these assessments (Chambers *et al.*,1989; Ashhy, 1990; Roling, 1990). Past experience with industrial research and development programs demonstrate that successful technological research and development programs are distinguished by a strong user orientation in advance of technology production (Zaitman, 1979). Permitting farmers' needs and constraints to define the demand structure for technological research and development can provide the basis for a strong user orientation. However, permitting farmers to identify constraints and using this knowledge to derive research agendas appears to be an advocacy, not practice. A common practice is for research agendas to be determined by researchers or prescripted by National Governments in order to meet their own scientific interests or developmental objectives. Local farmer knowledge about constraints, if collected, is often ignored or left unutilised by agricultural scientists (Chambers *et al.*, 1989).

Contrastingly, scientifically derived information is considered to be more reliable, transferable, if not superior (Kloppenburg, 1991). Rhodes and Booth (1982:129) acknowledge that "...scientists often perceive technical problems through different eyes than farmers." Second, farmers often have different goals from researchers. Small farmers may seek to minimise risks while researchers may be most concerned with yield maximisation. Some consider farmer-identified constraints to be highly subjective, random, unreliable, and of little use to researchers (Ilbery, 1978; Farrington and Martin, 1988).

An important assumption that guides those advocating the efficacy of using participatory methods is that farmers will identify and prioritise constraints differently from research scientists (Chambers, 1990). In order to justify the additional time and expenditure required to implement participatory research agenda and planning, this assumption needs to be validated. If the assumption is accurate, then comparing researcher and farmer knowledge will assist in the interpretation and utilisation of farmer knowledge to advance research agenda planning.

The term constraint is applied in the context of any condition or set of conditions that limit agricultural production in the agricultural development literature (Pinstrup-Anderson, 1982). Most commonly, they are identified as physical, biological, or socioeconomic factors that limit production (Pinstrup-Anderson, 1982; Shaner, 1982; Gladwin, 1983).

However, gaps exist in the methodology for understanding and using farmer specified constraints to orchestrate demand driven technological research and development. In this study, we used a participatory process to allow farmers to define constraints with the hope that comparing these with researcher derived constraints will expose perceptual differences and similarities and assist in the utilization of farmer knowledge.

Methodology

Information from two sources are used to analyse perceived agricultural production constraints. The first is a research review and prioritisation exercise conducted by the Ugandan National Agricultural Research Organisation (NARO) in 1994. The second is a 1994 survey of 543 farmers in 5 districts of Uganda (Masindi, Mukono, Iganga, Soroti and Muhende). The NARO priority setting exercise was based on inputs by a group of 60 participants, consisting mostly of senior and mid-level personnel from NARO, Extension, Makerere University, Uganda Farmers Association, Uganda Coffee Development Authority and Uganda Seed Project. This information was presented in the monograph "Agricultural Research Priorities and Programs" (1994) published and released by NARO with assistance from The International Service for National Agricultural Research (ISNAR). The 1994 Ugandan farmer survey was based on a multi-staged sampling procedure to select districts, counties, sub-counties, and villages as research sites. Systematic samples of 25 farmers were drawn from each village. Farmers were asked to list their three most important crops and most important production constraints associated with each crop. Responses reflect a subjective perception of constraints based on unique farmer experiences with the production of each crop. This procedure is consistent with the participatory methodology which emphasizes farmer perceptions of production constraints. The range of possible constraint responses was not known prior to the study. A wide array of constraint responses were recorded and later grouped across commodities using categories derived from the literature.

General constraint categories derived from farmer responses were compared with NARO responses (Table I). In Table 2 individual constraint responses by farmers for each crop are compared with NARO rankings across 7 crops including maize, finger millet, sorghum, banana (cooking), cassava, groundnuts, and coffee.

Findings

Whether NARO and farmers use the same topical areas to describe constraints is examined in Table 1. There is general agreement between farmers and researchers on a number of weed, post-harvest and insect constraints. Farmers are somewhat more likely than NARO informants to perceive insects and less likely to perceive diseases as priority constraints. Considerable differences exist in the rankings of priorities by farmers and NARO informants for all other constraint categories. Farmers mentioned vertebrate pests as priority problems on two commodities (maize and cassava) whereas this was not mentioned by NARO informants. Farmers identified labour, physical conditions (drought and poor soils), and marketing as priority constraints across commodities. These were not mentioned by NARO personnel for any of the commodities. NARO informants specified the lack of improved agronomic management practices, generally labeled as rotational or cropping system constraints, and lack of improved varieties as important constraints. No farmer mentioned agronomic management as a constraint, although specification of labour constraints may be considered to be a surrogate for this constraint area. Lack of improved varieties was mentioned by farmers only for cassava and groundnuts.

Crop specific constraints ranked by NARO informants and by farmers are listed in Table 2. In the case of maize, farmers and NARO informants agree that maize streak and stalk borers are important constraints. There was also similarity in the ranking of several other constraints, although the terminology used to describe these differed. NARO informants ranked weeds, particularly Striga, as a constraint, while farmers judged the lack of labour for weeding as the constraint. NARO informants specifically mentioned weevils while farmers mentioned the storage of maize as a problem. Constraints ranked by NARO informants, but which were not listed by farmers, included lack of improved varieties, inappropriate spacing, inadequate knowledge of intercropping, Northern Leaf Blight, and downy mildew. Constraints ranked by farmers but not by NARO, include vertebrate pests (monkeys, baboons, and wild pigs), marketing problems, drought, and termites.

Data on finger millet indicate that farmers and NARO informants agreed only on the importance of Striga as a constraint. The most important constraint identified by farmers for finger millet production was labour, particularly for weeding and harvesting. Although NARO informants mentioned Striga they did not mention other problematic weeds such as wild finger millet *(Elusine indica)*, nut grass *(Cyperus rotundus)*, or blackjack *(Bidens pilosa)*. NARO informants mentioned rotation and cropping system as constraints. Constraints listed by farmers but not by NARO informants included grasshoppers, drought, and army worms. Those listed by NARO informants but not by farmers included blast, Cylindrosporium leaf spot, tar spot, and lack of improved varieties.

Concerning sorghum, farmers and NARO informants agree on the two most important constraints: striga and stalk borers. Farmers also mentioned smut, labour for weeding, and storage problems. NARO informants mentioned lack of improved varieties, grain mould, and rotation and cropping system constraints.

NARO informants and farmers agreed on several of the priority constraints for bananas, which included weevils, nematodes, and sigatoka. Farmers mostly mentioned weevils as their priority constraint. Constraints listed by farmers but not NARO informants included drought, marketing, labour, and poor soils. By contrast, NARO informants tended to give greater importance to agronomic management practices such as poor stand population, improper tillage, inappropriate cropping systems, lack of pruning, Fusarium wilt and lack of genetic diversity.

There was general agreement that Cassava mosaic disease is the priority problem and that mites are also an important problem on cassava. Other constraints mentioned by NARO personnel focused on germplasm deficiencies including poor seed quality, lack of improved varieties, and genetic erosion of local germplasm. Farmers mentioned lack of improved varieties in reference to Cassava mosaic disease. They also mentioned vertebrate pests, particularly the mole rat in Iganga District, labour and poor soils.

Improved

Table 1. General constraint categories across comodities.

General constraint categories	Biological				Physical	Agronomic management	Lack of labour	Marketing	Technology improved varieties	storage	Lack of pesticides
	vertebrate Insects	Diseases	Weeds	Pests							
Maize	1(2)	3(1)	1(0)	0(1)	0(1)	2(0)	0(2)	0(1)	1(0)	1(1)	-
Finger millet	0(2)	3(1)	1(1)	-	0(1)	1(0)	0(2)	-	1(0)	-	-
Sorghum	1(1)	0(1)	1(1)	-	-	1(0)	0(1)	-	1(0)	1(1)	-
Banana	2(2)	2(1)	-	-	0(2)	4(0)	0(1)	0(1)	1(0)	-	-
Cassava	1(1)	1(1)	-	0(1)	0(1)	1(0)	0(1)	-	3(1)	-	-
Groundnuts	1(0)	1(1)	-	-	-	-	0(1)	-	1(1)	-	0(1)
R.coffee	1(1)	2(1)	0(1)	-	0(1)	0(1)	0(1)	0(1)	0(1)	-	-
Total	7(9)	12(5)	3(3)	0(2)	0(6)	9(0)	0(9)	0(3)	9(2)	2(2)	0(1)

R. coffee = *Robusta coffee*

Table 2. Specific crop constraints identified by NARO and farmer informants in Uganda.

NARO Informants	Crop	Farmer Informants
	Maize	
1. Maize streak virus		1. Stalk borer
2. Lack of improved varieties		2. Vertebrate pests
3. Inappropriate spacing plants		3. Marketing (Low prices)
4. Inadequate intercropping		4. Labour for weeding
5. Northern leaf blight		5. Maize streak virus
6. Weeds [principally Striga]		6. Post harvest storage
7. Weevils		7. Drought
8. Stalk borer		8. Termites
9. Downy mildew		9. Labour for harvesting
	Finger millet	
1. Striga		1. Labour for weeding
2. Blast		2. Labour for harvesting
3. Lack of improved varieties		3. Grasshopers
4. Cylindrosporium [finger millet]		4. Weeds (Striga)
5. Tar leaf spot [finger millet]		5. Drought
6. Rotation/cropping systems		6. Army worms
	Sorghum	
1. Striga		1. Stem borer
2. Stem borer		2. Striga
3. Lack of improved varieties		3. Smut
4. Grain mold		4. Labour for weeding
5. Rotation/cropping system		5. Post-harvest storage
	Banana	
1. Weevils		1. Weevils
2. Nematodes		2. Nematodes
3. Sigatoka		3. Drought
4. Poor stand (plant population)		4. Marketing problems
5. Fusarium wilt		5. Labour requirements
6. Lack of genetic diversity		6. Poor soils
7. Improper tillage practices		7. Sigatoka
8. Rotation/cropping systems		
9. Lack of pruning/de-suckering		
	Cassava	
1. Poor seed quality		1. Cassava mosaic disease
2. Cassava mosaic disease		2. Mites
3. Lack of improved varieties		3. Vertebrate pests [mole rat]
4. Green spider mite		4. Lack of labour
5. Rotation/cropping system		5. Poor soils
6. Lack of senetic diversity		6. Lack of improved varieties
	Groundnuts	
1. Lack of improved varieties		1. Rosette
2. Cercospora leaf-spots		2. Lack of pesticides
3. Thrips		3. Labour – weeding/harvesting
		4. Lack of improved seeds
	Robusta coffee	
1. Coffee leaf rust		1. Biting ants
2. Red blister disease		2. Weeds [couch grass]
3. Coffee berry borers		3. Labour – Weeding/harvesting
4. Lack of improved varieties		4. Marketing (low prices/delayed payment)
5. Drought		

*NARO = National Agricultural Research Organisation

Farmers overwhelmingly mentioned groundnut rosette disease and the lack of pesticides as major constraints on groundnut production. Generally, farmers were not aware that aphids are the vector for rosette but they were aware that the use of pesticides was vital if a good harvest was to be produced. Farmers also mentioned labour constraints particularly for planting, and lack of improved seed. NARO informants mentioned the lack of improved varieties, Cercospora leaf spot and thrips as top priority constraints.

Data on constraints encountered in robusta coffee production indicate that farmers constraints focused on labour, marketing, and drought. Their priority constraint was, however, biting ants which impact the harvesting of this crop. The prevalence of couch grass *(Digitaria scularum* (Schweinf)) as a farmer perceived constraint explains their ranking of labour for weeding as a constraint. NARO informants identified two disease constraints, namely, coffee leaf rust *(Hemilea vastatrix* Berk. & Br) and red blister disease *(Cercospora coffeicola* Berck. & Cooke), and the insect pest, coffee berry borer *(Stephamoderes coffeae* Haged). These diseases and insect pest were not listed by farmers.

Discussion

The assumption made by those who argue that local knowledge is different, thus requiring greater attention, is only partially demonstrated in this analysis. Farmers and NARO informants agree about some of the major constraints for each of the commodities reviewed here except for coffee and, to a lesser extent, groundnuts. NARO constraint rankings agreed with farmers regarding maize streak disease, stalk borer, and weeds on maize; stnga on finger millet; striga and stem borer on sorghum; weevils and nematodes on bananas; and, cassava mosaic and mites on cassava. In general, these constraints are widespread where the crop are grown, have had clearly demonstrated and visible impacts on crop yields, and have received research, extension and even media attention over the years. These areas of agreement appear to indicate high potential targets for future research investigation.

Some of the discrepancy in rankings may be explained by differences in terminology used by NARO and farmers. For example, with both sorghum and finger millet, NARO informants listed rotation and cropping system constraints, while farmers listed labour constraints particularly in regard to weeding. It has been established that rotating fields and extended fallow periods can provide some measure of control for weeds of fallowed land, and increase the period of time in which crops are grown in the same fields.

Additionally, farmers are more likely to specify constraints they can observe, associate with yield reductions, and thus experience. For example, farmers prioritised highly visible vertebrate pests and visible insects and diseases such as grasshoppers, termites, black ants, smut, and rosette. These constraints were not mentioned by NARO informants. Many other diseases and small insects (thrips) tend to not be known or recognised as yield reducing agents by farmers. Again, this contextual knowledge displayed by farmers lends credence to the assertion that farmer knowledge of constraints is determined more by ease of observation than precise knowledge of agents that cause yield reduction (Bently, 1992).

NARO informants ranked varietal improvement and its constraint counterpart, lack of improved varieties, as important constraints for all commodities. That farmers more rarely identify lack of improved varieties as a major constraint may allude to their lack of availability, suitability, or cost. Thus, an over-reliance on crop breeding programs to produce improved varieties for farmers who lack financial, infrastructural, or informational access to exogenous seed supplies at this juncture in Uganda's agricultural development might be questionable.

Several other issues emerge regarding plant breeding programs. The first is the acknowledged differences in selection criteria between farmers and scientists (Haugerud and Collinson, 1990). On-station plant breeding programs need to be exposed to farmer circumstances and priorities. An example is farmer recognition of drought as an important production constraint for four of the eight

commodities. Many parts of Uganda are or have recently been subjected to periods of reduced rainfall. Yet drought as a priority constraint is not mentioned by researchers. Although it is recognised that the symptoms of drought stress may invite or mask some disease symptoms, incorporation of drought tolerance into breeding programs would seem to be in order particularly for the preponderance of rain fed farming systems in Uganda. Another example is the well known use by farmers of multiple cultivars and intercropping, and labour constraints that prevent timely planting and weeding. This suggests that varietal selections need to be exposed to these conditions and the investigation of sub-optimal solutions (Carr, 1989). Although these notions may be referred to by NARO informants when they specify cropping constriants, the use of this term appears to lack the degree of specificity necessary for ranking rsearch priorities.

Finally it is revealing to note that NARO informants did not specifically mention labour, marketing, physical (drought and poor soils), or vertebrate pests as constraints. Several caveats are offered to explain thses discrepant findings. First, descriptions of the 60 persons who participated in the ranking exersise were not available. However, as stated in the monograph (NARO, 1994): "socioeconomic research is currently a relatively minor component of research activities in NARO." The absence of social scientists trained to provide emic descriptions of farmer production systems may be one explanation for these findings. Second, the proportion of farmers who participated in this exercise is not known. However, labour, marketing, and input availability are important constraints with farmers throughout much of Sub-Saharan Africa (Cleaver, 1993). That they did not figure prominently in the NARO rankings indicates that the proportion of farmers who participated was either low, or biased towards those with capital assets to off-set these constraints.

Conclusion

Both farmer and researcher generated constraints represent contextualized knowledge: knowledge that is shaped by each individual's background and experience. Thus, it should not be surprising that there are differences between farmers and researchers in constraint definition and prioritisation. However, to ignore farmers' definitions of constraints and rely solely on researcher specified constraints is to impose research agendas on farmers. If the past is any indicator, this approach has not proven to be very effective in promoting agricultural change and improved agricultural production among small farmers in Sub-Saharan Africa.

If agricultural research is to be responsive to farmers' needs then using farmer perceptions of constraints needs to be integrated into researcher efforts to prioritise and address constraints. Since this is the stated mission of NARES, methods to more systematically collect and incorporate this knowledge should be developed. Several improvements are recognised and suggested by this current effort.

First and foremost, there must be enhanced collaboration and communication between farmers and scientists regarding priority problems and constraints. This can best be accomplished by including farmers in priority setting exercises at the time when they occur. However, financial and logistical constraints may impede farmer participation. Thus, it may be more effective to conduct and then convey farmer research priorities to scientists prior to or during research prioritization exercises. This would compel scientists to adapt and adjust their constraint specifications to farmers' needs. Reversing this process, by first having scientists determine priorities and then subjecting these to farmer evaluation risks reinforcing "elite misconceptions" (Howes and Chambers, 1980) and would require an additional procedural step to have farmer evaluations fed back to researchers.

Second, knowledge of farmer constraints alone is insufficient. Farmers and their attendant constraints need to be differentiated by social, economic and agro-ecological variables. Using the terminology of farming systems research, these variables would form a recommendation domain. However, the sociology of agricultural sciences is currently under-informed as to the interplay between antecedent factors that influence problem choice by farmers, and is under-equipped to utilise

farmer knowledge to specify constraints (Busch and Lacy, 1983). Thus, the concept of farmer-definition of constraints needs to be linked to the agricultural and societal context to be a more meaningful tool for deriving demand for agricultural research.

Third, reliance on biological agricultural scientists to identify constraints appears to bias the results. They inevitably see biological factors or processes as priorities. In this study, diseases and improved varietal development were consistently prioritised by biological scientists. This disciplinary bias detaches the constraint from its social and economic context. This is a false dichotomy and a major impediment to orienting research towards farmers' needs. It leads to excessive scientific reductionism which distracts from more problem-oriented, people-oriented research.

Fourth, constraint identification by farmers and researchers can and do vary. They are subject to seasonal vicissitudes, disciplinary background, and experience with each crop. Farmers' perceptions of priority constraints may vary depending on when they are interviewed in the crop cycle. Thus, constraint identification and prioritisation can not be one-time efforts. They need to reflect continuous effort. However, the logistics and costs of a continuous effort to ascertain constraints argues against using multi-disciplinary teams of research scientists for this purpose. Perhaps, this is a role that local extension agents or representatives of farmer associations could play provided they received training and support for this activity. They could then contribute to priority setting exercises serving as knowledgeable representatives of local farmer interests. This would also strengthen the role of extension within farming systems teams and their contribution to participatory agricultural research.

Ultimately, utilisation of farmer perceptions of production constraints by research organisations will depend on their valuation of this knowledge. This may require a reorientation of the institutional reward structure to one that rewards technology adoption and rural development. In turn, institutionalised alterations in the reward structure may require organised social action on the part of farmers. It is only when small farmers organize to express their collective interests that their priorities will be heeded. This is termed farmer empowerment. In addition to technology development, it is an important by-product of participatory agricultural research.

Perhaps, the most significant contribution made in attempts to incorporate farmer identified constraints is that it forces us to address the knowledge and power differential between farmers and researchers. Talking to farmers and addressing their problem is another small step toward farmer empowerment. That the African small farmer has been left out of the power equation cannot he denied. Thus, efforts to improve the methodology for assessing and using farmer identified constraints must continue.

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Participatory breeding with advanced potato clones of population A in Southwestern Uganda

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Abstract

The primary objective of the potato program in Uganda is to develop improved varieties with high yields, late blight resistance, good agronomic characters, acceptable post-harvest qualities and adaptable to many environments. However, development of useful crop germplasm is only beneficial if it is distributed and subsequently utilized. Sixteen advanced potato clones, with Victoria and Kisoro varieties as standard checks, were evaluated in six seasons at Kalengyere Research Station for yield, resistance to late blight, and other agronomic traits. Farmers participated in the on-station evaluation process and selected six genotypes for on-farm and farmer field schools evaluations. As a result, genotypes 382171.4, 381403.8 and 575049 were released in 1999 as NAKPOT 1, NAKPOT 2 and NAKPOT 3 varieties, respectively, and genotypes CIP 381471.18 and CIP 387121.4 are at pre-release level. NAKPOT 1 and NAKPOT 3 were selected for their high yields, early bulking and resistance to late blight. CIP 387121.4 was selected for its resistance to late blight and red skin colour. CIP 381471.18 was selected for its high yields, round tuber shape, white skin colour, culinary qualities and high resistance to late blight, although it has a very long dormancy period and is relatively late maturing.

Key words: Farmer varietal selection, late blight, *Solanum tuberosum*, Uganda

Introduction

Major causes of high cost of potato (*Solanum tuberosum* L.) production in developing countries, Uganda inclusive, continue to be high cost and low quality of seed materials and the control of pests and diseases. Most of these yield-reducing constraints can be overcome by continued emphasis on the development of potatoes with durable resistance to major insect pests and diseases, which can underpin integrated pest management practices (Zandstra, 1996). Host resistance is the most effective way of controlling most plant diseases (French, 1994). Late blight (caused by *Phytophthora infestans* (Mont) de Bary) is the single most important biotic constraint to potato production in sub-Saharan Africa (Hakiza, 1999; Sengooba and Hakiza, 1999). The disease is very severe in the tropical highlands of eastern and central Africa where inoculum is almost continuously present. The problem of late blight

is associated with serious yield loss and costly fungicides; moreover, only a few late blight resistant varieties are available. Farmers have limited income to apply fungicides regularly, and the disease causes serious yield reductions in most years. In Uganda, apart from environmental concerns, chemicals are often not affordable and growers are obliged to accept the losses that the disease inflicts on their potatoes. Continued search for varieties resistant to late blight, therefore, offers hope to the resource-poor farmers who are responsible for production of potatoes in Uganda.

The primary objective of potato research and development in Uganda is to find the most effective means of generating and transferring improved potato production and utilisation technologies. In order to obtain high potato yields, especially in the Southwestern Uganda where late blight is very important, efforts have concentrated on breeding varieties that are resistant to the disease although the use of fungicides is still emphasised. Greater farmer involvement in identification of researchable questions, selection of potential solutions, on-farm evaluation, and validation of results could give a more efficient research process, and creative combinations of farmer wisdom and technical expertise (Francis *et al.*, 1988). Adoption of technologies that have only been tested on research stations has often been poor since it has generally lacked farmer involvement in the selection process and sufficient evidence of their applicability in farmers' environments. Verification of the usefulness of such technologies lies in effectively carrying out multi-locational and on-farm trials while working with farmers in their fields. In this study both on-station and on-farm evaluation of advanced potato genotypes for resistance to late blight and suitable agronomic characteristics was conducted. The major objectives of the study were (i) to obtain information on the performance of improved potato genotypes under a wide range of agro-ecologies in Uganda and assess the adaptability of the improved genotypes; and (ii) to test the promising genotypes on-farm so as to identify those for release.

Materials and methods

On-station evaluation

Tubers of cultivars and breeding lines were obtained from the previous cohorts of potato materials evaluated at Kalengyere Research Station but originally received from the International Potato Center (CIP), Lima, Peru. Most of these materials were introduced into Uganda in 1992 for evaluation for agronomic characteristics and resistance to late blight (Hakiza *et al.*, 1997; 1999). Field experiments were conducted at Kalengyere Research Station during six cropping seasons of 1997B, 1998A, 1998B, 1999A, 1999B and 2000A. The A and B refer to the first (February-July) and second (August-January) seasons, respectively. Sixteen potato clones selected for resistance to late blight were used in the study with Victoria and Kisoro varieties as standard checks.

In 1997B, 1998A and 1998B, planting was done on 10 September 1997, 10 March 1998 and 9 September 1998 while harvesting was done on 12 January 1998, 30 June 1998 and 14 December 1998, respectively. In these three seasons the potatoes were grown in a randomised complete block design replicated four times. Spacing was 70 cm between rows and 30 cm within rows. Plot sizes were 6.3 m^2 based on two rows that were 4.5 m long comprising of 30 plants. A fertiliser rate of 80 kg ha^{-1} of nitrogen, 50 kg ha^{-1} of phosphorus (P_2O_5) and 50 kg ha^{-1} of potash (KCl) was applied in a furrow in each row and mixed with soil using a hand hoe handle. This was followed by placement of seed tubers in these furrows after which the tubers were lightly covered with soil before ridges were made. Two weeding/earthing up operations were carried out; the first one about 25 days after planting and second one about 40 days after planting. Three sprays with Dithane M45 (Mancozeb 80% WP) at the rate of 2.5 kg ha^{-1} were applied at fortnight intervals starting immediately after the first weeding. Four late blight assessments were conducted at 10-day intervals, beginning on the day of the first spraying, using a scale of 0-100% (Henfling, 1987). In the 1999 season, the trial was planted on 27 April 1999. Plot size was 12.6 m^2 with plant spacing of 70 cm x 30 cm. One prophylactic spray of Dithane M45 was applied at 100% crop emergence, 34 days after planting. Four late blight assessments were done.

Harvesting was done on 13 August 1999. During 1999B season, planting was done on 16 August, and two prophylactic sprays of Dithane M45 were applied. Five late blight assessments were carried out at 10-day intervals. Plot size, spacing and agronomic management were similar to those in the previous season. Harvesting was done on 14 December 1999. For the 2000A season, planting was done on 6 March 2000 at similar spacing, plot size, and agronomic practices as those of the previous season. Two prophylactic sprays of Dithane M45 were applied, and harvesting was done on 4 July 2000.

The major attributes evaluated during the four seasons were number of tubers per plant, tuber weight, yield per hectare and late blight severity based on 0-100% score (Henfling, 1987). Area under disease progress curve (AUDPC), computed from the percent leaf area blightled recorded on each late blight assessment time, was the indicator of each clone's resistance to late blight. Mean relative AUDPC (Campbell and Madden, 1990) was calculated for each clone in each year for the Kalengyere Research Station data. Clones were then ranked basing on mean yield and relative AUDPC.

The research team and farmers were present at harvesting time to select, by consensus, genotypes to retain for further stages of testing and multiplication. Two field days were staged at Kalengyere Research Station to give farmers and district agricultural staff opportunity to participate in selection of materials that were likely to be their future varieties.

On-farm evaluation

Basing on the results of the on-station variety selection, six clones were selected for evaluation in the farmers' environments including farmer field schools (FFS). The clones selected for on-farm trials and farmer field schools were 382171.4, 384329.21, 387146.48, 381471.18, 387121.4 and 575049. Victoria, the most widely grown improved variety (and sometimes Rutuku), was used as a standard check during these on-farm evaluations. These farmer-managed trials were carried out with farmers in Kisoro, Kabale, Ntungamo and Mbarara districts. At each farm site the experiments were conducted on plots measuring 12.6 m^2 with a spacing of 70 cm x 30 cm in a randomized complete block design with three replicates. A total of 12 farmer field schools composed of >360 participants were involved in the evaluation of these selected genotypes in 1999B, 2000A and 2000B. In the farmers' field schools the genotypes were evaluated with or without fungicidal sprays. Two field days were held at harvesting in 4 farmer field schools.

Results

Relative AUDPCs for late blight were analysed separately for each season at Kalengyere Research Station. There were significant differences among clones for AUDPCs in each season (Table 1). The results in Table 1 clearly show that in all the five seasons the elite 16 genotypes, selected in previous trials for resistance to late blight, maintained resistance to the disease and were consistently less blighted than the two local checks, Kisoro and Victoria. Victoria had the highest late blight disease severity followed by Kisoro . This implies that among the materials evaluated there were some with better resistance to late blight than the already released varieties.

During 1997B, the five highest yielding genotypes were 387121.4, 381471.18, 382171.4, 384329.21 and 384316.9 (Table 2). In the 1998B season, Victoria had the highest late blight attack (AUDPC) although its yield (31 Mt/ha) was not significantly lower than that registered by genotype 387121.4, the best yielding genotype during the season (Tables 1 and 2). The highest yielding genotypes in 1999A season were 381471.18, 381403.8, 382157.30, Victoria and 387173.12 while the best performing genotypes in 1999B were 382171.4, 381471.18, Kisoro, 382173.12, Victoria and 387114.10. The best yielding clones during the 2000A season were 381471.18 and 387121.4, with yields of 33.4 and 28.9 Mt ha^{-1}, respectively (Table 2). In the 2000A season Victoria was heavily attacked by late

blight which in turn reduced its yield drastically (Tables 1 and 2).

Overall, the highest on-station yields were produced by genotypes 382171.4 and 381471.18 with mean average yields, over the six seasons, of 29.8 and 29.6 Mt ha^{-1}, respectively (Table 2). Although genotype 381471.18 was introduced to Kalengyere Research Station from CIP, Lima, in 1992, it did not gain prominence until farmers participated in on-station evaluations in 1998B and 1999B. Despite the fact that it is white-skinned and most farmers prefer growing red-skinned varieties due to market preferences, clone 381471.18 was selected by farmers based on its high yields, round tuber shape and high culinary quality. This clone has very high level of resistance to late blight but with a long dormancy period of 4-5 months.

Results from the farmer-managed on-farm trials revealed that farmers were able to identify genotypes that were high yielding and resistant to late blight. The highest yielding genotypes in Mbarara were 394329.21, 57049, 382171.4, 381403.8 and 387146.48 (Table 3). In Ntungamo, however, when working with the Nyabugando farmers' group, Victoria was the best yielding genotype followed by 387146.48 with yields of 29.9 Mt ha^{-1} and 23.6 Mt ha^{-1}, respectively (Table 4). In Nyamiyaga village (Kabale district) 387146.48 had the highest yield although not significantly higher than that of Victoria or 381471.18 (Table 4). At four individual farmers' fields in Kisoro district, genotype 382171.4 had the highest yield followed by 575049 and 384329.21. Victoria performed worst on these farms. These advanced clones yielded less at farmers' fields (Tables 4 and 5) compared to the results obtained at research stations (Table 6) but the yield difference between on-station and on-farm trials was much lower than that previously reported (Low, 1997).

Table 1. Relative area under disease progress curves (RAUDPCs) of 16 advanced potato clones during 1997B, 1998A, 1998B, 1999B and 2000A seasons at Kalengyere and their relative ranking starting with the most resistant clone to late blight.

Genotypes	Relative area under disease progress curve (RAUDPC)						
	1997B	1998A	1998B	1999B	2000A	Mean	Ranking
384329.21	5.5	12.3	5	3.4	14.3	6.8	1
575049	3.5	12.3	7	3.2	10.1	7.0	2
387114.10	31.0	23.1	6	6.3	15.7	7.0	3
387121.4	8.6	14.3	5	3.5	10.8	8.4	4
382171.4	11.4	12.0	5	3.9	14.2	9.3	5
381403.8	22.1	28.3	7	3.0	12.7	12.2	6
384316.9	11.1	28.7	7	3.7	13.1	12.7	7
382150.5	13.3	22.4	8	5.6	14.4	12.7	8
381471.18	18.9	22.7	8	5.4	10.7	13.1	9
387199.30[¥]	17.3	23.9	7	4.2	-	13.1	10
382173.12[¥]	-	14.9	6	4.7	17.4	13.1	11
386007.2	11.6	28.6	6	5.6	15.7	13.5	12
387143.37[¥]	-	30.9	3	5.8	15.1	13.7	13
382157.30	20.2	26.4	6	3.5	13.3	13.9	14
384287.12	31.8	18.8	8	4.3	14.4	15.5	15
387146.48	22.6	30.1	9	6.6	13.9	16.4	16
Kisoro	21.6	31.2	11	7.5	21.4	18.5	17
Victoria	49.2	41.9	13	9.8	18.6	26.5	18
$LSD_{0.05}$	9.5	5.2	3.8	2.3	4.3		
CV (%)	30.6	15.6	39.5	31.9	21.1		

[¥]The clones shown by a dash (-) were not evaluated during those particular, seasons.
xCheck varieties

yA and B refer to first (March - July) and second (September - January) seasons, respectively.

Discussion

The national potato breeding program in Uganda is dependent on the materials obtained from the International Potato Center breeding program. Previously, farmers were not actively involved in selection of useful potato genotypes although on-farm trials were being conducted on farmers' fields. Farmers knowledge of late blight was also limited. In this study, farmer participatory breeding was initiated to enable farmers participate actively in variety selection at early stages of variety development, bearing in mind that development of useful germplasm is only beneficial if it is distributed and subsequently utilized. To this effect farmers evaluated 16 advanced clones in researcher managed trials and identified 6 for further evaluation under farmer conditions. This exercise revealed that genotypes 382171.4 and 575049 were the best yielding genotypes and were highly resistant to late blight. These two genotypes were released at the beginning of 1999 as NAKPOT 1 and NAKPOT 3, respectively (Kakuhenzire *et al.*, 1999). Although genotype 384329.21 gave very high yield at Kachwekano and Kalengyere, and had high levels of resistance to late blight, farmers rejected it on the grounds that it produced poorly-shaped tubers.

Host resistance to late blight will continue to play a big role in integrated disease management since the population structure of *P. infestans* is changing (Davidse *et al.*, 1993; Deahl *et al.*, 1995), fungicide resistance is increasing (Fry *et al.*, 1993; Deahl *et al.*, 1995), and farmers are still unable to afford the high cost of fungicides. In this study, most of the elite genotypes exhibited higher levels of resistance to late blight than the current available cultivars. As a result, some of these genotypes have been released. For sustainable potato production, however, integration of host resistance and judicious use of fungicides into the farming systems is needed (Fry and Shtienberg, 1990). Information is also still

Table 2. Average yield of 16 advanced potato clones at Kalengyere Research Station during six seasons and their relative ranking in ascending order.

Genotypes	Yield (Mt ha^{-1})							
	1997B*	1998A	1998B	1999A	1999B	2000A	Mean	Ranking
382171.4	46.5	20.2	29	12.2	46.2	24.5	29.8	1
381471.18	39.9	22.1	24	15.4	42.7	33.4	29.6	2
Victoria†	24.6	21.6	31	14.3	31.9	14.1	27.5	3
387121.4	44.1	8.6	34	13.1	24.4	28.9	25.5	4
384316.9	36.1	31.8	20	8.8	27.6	23.1	24.6	5
Kisoro†	29.7	21.6	25	12.9	35.4	22.3	24.5	6
387146.48	34.5	22.6	19	12.5	28.8	23.1	23.4	7
382173.12¥	-	11.4	23	13.7	34.6	27.6	22.1	8
381403.8	34.5	31.0	25	14.9	13.9	11.4	21.8	9
387114.10	31.7	11.6	27	8.3	29.9	19.7	21.4	10
384287.12¥	33.2	-	18	7.6	29.5	16.2	20.9	11
382157.30	28.9	13.3	22	14.6	25.9	17.3	20.3	12
384329.21	39.4	11.1	21	6.9	23.1	19.4	20.1	13
382150.5	34.5	18.9	16	8.2	20.4	15.3	18.9	14
575049	29.5	3.5	18	9.3	27.7	21.1	18.2	15
387143.37¥	-	-	9	9.3	26.3	17.0	15.4	16
387199.30¥	21.5	17.3	15	5.8	12.4	-	14.4	17
386007.2	17.7	5.5	10	7.8	13.9	11.8	11.1	18
$LSD_{0.05}$	7.0	9.5	8.7	6.6	14.2	4.8		
CV (%)	12.4	30.6	28.5	42.9	36.5	16.4		

¥The clones shown by a dash (-) were not evaluated during those particular seasons.
†Check varieties
*A and B refer to first (March - July) and second (September - January) seasons, respectively.

Table 3. Performance of potato population A genotypes at Thorn Tree Farm, Nyakayojo (Mbarara) in 1998B and 1999B.

Entry	Thorn Tree Farm, Nyakayojo					
	1998B			1999B		
	Mean tuber # per plant	Mean tuber weight (g)	Yield (Mt ha^{-1})	Mean tuber # per plant	Mean tuber weight (g)	Yield (Mt/ha)
382171.4	7	96.4	23.7	6	85.9	22.4
384329.21	5	94.4	22.0	6	114.1	30.1
Victoria	6	39.7	9.8	6	47.2	11.2
381471.18	4	100.5	15.9	5	83.8	16.4
384287.12	4	58.4	9.2	8	66.5	19.3
318403.8	5	54.8	18.6	5	74.1	16.3
575049	6	74.4	19.6	11	63.1	27.7
382150.5	5	99.5	17.4	5	81.3	10.8
387146.48	4	109.8	19.3	6	94.9	22.6
387114.10	4	88.5	9.1	7	63.7	18.6
387121.4	5	60.7	11.1	9	54.7	21.1
382173.12*	-	-	-	7	55.1	14.2
384316.9	4	74.0	9.6	6	99.1	20.6
386007.2*	7	73.3	19.9	-	-	-
Kisoro	6	38.0	8.2	10	35.5	13.5
387143.37*	-	-	-	6	81.4	11.9
382157.30	4	61.1	6.6	8	52.4	13.6
387199.30**	4	68.3	10.4	3	59.7	1.1
$LSD_{0.05}$	3	24.5	4.4	2.4	14.4	6.2
C.V. (%)	26.6	19.7	19.8	22.2	12.1	21.5

*This clone was not planted at this site.
**The poor performance was due to high level of virus infection.

Table 4. Yield of five promising genotypes at four farms and two farmer field schools, in Ntungamo, Kisoro and Kabale districts during the second (B) season of 1998.

Genotype	Yield (Mt ha^{-1}) at farm sites						
	*Rugurira[1] David	Rwakare Justus	Kinahirwe Jeremina	†Munyankiko David	Nyamiyaga Farmers' Group	Nyabugando Farmers' Group	Mean
382171.4**	18.8	33.4	18.7	16.9	29.3	14.2	21.9
381403.8**	14.6	20.4	14.1	18.5	-	-	16.9
387146.48	11.0	24.5	12.4	18.8	36.7	23.6	21.2
575049**	17.6	34.2	15.1	20.1	-	-	21.8
Victoria	5.8	24.0	8.3	17.9	29.9	29.9	19.3
384329.21	13.5	28.3	9.9	24.6	26.2	20.7	20.5
387121.4	-	-	-	-	24.6	19.3	22.0
LSD (5%)	7.4	9.6	3.2	-	8.0	14.5	
C.V (%)	23.9	21.1	12.6	-	15.4	40.6	

[1]The materials from this farm were harvested and bulked and no statistical analysis could be done.
*Damage due to mole rats reduced yield especially for Victoria.
**These varieties were released in 1999. The official names for genotypes 382171.4, 381403.8, 575049 are NAKPOT1, NAKPOT2 and NAKPOT3, respectively.
†Farmer Rugurira, Rwakare, Kinahirwe and Munyankiko are from Kisoro district, Nyamiyaga farmers' group is in Kabale and Nyabugando farmers' group is in Ntungamo district.

Table 5. Comparative yields of six promising potato genotypes at four Farmers' Field Schools during the first (A) season of 2000.

Genotypes	Yield (Mt ha^{-1}) at each Farmers' Field School				
	Karubanda	Kabira	Rukaranga	Nyamiyaga	Mean
387146.48	11.1	15.0	19.7	18.8	16.1
384329.21	11.5	9.5	15.0	18.0	13.5
382171.4	15.6	17.4	17.0	18.0	16.8
575049	7.4	11.7	19.0	21.5	14.9
Victoria	10.6	17.2	19.0	18.2	14.7
Rutuku	7.3	16.1	12.9	20.6	
LSD 0.05	6.9	8.6	8.1	11.7	14.2
CV (%)	25.2	23.0	18.5	23.7	

Table 6. Mean yield of promising varieties at Kalengyere Research Station (Kabale), Maziba Technology Verification Centre (Kisoro), and Kachwekano District Farm Institute (Kabale) during 1998B and 1999B seasons.

Varieties	Yield (Mt ha^{-1})						
	Kalengyere		Maziba		Kachwekano		Mean
	1998B	1999B	1998B	1999B	1998B	1999B	
Victoria	31	31.9	9.1	32.5	53.1	28.0	30.9
387121.4	34	24.4	11.8	23.6	56.1	21.5	23.1
384329.21	21	23.1	13.7	23.8	57.6	25.9	27.5
382171.4	29	46.2	15.1	39.5	54.3	26.5	35.1
387146.48	19	28.8	7.9	18.9	54.1	30.3	26.5
381471.18§	24	42.7	16.5	37.4	-	30.3	30.2
575049§	18	27.7	19.0	21.7	50.4	-	27.4
LSD $_{0.05}$	8.7	14.2	4.3	15.1	12.4	10.9	
C.V. (%)	28.5	36.5	25.5	28.4	12.5	22.1	

§The clones were not evaluated at these locations during these particular seasons.

needed on the relationship between disease susceptibility and crop loss under different environmental and cultural regimes, as an aid to identifying the level of resistance at which the breeder should aim (Umaerus *et al.*, 1983). Additionally, a follow-up study should be made to assess the magnitude of crop losses incurred on varieties with different levels of resistance under judicious fungicide applications.

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The inheritance of resistance to finger millet blast disease

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Abstract

Finger millet is a very important cereal crop in Uganda. It is a major staple food crop and also provides cash for both the rural and urban people. Of the many diseases attacking the crop, blast (*Piricularia grisea* (Cooke) Sacc.)is the most important causing yield losses ranging from 10 – 90% across the country depending on the environmental conditions, varietal differences or cropping systems. Breeding for resistance has widely been recognised as the most effective control strategy for blast in finger millet. However, the mode of inheritance to the disease resistance has not been adequately studied. Two cultivars with distinct markers for grain/glume colour and head shapes and known blast reaction were used to study the mode of inheritance of resistance to blast in experiments conducted at Serere and Ngetta. It was found that a purple grain/glume colour conferred blast resistance more than a tan colour, and that a compact head shape also conferred blast resistance more than an open head. Higher levels of resistance were observed where the two characters were present together. The results also showed that resistance to blast is both dominant and additive.

Key words: Blast, grain colour, head shape, host resistance, phenotype, *Pyricularia grisea*, progeny

Introduction

Finger millet *(Eleusine coracana* (L) Gaertn) is an important cereal food crop in Uganda being second to maize. It is produced on an average of 300,000 ha yielding 450 metric tons annually (FAO, 1999). The crop is grown virtually in all parts of the country but with more concentration in the Eastern, Northern and parts of Western Uganda where it is a major staple food. In these areas, finger millet is also emerging as an important cash earner to the rural people. The crop is nutritionally superior to rice and wheat, having good malting properties as a result of high levels of amyloses (Purseglove, 1988). It also has high levels of vitamins and minerals making it the most suitable food for pregnant women, lactating mothers and children.

Unfortunately, finger millet is vulnerable to diseases. A wide range of fungal, bacterial and viral diseases have been reported on finger millet (Rachie and Peters, 1977; Adipala – Ekwamu, 1980). The most important of these diseases is blast caused by the pathogen *Piricularia grisea* (Cooke) Sacc. (Teleomorph *Magnaporthe grisea*).

The disease is very destructive and economically important causing over 50% losses in yield, especially in wet seasons (Adipala and Mukiibi, 1991). Field studies have recorded losses of 10 – 90% in Uganda (Emechebe, 1975). High rainfall, temperature (25 – 30°) and humidity (over 90%), are the most important predisposing factors.

Pyricularia grisea attacks finger millet at all stages of plant development from seedling to grain formation. The symptoms at seedling stage appear as small, brown, circular to elongated spots on the leaves which later coalesce into large elongated or spindle shaped lesions. The centres of these lesions eventually develop greyish mycelial fungal growth consisting of conida and conidiophores of the fungus. Severe infections may lead to seedling death. The leaf blast phase of the disease tends to be less severe. Crop loss is always greatest when the disease appears on the peduncle and/or finger causing neck and head blast respectively during flowering and grain formation. Depending on the

severity of infection, this may lead to total inhibition of grain formation or production of shrivelled seed. Rath and Misra (1975) reported that neck blast causes increase in spikelet sterility.

Blast screening nurseries in Serere (eastern Uganda) and elsewhere have shown a wide range of variability in resistance to blast, ranging from from almost complete resistance to total susceptibility. Variability in resistance has been attributed to differences in plant and grain colour, head shapes and maturity periods. Generally, dark seeded cultivars are more resistant than white seeded ones. Also, compact headed cultivars are more resistant than open headed ones. The very early maturing cultivars are more susceptible than the late maturing ones. In rice, which is attacked by *Piricularia oryzae* resistance to blast can be unreliable, with previous resistant cultivars showing high levels of susceptibility in the field within a few years of release (Kiyosawa, 1972). There have been numerous explanations advanced for the instability of resistance. These can be grouped into two broads themes: inadequate exposure of breeding materials to diverse pathogen populations, and hypervariability of the pathogen.

Inheritance of resistance to blast in finger millet has not been adequately studied. Yet efficient utilisation of breeding materials requires knowledge of modes of inheritance. This study was therefore instituted to provide information on the nature of resistance to the blast disease. It has been argued that like for other cereals, incorporation of genetic resistance is the best choice for disease management in finger millet and other cereals (Agrios, 1997).

Materials and methods

Development of breeding population

Two cultivars DR 3 SS and E 11 with distinct characters of grain/glume colour, head shapes and known blast reaction were selected for the study (Table 1). The two cultivars were chosen in such a way that factors controlling other traits were basically similar, so that the differences observed if any would primarily be a result of grain colour, head shape and blast reaction.

In order to make all possible crosses between the two cultivars, diallel crosses with their reciprocals were made. Hot water emasculation method was used in which the finger millet heads were dipped in hot water at 50°C for 2 minutes, just before flowering. F_1 plants were derived from crosses between parents. F_2 plants were derived by selfing F_1 plants. BC_1 plants were obtained by backcrossing F_1 plants to each of the parents. All the crosses were made in the greenhouse, at Serere.

Pathogen isolation and inoculum preparation

The pathogen was isolated from infested finger millet tissue by inducing sporulation on moist blotter paper in petri-dishes. Prior to plating, the infected seeds and glumes were surface sterilised by immersion in 10% sodium hypochlorite solution for about 11 seconds and wrinsed in sterile distilled water (SDW) thrice. The blotters were then put into the deep freezer for 12 hours at minus 4.5°C. The purpose of deep – freezing was to suppress the possible germination of the seeds during incubation. After deep freezing, the samples were then incubated under alteranting 12/12 hours under alternating near ultra-violet light (NUV) and darkness for seven days. The resultant spores were streaked on Agar plates and incubated at 28° C for 7 days. Single germinating conidia were picked and colonies grown on Potato dextrose agar (PDA) plates, and then stored as stock isolates.

Table 1. Description of finger millet varieties used in the blast resistance studies.

Variety	Blast reaction	Grain/Glume colour	Head shape
DR 3 SS	Resistant	Purple	Compact
E 11	Susceptible	Tan	Open

Stock isolates were re-cultured at Serere on PDA media with streptomycin added at 10 mg per 250 ml of medium to control bacteria. The plates were placed under continuous fluorescent light for 7 days at 28°C to induce sporulation. Conidia were scrapped from the incubated plates into 50ml of sterile distilled water. Spore suspensions were then filtered through nylon cloth. Spores from the resulting suspension were counted with a haemocytometer and appropriately diluted with sterile distilled water to make an inoculum suspension of 1 x 10^6 spores per millilitre. Two to three drops of Tween 20 were added to the inoculum as a wetting agent.

Disease and phenotypic evaluation

Disease and phenotypic evaluation were done at two locations, Serere and Ngetta in eastern and northern Uganda. The two locations are rather similar in weather conditions but with Serere being wetter (1230 mm per annum) than Ngetta (1100 mm). All the populations (P_o, F_1, F_2 and BC_1) were planted in the field to assess their reaction to blast disease and evaluate the phenotypes. The experiments were planted in a completely randomised design with two replications. Plot sizes consisted of two five-meter row plots for P_o, F_1, and BC_1 progenies and ten five-meter row plots for F_2 progenies. The objective was to obtain at least 60 plants for observation in P_o, F_1 and BC_1 and 300 plants in each F_2 per replication. Three hundred plants per replication were selected for the F_2 population because of the greater variation expected in this segregating generation.

Grain/glume colour and head shapes of the parental lines were observed to ensure that the lines were true breeding. These observations were also made on the F_1 plants to determine if they were actual crosses or were parental self-pollinations. Studies on gene dominance and inheritance patterns were carried out on the F_2 and BC_1 progenies. The identification of colour and head shape as dominant or recessive was determined by phenotypic classification of parental lines (Po), F_1, F_2 and BC_1 populations. Every individual panicle in F_2 and BC_1 populations were studied for the various phenotypic classifications and disease reaction. Only one panicle was examined among those that had tillered.

Blast reaction was evaluated on field inoculated plants. The panicles of all the populations were inoculated at head emergence by spraying the with spore suspensions until runoff. The inoculated panicles were bagged in pollinating bags for 4 days to maintain high humidity. Disease evaluation on the inoculated plants was conducted using a 1 – 5 scale where 1 = no visible symptoms, 2 = 1 – 10% of susceptible plant parts affected, 3 = 11 – 25% of susceptible plant parts affected, 4 = 26 – 50% of susceptible plants parts affected and 5 = over 50% of susceptible plant parts affected. A minimum of 20 plants per phenotype per generation was used to obtain a blast rating. In the final analysis, blast reaction was rated as follows: resistant (Ratings 1.0 – 2.5), moderately resistant (Ratings 2.6 – 3.5) and susceptible (Ratings 3.6 – 5.0).

Statistical analysis

Since no apparent differences were observed in either phenotypes or blast values in the two replications in each site, their observations were pooled for statistical analysis. To determine their dominance and inheritance and to establish linkage with blast reaction, phenotypic ratios were selected for goodness of fit by a chi-square test for the observed to the expected number of phenotypes within each of the F_2 and BC_1 populations. An analysis of variance was used to determine location and phenotypic effects. Fisher's LSD at 5% probability level was used to determine differences among the means.

Results

Phenotypes from crosses with minimal influence from other traits were selected for studying grain/glume colour and head shapes. Blast ratings differed for each of the phenotypic classifications (Table

2).

All F_1, F_2 and BC_1 progeny with purple glume colour and compact heads had low blast ratings (1 – 2) indicating resistance. The F_2 and BC_1 progenies that segregated for tan glume colour and open heads were susceptible (ratings 4 – 5). The F_2 and BC_1 progeny that segregated for tan glume colour and compact head or purple glume colour and open head had moderate disease ratings (3 – 3.5).

All the F_1 were purple coloured and compact headed and showed high levels of resistance. This indicated that resistance is dominant and is governed by purple glume colour and compact head. Genotypes with purple colour and an open head were more resistant than those with tan glume colour and compact head . This suggested that although both purple colour and compact head conferred blast resistance, purple colour conferred greater resistance than compact head. However, there appeared to be an additive effect, because when both purple colour and compact head were present, higher levels of resistance were observed.

The inheritance of purple colour and compact head were studied using the same parents and was tested for goodness of fit by chi-square analysis (Table 3). All the F_1 progenies had purple grain/glume colour and compact head shape. The F_2 progenies segregated in the expected 27:9:21:7 ratio for purple compact: purple open: tan compact: tan open: respectively. The F_1 x P_2 progenies segregated in the expected 3:1:3:1 ratio for similar phenotypic classification. F_1 x P_1 progeny all were purple, and compact. These ratios showed that purple grain/glume colour and compact head shape were inherited in a dominant manner.

Discussion and conclusions

In Uganda, blast is still the most important biotic constraint to finger millet production (Adipala, 1992) and considerable work has been done on breeding for resistance to the disease (Esele and Odelle, 1995). It is widely recognised that resistance is the cheapest and most effective strategy for the control of blast in finger millet (Rachie and Peters 1977; Esele, 1989; Viswanath and Seetharam, 1989; Pande *et al* .,1995).

The present results show that there is a strong relationship between glume colour and compactness. In general, the purple colour was associated with a higher blast resistance than tan colour and the compact head was more resistant to blast than loose/ open head. These findings coroborate earlier work of Esele and Odelle (1995) which showed that resistance is correlated with purple colour and compact

Table 2. Relationship between glume/head phenotype and blast resistance in DR 3 SS (P_1) x E 11 (P_2) crosses at Serere and Ngetta.

		Blast rating		
Generation	Phenotype	Serere	Ngetta	Mean
P_1	Purple, Compact	1	1	1a
P_2	Tan, Open	5	5	5f
F_1	Purple, Compact	1.5	1.6	1.55b
F_2	Purple, compact	2.0	1.7	1.85b
	Purple, Open	3.2	3.0	3.1c
	Tan, compact	3.4	3.4	3.4d
	Tan, open	4.6	4.5	4.55e
P_1x P_1	Purple, compact	1.0	1.0	1.0a
P_2 x P_2	Purple, compact	1.8	1.7	1.75b
	Purple, open	3.4	3.3	3.3d
	Tan, compact	3.5	3.5	3.5d
	Tan, open	5.0	4.8	4.9f
	Mean*	3.0_g	2.9_g	

*Means followed by the same letter are not significantly different at P = 0.05 using Fisher's LSD.

Table 3. Chi-square analysis for the inheritance of grain/glume colour and head shape in the DR 3SS (P_1) x E 11 (P_2) cross at Serere and Ngetta.

Generation	Phenotype	Serere				Ngetta		
		Ratio*	O	E	X^2	O	E	X^2
P_1	Purple, Compact	1	...	...	...	...	.....	....
P_1	Tan, Open	1	...	...	...	...	...	...
F_2	Purple, Compact	1	...	...	...	...	...	...
F_2	Purple, Compact	27	201	198	...	221	229	...
	Purple, open	9	56	59	...	61	68	....
	Tan, compact	21	188	183	...	197	211	...
	Tan, open	7	50	54	0.69a	48	51	2.1a
$F_1 \times P_1$	Purple, compact	1	...	...	...	...	...	...
$F_2 \times P_2$	Purple, compact	3	37	42	...	41	47	...
	Purple, open	1	34	56	...	30	52	...
	Tan, compact	3	28	14	...	29	15	...
	Tan, open	1	31	18	8.64a	33	16	6.2a

* = Expected segregation ratio for the phenotypes in each generation
O = Observed number of plants
E = Expected number of plants
... = All plants observed were of the same phenotypes, hence no analysis was performed.
A = X^2 values were all significant at P = 0.05

heads. In many pathosystems resistance is attributed to production of biochemical compounds that may either inhibit fungal entry or growth (Agrios, 1997). In the case of *P. grisea* it appears resistance is conditioned by multiple biochemical production in resistant cultivars. Indeed, Seetharam and Ravikumar (1993) reported that the total phenol and tannin contents of resistant cultivars were generally higher than those of susceptible ones. Darker colour in fnger millet is indicative of higher phenols and tannins levels. Tannins inhibit spore germination and mycelial growth (Kambal and Bate-Smith, 1976; Hahn and Rooney, 1985).

The results of this study have also shown that resistance to blast is heritable. When the inheritance was analysed by chi-square test, the results showed complete dominance of colour and head shape. Examination of the effect of different phenotypic classifications also showed that the resistance is additive. Higher levels of resistance were observed in progenies with both purple and compact heads. Viswanath and Seetharam (1989) obtained similar results. Their study of gene action through line x tester analysis revealed the role of both additive and dominant gene action. This is very useful information for disease resistance breeding programmes. It suggests good potential for conventional breeding methods (such as recurrent selection), and early generation testing and selection for resistance.

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Evaluation of 62 cowpea lines for resistance to false rust (*Synchytrium dolichi* (Cooke) Gaum) and scab (*Sphaceloma* sp.)

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Abstract

We evaluated 62 cowpea lines for field resistance to false rust (*Synchytrium dolichi*) and scab (*Sphaceloma* sp.). To increase disease pressure susceptible entries were grown two weeks prior to planting the test entries. The entries were grouped as resistant, moderate-resistant, moderately susceptible or susceptible on the basis of standardised Z-scores of areas under disease progress curves. In the case of scab, three entries, namely, TVU4630, *Ebelat* (local) and *Icirikukwai* (local) were rated resistant. Likewise, IT88D-643-1, IT90K-56 and IT90K-1026 were rated resistant to false rust but the majority of the local land races were susceptible to false rust.

Key words: Disease resistance, z-scores, *Vigna unguiculata*, Uganda

Introduction

Field screening of widely assembled germplasm has for a long time been used to evaluate different crops against many destructive diseases (Kwaje, 1975). As a result, cultivars with high levels of field resistance, that are non-specific to many pathogens of useful crops have been developed. Even a low level of resistance is important as it reduces the need to apply pesticides (Mathews, 1984). Since cowpea (*Vigna unguiculata* (L.) Walp) is a low value commodity, this approach is the cheapest pest management strategy for the crop.

In eastern Africa, cowpea is attacked by a wide range of diseases, but generally, the most destructive are false rust (*Synchytrium dolichi* (Cooke) (Guam), scab (*Sphaceloma* sp.), cowpea aphid-borne mosaic (caused by the cowpea aphid-borne mosaic potyvirus), Cercospora leaf spots (*Cercospora canescins* Ell. & Mart & *Cercospora cruenta*) and in some localities, white zonate leaf spot (*Dactuliophora tarri* Leakey) (Edema and Adipala, 1996; Edema *et al.*, 1997). Total crop failure as a result of some of these diseases have been reported in Uganda (Edema and Adipala, 1996). The objective of this study was to screen for possible sources of resistance to false rust and scab, two important diseases of cowpea in Uganda.

Materials and methods

The study was conducted at Kabanyolo (O°28'N, 32°37'E, 1,200m above sea level) and Serere (33°27'E, 1°31'N; 1,000 m above sea level) during the first season (March – June) and the second season (September – December) rains of 1994. About 33 to 230.6 mm (first season), and 94.9 to 210 mm (second season) was recorded at Kabanyolo during the growth period f the crop with a mean of 110.1 mm per month for the 1994 season. Mean daily maximum and minimum temperatures were 28.5°C and 13°, respectively. Soils are heavy, well drained and rather acidic (pH 5.0 – 6.0).

In the first and second seasons, 149.1 to 236.3 mm and 2.7 to 142 mm of rainfall, respectively, was

recorded at Serere with a mean of 123.2 mm per month for the 1994 season. Daily maximum and minimum temperatures averaged 27.5° and 22.5°C, respectively. Soils are sandy loams, with a pH of 5.5 – 6.5.

Establishment of experiments

Land used for the experiments was previously under cowpea for Kabanyolo, and under sorghum for Serere during both first and second rainy seasons, respectively. Fifty-four cowpea lines obtained from the International Institute of Tropical Agriculture (IITA) and eight local landraces from Uganda were used. The cowpea lines were planted in single-row plots of 3 m with a spacing of 60 cm between rows and 30 cm within rows. The experiment was of a randomised complete block design (RCBD) with two replications. Planting date was 27 April 1994 for Kabanyolo during the first rainy season. For the second season, planting dates were 23 October 1994 and 13 October 1994 for Kabanyolo and Serere, respectively. For each season susceptible entries were grown around experimental plots two weeks prior to planting the test lines. This was done so as to increase disease pressure. About 3 – 4 seeds were planted in each hole and the seedlings thinned to one plant per hill when plants were about 10 cm high. The experiment was weeded 2 – 3 times using a hand-hoe. During the second rains of 1994 Dimethoate (systemic) was applied at the rate of 20 ml/15l, and Decis (contact) at the rate of 50 ml/ 15 L to control insect pests. The insecticides were applied as tank-mixtures. Spraying was done at 7 – 10 day intervals commencing and 21 days after planting in Kabanyolo and 23 days after planting in Serere.

Data collection and analysis

Disease data were collected 67, 74 and 88 days after planting (DAP) in Kabanyolo during the first season, and 63, 70 and 79 DAP, and 46, 55 and 61 DAP for Kabanyolo and Serere during the second season, respectively. Five plants in each row were randomly selected, tagged and used for diseases assessment. Disease severity was rated using a modified Horsefall and Barret (1945) scale of 0, 1, 5, 10, 25, 50 and 75% of plant area affected. At maturity five plants from each row were harvested and the dry pods threshed and weighed.

The weekly severity ratings were averaged for each genotype and replicate, and areas under disease progress curves (AUDPCs) calculated and standardised (Campbell and Madden, 1990). Analyses of variance (ANOVA) were performed on disease and pod yield data using the one factor RCBD of M-Statc package (Russel D. Freed, Michigan State University, USA).

The varieties were classified as either resistant, moderately resistant, moderately susceptible or susceptible on the basis of their standardised Z-scores (Pataky and Darin, 1993). The Z-scores were calculated as Z = [(AUDPC-grand mean)/ standard deviation]. Lines with a Z-score > 0.8 were rated susceptible while those with scores < 0.8 were rated resistant. The moderately resistant and moderately susceptible lines had scores ranging from –0.2 to –0.8 and 0.2 to 0.8, respectively.

Results and Discussion

During the study period the following diseases were observed; false rust (*Synchytrium dolichi*), scab (*Sphaceloma* sp.), Dactuliphora leaf spot (*Dactuliophora tarri*), brown rust (*Uromyces phaseoli (Pers.)* Wint. and powdery mildew (*Erysiphe polygoni* de Candole). There was low severity of Dactuliophora leaf spot (0.12%), powdery mildew (0.68%) and brown rust (0.04%) in both seasons of 1994. This was probably due to the low rainfall (data not shown) which limited the infection process and development of the diseases. However, scab developed sufficiently well in both seasons and false rust during the second season at Serere to enable evaluation of varietal differences. The two diseases

appeared after the vegetative stage and were, therefore, scored from flower initiation to pod maturity: at this stage both scab and false rust symptom build-up is very rapid and symptoms are clearly visible.

There were significant differences ($P \leq 0.05$) among the lines in each of the two locations and disease levels varied significantly ($P \leq 0.05$) with season in Kabanyolo. In the first season, at Kabanyolo, scab severity ranged from 0 to 27.5% with an overall mean of 3.2%. Area under disease progress curve ratings (AUDPC) ranged from 8.5 to 20.2% for susceptible lines, 3.9 to 7.4% for moderately susceptible lines, 0.01 to 2.2% and 2.9 – 3.2%, for resistant and moderatly resistant lines, respectively. Based on the Z-scores 6 lines were rated susceptible, 13 moderately susceptible and 32 moderately resistant (Table 1). The lines IT86D-2014-1, IT88DM-363 and IT*(KD-245) were grouped as moderate resistant.

In the second season, the mean scab severity ranged from 1.1 to 41.0% with a mean of 17.6% at Kabanyolo. There was generally higher severity of scab in the second season compared to the first. This was attributed to the fact that the lines were grown in the field which was used for cowpea in the first season. Most likely, infested residue from the previous cowpea crop induced disease development (Singh and Allen, 1979; Nakawuka and Adipala, 1997). Thirteen (13) lines were rated susceptible, 9 moderately susceptible, 15 moderately resistant and 13 resistant during this season. These lines had Plant leaf araea affected (PLAA) rating of 29.8 – 48.3%, 20.8 – 28.1%, 11.6 – 17.9%, 2.6 – 9.6% and 19.1%, respectively. The 15 moderately resistant lines included TVU 11426, IT92KD – 258 – 9, IT89KD – 256, IT81 – 985, IT845 – 2246 – 4, IT87D – 941 – 1, IT91K – 93 – 10, IT90K – 76, IT92KD – 267 – 2, IT81D – 988, IT89KD – 355, IT89KD – 404-1, *Osu* (Arua) and *Amul* (Nebbi), while the 12 resistant lines included IT85D-3850-2, IT81D-994, IVX 1948-01F, TVU 11424, IT90K-56, IT86F-2062-5, IT92KD-404-1, *Ebelat* (Kumi), *Ebelat* (Bukedea), *Ebelat* (Butebo), *Icirikukwai* (Usuk) and *Icirikukwai* (Amuria).

In Serere 13 lines were rated susceptible to scab, 7 moderately susceptible, 25 moderately resistant and 9 resistant. These lines had PLAA ratings of 29.8-48.3%, 20.8-28.1%, 19.1-19.9%, 11.6-17.9% and 2.6-9.6%, respectively. The moderately resistant lines included IT92KD-258-9, IT85D-3850-2, IT89KD-260, IT81-994, IT81-985, TVX 1948-0IF, TVU 11424, IT90K 59, IT845-2246-4, IT87D-941-1, IT91K-118-20, IT91-93-10,IT90K-76, IT92KD-267-2, IT86F-2062-5, IT86D-880, IT8ID-1228-14, IT86F-2089-5, IT86D-715, IT89KD-391, IT81D-988, IT92KD-404-1, *Ebelat* (Kumi), *Osu* (Arua), *Amul* (Nebbi), *Ebelat* (Butebo) and *Icirikukwai* (Amuria). Five lines, namely IT89KD-288, TVU 4630, IT89KD – 355, *Ebelat* (Bukedea) and *Icirikukwai* (Usuk) were rated resistant.

More scab was observed in the second (mean 19.5%) than the first rainy season (mean 3.1%) in Kabanyolo. In a previous study, Iceduna *et al.* (1994) also consistently observed higher scab incidence and severity during the second season for reasons that have not yet been fully elucidated. Apparently, attack by scab is favoured by dry rather than wet weather. It may also be true that the low incidence of other fungal diseases during the second season reduced competition for surface area, hence scab flourished.

The main objective of the screening test was to isolate within the available germplasm lines that contain resistance to the specific diseases. Overall, therefore, seven lines namely, IT90-109, IT88D-643-1, IT92KD-263-4-1, IT90K-109, IT89KD-374-59, IT87-697-2 and IT88D-867 – were consistently rated susceptible to scab; six lines, i.e., IT89KD-245, IT86D-1010, IT83S-889, IT89KD-349 and IT88DM-3636 were rated moderately susceptible; 17 lines, namely, TVU 11426, IT92KD-258-9, IT85D-3850-2, IT8ID-994, IT81D-985, TVX 1948-01F, IT89KD-288, TVU 11424, IT90K-76, IT86F-2098-5, IT81D-988, IT89KD-355, IT92KD-404-1, *Ebelat* (Bukedea), *Amul* (Nebbi), *Ebelat* (Butebo) and *Icirikukwai* (Usuk) were rated resistant. In the previous study of Iceduna *et al.* (1994), the lines IT85D-3850-2, IT81D-994 and TVX 1948-O1F were classified as resistant.

There was very low incidence of false result in Kabanyolo, but higher levels developed in Serere (Table 2). As such, only data for Serere were used to rank the cowpea lines for resistance to false rust. Three (3) lines were rated resistant, 31 moderately resistant, 7 were considered moderately susceptible,

Table 1. Z-scores[a] for 62 cowpea lines evaluated for resistance to scab at Kabanyolo and Serere during the first and second seasons of 1994.

	Kabanyolo				Serere	
Entry	First season[b]	Reaction	Second season[b]	Reaction	Second season[b]	Reaction
TVX 4659-03E (Dc)	-0.5	MR	-	-	-	-
TVU11426 (D)	-0.5	MR	-0.5	MR	-0.9	R
IT92KD-258-9 (D)	-0.5	MR	-0.6	R	-0.5	MR
IT85D-3850-2 (D)	-0.5	MR	-1.1	R	-0.7	MR
IT89KD-256 (D)	-0.5	MR	1.1	S	-0.3	MR
IT89KD-256	-0.5	MR	-0.4	MR	0.1	MS
IT81D-994 (D)	-0.5	MR	-0.8	R	-0.4	MR
IT81D-985 (M/D)	-0.5	MR	-0.2	MR	-0.7	MR
TVX 1948-01F (D)	-0.5	MR	-1.1	R	-0.5	MR
IT89KD-288 (D)	-0.5	MR	0.0	M	-0.8	R
TVU4630 (D)	-0.5	MR	-1.1	R	-0.9	R
IT91K-45 (D)	-0.3	MR	-	-	-	-
IT89KD-245 (M/D)	0.3	MS	1.1	S	0.4	MS
TVU 11424 (D)	-0.5	MR	-1.0	R	-0.7	MR
TVU 12349 (D)	-0.5	MR	-	-	-	-
IT90K-59 (S/I/E)	1.1	S	0.6	MS	-0.3	MR
IT90-109 (I)	2.9	S	0.6	MS	1.0	S
IT92KD-371-1 (E)	0.9	S	-	-	-	-
IT845-2246-4 (E)	1.0	S	-0.2	MR	-0.2	MR
IT86D-1010 (E)	-0.2	MR	0.4	MS	1.3	S
IT87D-941-1 (E)	0.3	MS	-0.5	MR	-0.8	MR
IT86D-719 (E)	-0.2	MR	0.9	S	0.8	MS
IT88D-643-1 (E)	-0.2	MR	1.0	S	2.6	S
IT90K-56 (E)	0.2	MS	-1.1	R	-0.7	MR
IT91K-118-20 (E)	-0.5	MR	0.1	MS	-0.4	MR
IT90K-102-6 (E)	-0.5	MS	-0.9	R	1.1	S
IT91K-93-10 (E)	0.4	MS	-0.3	MR	-0.7	MR
IT90K-76 (S/E)	-0.5	MR	-0.5	MR	-0.8	MR
IT92KD-267-2 (V)	0.5	MS	-0.3	MR	0.2	MS
IT92KD-266-2-1 (V)	-0.5	MR	-	-	-	-
IT86F-2062-5 (V)	-0.2	MR	1.1	S	-0.5	MR
IT86D-880 (V)	-0.3	MR	0.6	MS	-0.4	MR
IT83S-889 (V)	0.3	MS	0.0	M	1.6	S
IT81D-1228-14 (V)	0.3	MS	2.2	S	-0.1	MR
IT92KD-263-4-1 (V)	0.2	MS	1.1	S	2.0	S
IT86F-2089-5 (V)	-0.3	MR	-1.3	R	-0.4	MR
IT86D-2014-1 (V)	0.0	M	0.0	M	-0.4	MR
IT88D-643-1 (S/M)	-0.5	MR	0.8	S	1.4	S
IT90K-109 (E/M)	-0.2	MR	1.0	S	0.9	S
IT86D-719 (M)	-0.5	MR	1.4	S	0.7	MS
IT89KD-374-57 (I)	0.1	MS	0.8	S	1.0	S
IT89KD-349 (M)	0.3	MS	0.7	MS	0.8	MS
IT86D-715 (M)	0.4	MS	2.1	S	-0.2	MR
IT87D-697-2 (M)	1.8	S	0.9	S	0.2	MS
IT88DM-363 (M)	0.0	M	0.5	MS	1.2	S
IT89KD-391 (I/M)	1.1	S	0.5	MS	-0.3	MR
IT81D-988 (M)	-0.5	MR	-1.0	MR	-0.8	MR
IT90K-277-2 (I)	0.6	MS	-	-	-	-
IT88D-867-11 (M)	0.3	MS	0.7	MS	1.3	S
IT/89KD-355 (M)	-0.3	MR	-0.2	MR	-0.9	R
IT89KD-245 (M)	0.0	M	0.0	M	0.2	MS
IT92KD-405-2 (S/M)	-0.5	MR	-	-	-	-
IT89KD-260 (M)	-0.5	MR	-0.1	MR	0.3	MS
IT92KD-404-1 (S/M)	-0.5	MR	-0.3	MR	-0.4	MR
Ebelat (Kumi)*	-	-	-0.9	R	-0.5	MR

Table 1. cont.

Osu (Arua)*	-	-	-0.2	MR	-0.4	M.R
(Bukedea)*	-	-	-1.3	R	-0.9	R
Icirikukwa	-	-	-	R	-	R
I(Usuk)			1.2		0.9	
Amul (Nebbi)*	-	-	-0.5	MR	-0.1	MR
Ebelat	-	-	-0.9	R	-0.6	MR
Icirikukwai (Amuria)*	-	-	-1.1	R	-0.5	MR

[a]
[b] Calculated as: [AUDPC rating-grand mean)/standard deviation]
<-0.8 = resistant, -0.2 to –0.8 = moderately resistant, 0.2 to 0.8 = moderately susceptible, between –0.2 to 0.2 [c] moderate and >0.8 = susceptible
[d] D = Dual purpose line (both for seed and vegetable), E = Early maturing line, I = Insect resistant line, S = Striga resistant line, M = medium length maturing line and V = lines for vegetable.
* Local cultivars

Table 2. Z-scores[a] for 62 cowpea lines evaluated for resistance to false rust at Serere during the second season of 1994.

Entry	Z-score	Reaction[b]
TVX 4659-03E (Dc)	-[d]	-
TVU 11426 (D)	0.3	MR
IT92KD-258-9 (D)	1.5	S
IT85D-3850-2 (D)	0.0	MS
IT89KD-260 (D)	-0.5	MR
IT89KD-256 (D)	-0.1	MS
IT81D-994 (D)	-0.5	MR
IT81D-985 (M/D)	-0.2	MR
TVX 1948-01F (D)	1.2	S
IT89 KD-288 (D)	-0.2	MR
TVU 4630 (D)	1.9	S
IT91K-45 (D)	-	-
IT89KD-245 (M/D)	-0.6	MR
TVU 11424 (D)	1.1	S
TVU 12349 (D)	-	-
IT90K-59 (S/I/E)	-0.8	MR
IT90-109 (I)	-1.0	MR
IT92KD-371-1 (E)	-	-
IT845-2246-4 (E)	-0.1	MR
IT86D-1010 (E)	-0.2	MR
IT87D-941-1 (E)	0.0	MR
IT86D-941-1 (E)	0.0	MR
IT86D-719 (E)	-0.6	MR
IT88D-643-1 (E)	-1.0	R
IT90K-56 (E)	-1.2	R
IT91K-118-20 (E)	1.7	S
IT90K-102-6 (E)	-0.8	R
IT91K-93-10 (E)	2.2	S
IT90K-76 (S/E)	-0.1	MR
IT92KD-267-2 (V)	-0.8	MR
IT92 KD-266-2-1 (V)	-	-
IT86F-2062-5 (V)	0.6	MS
IT86D-880 (V)	-0.1	M
IT83S-889 (V)	-0.4	M

Table 2. Cont.

IT81D-1228-14 (V)	-0.1	M
IT92KD-263-4-1 (V)	-1.0	MR
IT86F-2089-5 (V)	1.0	S
IT86D-2014-1 (V)	-0.7	MR
IT88D-643-1 (S/M)	-0.8	MR
IT90K-109 (E/M)	-0.3	MR
IT860-719 (M)	-0.3	MR
IT89KD-374-57 (I)	-0.5	MR
IT89KD-349 (M)	-0.7	MR
IT86D-715 (M)	-0.3	MR
IT87D-697-2 (M)	-0.8	MR
IT88DM-363 (M)	-0.8	MR
IT89KD-391 (I/M)	0.5	MS
IT81D-988 (M)	-0.5	MR
IT90K-277-2 (I)	-	-
IT88D-867-11 (M)	-0.4	MR
IT89KD-355 (M)	-0.1	MR
IT89KD-245 (M)	-0.4	MR
IT92KD-405-2 (S/M)	-	-
IT89KD-260 (M)	-0.5	MR
IT92KD-404-1 (S/M)	-0.1	MS
Ebelat (Kumi)*	0.8	S
Osu (Arua)*	1.7	S
Ebelat (Bukedea)*	1.0	S
Icirikukwai (Usuk)*	1.2	S
Amul (Nebbi)*	0.9	MS
Ebelat (Butebo)*	0.6	MS
Ebelat (Butebo)*	0.6	MS
Ebelat (Apopong*)	-0.8	-

[a] Calculated as: [(AUDPC rating-grand mean)/standard deviation

[b] <-0.8 = resistant, -0.2 to –0.8 = moderately resistant, 0.2 to 0.8 = moderately susceptible, between –0.2 to 0.2 = moderate and > 0.8 = susceptible

[c] D = Dual purpose line (both for seed and vegetable), E = Early maturing line, I = Insect resistant line, S = Striga resistant line, M = Medium length maturing line and V = lines for vegetable.

[d] Didnot germinate

[e] *Local cultivars

and 9 susceptible (Table 2). The three resistant lines were IT88D-643-1, IT90K-56 and IT90K-1026. The majority of the local landraces were susceptible to false rust.

These tests relied on natural inocula of the diseases and some of the lines did not always fall into the same resistance/susceptibility category in all seasons (Tables 1 & 2). Nevertheless, the present results suggest that the local landraces had low scab but high false rust infections. The low severity of scab observed on *Amul* and *Osu* and the low levels of false rust observed during the surveys (Edema *et al.*, 1997) on all the varieties could be a result of many factors, but to some extent, might reflect local specificity of the diseases in question.

Variable levels of susceptibility and partial resistance to both scab and false rust have been demonstrated (IITA, 1978; Mukalere, 1989; Iceduna *et al.*, 1994), and resistance has been shown to be highly heritable to these diseases (IITA, 1978; Nakawuka and Adipala, 1997). Therefore, future breeding programmes should consider incorporating resistance to false rust into high yielding local and elite cultivars. Also lines showing multiple resistance to false rust and scab should be used in cowpea improvement programmes. This is particularly important since the majority of farmers in Uganda can not afford use of chemical sprays.

Fourteen lines have been selected on the basis of higher yield potential and resistance to either scab or false rust, or both (Tables 1 & 2). These lines had other valuable attributes . For example, under the IITA conditions in Nigeria, TVU 11426, IT81D-985, TVX 1948-01F, IT89KD-288, TVU 4630, IT89KD-245, TVU 11424 were high seed yielders and good as vegetable; lines IT81D-985, IT89KD-245, IT88D-643-1, IT87D-697-2 and IT88DM-363 had a medium maturity; IT86D-1010 and IT88D-634-1 were early maturing lines; IT90K-109 and IT89KD-374-57 were insect resistant; IT92KD-263-4-1 was good for vegetable while IT88D-643-1 was resistant to striga (*Striga gesnerioides* (Wild.) Vatke). Three of these lines, namely, TVU 11426, IT81D-985 and IT89KD-288 were not only high yielders, but also resistant to both scab and false rust.

However, additional studies, especially under controlled conditions need to be done to confirm the yield potential, pest resistance, striga resistance and diseases resistance of the promising genotypes.

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Moulds and aflatoxin contamination of maize and groundnuts in Mayuge and Kumi districts of Uganda

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Abstract

Mycotoxins are produced by specific types of moulds that grow on inadequately processed and stored grain cereals and legumes. While they are known to have serious effects on the health of both human beings and animals, their incidence in Uganda has not been adequately studied. Thus, the objectives of this study were to identify moulds infecting maize and groundnuts in Uganda, and relate the incidence at farm level to levels of aflatoxin contamination in these produce at harvest and under and storage conditions. *Aspergillus*, *Fusarium*, *Penicillium* and *Rhizopus* were the predominant moulds isolated and occurred in more significant quantities in samples stored for five to seven months than in newly harvested samples. In Kumi, 48% of groundnuts stored for up to seven months and 28% of those newly harvested tested positive for aflatoxin with mean levels of 2.96 and 1.83 ppb, respectively. In Mayuge, 50 % of the groundnuts and 40% of the maize stored up to five months were positive fo aflatoxins, with mean levels of 5.38 and 1.64 ppb, respectively. No aflatoxins were found contaminating the newly harvested maize in Mayuge. The aflatoxin levels observed were low compared to those earlier reported in samples from markets, probably because of the low levels of moisture content of the stored kernels and low levels of insect damage. The results of this study indicate that mycotoxigenic fungi and aflatoxin contamination of maize and groundnuts starts at farm level and contamination occurs in both pre and postharvest phases. Since potential mycotoxigenic fungi rather than *Aspergillus* were isolated in significant quantities in this study, the occurrence of mycotoxins other than aflatoxins should be studied.

Key words: Fungi, hygiene, moulds, mycotoxins

Introduction

Maize (*Zea mayis* L.) and groundnut (*Arachis hypogaea* L.) are major staple foods for the majority of people in Uganda (Rwabwoogo, 1997). They are both usually harvested and sun-dried traditionally, and thereafter stored or utilised in different forms.

According to Busolo-Bulafu (1990) groundnuts is the second most widely grown grain legume, after common beans (*Phaseolus vulgaris* L.). Total groundnut production in the country has been estimated at 140,000 tons grown on 175,000 ha, mainly in eastern parts of the country (Busolo-Bulafu, 1990).Although mostly consumed locally, the use of groundnut as a food and cash crop has increased substantially because of an increased awareness of protein shortage in Uganda. The crop is consumed in a roasted form as nuts or ground into a paste. Albeit, the majority of the people consume it as groundnut source which is prepared by boiling a mixture of water and pounded raw nuts.

Maize, is also grown throughout the country but production is most intense in mid-altitude (900 -

1500 metres above sea level) and moist areas representing 75% of the production, dry mid-altitude - (900 - 1500 metres above sea level representing 15% of the production area, and highlands (>1500 metres above sea level) representing 10% of the production area (Kyetere, 1996). The crop is usually consumed as flour either made into a paste commonly known as posho, or into a porridge which is a very good infant food. It is also a good source of animal feed (Sebunya and Yourtee, 1990).

During storage, grain crops may be attacked by storage fungi but this may also occur before havest (Magan and Mercy, 1988). According to Magan and Lacey (1988) storage fungi are present in low numbers pre-harvest, but may develop rapidly under storage when conditions are suitable. The predominant grain storage fungal genera are *Aspergillus, Fusarium* and *Penicillium.*The danger possed by such infection is the production of mycotoxins which is a potentially serious public health issue.

Aflatoxins, an improtant mycotoxin, is produced by *Aspergillus flavus* and a *parasiticus.* These fungi grow on inadequately processed and stored foods like grains and legumes (Munimbazi and Bullerman, 1996). Although mycotoxins pose a serious health hazard to both humans and animals, their incidence in Uganda has not been adequately studied. However, studies conducted during the 1960s (Lopez and Crawford, 1967) on groundnuts sold for human consumption in Uganda showed that the population was exposed to high levels of aflatoxins. Alpert *et. al.* (1971) found that hepatoma frequency in Uganda was associated with aflatoxin content of maize and finger millet. Sebunya and Youtee (1990) also reported that maize, groundnuts and poultry feeds had aflatoxins, with some samples containing levels up to 20 ppb.

These studies concentrated on aflatoxin incidence in stored produce in markets but no studies were conducted on farm-level stored products. Additionally, traditional cereal and groundnuts processing technologies used by farmers such as sun-drying on bare ground, threshing and shelling by manual beating and winnowing, and poor storage conditions creats varied moisture content in dried grains (Odogola, 1994). Furthermore, traditional storage structures do not protect foods against moisture pick-up and put the produce at the risk of mould growth which are the likely sources of aflatoxin production (Odogola, 1994). Therefore, the objectives of this study were to identify moulds infecting maize and groundnuts at farm level in Uganda, determine levels of aflatoxin contaminating in maize and groundnut produce and to establish the influence of grain storage conditions on aflatoxin production.

Materials and Methods

Sample collection

Samples were collected from Kumi and Mayuge districts where both crops are important food crops (Rwabwoogo, 1997). Kumi district lies at an average altitude of 1,036 and 1,127m above sea level, and has high rainfall (1300 mm/year) and high temperature (25-30°C). Mayuge district lies at an altitude of about 1,070 - 1,161m above sea level with annual rainfall ranging between 1,250 and 2200 mm. Temperatures are always almost uniformly high, over 21°C. Samples of unshelled groundnuts were randomly collected twice from farmers in Akalabai and Atuturo villages, Atuturi sub-county, Kumi District on 29 March, and August 31, 2000. One sample was collected per farmer. Twenty five samples that were collected on March 29, 2000 were from crops harvested in July/August 1999. They had therefore been stored for about seven months. This storage period was selected because, a period of two months is long enough for aflatoxin development in *Aspergillus flavus*-infected foods (Sauer, 1987). The 25 samples collected on 31 August 2000 had just becn harvested that day. Farmers in Kumi leave harvested groundnuts in the field for one to two days before plucking the pods from the haulms. Analysis of these nuts would give an idea whether mould infection and aflatoxin development in these nuts start in the field or during storage. *Igola1* (commonly known as India), *Serere Red* (commonly known as *Erudulo arengan*), *Etesot* and *Erudurudu akwangan* are the varieties of groundnuts grown

in Kumi county. In this study, sampling was done irrespective of groundnut variety, although majority of samples collected were of *Igola 1*, the popular variety in this area due to its good yield and drought tolerance.

Twenty samples of unshelled maize and ten samples of unshelled groundnuts were similarly collected from farmers in Bugodi and Musita villages, Baitambogwe sub-county, Mayuge fomerly part of (Iganga district) on May 8, 2000. These samples had been harvested and stored in unshelled form for about 5-6 months. Twenty freshly harvested maize samples that had been dried for 5-6 days were collected from farmers in the same area on September 1, 2000. Analyisis of these samples would give some idea of whether moulds infect and produce aflatoxins prior to storage. Due to the drought that was experienced by farmers in this area during the previous two seasons, fewer groundnut samples were obtained from Mayuge during the first sampling period than in Kumi. During the second sampling period no samples were obtained from Mayuge.

During each season, about 500 g of groundnut pods and five cobs were obtained from each farmer, put in polyethylene bags and transported to the Department of Food Science and Technology, Makerere University, where they were stored at -10°C prior to mould isolation and aflatoxin analysis.

Isolation and identification of moulds

Fifty kernels of maize and groundnuts from each sample were assayed by direct plating technique for internal mould infection (Hocking, 1991; Pitt and Hocking, 1997). Samples were surface sterilised for 1 - 3 minutes with 10% commercial bleach (Jik), washed three times with sterile distilled water and placed directly on the surface of different agar media under recommended conditions. *Aspergillus flavus/A. parisiticus* were identified by direct plating on *Aspergillus flavus* and *A. parasiticus* agar (AFPA) medium (Pitt *et al.*, 1983). The plates were incubated upright at 30°C for 42 - 72 hours and then examined for the characteristic orange reverse colouration of *A. flavus/A. parasiticus*. Species of other *Aspergillus*, *Penicillium*, *Fusarium* and other moulds were isolated on malt salt agar (Tuite, 1969), transferred on acidified PDA several times for purification, and were identified using the mannuals and keys recommended by Tuite (1982) and Pitt and Hocking (1997) .

Determination of moisture content

Each of the collected samples was divided into two portions and their moisture content determined by the standard air oven method (AOAC, 1999). The samples were dried at 100°C to constant weight and the range and mean moisture content were calculated on dry-weight basis.

Determination of insect damage

Maize and groundnut samples were shelled and insect damage on grains assessed using a qualitaive scale of 0 - 4, where 0 = no damage, 1 = low (0 - 10 seeds), 2 (10 - 20 seeds) = moderate, 3 (20 - 30 seeds) = high and 4 = very high (>30 seeds) damage.

Aflatoxin analysis

Each of the samples was divided into two replicate lots and aflatoxins were extracted using methanol-water solution (80:20 vol) and quantified (ppb) using AflaTest Fluorometer according to the manufacturer's instructions (VICAM L. P., 313 Pleasant Street, Watertown, MA 02472, USA). The range and mean aflatoxin content of the samples were computed.

Results and Discussion

Results in Table 1 indicate that a wide range of moulds infect groundnuts and maize during storage in Kumi and Mayuge districts . *Aspergillus, Fusarium, Penicillium* and *Rhizopus* species were the most prevalent fungal genera found contaminating stored kernels in both districts . *Aspergilus flavus, A. parasiticus, A. niger, P. italicum* and *Rhizopus* spp. were isolated from groundnuts and maize. Of these, *A. flavus* and A. *parasiticus* occurred most often, with mean incidence of 7.2% on groundnuts from Kumi, 8.2% on groundnut and 9.6% on maize kernels from Mayuge. No particular species of *Fusarium* was isolated from groundnuts and maize in both districts. For example, *F. graminearum* was isolated from groundnuts in Kumi (1.52%) but not from those in Iganga, and was not found in maize. *F. moniliforme* on the other hand was isolated from groundnuts (0.96%) and maize (2.4%) in Mayuge but not in Kumi.

Identification of a fungus, particularly if frequent in a sample, will probably indcate that the grain or feed sample is potentially toxic (Tuite, 1982). Over 200 diferent mycotoxins have been reported (Cole and Cox, 1981) but only those occurring naturally in foods are of significance in terms of food safety. The mycotoxins are produced mostly by *Aspergillus, Penicillium* and *Fusarium* (Bullerman, 1979) and includes aflatoxins produced by *A. flavus* and *A. parasiticus*, ochratoxins by *A. ochraceous*, fumonisins by *F. moniliforme*, zearalenones by *F. graminearum*, vomitoxins by *F. graminearum*, citrinin by *P. citrinum* and patulin by *P. patulum*. Therefore follwoing previous suggestion the incidence of moulds and levels of mycotoxins in foods and feeds should be frequently and routinely determined by Munimbazi and Bullerman (1996). In this study, two of the important mycotoxin producing fungi *A. ochraceous* and *P. patulum* were detected (Table 1).

Mould growth and spoilage of stored grain is reportedly determined predominantly by the moisture content (or more precisely the availability of water) and the range of contaminating fungi and how they interact with temperature and gas composition (Magan and Lacey, 1988). For both crops studied the recommended safe storage moisture content (wet basis) for maize is about 10 - 14% and for groundnuts 8 - 9% (Odogola, 1994). In this study, the mean percentage moisture content for maize and groundnut kernels from both districts show that the samples were properly dried (Table 2). Conversly, Ssebukyu (2000) reported the presence of 11, 13 and 5 species of *Aspergillus, Fusarium* and *Penicillium*, respectively in markets samples from Kampala, Mpigi, Mubende and Mukono and attributed this to the high grain moisture content. In this study, fewer species of each of the above fungus were found in samples stored for five to six months (Table 1). Although damage and insect infestation have been strongly implicated in promoting fungal attack (Dunkel, 1988), none of the groundnuts and maize samples collected in this study were infested with insects. A combination of adequate storage moisture content and absence of insect infestation of the kernels tested, may thus explain the low levels of mycotoxigenic fungal infestation.

Inspite of the low fungal infestation, 48% of the groundnuts samples from Kumi, 50% of the groundnuts from Mayuge and 40% of the maize samples from Mayuge tested positive for aflatoxin. These results are similart to those of Alpert *et al.* (1971) who reported that 44.9% of maize and 17.8% of groundnuts from Uganda tested positive for aflatoxin content, which range between 1 - 1000 and 1 - >1000 ppb, respectively. Sebunya and Yourtee (1990) indicated that 77% maize and 36% groundnuts from Uganda tested positive for aflatoxin, with 2 samples out of 25 showing up to 20 ppb. Studies by Ssebukyu (2000) revealed that 50% of maize samples from markets in Uganda had 0 - 10 ppb aflatoxin levels.

It is therefore apparent that aflatoxin contamination is prevalent in stored grain produce in Uganda, although the amounts vary. Aflatoxin content in positive samples of groundnuts and maize tested in this study are comparable to those reported before, although the mean aflatoxin levels (Table 2) suggest that the kernels are safe for human and animal consumption (20 ppb and 25 ppb, respectively) as recommended by United States Food and Drug Authority (FDA) and United States Agency for International Development (U.S.A.I.D), respectively (FAO, 1982) . Among the groundnuts samples

Table1. Percentage of mould-infected groundnut and maize kernels collected from farmers in Kumi and Mayuge districts after five to seven months of storage.

Location	No. of samples tested		Moulds	% Mouldy kernels	
	Maize	Groundnuts		Range	Mean[a]
Kumi	NA	25	*Aspergillus* species		
			A. flavus/parasiticus	0 - 40	7.2
			A.candidus	0 - 20	0.32
			A.niger	10 -30	6.64
			A.tamarii	0 - 10	0.24
			spergillus spp	0 - 30	0.72
			Fusarium species		
			F.graminearum	- 40	1.52
			Fusarium spp	0 - 10	0.16
			Penicillium species		
			P.digitatum	0 - 30	1.20
			P.italicum	0 - 20	1.44
			P.citrinum	0 - 20	0.96
			Penicillium spp	0 - 10	0.08
			Rhizopus sp.	0 - 20	0.12
			Other moulds	0 - 10	0.04
Iganga	NA	10	*Aspergillus* species		
			A.flavus/parasiticus	0 - 50	8.2
			A.niger	0 - 30	2.2
			A.tamarii	0 - 10	0.8
			Aspergillus spp	0 - 10	0.2
			Fusarium species		
			F.moniliforme	0 - 30	0.96
			F.graminearum	0 - 20	1.6
			Fusarium spp	0 - 10	0.4
			Penicillium species		
			P.italicum	0 - 20	0.5
			P.xpansum	0 - 10	0.8
			P.citrinum	0 - 30	0.75
			Rhizopus sp.	0 - 20	0.62
			Other moulds	0 - 10	0.04
	20	NA	*Aspergillus* species		
			A. flavus/parasiticus	0 - 30	9.6
			A.oryzae	0 - 20	0.7
			A.candidus	0 - 30	0.3
			A.wentii	0 - 30	0.6
			A.niger	10 - 40	5.5
			Aspergillus spp	0 - 10	0.1
			Fusarium species		
			F.moniliforme	10 - 20	2.4
			Fusarium spp	0 - 10	0.2
			Penicillium species		
			P.digitatum	0 - 30	1.1
			P.italicum	0 - 20	1.9
			P.expansum	0 - 10	1.1
			Penicillium spp	0 - 10	0.8
			Rhizopus sp.	0 - 40	2.1
			Other moulds	0 - 20	0.72

[a] Means are for 50 kernels per sample. NA = Not applicable

from Kumi, only one sample out of 25 had aflatoxin levels of 22 ppb, while for Mayuge, only one out of 10 had levels of 18 ppb. The highest aflatoxin level in maize was 5 ppb, and was observed in only 2 of the 20 samples.

For toxic production by fungi on grains and foodstuffs, environmental and storage conditions must be favourable. The optimal environmental conditions for the growth of *A. flavus* and aflatoxin production are; temperature of about 20 - 35°C, relative humidity of 85% and above, in equilibrium with a moisture content of 14 - 30% in grains (Abate and Gashe, 1985). Since the moisture content of the tested kernels was lower than 14%, this could explain the low levels of aflatoxins although the storage temperatures was within the range of 20 - 35°C.

Table 3 shows the levels of mould infection of the newly harvested maize and groundnut samples. *Aspergillus, Fusarium, Rhizopus, Cladosporium* and *Mucor* species were commonly found on these grains. Compared to results in Table 1, *Aspergillus, Penicillioides, Cladosporium herbarum* and *Mucor* species were isolated in newly harvested produce but not in samples stored for five to seven months.. Although a higher percentage of maize kernels were infected by *F. graminearum* and *F. moniliforme*.there were less *Aspergillus* and *Fusarium* species in the newly harvested samples than in those stored for 5-6 months. *Aspergillus flavus* was only isolated from groundnuts and not maize samples, although it is known that *A. flavus* can grow in maize in the field (Sauer, 1986). *Penicillium* was not isolated from any samples (Table 3). These results support the findings of Lacey (1971) and Flannigan (1978) who reported that at harvest, storage fungi may be present at low levels but their numbers increase during drying or when grain is placed in contaminated storage structures. The rare occurrence of *Penicillium* species has also been reported by other workers such as Malloch (1981) who reported that over 20 species of *Penicillium* occur in maize but only a few (5 - 8 species) were common storage fungi.

Aflatoxin contamination was found only in groundnut but not maize (Table 4). Twenty eight percent of the samples tested positive with mean aflatoxin levels of 1.83 ppb from previous studies reported aflatoxin content of groundnuts from one of the regions in Mozambique at harvest time was in the range of 0 - 1320 ppb with a mean of 750.8 ppb which is much higher than levels observed in Kumi groundnut samples (van Wyk *et al.*,1999).

Table 2. Moisture content, insect damage and aflatoxin contamination of groundnut and maize kernels collected from farmers in Kumi and Mayuge districts after five to seven months of storage

Location	No. of samples tested		Moisture content (%)		Insect damage	Aflatoxin levels (ppb)		Positive samples (%)
	Maize	Groundnuts	Range	Mean		Range	Mean	
Kumi	NA	25	7.05 - 8.09	7.72	0	0 - 22	2.96	48
Iganga	NA	10	7.52 - 9.58	8.89	0	0 - 18	5.38	50
	20	NA	8.69 - 12.31	9.58	1.05	0 - 5	1.64	40

NA Not applicable

Ranked from 0 - 4 (0 = No, 1 = Low, 2 = Moderate, 3 = High and 4 = Very high)

Table 3. Percentage of mould-infected groundnut and maize kernels collected from farmers in Kumi and Mayuge districts at harvest (groundnuts) and after two to five days of drying (maize).

Location	No. of samples tested		Moulds	% Mouldy kernels	
	Maize	Groundnuts		Range	Mean
Kumi	NA	25	*Aspergillus* species		
			A.flavus/parasiticus	0 - 60	2.2
			A.niger	0 - 60	16.6
			A.tamarii	0 - 20	0.16
			A.penicillioides	0 - 60	2.56
			Fusarium species		
			F.graminearum	0 - 60	5.18
			F.moniliforme	0 - 40	3.45
			Rhizopus sp	0 - 60	3.42
			Cladosporium herbarum	0 - 200	18
			Mucor sp	0 - 20	1.41
Iganga	20	NA	*Aspergillus* specie		
			A. niger	0 - 20	0.08
			Fusarium species		
			F.moniliforme	0 - 60	5.4
			Fusarium graminearum	0 - 100	12
			Rhizopus sp	0 - 40	2.1
			Cladosporium herbarum	0 - 10	0.14

[a] Means are for 50 kernels per sample.
NA = Not applicable

Table 4. Moisture content, insect damage and aflatoxin contamination of kernels collected from farmers in Kumi and Mayuge districts at harvest (groundnuts) and two to five days of drying (maize).

Location	No. of samples		Moisture Conten (%)		Insect damage	Aflatoxin levels (ppb)		Positive samples(%)
	Maize	Groundnuts	Range	Mean		Range	Mean	
Kumi	NA	25	24.23 - 41.32	35.41	0	0 - 5	1.83	28
Iganga	20	NA	14.74 - 28.70	18.15	0	NA	0	0

NA = Not applicable
Ranked from 0 - 4 (0 = No, 1 = Low, 2 = Moderate, 3 = High and 4 = Very high)

Conclusion

The results of this study indicate that mycotoxigenic fungi and aflatoxin contamination of maize and groundnuts start at farm level and contamination occurs in both pre and postharvest phases. However, mould incidence and aflatoxin contamination levels were low compared to those reported at market level for the same commodities. This indicates that farmers are at a low risk with regard to consumption of oxic foods compared to consumers who purchase produce from markets. It is recommended that produce should be properly dried and stored both at farm and market levels to control mould and aflatoxin contamination of produce. In order to improve the export potential and generate increased incomes from farm produce, farmers and traders should be educated on management of moulds and mycotoxin contamination. Since potential mycotoxigenic fungi rather than *Aspergillus* were isolated in significant quantities in this study, the occurrance of mycotoxins other than aflatoxins should be studied.

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Observations on field parasitism of the subterranean termite *Pseudacanthotermes* sp. (Termitidae: Macrotermitinae) by *Megaselia scaralis* (Diptera: Phoridae) in Uganda

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Abstract

We carried out continuous field sampling, laboratory culturing and dissecting over two maize growing seasons in 1997 and 1998 to establish the status of the phorid fly, *Megaselia scaralis* as a parasitoid of the subterranean termite *Pseudacanthotermes* and it's relative abundance in Iganga and Wakiso districts of Uganda. Evidence was obtained that under field conditions the phorid is a primary parasitoid and probably a significant mortality factor in populations of *Pseudacanthotermes* species. *M. scalaris* was more abundant at Namulonge (Wakiso) compared to Ikulwe (Iganga) and percentages of parasitised termites higher in surface foragers under mulch than in underground nesting termites. To follow-up on this preliminary work, we recommend studies on the biology and ecology of the insect focussed on assessing whether it's activity could be of practical use in an integrated management strategy for termites in maize-based cropping systems in Uganda.

Key words: *Megaselia scalaris*, termites, Uganda, *Zea mays*

Introduction

The termite *Pseudacanthotermes* sp. is among the important termite pests of crops in Uganda. Recent studies have indicated that this termite often causes more damage than other genera to crops in eastern and central Uganda, contributing significantly to crop losses in maize (Sekamatte, 2000). The termite feeds virtually on every part of the maize plant; prior to the green-cob stage the termite attacks prop roots, the lower leaf sheath, and the stem base, causing plants to lodge. Later, the termites burrow into the plant stems. The species *P. militaris* and *P. spiniger* commonly forage on crop residues used as mulch and are probably responsible for the rapid breakdown of mulches in plantain crops. Results of farm surveys of five major maize producing districts of Uganda indicate high levels of damage (up to 80%) to maize plants by *Pseudacanthotermes* species (Sekamatte *et al.* 2001).

Attack levels vary between the central and eastern regions of Uganda but the reasons are not yet known. Predation especially by Myrmicin ants, however, has recently been observed and presumed to a major factor contributing to this location variation (Sekamatte *et al.* 2001). Termite predation by ants has been fairly better documented (Wheeler, 1936; Weber, 1964; Longhurst *et al.*, 1978; Lapage and Darlington, 1984; Cornelius and Grace, 1996) compared to mortality due to pathogens and parasites (e.g. Grace, 1997). In particular, there has been almost no research on parasites and their role in termite control is very poorly understood. Nevertheless, phoretic mites and nematodes have

frequently been mentioned (Phillipsen and Coppel 1977; Costa-Leonardo and Soares 1993).

A wealth of information exists on the invasion of laboratory termite cultures by phorid parasitoids, including species of *Megaselia* (Disney, pers. comm.). Notable among the notorious phorid species recorded in the tropics is *Megaselia scaralis* which, however, is only documented as a secondary invader of laboratory cultures. Observations in Uganda indicated that *M. scaralis* is abundant in maize fields and in places with decomposing crop residues where termite activity is also noticeably high but its relationship with the termitidae is not known. To obtain insight into this phorid-termite relationship, the present study was carried out. The objectives of the study were: (a) to establish the relative incidence of *M. scaralis* in two major maize agroecologies in Uganda and (b), to ascertain the relationship between *M. scaralis* and the termite *Pseudacanthotermes* under field conditions.

Materials and methods

Sampling and laboratory handling of termites

The study was conducted at Ikulwe (Iganga district) and Namulonge (Wakiso district), in East and Central Uganda respectively, during the second (short) rainy season of 1997 and the long rains in 1998. The first samples were taken from a heap of decomposing bamboo (*Guadua angustifolia* Kunth) on a verandah of the termite laboratory and from experimental plots of maize at Namulonge. During the second trial season (first rainy season of 1998), termite samples were obtained from decomposing stover in maize fields and from soil. Soil samples were collected by digging up to 30 cm deep pits during destructive sampling in 15m x 20 m experimental plots of maize at Namulonge and Ikulwe Farm Institute in Iganga district. The soil samples were collected in plastic trays and processed in the laboratory.

In the laboratory, soldier and worker castes were carefully sorted out and samples of different castes, each containing 10 termites, were placed onto petridishes. Each petridish was lined with moistened filter paper, and a double layer of toilet paper to serve as food for the termites. The petridishes were covered with a lid, labelled and kept in a dark chamber. Laboratory temperatures were uncontrolled and were usually 23 - 25°C. The termites survived under these conditions up to 14 days.

Two millilitres of distilled water were added to each petri-dish after every other day to keep the filter paper constantly moist. Water continued to be added until parasitoid emergence from termite cadavers was noticed.

To establish whether the fly actually acted as a primary parasitoid, the sample size was increased to 20 termites per petridish during the 1998 season. One set of such samples was for regular dissection of the termites. The termites were dissected under a binocular microscope to recover the early stages of the parasitoid before death of the host.

Data analysis

Parasitism rates (seasonal means for all castes) were compared between samples collected from pits and those from under mulch or surface foragers. The data on *M. scalaris* incidence at Namulonge and Ikulwe were plotted and also compared using t-test and analysis of variance. The data on termites with immature phorid larvae together with those on larvae emergence from cadavers were used to measure the level of field parasitism.

Results

Incidence of *M. scaralis*

Emergence of *M. scaralis* from termite cadavers was significantly ($P<0.05$) greater at Namulonge

compared to Ikulwe (Fig 1., Table 1). There were fewer parasitised individuals from Ikulwe throughout the season than from Namulonge. Mean (± S.E) peak parasitism of termites was 23.7± 2.89 individuals at Ikulwe against 96.8.0±10.3 individuals at Namulonge; ($t = 4.44$; $P < 0.01$) between 10 and 11 weeks after maize germination (Fig. 1).

Qualitative differences were not apparent among sampling dates in samples collected from under mulch at Namulonge. Phorid abundance was higher in the second season of 1997 than in the first season of 1998 (Table 1), presumably because of the heavier rains in the later season. There were significantly greater numbers of parasitised termites under mulch than from any other source (t-value = 8.97, $P<0.01$) (Table 1). In both seasons, the mean percentages of termites parasitised by *M. scaralis* under mulch were significantly ($P<0.05$) greater at Namulonge than at Ikulwe. Parasitism rates in mulch collected samples varied over time, but in all cases were consistently higher than those from pit collected samples.

Larvae recovery in dissected termites

Differences between mulch samples and pit samples were further reflected in parasitism rates in dissected major soldiers and worker termites (Table 2). Single immature phorid larvae were found just underneath the pronotum of major soldiers where the eggs are apparently deposited by the female fly. Most immature phorid larvae were recovered from major soldiers and were more frequently found in samples collected from Namulonge than Ikulwe and more in samples collected under mulch. No parasitised minor soldiers were found.

Table 1. Megaselia scaralis emergence from termite cadavers collected from pits and under mulch at Namulonge and Ikulwe during the short rainy season of 1997 and long rains in 1998.

Caste	Namulonge		Ikulwe	
	Pit	Mulch	Pit	Mulch
1997 Season				
Major soldier	14.5 ± 1.3	59.0 ± 3.5	6.1 ± 1.6	16.1 ± 2.9
Worker termites	13.4 ± 1.4	49.9 ± 3.64	2.8 ± 0.7	3.8 ± 0.07
Minor soldiers	0.2 ± 0.2	0.4 ± 0.2	0.1 ± 0.7	0.1 ± 0.1
General mean	9.37	36.43	3.00	6.43
1998 Season				
Major soldier	0.5 ± 0.1	14.8 ± 3.3	1.6 ± 0.1	5.1 ± 0.9
Worker termites	0.0 ± 0.0	9.8 ± 1.6	0.9 ± 0.1	2.2 ± 0.5
Minor soldiers	0.0 ± 0.0	0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
General mean	0.17	8.33	0.83	2.43

Table 2. Mean percentage of immature larvae of Megaselia scaralis obtained from dissected termite samples collected from Namulonge and Ikulwe in1998.

Caste	Namulonge		Ikulwe	
	n	%	n	%
Major soldier	360	52.5	482	14.6
Minor soldiers	235	0	370	0
Worker termites	240	32.1	430	6.9

Discussion

This study has established the status of *Megaselia scalaris* as a primary parasitoid of *Pseudacanthotermes* sp in Uganda. The phorid was more prevalent in heaps of decomposing crop residues in which it gets greater opportunity to oviposit in termites and the larger sized caste, the major soldiers are more vulnerable to attack by the phorid.

The parasitism rates were higher in samples collected from mulch than in samples obtained from pits. The response of phorids to crop mulches was apparently mediated by a number of factors including food needs, aspects of habitat suitability and movement patterns of the host termite, *Pseudacanthotermes*. The higher parasitism under mulch was probably not due to the presence of mulch itself, but rather due to the modified behaviour of the termites. We observed that, instead of constructing surface soil tunnels, the termite forages for most of the time on or inside dry, hollow maize stalks which offer comparatively poor protection against the phorids compared to the continuous soil tunnels on unmulched ground.

The results suggest that termite parasitism by phorids is favoured by presence of mulch. The mulch presents a concentrated food source for the host termites and probably causes microclimatic changes such as increased relative humidity, lowered temperatures and reduction in wind turbulence that allows easy movement of the phorid fly. We have also observed in related studies that, termite mortality resulting from fungal infection of termites by a local *Beauvaria* isolate was greater under cover of mulch (Sekamatte *et al.*, 2000) suggesting that the phorid flies occasionally find 'sick', weak defenceless termites in this type of environment which they attack relatively easily.

Although the maize mulch and bamboo stalks in these experiments seem to be very important in increasing parasitism rates of *Pseudacanthotermes*, other factors may as well be influential. The cause

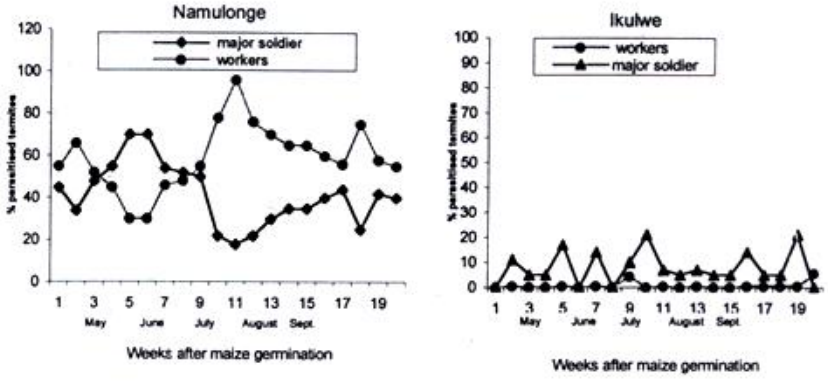

Figure 1. Percent parasitised worker and soldier castes of Pseudacanthotermes termites by M.scaralis at Namulonge and Ikulwe, May-September 1998.

and effect relationships of parasitism rates and the role of, for example, increased activity of *Myrmicin* and *Lepisiota* ants under mulch was not directly testable during these preliminary trials. It is suspected that activity of predatory ants was a confounding variable that was not controlled. This however seems to suggest the possibility of a complimentary role of ant predators and phorids.

Rates of phorid attack on the subterranean termites as determined by the present experiments provide the first recorded evidence of *M. scaralis* as a primary parasitoid of termites under field conditions. The greater parasitism rates observed at Namulonge compared to those at Ikulwe could be part of the reason for the substantially higher incidence of termite damage to maize at Ikulwe by this termite (Sekamatte, 2000). The parasitoid efficiency rates were significantly higher under mulch conditions on which higher activity of predatory ants was also recorded (Sekamatte *et al.*, 2000).

The high occurrence of higher numbers of termites under mulch compared to unmulched fields was expected and appears to agree partially with the resource concentration concept discussed in the review by Logan *et al.* (1990) but, the limited scope of our present studies cannot allow a fair prediction on how *M. scaralis* would perform under different conditions, for example, the different crop mixtures that characterise the smallholder maize-based cropping systems in Uganda.

We suggest the need for determination of the host range of *M. scalaris*, assessing the importance of alternative host, if any, and determine if it is likely to prove an effective parasitoid worth devoting further research effort. It is also necessary to determine whether it's incidence under the common conditions of the maize-based cropping systems which are mostly polycultural (Sekamatte, 2000), are due to prey densities or to other agro-ecosystem factors, causing microclimatic modifications in the habitat.

The major contribution of this study, however, is that it has provided an additional biological control option to be evaluated against termites in an overall integrated management strategy. Further, the study has provided some insight into possible mechanism underlying the theory of mulching, and termite damage to crops (Logan *et al.*, 1990). Based on these results, more focussed studies should be conducted on aspects of ecology of this phorid and elucidate it's potential for further development as an agent for either classical biological control or enhancement through various cultural practices against termite pests. In general, however, these results have revealed that research on the potential of biological control options against termites could be worthwhile.

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provide the critical nutrients (energy, protein, minerals and vitamins) that are lacking in the roughages (Mpairwe *et al.*, 1998). Maize bran has for long been used to suppliment low quality feeds and improve milk yield. Recent studies have shown that intercropping *Pennisetum purpureum* with forage legumes can increase fodder dry matter (DM) yield per unit area of land and at the same time improve the nutritive value of the fodder, which in turn improves milk yield from dairy cows (Katuromunda, 2000). Siratro (*Macroptilium atropurpureum*) is such a forage legume that has shown potential of increasing livestock productivity when it is integrated into *Pennisetum purpureum*. However the effect of supplementing Siratro and or maize bran on feed intake and milk yield and composition on crossbred cows fed on *Pennisetum purpureum* basal diets has not been investigated.

Therefore, this study was undertaken to evaluate the effects of supplementation with Siratro and maize bran on DM intake and subsequent milk production of crossbred (*Bos indicus* x *Bos taurus*) cows fed *Pennisetum purpureum* basal diets.

Materials and methods

The experiment was conducted at Makerere Univeresity Agricultural Research Institute Kabanyolo (MUARIK) which is located in the fertile Lake Victoria crescent area, about 19 km north of Kampala (0° 28' N, 32° 37' E) and altitude 1204 m. The climate of the area is sub-humid with moderately well distributed bimodal rainfall. During the experimental period, the annual total rainfall was 1563 mm. The mean maximum and minimum air temperatures were 17.5 and 15.0 °C, respectively. The highest and lowest relative humidity values were 87 and 63 %, respectively. The soils at Kabanyolo are deep red, highly drained red soils and are classified as Latosols.

First ploughing of the land was carried out in August 1999, just before the on-set of the rainy season and was repeated three weeks later. Planting of the fodder was done in September 1999. Siratro seeds were obtained from seed producers in Mukono District and *P. purpureum* planting material were obtained from one of the progressive farmers located within the study area. *Pennisetum purpureum* was planted on a 0.7-hectare plot at a spacing of 0.9 m between rows and 0.6 m between plants within each row. Siratro seeds were then sown in single alternate rows with *P. purpureum* immediately after planting the latter . A separate 0.7-hectare plot of Siratro alone was also established in order to ensure that enough Siratro herbage for the feeding trial is obtained. As a sole crop, Siratro was planted at a spacing of 0.5 m between hills and between rows. Three to five seeds were planted per hill. All the plots were weeded one month after planting and this was repeated eight weeks later.

Siratro herbage, both in the *P. purpureum*/Siratro mixture and sole crop was ready for harvesting after about 22 weeks from planting, while by this time *P. purpureum* was ready for the second round of harvesting. However, the feeding trial delayed for two months due to shading of leaves by Siratro during the dry spell that occurred in February 2000. The feeding trial commenced in May and lasted for three months. Siratro and *P. purpureum* fodder for feeding was harvested daily using a hand slasher and matchet, respectively. The harvested fodder was transported to the stall, chopped into pieces a matchet and then fed to cows according to assigned treatments.

Experimental design and animal management

Two Friesian (*Bos taurus*) x Zebu (*Bos indicus*) and one Jersey (*Bos taurus*) x Zebu (*Bos indicus*) crossbred cows were used in a 3 x 3 switchover Latin square design (Table 1). The animals were selected from MUARIK dairy herd and were in their first month of second lactation. Prior to the commencement of the experiment, their weights were taken using a heart girth tape measure and their mean live weight was 465 ± 93 kg. This was repeated at the end of every two weeks until the experimental period was over. The cows were housed individually in well-ventilated stall-feeding units. They were drenched with Levamisole hydrochloride (Nilzan) and sprayed with Delnav acaricide to control worms and ticks, respectively.

Diets and feeding management

At the commencement of the experiment, the diets were assigned to the cows randomly. The amount of Siratro fed was in accordance with the amount fed by smallholder farmers. The feeder-troughs were filled with *P. purpureum* fodder twice a day at 7.30 a.m. and at 5.00 p.m. to ensure *ad libitum* feed supply to the animals. Siratro and maize bran were given to the animals in the morning before giving them *P. purpureum*. The experimental diets were maintained for a period of 28 days, which included 14 days of adjustment to the diets and 14 days for data collection. Fresh, clean tap water was availed daily to the animals *ad libitum*.

Sampling and measurement

Feed and feed refusal samples, each weighing 0.5 kg were taken daily during the last two weeks of each period and kept in a fridge at 0 °C. At the end of each period, the feed samples were bulked together, mixed thoroughly and a composite sample weighing 0.5 kg taken. Similarly, feed refusal samples were bulked, mixed and a composite sample weighing 0.5 kg taken. The composite feed and feed refusal samples were oven-dried at 60 °C to a constant weight.

Chemical analysis

The dry feed and feed refusal samples were ground to pass through a 1 mm sieve and subsequently analysed for CP and ash using the AOAC (1990) procedures, for NDF by the Van Soest and Robertson (1985) method and *in-vitro* organic matter digestibility (IVOMD) by the Tilley and Terry (1963) technique. Calcium (Ca) and phosphorus (P) contents were determined by first digesting the samples with a tri-acid mixture of sulphuric, perchloric and nitric acids (1.5:2:3). Then Ca was assayed using an atomic absorption spectrometer and P content was determined using the ascorbic acid procedure (Okalebo, 1985). Gross energy of feed (GEF) was determined by complete oxidation of sample in presence of oxygen in an adiabatic bomb calorimeter (AOAC, 1990). Metabolisable energy of feed (MEF) was estimated from the digestibility of organic matter in the dry matter (DOMD) using the formula, MEF = 0.15 DOMD % MJ kg^{-1} DM (MAFF, 1987) and the ME intakes were then calculated.

Milk yield and composition

The animals were hand-milked twice a day, in the morning at 7.00 a.m. and in the afternoon at 4.30 p.m. throughout the experimental period. Milk yield values were converted to 4 % fat corrected milk (FCM) yield and recorded. In the last week of each feeding period, milk samples of each cow were

Table 1 Design for the feeding experiment.

	Animals	Feeding periods	
	1	2	3
1	PSM[y]	P	PS
2	PS	PSM	P
3	P	PS	PSM

[y]Treatments: Each animal received each treatment once.
P Animals fed *ad-libitum Pennisetum purpureum* fodder only.
PS Animals fed *ad-libitum Pennisetum purpureum* supplemented with 4 kg day^{-1} of Siratro.
PSM Animals fed *ad-libitum Pennisetum purpureum* supplemented with 4 kg day^{-1} of Siratro and 2 kg day^{-1} of maize bran.

taken daily in the morning and afternoon, bulked into one sample and analysed for the butter fat content using Gerber method (British Standards Institute, 1989).

All the data collected were subjected to statistical analysis using the analysis of variance (ANOVA) procedure for a Latin square design of the MSTATC computer software package to determine the treatment effects on feed intake and milk yield and composition. Means for the different parameters were separated using the least significant difference procedure at 5 % level of significance.

Results and discussion

Chemical composition and IVOMD of experimental feeds

Chemical composition of the feeds used in the experiment is presented in Table 2. Mean DM, CP and NDF contents of *P. purpureum* were 22.9, 10.2 and 65.3 %, respectively. The CP content was greater than the limiting CP level (7 %) for ruminant production, but lower than the level (11-12 % CP) required for moderate levels of production (Forbes, 1986). These values were close to those reported by Fernandes and Deshmukh (1988) but higher than those reported by Saamanya (1996) and Kabirizi *et al.* (2000). The differences in these values could be attributed to the age at cutting, season of the year and site differences (Sanchez, 1982; Saamanya, 1996).

Siratro contained 18.6, 20 and 55 % DM, CP and NDF, respectively. The CP content of Siratro was twice that of *P. purpureum* and the NDF of Siratro was lower than that of *P. purpureum*, indicating that Siratro was better in nutritive quality compared with *P. purpureum*. However, the DM content of Siratro was lower than that of *P. purpureum*. Maize bran had the highest DM content as expected and was slightly higher in CP content than *P. purpureum* and very low in NDF. IVOMD was highest in maize bran due to its low NDF content and lowest in Siratro due to the presence of tannins, which protect the protein in Siratro from enzymatic breakdown (Norton and Poppi, 1995). Phosphorus (P) content was higher in Siratro and least in maize bran while calcium (Ca) content was higher in Siratro and lowest in *P. purpureum*.

Table 2. Chemical composition (% DM basis), IVOMD and energy content of the feeds used.

Parameter	Feeds		
	P. purpureum	Siratro	Maize bran
Dry matter	22.90	18.64	86.00
Organic matter	91.25	92.60	92.48
Crude protein	10.22	20.00	12.26
Neutral detergent fibre	65.31	54.97	24.00
Ash	8.75	7.40	7.52
IVOMD	74.48	62.14	87.24
DOMD	67.96	57.54	80.68
Calcium	0.27	1.02	0.48
Phosphorus	0.22	0.25	0.18
GEF (MJ Kg^{-1} DM)	19.16	17.04	18.10
MEF (MJ Kg^{-1} DM)	10.20	8.63	12.10

DOMD = Digestible organic matter in the dry matter; GEF = Gross energy of feed;
MEF = Metabolisable energy of feed = 0.15 x DOMD % (MAFF, 1987).
IVODM = *In vitro* dry matter digestibility

Feed intake by lactating dairy cows

The effects of supplementing *P. purpureum* basal diet with Siratro and maize bran on dry matter, CP, energy and mineral (Ca and P) intake are presented in Table 3. Supplementation with Siratro alone and a combination of Siratro and maize bran significantly ($P<0.05$) improved both the *P. purpureum* and total DM intake by lactating cows. When daily total DM intake was expressed on per unit metabolic body weight, there was a significant ($P<0.05$) difference between the unsupplemented and supplemented diets. The significant ($P<0.05$) increase in DM intake with supplementation could be attributed to the high CP content of Siratro and maize bran, as compared to that of *P. purpureum*. An increase in CP content in the diet could have resulted in improved availability of nitrogen to the rumen microbes (Bamualim *et al.*, 1984). This in turn could have increased the rate of digestion and clearance of DM from the rumen (Bonsi *et al.*, 1994). Thus supplementation with Siratro and maize bran could have increased the amount of amino acids that were absorbed from the diet which could have also stimulated the increase in DM intake (Osuji *et al.*, 1995). The low DM intake values obtained when sole *P. purpureum* diets were fed to the cows could be attributed to coarseness and chemical composition of *P. purpureum*. In addition, low CP levels could not provide enough nitrogen that would stimulate microbial activity, which would in turn lead to higher rate of digesta breakdown.

Supplementation of *P. purpureum* basal diets with Siratro and a combination of Siratro and maize bran significantly ($P>0.05$) improved the total CP intake, as compared with the unsupplemented diets. The CP intake was higher with Siratro and maize bran supplementation (1.55) than when Siratro alone was provided (1.41). Both supplements were richer in CP and had lower NDF than *P. purpureum* fodder. Thus, they were able to supply more CP required by the rumen microbes and also the dairy cows as by-pass CP.

Supplementation significantly ($P<0.05$) increased the metabolisable energy (ME) intake of the lactating cows, as compared with the unsupplemented basal diets. But there were no significant ($P>0.05$) differences among the supplemented diets. The highest ME intake among the supplemented diets (147.1 MJ head^{-1} day^{-1}) was obtained when *P. purpureum* basal diets were supplemented with a combination of Siratro and maize bran. The unsupplemented diets provided 87.7 MJ head^{-1} day^{-1}, which was lower than the estimated daily ME requirement (95 MJ head^{-1} day^{-1}) of a lactating cow weighing 400 kg and producing 8-12 kg milk of 4 % butter fat (MAFF, 1987). The DE intake followed the same trend as the ME intake. The gross energetic efficiency for milk production of the supplemented diets was not significantly ($P>0.05$) different from that of unsupplemented diets. This probably could be due to the fact that the animals received sub-optimal amounts of energy from both the supplemented and unsupplemented diets. Consequently, the gross energetic efficiency values for milk production for supplemented and unsupplemented diets were very low.

Supplementation significantly ($P<0.05$) increased the intake of Ca and P, as compared to the unsupplemented diets (Table 3). The differences in the mineral intakes could be attributed to the higher Ca concentration in the supplements as compared with the *P. purpureum* basal diets (Table 2). The Ca:P ratio was significantly ($P<0.05$) higher in the supplemented than in the unsupplemented diets. Also, the Ca:P ratios of the supplemented diets were significantly ($P<0.05$) different from each other. The estimated Ca and P requirements of dairy cattle weighing 400 kg and producing 8-12 kg milk of 4 % butter fat are 36.6 and 27.4 gms head^{-1} day^{-1}, respectively (NRC, 1989). Thus, the results of this study indicated that the intake of Ca and P was adequate only for the supplemented diets. Also, the estimated Ca:P ratio intakes were above the recommended range (1-2:1). But it has been reported that ruminants are able to tolerate high Ca:P ratios without detrimental effects (NRC, 1989).

Milk yield and composition

Results of the effect of supplementing *P. purpureum* basal diets with Siratro and maize bran on daily

milk yield and butter fat content are presented in Table 4. Supplementation of *P. purpureum* with Siratro alone (PS) and in combination with maize bran (PSM) significantly ($P<0.05$) increased FCM yield. However, supplementation of *P. purpureum* basal diets with a combination of Siratro and maize bran had no significant ($P>0.05$) advantage in milk yield over the *P. purpureum*-Siratro diet. Supplementation yielded 1.75 kg day^{-1} more FCM milk than the unsupplemented basal diets. The increase in milk yield when *P. purpureum* basal diets were supplemented with Siratro alone and a combination of Siratro and maize bran could be attributed to the high CP and Ca contents in the supplements. Sole *P. purpureum* basal diets provided minimal quantities of CP (0.87 kg day^{-1}), ME (87.7MJ head^{-1} day^{-1}) and minerals (Ca and P).

Supplementation had no significant ($P>0.05$) effect on the butter fat content of the milk and the fat content in the milk of unsupplemented diets was almost equal to that in the milk of the supplemented diets. This could be attributed to better utilisation of dietary fibre contained in the *P. purpureum* diets from which, precursors for mammary lipid synthesis are derived (Susmel *et al.*, 1995). Mean daily changes in body live weights of the lactating cows were not significantly ($P>0.05$) different and all the treatments exhibited negative body weight changes (Table 4). Daily body live weight losses were greatest when the cows were given the *P. purpureum* basal diets alone. Losses in live weights of the

Table 3. Daily dry matter, crude protein, energy and mineral intake of lactating cows fed P. purpureum basal diets supplemented with Siratro and maize bran.

Parameter	Treatments			SEM	F-test
	P	PS	PSM		
Dry matter (kg day^{-1})					
P.purepureum	8.83a	12.17b	11.69b	0.51	*
Siratro	-	0.82	0.82	-	-
maize Bran	-	-	1.73	-	-
Total	8.63a	12.99b	14.24b	0.74	*
Total (g DM/kg BW$^{0.75}$)	90.83a	137.02b	144.62b	10.61	*
Crude protein (kg day^{-1})					
P.purepureum	0.87	1.25	1.18	-	-
Siratro	-	0.16	0.16	-	-
maize Bran	-	-	0.21	-	-
Total	0.87a	1.41b	1.55b	0.09	*
Energy (MJ head^{-1}day^{-1})					
ME	87.70a	131.03b	147.08b	6.80	*
[Y]DE	106.97	159.73b	179.37	8.16	*
[b]GEE of DE utilisation for milk production (%)	15.8	14.5	12.6	0.91	NS
Minerals (g head^{-1} day)					
Calcium (Ca)	23.22a	40.98b	48.14b	3.90	*
Phosphorus (P)	18.91a	28.69b	30.85b	1.61	*
Ca:P ratio	1: 2:1a	1: 4:1b	1: 6: 1	0.02	*

SEM = Standard error of mean; BW = Body weight; BW$^{0.75}$ = Metabolic body weight;
DE = Digestible energy; GEE = Gross energetic efficiency;
NS = Non-significant ($P>0.05$); * = Significant ($P< 0.05$).
[Y] Multiplication factor.for converting DE to ME = 0.82 (ARC, 1984).
[b] Percent GEE of DE utilisation for milk production was calculated using 3.14 MJ kg^{-1} (0.75 Mcal kg^{-1}) as the estimated energy content of 4 % FCM (Close and Menke, 1986).
Thus, GEE of DE utilisation for milk (%) = Energy content in the milk (MJ kg^{-1}) x 100
Digestible energy intake (MJ head^{-1} day^{-1})

Table 4. Daily milk intake, butterfat content and changes in body weights of crossbred lactating cows fed ad-libitum Pennisetum purpureum diet supplemented with Siratro and maize bran.

Parameter	Treatments			Mean	SEM	F-test
	P	PS	PSM			
Milkl ouput (kg day^{-1})	5.4	6.9	7.3	6.6	-	-
FCM milk output (kg day^{-1})	5.5a	7.3b	7.2b	6.7	0.31	*
Butterfat content (%)	4.1	4.3	3.9	4.1	0.32	NS
Changes in body wieghts (kg day^{-1})	-0.8	-0.2	-0.7	-0,6	0.23	NS

NS = Non-significant (P>0.05); * = Significant (P<0.05).
Means within the same column followed by different lettersare significantly different at P<0.05.

animals during the experimental period indicated that milk yield was, in part, at the expense of the animals' body weights. These cows had just delivered and energy requirements are highest during

Conclusion

The results of this feeding trial experiment have indicated that unsupplemented *P. purpureum* is nutritionally poor and thus does not provide adequate nutrients to crossbred lactating cows for milk production. However, when supplemented with small quantities of Siratro alone and a combination of Siratro and maize bran, the intake of crude protein and energy and milk yields are significantly (P<0.05) increased. Therefore, Siratro would serve as a cheap locally produced supplement alternative to purchased concentrates, especially under smallholder dairy production systems.

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