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The improvement of Bambara groundnut production in Northern Namibia by means of breeding strategies and agronomic investigations

Klaus Werner Emil Fleißner

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List of Abbreviations:

AFLP	Amplified Fragment Length Polymorphisms
ANOVA	Analysis of Variance
BBVT	Bambara Groundnut Basic Variety Trial
BGIP	Bambara Groundnut Improvement Programme
BIYT	Bambara Groundnut Improved Yield Trial
BLCT	Bambara Groundnut Land Races Comparison Trial
BNON	Bambara Groundnut Observation Nursery
CF	Cooperation Française
CGIAR	Consultative Group on International Agricultural Research
COB	Client-oriented Plant Breeding
CV	Coefficient of Variation
DA	Developmental Analysis
DAS	Days after Sowing
DFID	Department for International Development
DNA	Deoxyribonucleic Acid
EU	European Union
F_1	Filial Generation 1
FAO	Food and Agricultural Organisation of the United Nations
FSRE	Farming Systems Research and Extension
GA	Growth Analysis
GTZ	Gesellschaft für Technische Zusammenarbeit
ICRISAT	International Research Institute for the Semi-Arid Tropics
IITA	International Institute for Tropical Agriculture
IPGRI	International Plant Genetic Resources Institute
ISNAR	International Service for National Agricultural Research
NARS	National Agricultural Research System
NCA	Northern Communal Areas
NCD	North Central Division
NGO	Non-governmental Organisation
ODA	Overseas Development Agency
PCR	Polymerase Chain Reaction
pH	potentia Hydrogenii
PPB	Participatory Plant Breeding
PRA	Participatory Rural Appraisal
PSP	Plant Science Programme
PVS	Participatory Varietal Selection
RAPD	Random Amplified Polymorphic DNAs
RCBD	Randomized Complete Bloc Design
RRA	Rapid Rural Appraisal
SSR	Simple Sequence Repeats
ZOPP	Zielorientierte Projektplanung

1. INTRODUCTION

1.1. The Bambara groundnut

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an annual herbaceous grain legume, which belongs like the cowpea (*Vigna unguiculata)* to the *Vigna* botanical family. Like cowpea and many other leguminous crops Bambara groundnut is self-pollinating, and due to the positioning of the flowers and the flower morphology natural cross-pollination has never been reported (ADU-DAPAAH and SANGWAN, 2003). Artificial hybridization is possible, but extremely difficult and very low success rates have been reported (<2% harvested hybrid seeds from number of performed crosses) (MASSAWE *et al.*, 2003).

Picture 1. A Bambara groundnut plant at flowering stage

The name already provides an indication that Bambara groundnut is actually a bean, which develops its fruits in or under the soil ("*subterranea"*). The fruits are pods with a hard shell (similar to groundnut [*Arachis hypogaea*]) and usually contain one or two seeds.

Picture 2. A mature Bambara groundnut plant uprooted for harvesting

A more detailed botanical description of Bambara groundnut can be found in PURSEGLOVE's standard work "Tropical Crops – Dicotyledons" (1968) and J.T. Williams' book "Underutilized Crops: Pulses and Vegetables" (LINNEMANN and AZAM-ALI, 1993).

The center of domestication of the Bambara groundnut has for a long time been an issue of controversy (BEGEMANN, 1988) and has now been determined to be within a latitude range from 6°30 N to 11°00 N from western Nigeria to Eastern Sudan (PASQUET, 2003). It can therefore be considered as a truly indigenous African crop. From Nigeria the cultivation of the crop has spread to all parts of Africa. In 2002, FAO estimated global Bambara "bean" production at 58 900 Mt, and only Burkina Fasso and Mali were listed as producers (36 200 and 22 700 Mt respectively (AZAM-ALI *et al.*, 2003). Begemann, however, estimated Bambara groundnut production in Africa alone at 330 000 Mt with production figures from 11 countries. Looking at the origin of accession in IITA's Bambara groundnut germ plasm collection, it is obvious that the crop is found in almost all parts of Sub-Saharan Africa. Nowadays it can also be found in Asia (Thailand, Indonesia) and some American countries (BEGEMANN, 1988). A global mapping exercise initiated by FAO to identify areas, which are suitable for Bambara groundnut production, revealed a huge production potential for the crop in the warmer climate zones of the earth (AZAM-ALI *et al*, 2001). In Ben-Erik Van Wyk's and Nigel Gericke's book "People's plants - a guide to useful plants of Southern Africa" (VAN WYK and GERICKE, 2000) the statement can be found that "nowadays there is a renewed interest in jugo beans" (as Bambara groundnuts are called in South Africa*)*," because of their ability to produce reasonably well under extreme conditions (drought and poor soil). It is considered to be one of the most under-estimated and under-developed crop plants of the world". This statement summarizes, what has been expressed in numerous other publications (AZAM-ALI, 1992, UNIVERSITY OF NOTTINGHAM, 1997, HELLER *et al.* (eds.), 1997, BOTSWANA COLLLEGE OF AGRICULTURE, 2001, BEGEMANN, *et al.* (eds.), 2003, SESAY *et al.*, 2003).

In Namibia, Bambara groundnut is the second most important legume after cowpea in the communal farming areas of the Northern regions. Contrary to cowpea it is mostly mono-cropped in small plots on selected, suitable sites (= sandy soils with a pH below 6.5). A typical plot of Bambara groundnut in Northern Namibia can be seen in picture 3 on the next page.

The total production area of Bambara Groundnut has been estimated at around 3000 ha. Use in the household diet and selling as cash crop are of equal importance, although in some areas (around urban settlements) farmers have specialized on Bambara Groundnut production for cash income. Production figures are very variable, depending on the rainy season. Due to wide spacing (± 6 – 8 plants/m²) and the lack of improved varieties, yield rarely exceeds 500 kg/ha. Taking 250 kg/ha as an overall average the total annual production calculates to 750 t/year. This does not satisfy the market requirements and a considerable amount of Bambara Groundnut is informally imported from Southern Angola and sold with the local harvest on traditional markets (FLEISSNER, 1998).

Picure 3. A typical plot of Bambara groundnut in Northern Namibia

1.2. The Namibian Bambara groundnut improvement program

1.2.1. Background

Since Namibia's independence in 1990, communal farmers, NGO's, agricultural researchers and extension workers were discussing the need for an improvement of Bambara groundnut production. Before independence this indigenous African grain legume (just as other traditional crops) has not received any attention from the formal research system, which has been dominated by the South African administration and their vision of commercial agricultural production, which in the case of Namibia focused mainly on meat production. However, Bambara groundnut has always been and today still is an important crop in the livelihood of the indigenous population in Namibia's Northern Regions and is widely grown there by communal small-scale subsistence farmers. It has been established that Bambara groundnut is considered by farmers in the four North Central regions (Omusati, Ohangwena, Oshana, Oshikoto) as third to forth most important crop, cultivated by 82 % of farming households (MATANYAIRE, 1998, DAYOT 1998, MCDONAGH and HILLYER, 1998, FARMING SYSTEMS RESEARCH EXTENSION UNIT, NORTH CENTRAL DIVISION, 1999). Among these regions the Omusati region stands out among the others concerning the production of Bambara groundnut. It might be of interest to add that this region has not only marginal conditions for crop production, but also the highest percentage (42%) of households in the NCA solely depending on agriculture as income (CENTRAL STATISTICS BUREAU, 1997). In the Kavango region, where the climatic conditions allow a broader diversity of crops, Bambara groundnut is rated slightly lower as sixth most important crop and is grown by 67% of the farmer (MATSAERT, 1996, MATANYAIRE, 1998).

Some problems of Bambara groundnut and demands that have emerged from farmers during participatory appraisals in the late 90's were the lack and quality of seed, termites and storage pests (bean weevil) (KAVANGO FARMING SYSTEMS AND EXTENSION PROJECT TEAM, 1995). No defined and described varieties of the crop existed and seed was either farm-saved or purchased as grain from local markets. Production guidelines for Bambara groundnut were not available. Production methods and agronomic practices for Bambara groundnut were not uniform and varied widely across villages and regions (FLEISSNER, 2001).

However, the tolerance of Bambara groundnut to drought and poor soils, its benefits as a legume in a grain-dominated farming system (MCDONAGH, 1998) and its market potential justified the calls for an improvement in the cultivation of Bambara groundnut regarding genetic as well as agronomic aspects. Seed size was mentioned by farmers as an important factor for the marketing of Bambara Groundnut and the development of improved varieties would need to target, beside an increase in production, also at an improvement in this characteristic.

This need for research on Bambara groundnut was manifested 1996 in the first Namibian Agricultural Research Plan (MINISTRY OF AGRICULTURE, WATER AND RURAL DEVELOPMENT, 1996), where research on Bambara groundnut was characterised as a high priority research activity. To address the demand for research into the improvement of Bambara groundnut production a "Bambara groundnut improvement program" has been launched already in 1995 in the sub-division Agronomy Research of the then Ministry of Agriculture, Water and Rural Development (today Ministry of Agriculture, Water and Forestry) with the objective to "increase the production of Bambara groundnut and with it improve income, household food security and nutritional status of households in the northern communal areas of Namibia".
The following outputs for the program have been identified:

- the selection of improved, drought tolerant and high-yielding Bambara groundnut accessions, which are accepted by farmers
- the development of a popular improved variety for registration and official release to initiate seed multiplication and availability as registered seed
- the development of improved cultivation methods with farmer's participation

At the time of launching the improvement program the methodology to approach the improvement of Bambara Groundnut in Namibia was subject to the following considerations and constraints:

- ICRISAT had already conducted a germ plasm collection of agricultural crops in Namibia during 1991/92, in which Bambara groundnut germ plasm was also collected. Samples of the collected material were kept in Namibia at Omahenene Research Station (Omusati region, North Central Namibia) and at the National Botanical Research Institute
- However, none of the CGIAR centres or big research/plant breeding organizations has ever put a concerted effort in the breeding or improvement of Bambara groundnut
- No successful cross pollination/hybridization of Bambara groundnut had ever been performed
- The sub-division agronomy research in the Ministry of Agriculture, Water and Rural Development and its research stations were inadequately equipped to perform meaningful scientific research work (e.g. no green houses, no laboratories or basic scientific equipment, low capacity computer equipment with poor scientific software).

- Human resources in the Directorate of Research and Training were also limited (six agronomy researcher posts for the whole of Namibia and all agronomic research fields including horticulture; therefore only one scientist could be part-time available for the program).
- There were no qualified plant breeders or other suitable supporting scientists available in Namibia, who could be involved into the program (e.g. the Faculty of Agriculture of the University of Namibia was only established in 1996)
- No additional financial resources for the program could be sourced at the beginning
- In comparison to the more "conventional" crops (e.g. maize, pearl millet, cowpea), scientific information on Bambara groundnut was hardly available in Namibia and scattered around the world (there was nowhere a "Bambara Groundnut Research Centre") ; additionally the Internet was not yet available
- No research work on Bambara groundnut has previously been carried out in Namibia
- Bambara groundnut did not have an influential lobby with financial and/or economic interests in the crop, which was willing to support the program
- Communal small-scale subsistence and mostly illiterate farmers were the most knowledgeable resource persons on the crop in Namibia

Considering these circumstances, it was obvious that conventional crop improvement strategies as applied for "world crops" (like maize, wheat or soybean) or in crop improvement programs of developed countries could not be appropriate for the Namibian Bambara groundnut improvement program. Fact was that a crop improvement program should be created for an indigenous crop of regional importance and non-influential beneficiaries, with limited resources and without outside support. Another pre-condition was that this should take place within a limited period of time (approx. 10 years). These conditions did not only apply to Bambara groundnut, but to numerous other indigenous, under-utilized plants targeted for improvement. An alternative crop improvement strategy needed to be developed and a suitable methodology for the Namibian Bambara groundnut improvement program was found in the field of farmer participatory crop improvement approaches.

1.2.2. The concept of participatory plant breeding

The 1980's marked a turning point in agricultural development. Participatory approaches like ZOPP (goal oriented project planning), FSRE and Action Oriented Research, which were developed by development agencies like GTZ (Germany), ODA (now DFID, United Kingdom) and CF (France), were now seen as the key for development in the agricultural sector of developing countries (GTZ, 2005). These new approaches found their way directly with development projects or through the CGIAR centres (like ISNAR) to the national agricultural research systems (NARS) of many African countries and with some delay also to Namibia. First focussing more on agricultural extension and rural development e.g. with PRA or RRA, participatory methodologies were in the 1990's also introduced into research and breeding programmes One of the pioneer organizations in participatory plant breeding (PPB) is the Plant Science Programme of the Overseas Development Institute at the University of Wales in Bangor, which based its descriptions on Witcombe and Joshi's work on participatory crop improvement in Asia (WITCOMBE *et al*, 2001, JOSHI *et al*, 2002, WITCOMBE *et al*, 2003, JOSHI and WITCOMBE, 2003, WITCOMBE *et al*, 2005) . The term participatory plant breeding has meanwhile been modified to client-oriented breeding (COB) (WITCOMBE *et al*, 2005). Participatory varietal selection (PVS) is another term used in the field of participatory crop improvement, which does not deal with the development of new varieties (breeding), but with farmer's preferences for existing varieties. The following are short descriptions taken from DFID's Plant Sciences Research Programme website (DFID, 2005).

1.2.2.1. Participatory varietal selection

"The justification for farmer participatory approaches in crop development was that many farmers in developing countries grew old varieties or landraces, and hence failed to benefit from the most modern products of plant breeding. One of the main reasons for low cultivar replacement rates seemed to be that farmers had inadequate exposure to new cultivars. One way of increasing the speed of adoption of new varieties was for farmers to be given a wide range of novel cultivars to test for themselves in their own fields. This method was termed participatory varietal selection (PVS).
PVS assumes that varieties exist that are better than those currently grown, but which farmers have not had the opportunity to test. The cultivars should be selected carefully. To save time and ensure availability of seed, already-released cultivars, not only from the target region, but also from other regions or countries can be used. For example, in India, rice and maize cultivars can be found that have only been released and are widely grown in a single state, yet have a potential to be useful also in other parts of the country. PVS is limited, however, to employing the existing variation among cultivars, and sometimes well-accepted cultivars cannot be found. In this situation we can turn to participatory plant breeding or client-oriented breeding".

1.2.2.2. Client-oriented or participatory plant breeding

"Client-oriented breeding, COB, (often also referred to as participatory plant breeding, PPB), in which farmers select from segregating material, is a logical extension of participatory varietal selection (PVS) and is desirable when the possibilities of PVS have been exhausted. COB/PPB is more powerful than PVS as it creates new variability rather than relying on existing varieties. The results of PVS are exploited in the COB/PPB programme by using cultivars as parents of crosses. Weaknesses in cultivars are identified in the PVS programme so that cultivars can be crossed with varieties that have complementary traits to eliminate those weaknesses. For example, one can cross a high-yielding but low-grain-quality variety with one with superior grain characteristics. A key COB method is the collaborative participation of farmers who grow a bulk in their own fields and select amongst it. In other methods, breeders may consult farmers who may, for example, give opinions on material grown by breeders on research stations. Another great advantage of COB/PPB is that it is much faster than conventional breeding.

What has been found is that PVS and PPB get to be used in combination. We start with PVS and that helps to identify parents, then we carry out PPB. As soon as there are products from this COB/PPB, we test them in PVS trials. This can be a continuous process because new varieties, whether introduced or from COB/PPB, are always becoming available that can be tested by PVS."

It should be mentioned that participatory plant breeding has meanwhile become an acknowledged research discipline, which has been described multifaceted and been applied in crop breeding programs around the world.

1.2.3. Collaborative research work on Bambara groundnut

Participatory principles also formed an integral part of a collaborative EU-funded research project on Bambara groundnut (acronym: BAMFOOD), which was integrated into the Namibian Bambara groundnut improvement program from 2000 to 2003 and created the unique opportunity to break the isolation of the Namibian program, join a multi-national group of scientists and feed additional (human and financial) resources into the Namibian program. With this project the Namibian program also gained a more systematic and scientific approach and some meaningful agronomic and farmer participatory investigations could be carried out. The objectives of BAMFOOD were:

General objective of the research:

To increase the productivity of Bambara groundnut for sustainable food production in semi-arid Africa.

Specific scientific and technological objectives:

1) Identify Bambara groundnut `ideotypes' for local conditions in Botswana, Namibia and Swaziland using a farmer survey.
2) Characterise the genetic and agronomic performance of Bambara groundnut landraces from Botswana, Namibia and Swaziland in field, controlled glasshouse and on-farm environments.
3) Evaluate genetic diversity in Bambara groundnut germ plasm using molecular strategies.
4) Produce a robust Bambara groundnut model to match suitable ideotypes to contrasting environments and end users.
5) Establish an operational method of crossbreeding for intra-specific hybridisation in Bambara groundnut.
6) Develop a strategic Bambara groundnut breeding programme based on morphological and molecular considerations.
7) Provide a blueprint of how the methodology established for Bambara groundnut can be applied to other underutilised crops.

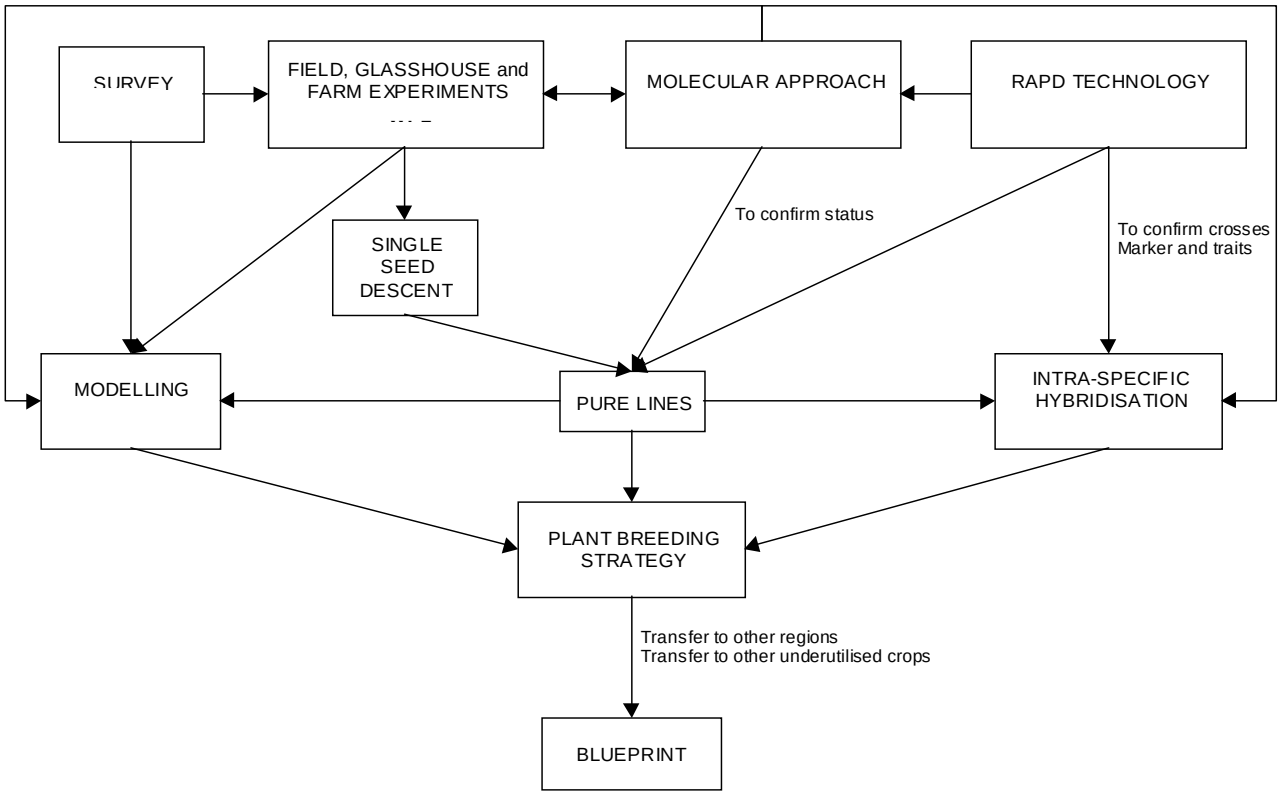
To address the objectives six work packages were developed and for each work package a number of deliverables with a relevant time frame was developed. BAMFOOD included 5 partner institutions from two European and three African countries: University of Nottingham (United Kingdom), Technical University of Munich (Germany), Botswana College of Agriculture, University of Swaziland, Ministry of Agriculture, Water and Rural Development (Namibia). Each work package was assigned according to the available resources and capacities to one of the 5 partner institutions, which should be the responsible leader of that package. Namibia was assigned the leadership for work package 2 "Characterization of genetic and agronomic traits".

An overview on the deliverables and their relevance to this thesis can be found in Table 1. A diagrammatic representation of the relationships between the different work packages of the BAMFOOD project is displayed in Figure 1. A possible option for the blueprint model, based on practical experience, will be introduced later in this thesis.

Table 1. List of deliverables of the BAMFOOD project

Deliverables list	
Deliverable title	**Discussed in this thesis**
Ideotypes of bambara groundnut identified for each growing region	X
Selection criteria for landraces that suit local conditions and preferences	X
List of achievable breeding objectives for model development	X
Yield potential of selected landraces for contrasting environments	X
Variation of agronomic traits in selected landraces	X
Description of landraces using IITA descriptor list	X
Morphological relationships between core collection and landraces	
Performance of bambara groundnut under on-farm conditions evaluated	X
Defined core collection	X
Database on molecular markers in core collection and selected landraces	X
Grouping of accessions according to genetic data	X
Genetic fingerprint of germplasm	X
An efficient and simple DNA protocol for use in bambara groundnut	
Manual for RAPD Standardisation Kit	
Researchers trained in use of RAPD Kit	
Theoretical ideotypes modelled for contrasting environments	
Model predictions for landraces in contrasting environments	
An operational method of crossbreeding in bambara groundnut	

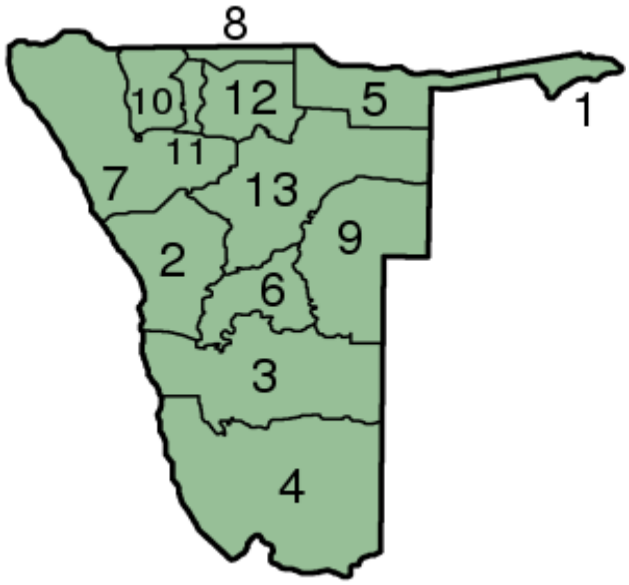
Figure 1. Relationships between work packages of the BAMFOOD project



1.2.4. Short description of the physical and agro-ecological environment of the Namibian Bambara groundnut improvement program

Namibia is situated along the Tropic of the Capricorn, between 18 º and 29 º Southern latitude and is bordering the Atlantic coast line of the African continent. It is part of the Southern hemisphere's subtropics and covers an area of about 825 000 km², of which only 1% is considered to be arable. Namibia is the driest country in Sub-Saharan Africa and most of the country is arid and semi-arid. Approximately two third of Namibia's total population of about 2 million people is living in a belt of ± 200 km South of the border to Angola.

Picture 4. Regions of the Republic of Namibia



This area is also referred to as the Northern Communal Areas (NCA), which is also the major area suitable for dry land cropping, mainly as communal small-scale subsistence farming. The regions of the NCA are (numbers refer to the map above):

1 = Caprivi
5 = Kavango
7 = Kunene
8 = Ohangwena
10 = Omusati
11 = Oshana
12 = Oshikoto

The so-called maize triangle is situated south of the NCA in the Otjozondjupa region (= 13) and is used by commercial farmers for cash crop production. The major part of the NCA's cropping areas belongs to the Kalahari Basin and the dominant soil type is Cambic Arenosol. A strip of Orthic Solonetz follows in the Western part (in the North Central Regions, which are no's 8, 10, 11 and 12)), indicating the Cuvelai floodwater system. Rainfall is highest in the far North East (Caprivi = 1), the only area with a sub-humid climate and an average of around 700 mm/year and declines towards the South and West. Dependable growing periods reduce from above 120 days in the North East, to a 61 to 90 days' growing period with a very short dependable growing period in the marginal farming areas of the North West (Omusati and Kunene) (FLEISSNER, 1998).

Precise data on the cropped area in the NCA vary considerable depending on the rainy season (a bigger area is cultivated after good rains), and because of shifting cultivation, which is still

practiced in the North East. Even for the number of farm households, the figures differ: the Directorate of Planning of the Ministry of Agriculture, Water and Forestry estimates the number of farm households in the NCA at around 112 000. This is somewhat below the figures, which are given from Extension Services, another directorate of the Ministry. They give a number of 114 000 farm households for the four North Central Regions alone (Planning Division: 80 000). Using the figures from the Directorate of Planning and an average of 4 ha per farm household (own estimation), the total area of cropped land in the NCA calculates to ca. 448 000 ha.

Crop production in the NCA is dominated by cereals. Among these (and also in total), pearl millet (*Pennisetum glaucum*) is the major staple crop and has in > 90 % of the households the biggest share in the production system (CENTRAL STATISTICS BUREAU, 1997). Sorghum (*Sorghum bicolor*) reaches only in the North Eastern regions (Kavango and Caprivi) major importance, although it is planted all over the NCA in minor shares for traditional beverages. Maize *(Zea mays*) is also planted on the majority of the farms, but has only a subordinate status as dry land crop in the Central and Western parts, because of a high risk of production failure due to unreliable rainfall,. Only in the Caprivi region in the far North-East maize production exceeds the one of pearl millet.

Cowpea (*Vigna unguiculata*) is the most important legume in Northern Namibia. 95 % of farmers in the North Central Regions and about 60 % in the North East plant it (MATANYAIRE, 1998), mostly intercropped with a cereal cover crop in a ratio of 6 – 10 (cereal) : 1 (cowpea). Bambara Groundnut (*Vigna subterranea* (L.) Verdc.) is usually the second most important legume. Other legumes of minor importance are groundnut (*Arachis hypogaea*), lablab (*Lablab purpureus)* (in homesteads), and, recently introduced, pigeon pea *Cajanus cajan)* . Pumpkins, melons (*Citrullus spp.)* and indigenous vegetables (e.g. *Hibiscus sabdariffa*) are intercropped with cereals where sufficient moisture is available.

1.3. Scope of the thesis

This thesis describes the efforts that have been undertaken to achieve an improvement of Bambara groundnut production in Namibia. It includes some basic plant breeding activities, which link to the principles of participatory plant breeding, but also addresses some agronomic investigations that have been carried out. This thesis describes the activities of the leading scientist of the Namibian Bambara groundnut improvement program (BGIP) over a period of 10 years from the first ever research work carried out in Namibia on a so far neglected, under-utilized, indigenous African crop, to the handing over of an improved Bambara groundnut variety to the formal seed sector. The thesis covers the following five areas of intervention for the improvement of Bambara groundnut production:

- Germplasm collection and description
- Breeding strategies
- Agronomic characterization and evaluation
- Agronomic investigations
- Farmer participatory research activities

2. MATERIALS AND METHODS

2.1. Rainfall records of Omahenene Research Station

Because Omahenene Research Station was the centre of the program and all activities, which are reported here, were carried out at this research station, a summary of monthly rainfall data for the 1995/96 to the 2004/2005 season has been compiled (Table 2).

Table 2. Rainfall records of Omahenene Research Station from 1995 to 2005

Monthly and seasonal rainfall in mm rain (=l/m²) at Omahenene Research Station									
Season	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total**
1995/96	0.0	28.5	9.2	207.6	32.6	36.6	0.0	0.0	314.5
1996/97	0.0	15.0	21.5	117.0	169.3	166.7	0.0	0.0	489.5
1997/98	0.0	5.8	163.1	73.0	69.0	52.5	25.8	0.0	389.2
1998/99	3.6	17.4	81.7	110.1	42.5	139.4	6.5	0.0	401.2
1999/2K	1.5	122.7	200.8	46.5	37.7	128.0	28.4	30.6	596.2
2000/01	5.4	0.7	24.6	64.4	118.7	111.0	110.8	2.1	437.7
2001/02	0.0	29.2	27.4	70.4	122.6	118.1	0.7	0.0	368.4
2002/03	26.1	90.1	62.8	156.3	87.0	79.3	67.1	0.0	568.7
2003/04	18.0	53.1	33.0	110.9	179.6	73.1	32.2	0.0	499.9
2004/05	45.8	61.6	3.0	210.7	77.3	76.1	0.3	0.9	476.7

Omahenene research station is situated in the Omusati Region in North-Western Namibia, approximately 8 km south of the Angolan border. Rainfall is the only meteorological data that is recorded at the station. The average for the 10 seasons in the table is 454.2 mm, with a maximum of 596.2 mm (131.3% of average) and a minimum of 314.5 mm (69.2% of the average). Rainfall distribution is not uniform, sometimes unimodal (1996/97, 2000/01, 2004/05), sometimes bimodal (1998/99, 1999/2000). Bimodal rainy seasons are usually characterized by a mid-season drought, which can seriously affect the productivity of crops. An early end of the rainy season (2001/02) affects late maturing and late planted crops. Droughts (1995/96, 1997/98) frequently occur and result in low crop production and subsequent food shortages. No rainfall usually occurs from May to September (meteorological winter). In general the most reliable months for rain are January, February and March. Therefore planting of research trials at the station is usually done after a good rain spell in January. Dry spells but also excess rain after planting can affect the germination of Bambara groundnut negatively.

2.2. Collection and agronomic characterization of germ plasm

2.2.1. Initial activities

The first activity of the program was to create an entry point. In informal interviews with farmers around Omahenene research station in the Omusati region, which would be the centre of the program, important characteristics of the crop and crop management practices were identified, the two most important traits at that stage being yield and seed size. The Bambara groundnut germ plasm collection at Omahenene was exposed to a small group of farmers, who then selected favoured accessions according to their own criteria. Beside these, seed from a local farmer, from the Oshakati open market (ca. 110 km from Omahenene), one variety, which was imported as seed from Botswana and sold to farmers by Extension Services and a collection of Bambara groundnut accessions, which was received from Dr. Swanevelder from the Oil and Protein Seeds Centre in Potchefstroom/South Africa, formed the first pool of test material.

2.2.2. Overview of the collection periods

Germ plasm has been obtained or collected and screened in several phases during the duration of the program. The seasons in which germ plasm was screened for the first time in nurseries or trials at Omahenene research station are listed below:

1995/96: 14 selected accessions from the Namibian germ plasm collection, two accessions from a local farmer, four accession from the Oshakati open market (grain mixture, sorted according to colour), one accession sold by Extension Services as seed (imported from Botswana), 39 accessions from South Africa; planted in a trial and an observation nursery (depending on the available quantity of seed)

1997/98: 19 accessions from a farmer's seed fair in the Kavango region, 2 accessions from the Namibian central gene bank in Windhoek; planted in an observation nursery

1998/99: 20 accessions from the Bambara groundnut collection of the International Institute of Tropical Agriculture (IITA); planted in an observation nursery

2000/01: 6 accessions from BAMFOOD partners (Swaziland and Botswana); planted in a multi-locational trial

2004/05: 46 accessions from farmer's seed fairs in Kavango, Ohangwena and Omusati region; planted in an observation nursery.

2.2.3. On-station screening and agronomic characterization of Bambara groundnut germ plasm in observation nurseries

Because available seeds were in most cases very few (ca. 10–20), entries in the observation or screening nurseries were planted in single row, non-replicated plots. Plot size was 3m² (4 m row length x 0.75 m between rows) and the whole plot was harvested as net-plot. Distance between plants in the row was 25 cm with one seed planted per station. Planting was done when soil moisture was sufficient for germination and rains have established in Northern Namibia. No fertilizer was applied. Plots were kept free of weed by hand hoeing. When 100% of the plants flowered, the plots were earthed-up manually with a hoe. Harvesting was

also done manually at physiological maturity, when the leaves of the plants turned yellow and pods started to dry up.

In the 1995/96 season 60 Bambara groundnut accessions were planted in the first observation nursery of the program and the following data have been recorded:

Individually collected data for each harvested plant:

- Yp = pod yield (in gram)
- Ys = seed yield (in gram)
- Np = number of pods

Data, which could be calculated from these records, included average seed mass per pod in gram (Ys/Np) as an indicator for seed size, and shelling percentage ({Ys/Yp}x100). From these individual records, the following calculations for the accessions could be made:

- yield/plot in gram(= $\sum$Ys {for all plants of the same accession}) and yield in kg/ha (= {$\sum$Ys/3}x 10)
- yield of accession expressed as % of the yield average of the nursery: %M = [$\sum$Ys/{($\sum_{n=1-60}\sum Ys_n$)/60}] x 100

Data, which were collected for the plot as a whole, included:

- Agronomic scores (average from three scorings)
- Number of harvested plants per plot
- Percentage of plants flowering 75 days after planting
- Uniformity of plants of one accession
- Maturity scoring (early, medium, late) 100 and 113 days after planting

Some of these data and other information appear in the result table of the 1995/96 Bambara groundnut observation nursery under the following abbreviations (with the measurement unit in []):

- Acc.-No.: Accession number
- Yield [kg/ha]
- %M: yield of accession expressed as % of the yield average of the nursery [%]
- Ph: plants harvested/plot
- AS: average agronomic score for the accession from 3 scorings (35 days after planting, 48 DAP and 55 DAP) [1 for good, 5 for poor]
- %F: Percentage of plants flowering 75 days after planting [%]
- Y/pl: average yield per plant (for accession) = $\sum$Ys/ Ph [g]
- S/P: average seed mass per pod (for accession) = $\sum$(Ys/Np)/ Ph [g]

The nurseries in 1997/98 and 1998/99 were planted and managed in the same way as the first nursery, but data collection was due to a shortage of technical staff at the station and new commitments of the leading scientist in the newly established farming system research and extension units limited to post harvest data (plants harvested, total seed yield, 50/100 seed weight).

The six accessions from Botswana and Swaziland were planted together with three Namibian elite accessions for three seasons in a replicated, multi-locational trial in two locations each in Botswana, Namibia and Swaziland, which will be described at a later stage.

The 2004/2005 screening nursery followed the layout and the procedures of the 1997/98 and 1998/99 nurseries.

2.3. Single plant selection as breeding strategy and means for genotype purification

2.3.1. Selection criteria for single plant selection

Single plant selection as a breeding strategy for self-pollinated crops and as means for genotype purification was carried out in the first season of the program (1995/96), when 1 561 plants have been harvested individually from the first Bambara groundnut observation nursery and the first Bambara groundnut land races comparison trial and categorized in nine grades according to their individual yield and calculated seed size (expressed as grams air dried seed per pod). The selection criteria, which have been used to identify single plants for the breeding programme, are shown in table 3.

Table 3. Selection criteria for Bambara groundnut single plant selection

Yield target (air dried seed)	Fixed at 1000 kg/ha	From 53 333 plants/ha; calculated from a spacing of 0.75m between rows and 0.25m in row (0.1875 m²/plant)
Required seed mass/plant	18.75g/plant	1000 kg/ha : 53 333 plants/ha
Seed size target	0.8 g seed/pod (air dried)	From a market sample (= marketable seed size); Seed mass/plant : number of pods

A second single plant selection with the same criteria as the first one (seed yield/plant and seed weight) was carried out from evaluation trials with the selected material in the 1997/98 and 1998/1999 season.

2.3.2. Evaluation of purified lines

Based on the selection criteria mentioned in the last chapter the following selection grades have been determined to categorize all harvested plants from the 1995/96 season. They are displayed in table 4.

Table 4. Grading categories for Bambara groundnut single plant evaluation

Grade 1	≥ 0.8 g seed/pod	≥ 18.7 g seed /plant
Grade 2	≥ 0.6 g seed/pod	≥ 18.7 g seed/plant
Grade 3	≥ 0.4 g seed/pod	≥ 18.7 g seed/plant
Grade 4	≥ 0.8 g seed/pod	≥ 9.3 g seed/plant
Grade 5	≥ 0.6 g seed/pod	≥ 9.3 g seed/plant
Grade 6	≥ 0.4 g seed/pod	≥ 9.3 g seed/plant
Grade 7	≤ 0.4 g seed/pod	≥ 18.7 g seed/plant
Reserve: Plants above plot average from plots above nursery average (yield)		

Only plants from Grade I and II were considered for progeny testing.

The progeny of the selected pure lines was tested during the following three seasons for their performance and stability in yield and seed size.

In the 1996/97 season the selected pure lines were (due to the limited amount of seed) only evaluated in a single row, non-replicated trial against the parent (=original) material. The selected pure lines were planted next to their 25 parents and compared in yield and seed size. The trial design was the same as for the Bambara groundnut observation nursery in 1995/96.

From this evaluation, which also served as seed multiplication, the best 15 pure lines were given accession numbers and taken in the 1997/98 season into a replicated evaluation trial with five of the parents, which was repeated in the same way in the 1998/99 season. The trial had three replications and followed a Randomized Complete Bloc Design, but within a replication 3 pure lines were always followed by a parent line. Plot size was 1.5 x 4.0 m with a row distance of 0.75 m and therefore each plot consisted of two rows. Distance between plants was reduced to 15 cm. Management practices were the same as for the nurseries.

The three best performing accessions from these trials entered from the 1999/2000 season on the Bambara groundnut land races comparison trial.

A second and final selection of single plants was carried out from the two progeny test trials in 1997/98 and 1998/99. The reasons for this were final genotype purification of the previously selected material (to eliminate potential contamination) and, because of the drought situation in these two years, an opportunity for the identification of drought tolerant lines was expected (lines, which could despite the drought conditions meet the selection criteria). A grading like it was done for the first selection was not carried out and only plants, which met the criteria for grade I or II, were selected.

From the selected material, the 40 pure lines with the best records were given accession numbers and went to progeny testing in the 2000/2001 season against their parent material (20 accessions, which comprised of original land races, but also pure lines from the first

selection). The design followed the progeny test after the first selection. The best 11 pure lines from this progeny evaluation were then taken to the 2004/05 Bambara groundnut landraces comparison trial to compete against the elite accessions of the BLCT.

2.4. Agronomic evaluation of land races on station

2.4.1. Selection of entries and objectives of the evaluation trials

Agronomic evaluation of land races happened in four phases, which differed in the selection of entries and their objectives: the first in the 1995/96 season, the second from the 1996/97 to the 2000/01 season, the third from the 2000/01 to the 2002/03 season and the last from 2003/04 onwards.

Table 5. Overview of number entries in agronomic evaluation trials

Trial name	Season	Number of entries	New entries	Entries discarded
BLCT	1995/96	12	12	-
BBVT	1996/97	9	9	-
BIYT	1996/97	8	4	8
BLCT	1997/98	14	3	6
BLCT	1998/99	16	3	1
BLCT	1999/2000	16	3	3
BLCT	2000/01	16	0	0
BAMFOOD 1	2000/01	9 (3 from BLCT)	6	-
BAMFOOD 2	2001/02	9	0	0
BAMFOOD 3	2002/03	9	0	0
BLCT	2003/04	15	11 (refers to last BLCT)	12 (refers to last BLCT)
BLCT	2004/05	24	11	2
BLCT	2005/06	24	0	0

The first Bambara groundnut landraces comparison trial was planted in the 1995/96 season. The number and selection of entries for this trial was based on the availability of seed. The objective was to receive a first set of data from a randomized and replicated trial, which could be analysed statistically to evaluate the seed sold by Extension Services and from the open market (“outside seed”, unknown source) against seed from the germ plasm collection and from a farmer (“inside seed”, known source).

In the 1996/97 season, two different comparison trials were planted (BBVT, BIYT), which included mostly promising accessions from the 1995/96 nursery, which now had sufficient

seed to participate in replicated trials. The BBVT consisted of 8 new accessions and a local variety from the Omusati region as control, while 4 top performing entries from the 1995/96 BLCT competed against 4 new accessions in the BIYT. The objective for these two and all following BLCT trials was an agronomic comparison of Bambara groundnut accessions to identify the most consistent, high yielding variety with an acceptable seed size for a possible delivery to the formal seed production system in Namibia.

In the 1997/98 season the BLCT started off with 14 accessions that showed potential for good yield and big seeds in the two years since the start of activities. Weak performing entries were subsequently replaced with promising new accessions. From the 1999/2000 season on, elite accession from the breeding program entered the trial to be evaluated against the top accessions from previous BLCTs.

Agronomic evaluation of nine land races from Namibia, Botswana and Swaziland was carried out from 2001 to 2003 under the auspices of the BAMFOOD project protocol of work programme 2 (characterization of agronomic and genetic traits). It was done in form of a multi-locational on-station field experiment, that was conducted with the same nine land-races from Botswana, Namibia and Swaziland (3 each) and the same experimental plan in two locations of each African partner country (Botswana, Namibia, Swaziland) for three consecutive seasons. For Namibia the experiment was conducted at Omahenene Research Station and Mashare Agricultural Development Institute. Omahenene had low and unreliable rainfall, which usually started around Christmas. Mashare was located in the Kavango Region in the North-east of Namibia and was characterised by higher (average >500 mm per year) and more consistent rainfall, which could start as early as end of October. Sites differed also in regard to soil type, sandy soil in Omahenene and loamy soil in Mashare.

From the 2003/04 season onwards the BLCT continued with elite accession from previous trials and promising new accessions from the single plant selection and the screening nurseries. The 2004/05 BLCT had a record number of 24 entries, when 11 lines from the second single plant selection joint the 13 remaining accessions from the 2003/2004 trial. The high number of discarded accessions in the 2003/04 trial resulted from the fact that after the Bambara groundnut producer survey, which was conducted in 2001 to identify criteria for a Bambara groundnut ideotype (see also page 27), two additional characteristics, seed colour and maturity records, were added in the third cycle of the BLCT to evaluate the accessions of the on-station trials. From the six most important characteristics that farmers have mentioned in the survey, five were now assessed on-station, only “taste” as a subjective, non-measurable characteristic could not be evaluated (although taste was according to the informants of the survey subjectively linked to colour).

2.4.2. Experimental design and protocol of evaluation trials

Layout and protocol of the trial was the same for the first and second phase. A randomized complete bloc design was used. Plot size was 1.5 x 4.0 m and the whole plot was harvested as net-plot. Row distance was 0.75 m and therefore each plot consisted of two rows. Distance between plants was 20 cm and one seed was planted per station. The trials had due to an initial shortage of seed only three replications in the first two years, from 1997/98 on four replications. Fertilizer was not applied and crop management (weeding, earthing-up) was done by hand. The trials were always planted after a good rain spell in January and harvested at physiological maturity. The data collection protocol for the BLCT trials can be seen from the data sheets (one for field, one for post-harvest data collection), which are attached under Annex 1.

Picture 5. BLCT trial at Omahenene Research Station (in the background: cowpea trial)

Trial design and protocol for the third phase of agronomic evaluation was due to an externally prescribed protocol and the availability of additional technical staff more sophisticated than for the previous trials. Plot size was increased to6 x 6 m with 12 rows spaced at 50cm and an intra row spacing of 30 cm, giving 252 plants per plot (21 plants/row or 7 plants/sq metre).

Picture 6. The BAMFOOD experiment at Omahenene Research Station

Landraces to be used by all countries for the duration of the experiment (three seasons) were (the Namibian entries were selected to represent a diversity of traits):

Table 6. Entries for the phase 3 agronomic evaluation (accession numbers have been used in many result tables)

Origin	Landrace	Accession Number	Source	Description
Swaziland	Nyakeni C1	8	Farmer at Nyakeni	Cream testa, black eye pattern
	Nyakeni C2	9	Farmer at Nyakeni	Cream testa, brown eye
	Swazi Red	7	Manzini market	Red testa, white helium
Namibia	AHM 753	3	Namibia germplasm	Red testa, early maturing
	AHM 968	2	Namibia germplasm	Tan testa, medium maturing
	AS 17	1	South Africa	Cream testa, late maturing
Botswana	DIPC	5	BCA germplasm	Cream testa, black eye
	GABC	4	BCA germplasm	Cream testa, brown eye
	OM1	6	BCA germplasm	Cream colour, butterfly eye

Seed were sown double (at half intra-row spacing) and thinned to the required plant density at 21 days after sowing. Seeds should not have been inoculated, but seed dressing should have been applied, the chemical to be used was CAPTAN. Spraying of pesticides (e.g. against aphids) was based on monitoring and not as a routine. All countries were requested to do earthing-up at 100% flowering. Additional irrigation to supplement rainfall and to prevent the crop from dying was allowed. The amount of water applied needed to be recorded.

The protocol differed substantially from the previous trials and prescribed the following data recordings, which, however, had to be adjusted several times due to unforeseen circumstances and problems. Below the initial instruction for data collection:

Emergence counts:
Two rows (rows 3 and 4 in each plot) were used for emergence counts. Seedlings that have emerged on the whole row should be counted (for each of the two rows separately) at a specific time each day of counting. The method was to do this cumulatively each day until emergence has finished. A seedling was defined as having emerged when the first true leaf is visible.

Developmental analysis and sampling for growth analysis:
After emergence 10 plants per plot were selected randomly from each plot and tagged for developmental analysis (flower/leave count from 21 day after emergence on twice weekly until earthing-up/harvest). Eight plants per plot were harvested at prescribed dates for sequential growth analysis (not in row 2, 3, 4, and 5). Growth analysis started 21 days after sowing and was carried out subsequently at 14 days intervals e.g. 35, 49, 63, 77, 91, 105 and 119 DAS. A sampling matrix was designed for all plants that needed to be sampled to ensure selection is random, non-biased and to avoid border effects.

Final harvest:
The net plot for final harvest should be reserved for rows 3 and 4. Seed weight should be determined at oven dry weight and converted to 10% moisture. From each edge of the plot, 0.6 m was measured in (=two plants). These plants were discarded and 4.8 m in the centre of the rows were harvested. Rows 2 and 5 were guard rows and therefore, plants in these rows should not be used for growth analysis. For 10 randomly selected plants from the net-plot pods were counted and recorded individually, but later returned to the rest of plot for post-harvest data collection

For the last phase, the distance between rows was (compared to the first two phases) decreased to 50 cm and spacing between plants was increased to 25 cm. These new specifications resulted from experiences made in the previous phase of agronomic evaluation trials. The length of the plot was reduced again to 4 m. Plot size and net-plot were now 1 x 4 m. Other protocol specifications (e.g. RCBD with four replication) and management practices were again the same as for the first and second phase.

2.5. Agronomic investigations

The agronomic investigations targeted the “temper” of the Bambara groundnut with the objective to identify agronomic interventions for a more constant and reliable production. Yield of Bambara groundnut has been reported all over the world to be variable and unreliable, but no reasons for this have been identified. However, should Bambara groundnut production be ultimately improved, this had to be done not only by breeding strategies but

also through agronomic measures. Due to the limited manpower of the Namibian BGIP, agronomic investigations in Namibia were in most cases only possible through outside support, either through cooperation with other institutions or the BAMFOOD project. The agronomic issues that have been addressed in Namibia, were

- germination and emergence
- plant density
- earthing-up
- identification of pests and diseases.

A number of similar agronomic experiments like in Namibia were also conducted in other African countries, but due to more available human and financial resources they could be conducted there with more depths and detail.

2.5.1. Germination pot experiment

Variable germination and emergence was one of the issues, which contributed significantly to production fluctuations. A small open-air pot experiment was therefore conducted in October 2002 at Omahenene Research Station to investigate some factors, which were suspected to have an influence on the very variable plant establishment of Bambara groundnut that has been observed over the years in on-station trials and has also been reported from farmers. The trial had only the objective to identify possible factors influencing germination and emergence, which should thereafter be examined in more sophisticated trials. The factors investigated were seed depth (3 levels), seed size (small, big) and water regime (daily, weekly). Seed colour has at this stage not been investigated and all accessions belonged to the cream seed type. The seed used in this experiment came out of the BAMFOOD material and originated from two accessions, for which poor germination has previously been observed and one accession with a good germination record. From each accession 4 seeds were planted in two pots (which were filled with soil from one of the station's fields) for each possible combination of the other three factors. The experiment therefore comprised in total of 72 pots (with 144 seeds). The only data recorded was days to emergence (germ bud visible), from which the germination percentages could be calculated. The factors of the experiment are shown in table 7.

Table 7. Factors in the germination pot experiment

FACTOR	Level 1	Level 2	Level 3
Accession	AS 17	OM 1	NYAK C2
Seed depth	3cm	6cm	9cm
Seed size	Small (100 SW < 40g)	big (100 SW >60g)	
Watering	0.5 l daily	1 l weekly	

2.5.2. Seed colour and germination

The BLCT of the 2004/05 planting season was the biggest Bambara groundnut ever planted at Mahenene Research Station (see chapter 2.5.1. for trial layout and management). It

comprised of 24 elite accessions with four different seed colour types: cream, red, brown/tan, black. They have been identified during the previous years as potentially high-yielding varieties with big seed size, the major evaluation parameters. The trial was planted on 18 January 2005 during a period of excessive rainfall, which resulted in a record for this month since 1989. During a visit to the station on 24 February, it was observed that despite the good rainfall, germination in some plots of the Bambara groundnut trial was extremely poor. Germination figures have been recorded for each plot individually (plant counts) and were analyzed to investigate this phenomenon.

2.5.3. Effect of sowing density on yield and yield components in two Bambara Groundnut land races in Namibia

An investigations into the optimal plant density is usually part of the first agronomic research activities in a crop improvement program. In cooperation between the Namibian BGIP and the Technical University of Munich in Freising-Weihenstephan, a Namibian student at the University, Mr. G.Wölbling, completed in 1998 a degree dissertation on this subject with the title "Effect of sowing density on yield and yield components in two Bambara Groundnut (*Vigna subterranea* (L.) Verdc.) land races in Namibia". The results have also been presented with a more sophisticated data analysis and in a new format in 2001 at a BAMFOOD workshop in Swaziland (STICKSEL *et al.* 2001). The plant density trial has been designed and planted in the 1997/98 season at Omahenene Research Station, where the student conducted his field data collection under the supervision of the Namibian scientist. After completion of the field work, data analysis and writing was done in Weihenstephan under the guidance of scientists of the Chair of Agronomy and Plant Breeding.

Description of the trial site

The trial was planted at the Omahanene Research Station in Northern Namibia during the 1997/98 season period. The trial site is classified as Rhodi Ferralic Arenosol (KUTUAHUPIRA and MOUTON, 1998). Surface pH varied between 5.8 and 8.9. Organic matter content and nutrient status were low, except for phosphorus. Preceding crops were pearl millet and cowpea.

Design of the trial

The trial consisted of the factors variety and seed density. There were two levels for the factor variety, and five levels for the factor seed density, respectively. The two accessions used for the experiment, AHM 1125 and AS 17 represented two different growth types. Variety AS 17, which was obtained from the Grain Crops Institute in Potchefstroom, Republic of South Africa, was selected as top performer on 100 seed weight. Variety AHM 1125 was an accession from the Namibian germ plasm collection and records showed consistently high pod production with a small to medium seed size. The range of the plant density was 4.3 up to 13.3 seeds per m^{-2} which is corresponding to values observed on farms in northern Namibia.

Table 8. Factors and factor levels of the plant density trial 1997/98

Variety	AS17		AHM 1125		
Density (seeds m^{-2})	4,3	5,3	6,7	8,7	13,3

The trial was designed as Randomised Complete Bloc with three replications. Plot size was 6 m^2 (4 m x 1.5 m) including 2 rows 0.75 m apart. Missing plants were re-sown at the end of January.

Harvesting and Post-harvest data collection

A single plant harvest was done. Pods per plant were counted and dried. Dry pod mass was weighed, after shelling the number and dry mass of seeds was recorded. The values were further used to calculate the single plant yield, number of seeds per pod and 1000-kernel mass. The total kernel yield was used to calculate the kernel yield per ha.

2.5.4. Earthing-up experiment

One of the two Namibian project assistants, who were employed during the duration of the BAMFOOD project, Ms. Theresia Kaulihowa, conducted a small field experiment during her final year (1999) at the Ogongo agricultural college to investigate the effect of earthing-up on Bambara groundnut yield. Earthing–up is usually done at flowering and is considered by farmers as an indispensable measure to obtain good yield.

Picture 7. Earthing-up of Bambara groundnut in a farmer's field

Ms. Kaulihowa investigated the effect of earthing-up against non earthing-up in a small replicated field trial with three Bambara groundnut accessions, she had received from the BGIP at Omahenene Research Station. The trial had three replications and randomized complete bloc design, further information on trial design, layout and management are not available. However, it has been established that all plots have been of the same size and were treated in the same way. For each accession two plots have been planted, one for earthing-up, one without earthing-up as a control. Although the experiment was very small in size, has been conducted in a semi-scientific environment and only the plain results are available, the results of the experiment have been included in this thesis, because some results have been confirmed through a paper presented in 2003 at the International Bambara Groundnut Symposium in Botswana by scientists of the Botswana College of Agriculture.

2.5.5. Overview of important pest and diseases of Bambara groundnut in Namibia

Over the years a number of pests and diseases of Bambara groundnut in Namibia were noted and have been recorded through photographs. An unidentified leaf disease could be observed on Bambara groundnut in several seasons especially during dry spells. The disease also occurred during the first season of the BAMFOOD experiment and the influence of this disease on pod production was investigated. This was the only time when the damage of pests or diseases on Bambara groundnut production could be manifested. Due to the limited available resources no further investigations or interventions have yet been carried out in Namibia in regard to these pests and diseases.

2.6. Agronomic evaluation on farm

The agronomic evaluation of Bambara groundnut accessions with the active participation of Namibian communal, small-scale subsistence farmer happened in two different ways, which differed substantially in their methodology, intensity and results. The begin of farmer-participatory activities dates back to the 1997/98 season and was performed in collaboration with the Extension Services North Central division's FSRE Unit. Due to a lack of experience with participatory approaches, a resulting unclear protocol and limited resources the activities were quite superficial and did not generate significant outputs. Different the participatory work of the BAMFOOD project: a clear protocol and clear objectives combined with the necessary human and financial resources produced meaningful and substantial achievements. The same observations have also been made and described for farmer-participatory work on other crops e.g. cowpea (FLEISSNER and BAGNALL-OAKELEY, 2001)

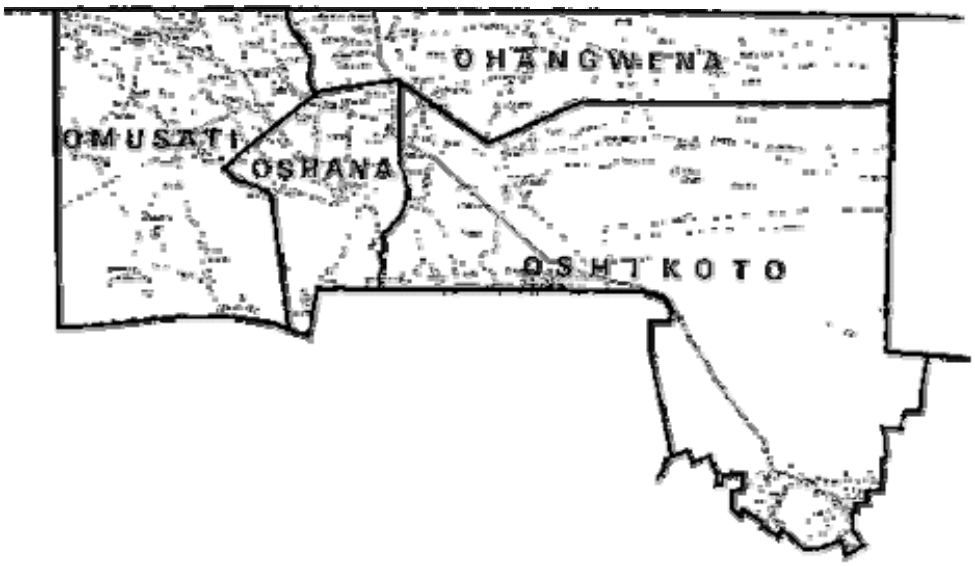
2.6.1. Identification of partners for on-farm evaluation

1997/98 and 1998/99 seasons

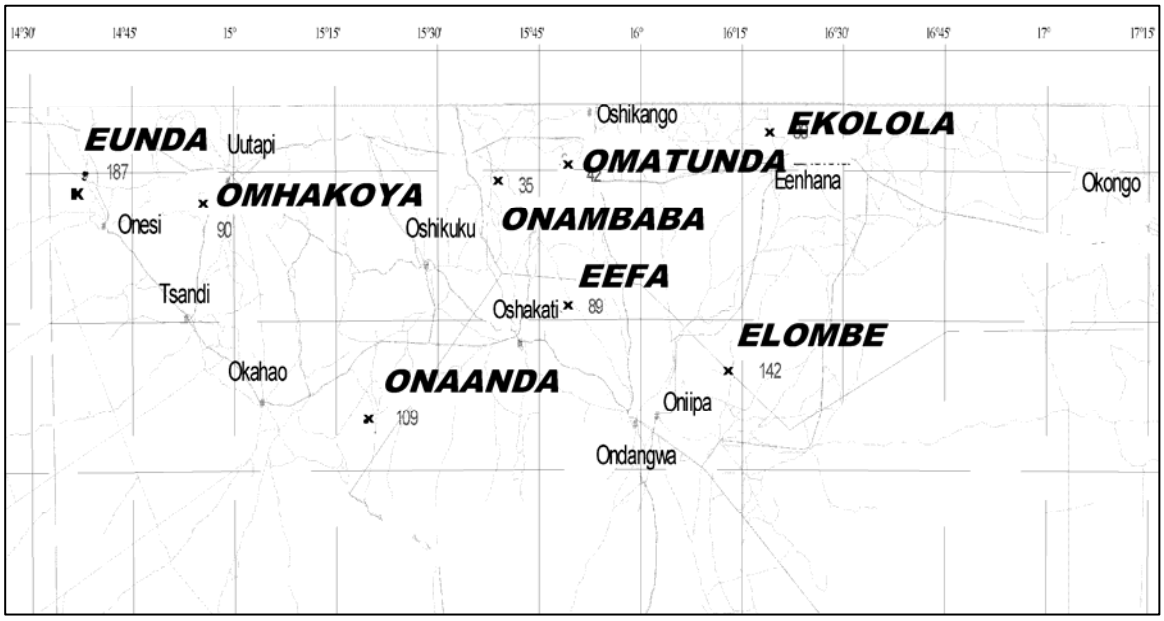
Identification of partners for on-farm evaluation through the North Central FSRE unit, which was operating from the Extension headquarters for the North Central Regions (Omusati, Oshana, Ohangwena, Oshikoto) in Ongwediva, happened through members or collaborators (projects, NGOs) of the unit. The unit identified eight focus communities in different agro-ecological zones of their operating area, which are shown in the maps displayed in pictures 8 and 9. Bambara groundnut tests were conducted in all communities except Ekolola and Onambamba.

After the focus communities have been identified, community (or general) meetings were held with the farmers of these communities and farmers were asked, which kind of activities they would like to undertake. Bambara groundnut evaluation was mentioned in six out of the eight communities. During general meetings, the community members, with the facilitation of members of the FSRE unit, also identified host farmers for the different on-farm trials. In each of the six identified communities for Bambara groundnut evaluation, six host farmers for the Bambara groundnut on-farm trials were nominated.

Picture 8. Map of the North Central Regions



Picture 9. Location of FSRE communities in the North Central Regions



2001/02 and 2002/03 seasons

The partner communities for the BAMFOOD project were identified through personal communication with the staff of the North-Central Extension Division. They were Ompundja and Iiviyongo in the Oshana region and Okahao-Kangala in the Omusati Region. A major criterion was that the community should have experience in Bambara groundnut production

and an interest in an improvement thereof. Agricultural Extension technicians were the major resource persons to assist in the identification, because they were working with farmers on a day to day basis and were aware of the needs in their communities. The starting point for the farmer-participatory work of the BAMFOOD project were surveys in the partner communities to collect (before any intervention) all locally available information on Bambara groundnut production and identify characteristics for an ideotype Bambara groundnut. On-farm evaluation only began after the surveys were completed in the second year of the BAMFOOD project.

2.6.2. Producer survey

A Bambara groundnut producer survey was conducted in 2001. It was based on elements of Participatory Technology Development, using a range of participatory tools in the process. The initial survey was done in Ompundja (Oshana region) and conducted with semi-structured interviews using a checklist of topics that needed to be covered (see Annex 2).

This checklist has been designed during a workshop on survey methodology for project staff, agricultural research and extension officials at the North Central Extension head quarters in December 2000 in Ongwediva. Workshop participants, especially extension staff, felt that the checklist should not be too long and that the interview time should range between 30 and 45 minutes to prevent farmers of becoming bored or tired. The workshop participants then tested the checklist with 6 farmers in a near-by area (Uukwangula), of which five farmers have been interviewed as a group.

For the survey in Ompundja, which took place during the first week of August 2001, the same checklist was used, this time, however, enumerators were recruited. A little workshop was organised for new project staff and the enumerators to familiarise themselves with the participatory nature of the survey. Then a farmer‘s meeting was organised by the Agricultural Extension Technician of Ompundja to introduce the project and its staff to the community. At the end of the meeting 20 households from 7 settlements were nominated by the farmers to participate in the survey. Appointments for the visits and interviews were made according to the preference of the farmers. The interview groups for the survey consisted of three people, one asking the questions, one taking notes and one checking if all topics have been covered and asking questions for clarification. The total number of respondents for the survey in Uukwangula and Ompundja was 29.

Later in the year, the Bambara groundnut producer survey continued in Okahao-Kangala. Okahao-Kangala was a village situated ca. 8 km from Okahao, the tribal centre of the Ongandjera and a traditional Bambara groundnut production area (the Ongandjera are considered by many people in North-Central Namibia as specialists in Bambara Groundnut production). The survey was carried out from 11 to 14 December 2001 and 10 farmers were interviewed.

2.6.3. Consumer survey

A trader and consumer survey was conducted in the year 2002 at different open (traditional) markets in two Northern Namibian towns:
Rundu is situated along the Okavango, which also forms the Namibian border to Angola. It is the economic and administrative centre as well as the biggest town of the Kavango Region. Trade with Bambara groundnut involves local producers from surrounding villages as well as Angolan farmers from across the border.

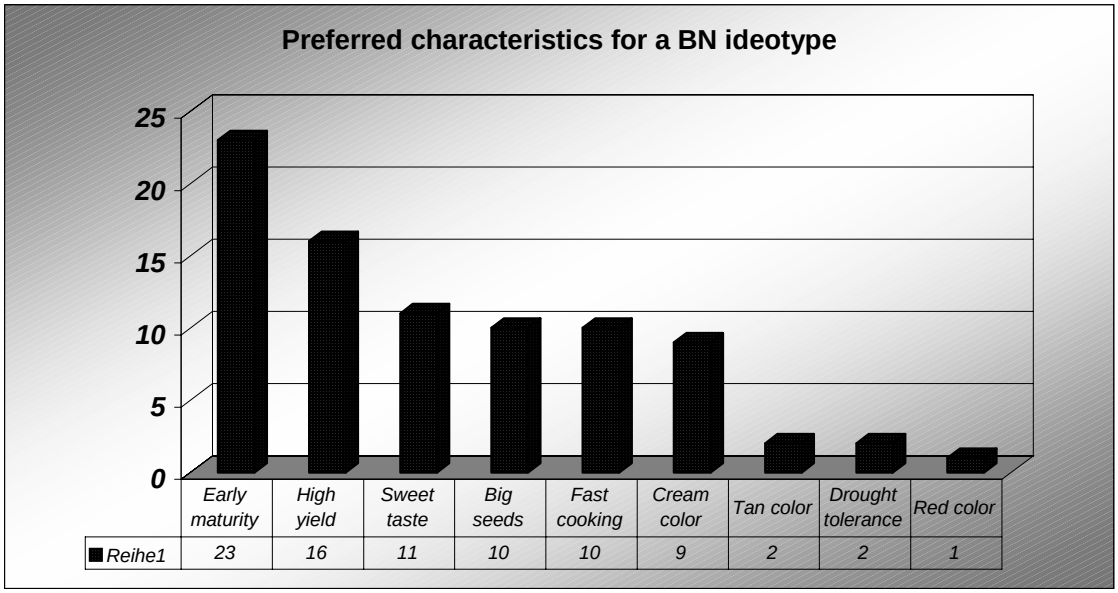
Oshakati in the Oshana Region is the economic centre of North Central Namibia and is located in the heart of the major Bambara groundnut production areas in Namibia.

Short visits to three open markets in Rundu were made during the morning and traders were interviewed in an informal way, consumers were not yet present. The survey in Oshakati was more intensive and was conducted for five consecutive days. An enumerator went every day to the market to conduct semi-structured interviews (with a checklist) with traders on three days, with consumers on two days. One-day surveys with semi-structured interviews were also planned for the open markets in towns in Central and Western Namibia with a high number of migrating workers from Northern Namibia, but could due to logistic problems (time, funds, appointments) not be conducted.

2.6.4. Identification of a Bambara groundnut ideotype

The identification of a Bambara groundnut ideotype was a crucial point in the focused development of a Bambara groundnut variety accepted by the farming community and consumers. The characteristics of this ideotype should guide the breeder in the development of a Bambara groundnut variety, which should express as many of these characteristics as possible. This would ensure acceptance of the new variety by producers, traders and consumers and keep the breeding program focused without wasting valuable resources. Accessions with desired traits could then be identified from the characterized germ plasm and cross-breeding should in the end combine as many of the desired traits as possible in one variety. This is exactly what has previously been introduced as client-oriented or participatory plant breeding. Figure 2 below gives an overview of the most desired characteristics for a Bambara groundnut ideotype, which were identified in the producer surveys.

Figure 2. Number of listings for characteristics of a Bambara groundnut ideotype



From the consumer surveys, it was found that three from the above characteristics, were also important for consumers. Common statements for the 16 consumers that have been interviewed at Oshakati, were:

- they prefer a good colour and pods of big size
- they like to eat Bambara groundnuts because they are sweeter and tastier than beans

One new trait was added by a Bambara groundnut trader in Oshakati: customers would prefer Bambara groundnut, which have a golden brown shell, when cooked, because they are considered to be the most delicious.

2.6.5. Participatory variety selection

1997/98 and 1998/99 seasons

For the first on-farm evaluation activities of Bambara groundnut in the focus communities of the North Central FSRE unit, which took place in the 1997/98 and 1998/99 seasons, the following 6 Bambara groundnut accessions from the BLCT were selected, who showed a good yield potential and differences in the expression of different traits e.g. colour and texture of the seed, seed size or maturity:

- KFBN 9601
- AHM 968
- AHM 753
- SB 4-4 C
- AHM 1125
- SB 2-1

2001/02 and 2002/3 seasons

For the farmer participatory on-farm trials of the 2001/02 and 2002/03 seasons, the involvement of farmers was intensified and a new protocol was developed. These activities took place independently from the FSRE unit and focused only on Bambara groundnut. Meetings were held with the partner communities in 2001 to identify the land races, which farmers would like to test. Samples from all accessions of the phase 3 agronomic evaluation were shown to farmers and they could select four (out of the nine) land races according to their own preferences. Farmers were also asked to give local names to the accessions for easier identification. Farmers were also requested to include their own land race as a comparison in the test. Each partner community could select its own set of accessions. In the second season they could replace the accessions, which they did not like, with new ones. An overview on the number of participating farmers and the accessions, they selected can be found in table 9.

Farmer‘s input in variety characterization and selection also happened during visits of farmer groups from focus/partner communities to Omahenene Research Station during the cropping season, where they were exposed to the available Bambara groundnut material and asked for judgement.

Table 9. Overview on accessions tested and number of participating farmers for the 2001/02 and 2002/03 on-farm trials

Village	2002		2003	
	No. of participating farmers	**Accessions tested**	**No. of participating farmers**	**Accessions tested**
Ompundja	10	AS 17 AHM 968 Nyak C2 Dip C Local	8	AS 17 AHM 968 Gab C Uniswa Red Local
Iviyongo	6	AS 17 AHM 968 Nyak C2 Dip C Local	8	AS 17 AHM 968 Gab C Uniswa Red Local
Okahao-Kangala	10	AS 17 AHM 968 Nyak C2 Dip C Local	8	AS 17 AHM 968 Gab C Nyak C2 Local

2.6.6. Farmer managed participatory research trials

Farmer managed participatory research trials are a core activity of participatory plant breeding. It implies that farmers plant trials on their field according to their own practice and experience, which means that no layout, no design and no management practices will be prescribed. In variety evaluation this means that farmers are simply given seed of different varieties with the request to plant them as they used to do with their own crop. The only instructions they had to follow were not to mix of the different accessions, add their own land-race as a comparison and assign each accession an area with similar conditions (soil type, amount of sun/shadow etc.). Each accession should be treated in the same way (day of planting, weeding etc.) and the area, where each accession is planted should be demarcated and noted. Farmers should keep simple records e.g. date of planting, date for major management activities, rainfall, any special observation (e.g. pest).

2.6.6.1. On-farm trials of the North Central FSRE Unit

Activities in the North Central FSRE focus communities were conducted in the 1997/98 and 1998/99 seasons.

Before the planting season, 100 g of seed for each accession were delivered to the Extension Technicians of the focus communities, who delivered them to the host farmers. Evaluation of these on-farm trials was done in two steps:

1. Mid-Season Monitoring Summary

For the mid-season monitoring the members of the FSRE unit were divided in three multidisciplinary groups, of which two groups had to visit three communities, while the third group only visited two communities. All trials and tests in the focus communities should be

visited on site (farmer's field). If possible, other farmers should also join the group and contribute to the discussions. However, in some communities not all sites could be visited, because of the high number and the limited time for the visits and not everywhere other farmers joined the monitoring. Feedback from the monitoring visits was done in form of reports presented at the meetings of the FSRE unit.

2. End-season Evaluation
For the end-season evaluation a different approach than for the mid-season monitoring was followed. It was agreed that the evaluation of tests and trials should be carried out subject related in topic oriented community meetings. Matrix Ranking was used as a participatory evaluation tool for suitable subjects. The subjects were according to the eleven (active: nine) working groups of the FSRE unit. To avoid too many meetings, subjects were combined where possible. As a result of that, it was decided to combine the evaluation of cereal trials and legume tests. The meetings in the six focus communities with legume tests took place between 10 June and 15 July 1998.

Visit of farmer groups to Omahenene Research Station were also a regular feature in the activities of the North Central FSRE unit.

2.6.6.2. On-farm experiments of the 2001/02 and 2002/03 seasons

These trials were planted in the 2001/02 and 2002/03 season in the villages of Ompundja, Iiviyongo and Okahao-Kangala. Seed (100 g of each accession) was distributed to each participating farmer before the start of the rains in early December through the resident Extension Technician. During March the first monitoring visits to participating farmers were conducted to verify and discuss trial establishment. Data such as planting date, area planted and spacing were recorded. During the second monitoring in April quantitative data collection was initiated according to the following protocol:

- each participating farmer receives a note book, pen and 5 plastic bags with zip
- 10 plants of each accessions, next to each other in a randomly selected, uniform area of the experimental plot, are marked during the first monitoring visit with red adhesive tape by project staff
- farmers should harvest the labelled plants according their common practice
- the number of pods for each plant should be counted and recorded in the note book, one page per accession (should the farmer be illiterate, she/he should ask assistance from other family members (e.g. school children)
- pods of all plants of the same accession should be bulked, dried and kept in the plastic bags
- during a meeting at the end of season project staff will weigh the total pod yield of each accessions for each farmer (with a mobile scale), collect the data from the note book and draw a sample of 100 randomly selected pods from each entry for further data collection at the research station

Picture 10. Farmer managed on-farm trial: accessions have been separated by a line of cowpea; in front: plant tagged with red adhesive tape for data collection

With this protocol farmers took over the responsibility of harvesting at the right time and the collection of basic quantitative harvesting data. It also allowed to follow the same post harvest data collection procedures as for the on-station trial and therefore made a direct comparison between on-station and on-farm results possible. Another important advantage was: except the 100 pods, which were taken to the research station, the entire harvest of the trials remained with the farmer and created a feeling of ownership for them.

Beside quantitative data collection, a series of participatory activities ensured the collection of qualitative data. These included:

- semi-structured interviews with participating farmers during the monitoring visits
- a field day at Omahanene Research Station, where farmers from all partner communities participated and exchanged their views, including a cooking session and discussion of the on-station experiment
- a final evaluation meeting in each partner community, where individual experiences from the experiment were discussed in a group

2.7. Overview of computer software used for data analysis and visualization

The results presented have been analysed with a variety of software packages. Statistical software used was STATOGRAPHICS, SIGMA STAT and SPSS. Tables and Figures have been generated with SIGMA STAT, SPSS or MS EXCEL.

3. RESULTS

3.1. Agronomic characterization of germ plasm

The most detailed agronomic characterization of germ plasm was done for the 1995/96 nursery. There were two reasons for this: firstly, it was the start of the program and there was a need to collect as much basic information on Bambara groundnut as possible (because no other information existed) and secondly, the focus of activities in the later years was more on evaluation than description.

Picture 11. Single plant harvest at Omahenene Research Station

For each of the 60 entries of this nursery, all plants from the plot were harvested and post harvest data were recorded individually. A summary of data for the 24 highest yielding and 6 lowest yielding accessions is displayed in table 10. The full set of data for all 60 accessions can be found under Annex 4.

Table 10. Data summary for the top 24 and last 6 ranking accessions (for yield) of the BNON

Acc.-No	Origin	Rank	Yield	%M	Ph	AS	%F	Y/pl	S/P
SB 2-1	SA	1	859	227	15	1.5	70	17.2	0.50
AHM 787	NAM	2	834	220	22	2.0	40	11.4	0.51
AHM 760	NAM	3	812	214	19	1.5	25	12.8	0.33
AHM 968	NAM	4	786	207	18	2.0	15	13.1	0.43
AHM 780	NAM	5	756	199	23	1.0	50	9.9	0.39
KFBN 9501	NAM	6	742	196	19	2.7	5	11.7	0.55
AHM 1125	NAM	7	715	189	12	2.3	40	17.9	0.63
SB 16-5A	SA	8	707	187	19	1.7	40	11.2	0.38
AHM 867	NAM	9	694	183	21	1.2	50	9.9	0.41
SB 19-3	SA	10	629	166	9	2.7	35	21.0	0.65
AS 17	SA	11	627	165	14	2.0	25	13.4	0.66
SB 10-2	SA	12	607	160	15	3.2	50	12.1	0.52
means 1-12			**706**			**2.0**	**37**	**13.5**	**0.50**
AHM 512	NAM	13	605	160	14	1.0	40	8.6	0.42
AHM 1056	NAM	14	598	158	16	1.0	10	11.2	0.42
SB 4-4C	SA	15	555	146	14	1.8	30	11.9	0.44
Swazi-VSA	SA	16	526	139	10	2.2	0	15.8	0.55
S13	SA	17	521	137	10	2.7	25	15.6	0.62
SB 17-1	SA	18	472	125	18	2.7	20	7.9	0.80
SB 4-2	SA	19	450	119	15	3.5	35	9.0	0.45
SB 11-1	SA	20	446	118	12	3.3	10	11.1	0.66
KFBN 9505	NAM	21	440	116	16	1.0	25	8.3	0.44
SB 9-1	SA	22	439	116	14	3.0	30	9.4	0.64
AHM 1064	NAM	23	435	115	21	3.2	10	6.2	0.42
AHM 449	NAM	24	376	99	9	3.3	10	12.5	0.68
means 13-24			**489**			**2.4**	**20**	**10.6**	**0.55**
SB 4-4E	SA	55	109	29	10	2.5	30	3.3	0.42
AS 9	SA	56	100	26	10	3.3	0	3.0	0.31
AS 13	SA	57	76	20	6	4.2	10	3.8	0.52
Potgieter 3	SA	58	76	20	4	2.8	15	5.7	0.34
AS 7	SA	59	68	18	6	3.0	5	3.4	0.47
S4	SA	60	47	12	8	2.5	15	3.5	0.40
means 55-60			**79**			**3.1**	**13**	**3.8**	**0.41**

The high number of accession in the nursery (60) allowed also a statistical analysis of the qualitative and objective (measurable) data. Through a stepwise regression for total yield and yield per plant as dependent variable, a significant influence of pods per plant, plants harvested and seed weight on total yield and pods per plant and seed weight on yield per plant could be determined (see tables 11 and 12). The calculated value yield per plant was not significantly correlated to total seed yield and was therefore not included in the model. As could be expected the factor "plants harvested" fell out after calculation to yield/plant, a data transformation, which did not affect the results for the other yield parameters. This fact plays an important role for the use of (the calculated) yield per plant data for performance comparison of accessions in agronomic evaluation trials, which did due to the differences in harvested plants not generate meaningful results. This measure has therefore been used in evaluation trials, in which significant differences in the number of harvested plants have been detected.

Table 11. Results for stepwise regression for total seed yield

Coefficients(a)

Model		Non-standardized coefficients		Standardized coeffizients	T	Significance
		B	Standard-error	Beta		
1	(Constant)	-12,034	13,802		-,872	,387
	Podplant	6,979	,710	,796	9,831	,000
2	(Constant)	-71,267	10,181		-7,000	,000
	Podplant	5,903	,440	,673	13,430	,000
	Plantsharvested	6,279	,627	,502	10,016	,000
3	(Constant)	-160,287	16,551		-9,684	,000
	Podplant	6,001	,341	,684	17,584	,000
	Plantsharvested	7,323	,515	,585	14,213	,000
	Seedweight	146,032	23,863	,246	6,120	,000

a Dependent variable: Yield

Table 12. Results for stepwise regression for yield/plant

Coefficientc(a)

Model		Non-standardized coefficients		Standardized coeffizients	T	Significance
		B	Standardfehler	Beta		
1	(Constant)	,972	,684		1,421	,161
	Podplant	,450	,035	,863	12,804	,000
2	(Constant)	-7,787	,643		-12,117	,000
	Podplant	,481	,016	,922	30,980	,000
	Seedweight	16,157	1,049	,458	15,404	,000

a Dependent variable: Yieldplant

Looking at the results and the variation of different agronomic traits that are displayed in table 10, grouped according to the origin of the accession (Namibia, South Africa), it was found that Namibian accessions had advantages in total seed yield, plants harvested, yield per plant and pods per plants towards the South African material, which on the other side had an

advantage in seed size. Significant differences between the South African and Namibian accessions were detected with one-factorial ANOVAs for total seed yield and the number of plants harvested. The differences in the number of plants harvested were the cause for the significant differences in seed yield. These differences disappeared, once they have been converted to yield per plant. Shelling percentage was about the same for accessions of both countries. Although it appeared from the results that early flowering could have an influence on yield, no significant influence was found with statistical analysis, neither for the Namibian nor the South African material. Except for pods per plant the variation in the different traits was always higher in the South African accessions than in the Namibian material. The largest variation (average of both origins) was found in seed yield and related to that in pods and yield per plant, the lowest in shelling percentage (for detailed results see Annex 4).

Overall good performing accessions from the nursery, which produced sufficient seed for a replicated trial (marked bold in the table above), were tested in the 1996/97 season in the Bambara groundnut basic variety trial (BBVT).

Data collection from the nurseries, which were planted after 1996, was less sophisticated than for the first nursery. The data recorded were limited to post-harvest data (pod yield, seed yield, and 50 seed weight if number of seeds were sufficient). Only the number of established plants was recorded as data from the field. This reduced data collection resulted from the experiences from the first nursery and a shift in the main emphasis from descriptive to evaluating activities. Therefore only yield and seed size determined in future, which one from the accessions screened would be taken to evaluation trials.

3.2. Single plant selection as breeding strategy and means for genotype purification

3.2.1. 1. Selection

The first selection was carried out from the 19995/96 nursery and landraces comparison trial. 1561 plants were harvested one by one and post-harvest data (number of pods, pod weight, seed weight) were recorded for each plant individually. After recording the data the plants were assigned to eight categories.

The grading results from the nursery for all accessions, which produced Grade I and II plants, are shown in table 13.

Table 13. Grading table for single-harvested plants of selected varieties of the BNON (figures are the number of plants in a category)

Acc.-No	I	II	III	IV	V	VI	VII	Reserve	Rest
AHM 1104	**2**					1			3
AHM 201 B		**1**			1	1			11
AHM 449	**1**	**1**			3	1			3
AHM 867		**1**	2					3	9
AHM 1064		**1**				2		1	10
AHM 787		**2**	1		3	3			8
KFBN 9501	**1**	**1**	1	1	2	4			7
AHM 1056	**1**	**1**			1	1	1		11
AS 17	**1**	**2**	1	1	3				3
29 SB 16-5 B		**1**	1		1				7
SB 7-1B		**1**				1			5
SB 11-5	**1**				1				4
SB 2-1		**1**	4			2		1	7
SB 10-2		**1**	3		1	2	1		3
SB 17-1 B	**1**	**1**		2					2
SB 11-1	**2**	**1**			1	1			5
SB 16-5 A	**1**	**3**	1	2	1	1			3
SB 9-1		**1**	1		3				5
Swazi VSA		**1**	1		1	5			2
SB 19-3		**4**			2				3
SB 13		**3**	1		1	1			3

The same grading exercise was done for the plants from the land races comparison trial. The summary of results for each of the 12 entries is shown in table 14 (all three replications combined).

Table 14. Grading table for single-harvested plants of selected varieties of the 1995/96 BLCT (figures are the number of plants in a category)

Acc.-No	I	II	III	IV	V	VI	VII	Reserve	Rest
AHM 760		**1**	7		1	9	5	9	60
AHM 201 B	**1**	**2**	4		5	8		7	51
AHM 787		**1**	3	1	1	6	9	18	56
AHM 780			8		2	10	7	3	51
AHM 753		**1**	4			4	7	5	50
KFBN 9501		**3**	8	1	7	12	3	6	51
KFBN 9502		**2**	1		1	12		3	60
KFBN 9503			1		1	5			21
KFBN 9505	**1**	**3**	1	1		7	1		26
KFBN 9506			1	1		4	1		37
Botswana								3	13
Omahenene Local			6	1	2	12	2	3	43

54 plants, 39 from the nursery and 15 from the BLCT, were categorized as grade I or II. These 13 Grade I and 41 Grade II plants were selected as superior lines for progeny testing. The 54 selected plants formed around 3.5 % of the test population. The number of "parents", from which the selected plants originated, was 25.

Seeds from grade III and VII plants (high yield grades) from the nursery and the BLCT were bulked together and accessions, which had sufficient seed in these categories for a replicated trial (marked bold in the two tables above plus AHM 968 and AHM 1125 from table 10 (written in *italic)*, were planted in the 1996/97 season in an improved yield trial (BIYT).

3.2.2. Progeny test of the first selection

A comparison of the selected plants against the parent material (progeny test) was carried out in the 1996/97 season. This is a summary of the findings (for detailed results see Annex 5):

1. 40 pure (selected) lines achieved individually a better pod yield than the parent material, 12 lines had lower yield and 2 lines had poor or no germination. The results for seed size were similar: 35 pure lines were better, 4 the same and 13 worse than the parent material
2. The average pod yield for all parents was 966 kg/ha, for the pure lines 1231 kg/ha, which gives an overall improvement index of 127% (parent average = 100)
3. The average improvement index (selected lines vs. parent lines) for seed size was 110%
4. The best individual result (for yield) had an improvement index of 234% against the parent, the worst result was 51%, for seed size the best result was 230%, the worst 66%
5. The highest yield recorded was 2204 kg/ha unshelled pods, the lowest yield was 498 kg/ha, the highest 100 seed weight was 98g, the lowest 31g

6. The average for the selected material from the same parent line was in 16 cases better than the parent (average improvement index 154%, yield of the parent was 868 kg/ha), in 5 cases less than the parent (84%, 1035 kg/ha) and in 4 cases more or less the same (99%, 1273 kg/ha)

26 out of the 54 selected pure lines showed an improvement of yield **and** seed size towards the parent material.

The best 15 pure lines (with the highest advantage over the parent material) were evaluated in replicated trials in the 1997/98 and 1998/99 season against 5 parent lines. Unfortunately the two seasons had below average rainfall and a poor rainfall distribution. Additional planting mistakes in the 1997/98 trial made harvesting and data collection for that year very difficult. The low yield level (average for the trial was 174 kg/ha) and the planting mistakes led to a high coefficient of variation of 56.5 for the trial. Therefore the statistical analysis did not produce any significant differences between accessions. The results for the top 5 yielding entries should nevertheless be mentioned (table 15), because they are important in the further process (for detailed yield results look Annex 6). The averages are for the three replications (notice the significant drop in yield between KFBN 9713 and KFBN 9501).

Table 15. Five top-yielding entries of the 1997/98 progeny trial for the first selection

Acc.-No.	Average yield/plot [g]	CV for yield	Average seed size [g]	CV for seed size
KFBN 9709 (pure line)	192.6	57.6	0.67	17.4
AS 17 (parent line)	186.4	99.7	0.66	40.5
KFBN 9704 (pure line)	167.0	44.3	0.58	5.0
KFBN 9713 (pure line)	165.2	6.5	0.58	14.4
KFBN 9501 (parent line)	124.4	45.8	0.52	15.7

The high CV in yield for AS 17 resulted from an extraordinary performance in one plot (yield 6.5 times higher as the weakest plot, by far the highest individual plot yield in the trial). It might be interesting to mention that the parent line for KFBN 9709 ranked 6th in yield with 120.9g, while the parent line for KFBN 9704 is the accession on rank 5 (KFBN 9501). The parent line for KFBN 9713 was not included in the trial.

Although the 1998/99 trial did not have planting mistakes, the yield level for the trial was again low (trial average 410.9 kg/ha) due to a severe dry spell in January and February 1999. Again the coefficient of variation was high (35.3), ranging between 10.6 and 61.1 for individual entries. As a result again no significant differences between accessions in regard to yield could be detected after statistical analysis. However, another look at the top five entries revealed some interesting parallels to the previous season (table 16):

Table 16. Five top-yielding entries of the 1998/99 progeny trial for the first selection

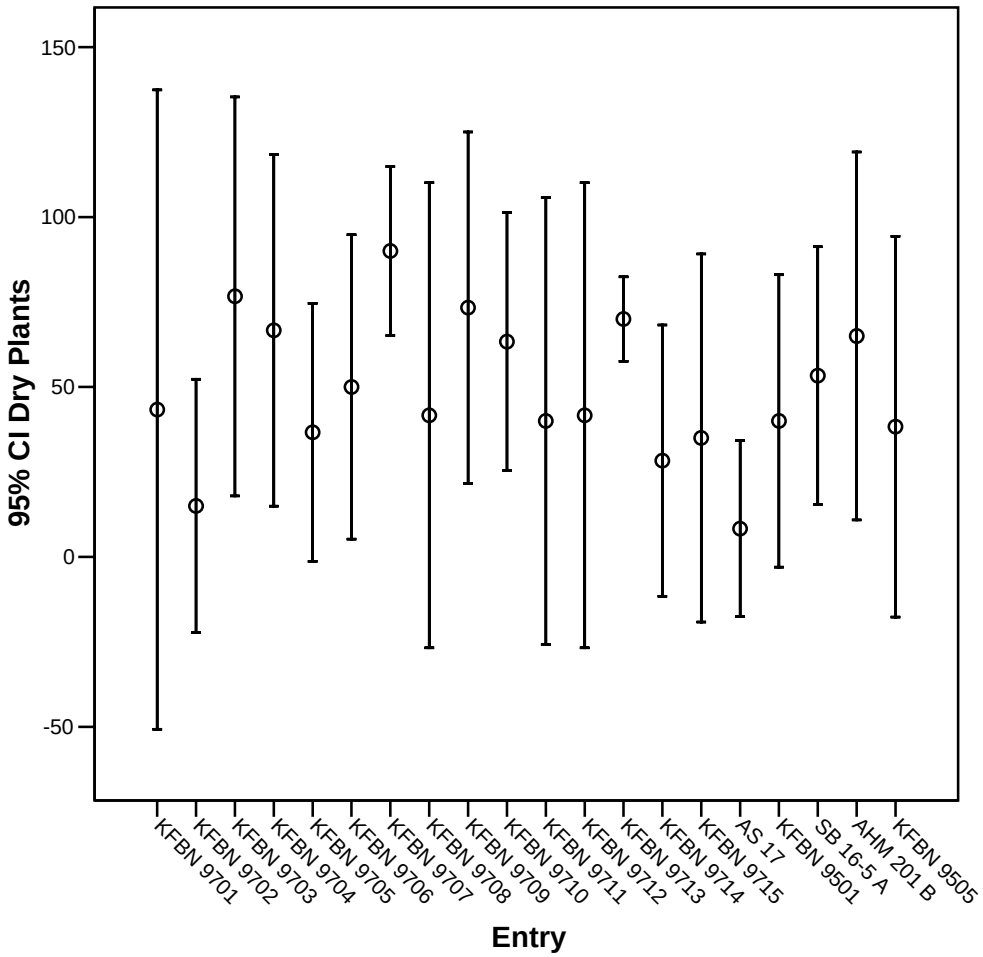
Acc.-No.	Average yield/plot [g]	CV for yield	Average seed size [g]	CV for seed size
KFBN 9713 (pure line)	349.2	37.3	0.53	5.0
KFBN 9704 (pure line)	314.9	43.6	0.63	19.4
KFBN 9709 (pure line)	313.5	42.5	0.66	6.1
KFBN 9703 (pure line)	286.1	15.7	0.58	10.1
KFBN 9707 (pure line)	279.8	18.3	0.52	12.6

The same three pure lines, which made it to the top five in 1997/98, were again found on the top for yield in 1998/99, while the two parent lines from the first trial have dropped out from the top five (6^{th} and 12^{th} rank in 1998/99) and were replaced by two other pure lines (rank 7 and 8 in 1997/98). In this trial the parent line for KFBN 9704 ranked 6^{th} (276.3g) and for KFBN 9709 ranked 10^{th} (250.3g). The detailed yield results can again be found in Annex 7.

The yield advantage of the pure lines KFBN 9704 / KFBN 9709 over their parent lines was in the first trial 34.2% / 59.3% and in the second 14.0% / 25.2% respectively. The results for seed size were less meaningful and indifferent: +12.5%/-10.7% (1.year) and -7.5%/+3.1% (2.year).

An assessment for early maturity (expressed as percentage of plants that were dry [= ready for harvest] 128 DAS) was also carried out in the 1998/99 season. By analysing the data with the SPSS statistical software package, significant differences between accessions in maturity were detected through a one factorial ANOVA. The 4 accessions with >70% of plants dried up 128 days after sowing were KFBN 9707 (90%), KFBN 9703 (76.7%), KFBN 9709 (73.3%) and KFBN 9713 (70%). Figure 3 shoes the error bar for the percentage of plants dried up with the means of entries and least significant difference at 5% error probability. The last entry out of the top yielding entries of the 1998/99 season (KFBN 9704) ranked fifth with 66.7%. Comparing the three pure lines KFBN 9703, KFBN 9704 and KFBN 9709 with the parent material present in the trial (KFBN 9501, AHM 201 B), it could be found that all three selected lines had earlier maturity than their parents.

Figure 3. Error bar for the percentage of plants dried up at 128 DAS with the means and least significant difference at 5% error probability



3.2.3. 2. Selection

25 plants were selected from the 1997/98 progeny trial (from 1754 plants) and 41 plants from the 1998/99 trial (from 2834 plants). From the 1997/98 trial, 19 plants originated from the pure lines of the first selection, 6 lines from the parent material, for the 1998/99 trial, 29 plants came from the pure lines, 12 from the parent material. The detailed results for the second selection can be found in Annex 8.

3.2.4. Progeny test of the second selection

The progeny test for the second selection was carried out in the 2000/01 season. The very untypical bimodal 1999/2000 rainy season with a very high total rainfall for the season seemed not appropriate for the evaluation and therefore it was decided to shift it to the following season. Total rainfall in the 2000/01 season was slightly below average, but with a good distribution of rain for the main growing period (January, February, March).

The progeny test was non-replicated and therefore the results were not analysed statistically. Evaluation was done in the same way as for the first selection. As could be expected (through the genotype purification that took already place with the first single plant selection) the second selection did not reach the same level of improvement than the first selection. From

the 40 test lines, 16 had a >10% better yield than the parent line, 11 showed a difference of ≤10% and 12 lines were considerably (>10%) weaker than their parent. Approximately the same applied for seed size. One test line did not have a parent line in the experiment.

As could be expected for a second generation selection, the overall improvement index for yield (average of selected lines vs. average of parent material) dropped from 127% after the first selection to 115% for the second selection, the index for seed size went down to 102%. Nevertheless, 11 lines were taken after the progeny test to the 2004/05 Bambara groundnut landraces comparison trial considering their performance in the following characteristics:

1. seed size
2. yield/plant
3. seed colour

3.3. Agronomic evaluation of land races on-station

3.3.1. Results of the first phase

The data summary for the first BLCT is shown in table 16. The data have been analysed with the STATGRAPHICS statistical software package. The following abbreviation has been used additionally to those of chapter 3.1.:

CV: Coefficient of variation

Table 16. Post harvest data of the 1995/96 BLCT

Acc.-No	Rank	Yield	%M	CV	AS	%F	Y/pl	S/P	Origin
AHM 787	1	562.5	167	21.3	1.3	52	10.6	0.34	Germplasm.
KFBN 9501	2	553.7	164	19.4	1.7	33	10.9	0.44	Farmer
AHM 760	3	518.7	154	45.0	1.5	37	11.3	0.39	Germplasm
AHM 760	4	515.7	153	29.2	2.9	15	10.0	0.39	Germplasm
Omah. Local	5	420.9	125	37.7	1.7	32	11.0	0.41	Farmer
AHM 753	6	378.9	112	10.4	2.8	27	9.7	0.35	Germplasm
AHM 201 B	7	358.6	106	17.0	2.4	33	8.6	0.42	Germplasm.
KFBN 9502	8	283.3	84	32.7	2.4	23	6.3	0.44	Farmer
KFBN 9505	9	178.1	53	55.3	2.6	18	6.4	0.48	Market
KFBN 9506	10	151.9	45	34.5	3.3	15	6.4	0.38	Market
KFBN 9503	11	107.6	32	13.3	4.1	17	7.4	0.46	Market
Botswana	12	24.2	7	42.2	3.8	10	3	0.51	Extension

Yield mean	337.4
LSD 5%	176.8
LSD 1%	239.4
SED	85.8

Despite a high CV for some entries (3, 9, 12), statistically significant differences between the accessions occurred. With an error probability of 5% the five top ranking entries and four lowest ranking entries form two homogenous groups which are statistically significant different from each other. Entries 6, 7 and 8 bridge the gap between the two groups, but are closer to the top than to the low ranking entries. It is interesting to note that the low yielding group all belong to the so-called "outside seed" accessions from unknown sources. Increasing yield seemed to be correlated to good agronomic scores and early flowering.

3.3.2. Results of the second phase

Trial data have been analysed using different statistical software packages: for the 1996/97 season STATGRAPHICS, for the next two seasons SIGMA STAT and for the last two seasons SPSS. Tables and graphs have been generated with MS EXCEL. Table 17 and 18 give a summary of yield and 100 seed weight data for the BLCT from 1996/97 to 2000/01. Eight accessions participated continuously in the trial, while some were taken out and replaced with new ones. Because of the high variations in absolute yield from year to year (see column 3), the yield of the accessions has been expressed in the table 17 as a percentage of the trial mean. This allowed a better comparison between the accessions over years. Entries with red figures had over the five season a >10% overall yield advantage, calculated as the mean from the annual % advantages over the trial means of the five seasons. Bold figures indicate an overall advantage between 5 – 10%.

Table 17. Summary of yield data for the 1996/97 to 2000/01 BLCT

Summary of yield data

		Trial mean	AHM 968	AHM 753	ahm760	kfbn9501	sb2-1	ahm512	sb10-2	AS 17	ahm867	ahm1056
blct	00/01	692,4kg/ha	85,1	**89,1**	78,6	91,5	78,6	**105,5**		**107,4**	**103,1**	116,2
blct	99/00	759,5kg/ha	64,2	**119,8**	130,5	72,9	107,9	**102,3**		**81,2**	**116,8**	82,4
blct	98/99	625.7kg/ha	100,3	**97,1**	98,3	96,4	109,5	**117,5**	out	**95,3**	**117,5**	109,2
blct	97/98	512.2kg/ha	109,6	**109,0**	69,7	132,0	101,6	**out**	83,2	**149,3**	**out**	57,8
bbvt/biyt	96/97	949.9kg/ha	133,0	**118,1**	103,7	124,5	95,0	**126,8**	70,8	**109,4**	**106,4**	95,3
		Average	98,4	**106,6**	96,2	103,5	98,5	**113,0**	77,0	**108,5**	**110,9**	92,2

			sb16-5a	s13	sb19-3	sb4-2	ahm787	ahm1125	kfbn9601	kfbn9704	kfbn9709	kfbn9713
blct	00/01	692,4kg/ha	115,2		**94,3**	**92,8**			115,2	108,7	**135,6**	83,0
blct	99/00	759,5kg/ha	80,5	out	**131,4**	**122,7**	out	out	85,7	91,2	**88,4**	121,9
blct	98/99	625.7kg/ha	94,5	82,4	**113,9**	**97,4**	93,3	74,1	103,4	new	**new**	new
blct	97/98	512.2kg/ha	97,3	97,7	**123,4**	**120,1**	85,0	64,3	out			
bbvt/biyt	96/97	949.9kg/ha	95,1	new	**new**	**new**	105,3	103,0	108,0			
		Average	96,5	90,0	**115,7**	**108,2**	94,5	80,5	103,1	100,0	**112.0**	102,5

For seed size the variation was less and therefore the absolute figures could be used (table 18). The five year average for each entry has been calculated (figure under the line) and then put in relation to the overall mean (mean of all five year averages), which has been set as 100. Accessions more than 10% above the overall mean are marked in red, accessions between 5 and 10% over this mean are written in bold figures.

Table 18. Summary of data for 100 seed weight for the 1996/97 to 2000/01 BLCT

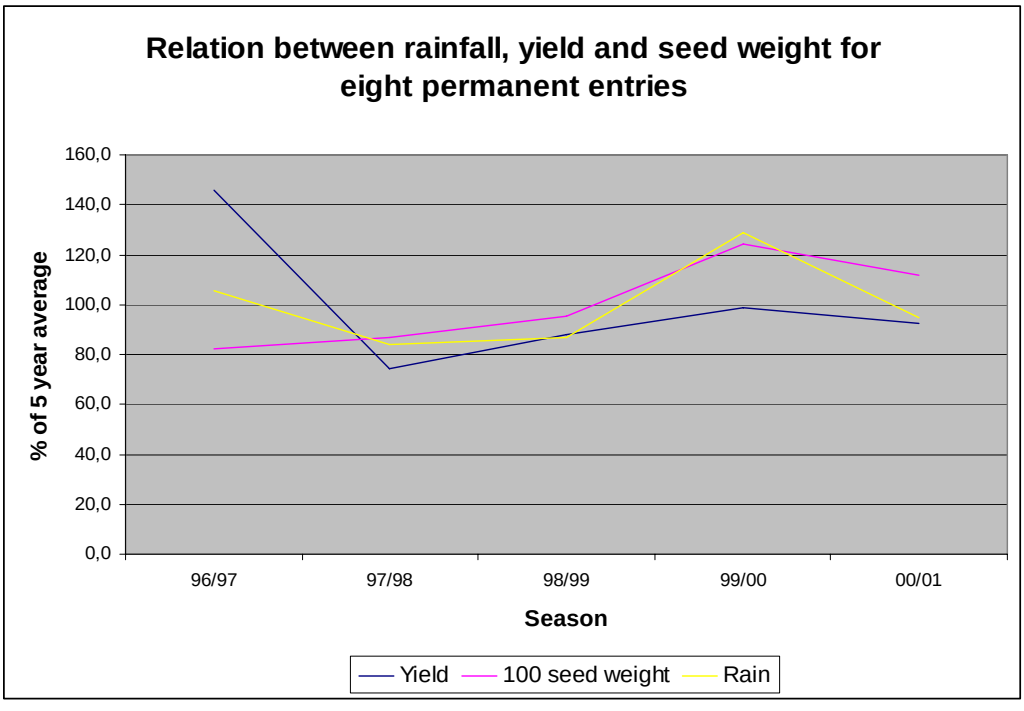
Summary of 100 seed weight

		Trial mean	AHM 968	AHM 753	ahm760	kfbn9501	sb2-1	ahm512	sb10-2	AS 17	ahm867	ahm1056
	00/01	56.9	50,8	47,3	51,8	**60,8**	48,3	**58,3**		**69,8**	54,5	56,0
	99/00	68.5	58,7	57,5	52,2	**80,3**	49	**71,3**		**76,0**	71,2	59,0
blct	98/99	47.4	37,4	39,9	39,9	**53,3**	45,3	**50,4**	out	**68,2**	47,0	43,5
blct	97/98	42.3	35,5	35,7	37,4	**47,6**	38,0	out	35,8	**66,1**	out	43,0
bbvt/biyt	96/97	39.8	34,6	32,2	33,8	**40,6**	35,2	**40,4**	36,6	**63,0**	36,3	45,4
Average (overall 51.9)			43,4	42,5	43,0	**56,5**	43,1	**55,1**	36,2	**68,6**	52,2	49,4
% of overall average			83,6	81,9	82,9	**108,9**	83,1	**106,1**	69,8	**132,2**	100,7	95,1

			sb16-5a	s13	sb19-3	sb4-2	ahm787	ahm1125	kfbn9601	kfbn9704	kfbn9709	kfbn9713
	00/01	56.9	**74,5**		52,0	50,8			**58,8**	**65,8**	**57,3**	**53,5**
	99/00	68.5	**78,8**	out	66,0	63,4	out	out	**77,2**	**84,5**	**81,6**	**69,0**
blct	98/99	47.4	**64,5**	46,6	51,4	50,1	35,7	37,3	**48,4**	**new**	**new**	**new**
blct	97/98	42.3	**52,4**	43,5	41,9	41,3	39,9	34,6				
bbvt/biyt	96/97	39.8	**53,2**	new	new	new	33,1	32,5	**40,9**			
Average (overall 51.9)			**64,7**	45,0	52,8	51,4	36,2	34,8	**56,3**	**75,1**	**69,4**	**61,3**
% of overall average			**124,6**	86,7	101,7	99,0	69,8	67,0	**108,5**	**144,7**	**133,7**	**118,0**

The presence of the same eight accessions over five seasons in the BLCT gave an opportunity to investigate the relationship between seasonal rain fall, yield and seed size of Bambara groundnut (Figure 3). For this the overall mean for yield and seed weight of the eight accessions over five seasons has been calculated and then the annual average (of the eight accessions) was set in relation to this overall average.

Figure 4. Relationship between seasonal rainfall, yield and seed size



Yield basically followed the rainfall pattern. Higher/lower absolute rainfall for a season also meant a higher/lower yield average for the eight entries. Rainfall distribution probably also played a role and is most likely responsible for the extent of the reaction to the absolute rainfall. 100 seed weight reacted slightly different (higher in 1997/98 despite lower absolute rain fall).

Yield data

Statistically significant yield differences between accessions were rare during the second phase and in most cases not conclusive. Table 18 gives an overview of the statistical results:

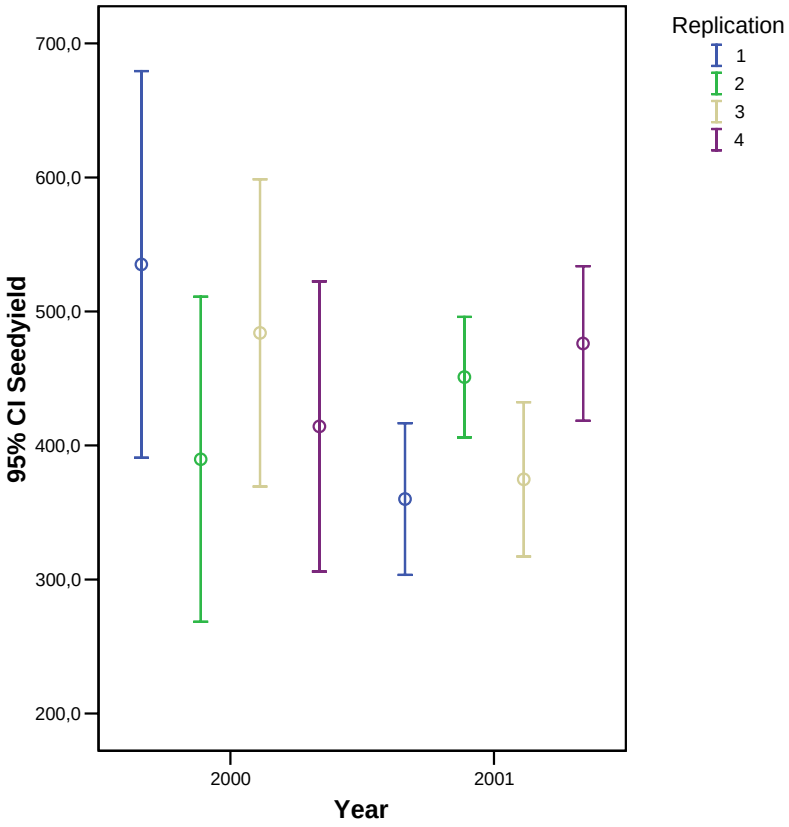
Table 18. Overview of statistical results for yield of 1996/97 to 2000/01 BLCT

Trial and Season	Results of statistical analysis (ANOVA) for seed yield
BBVT 1996/97	*
BIYT 1996/97	n.s.
BLCT 1997/98	*
BLCT 1998/99	n.s.
BLCT 1999/2K	n.s.
BLCT 2000/01	n.s.

* = significant differences in yield between entries
n.s. = no significant differences

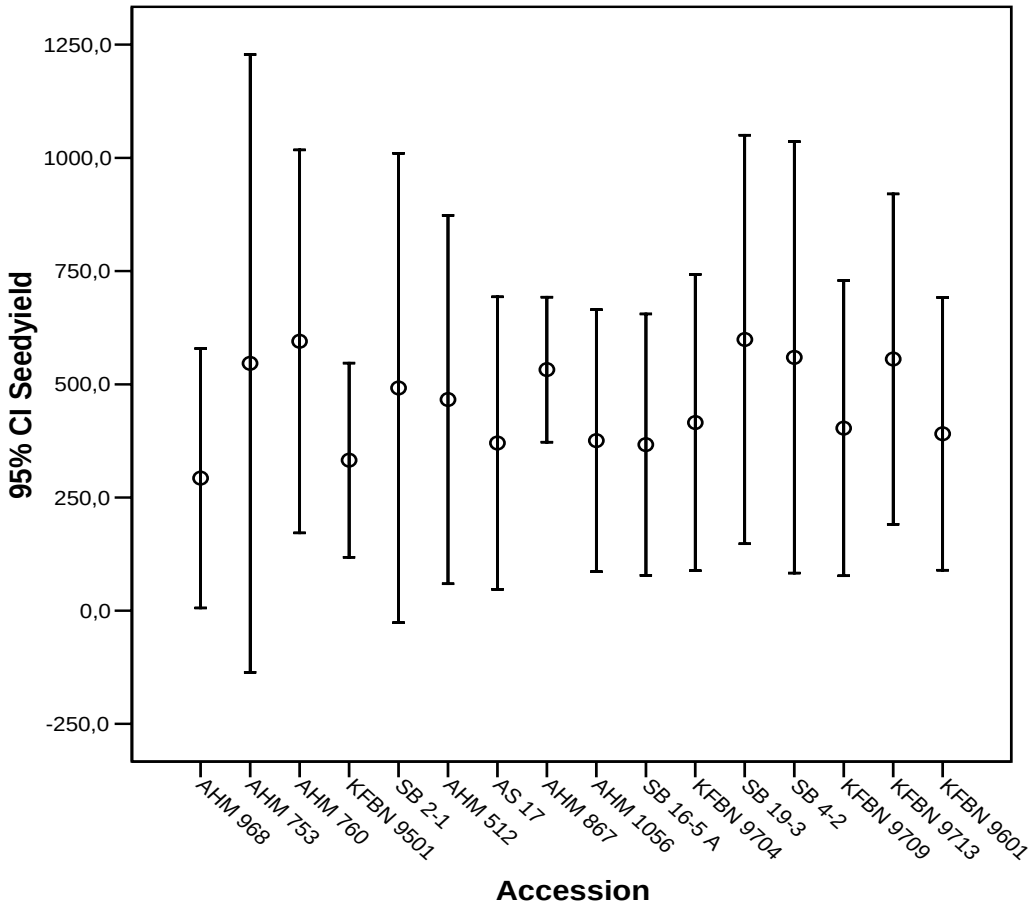
Differences between replications were, although the trial site was shifted three times, in most cases the same or higher than the differences between accessions. An example from the 1999/2000 and 2000/2001 seasons (were all entries of the BLCT have been the same) will demonstrate this. The following error bar diagram (figure 4) shows the means of the replications for these two seasons and their least significant difference (5% error probability)

Figure 5. Comparison of variation of means for replications in the 1999/2K and 2000/01 BLCT



The means of the replications (which should more or less be same) differed in both years with 100 to 150g (= 160 to 250 kg/ha), which was more than 20% of the trial means for these two seasons. This is about the same dimension as the variation of the individual accessions around the trial means. Figure 6, which displays an error bar diagram for seed yield with least significant difference for the means of accessions from the 1999/2000 trial (a trial with no statistically significant yield difference between entries), will serve as an example for the dimension of data variation.

Figure 6. Error bar Figure for seed yield with least significant difference of the mean (5%) of the 1999/2000 BLCT



To assess the yield performance of entries in the second phase with in most cases no statistically significant differences and compare it over a number of seasons, the average yield of an accession in a trial was therefore converted to percentages of the trial means (as they have been used in the summary table in chapter 3.3.2.). An accession with continuous above average performance (value > 100, e.g. AHM 512) was regarded superior in yield compared to an accession with percentages below 100.

100 Seed weight (= seed size)

The second important evaluation factor was seed size, expressed in the 100 seed weight. Here very reliable data were obtained. Coefficients of variation for 100 seed weight were usually below 10 (although a few accessions showed a higher variation in the last years) and in each of the 5 seasons statistically significant differences between the accessions could be detected. Scatter plots of column means with standard error of the mean and error bar diagrams with least significant difference for the means are suitable for descriptive statistical analysis. Two examples are shown in Figure 7 and 8 for the 1997/98 and 2000/2001 season respectively. Because the graphs have been generated from different statistical software packages, they could unfortunately not be uniformly formatted and have to appear in the original layout.

Figure 7. Scatter plot Column means with standard error of the mean for 100 seed weight of the 1997/98 BLCT

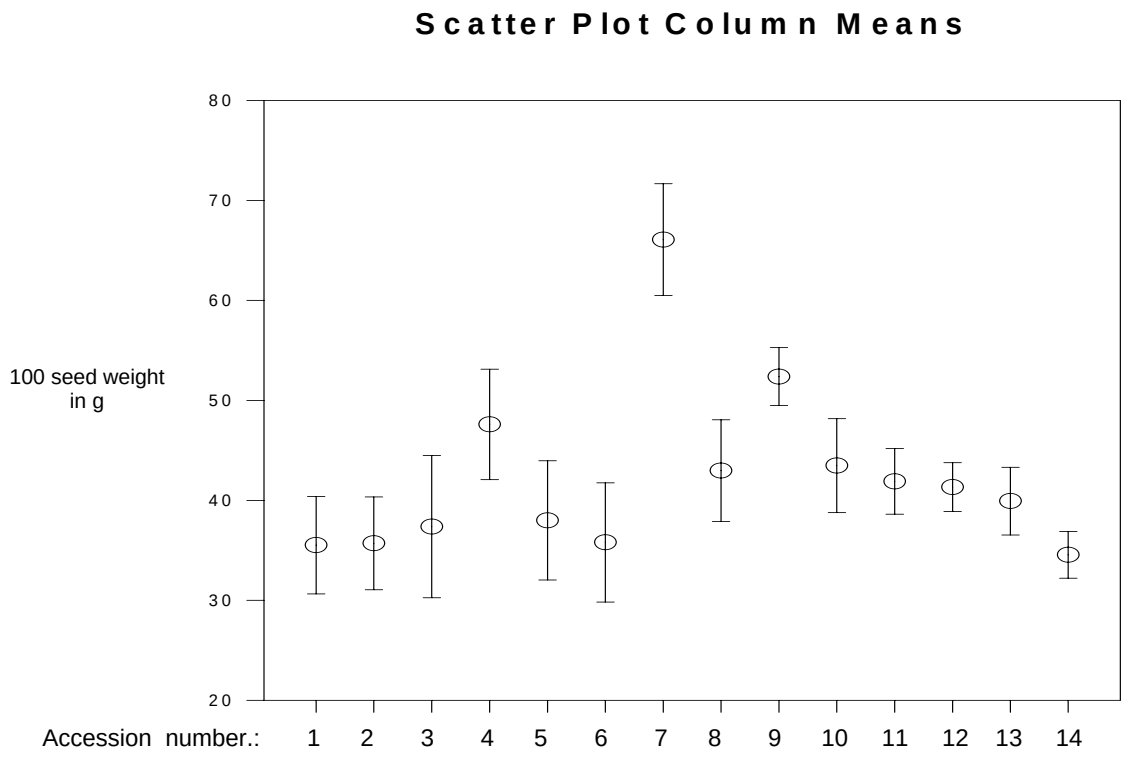
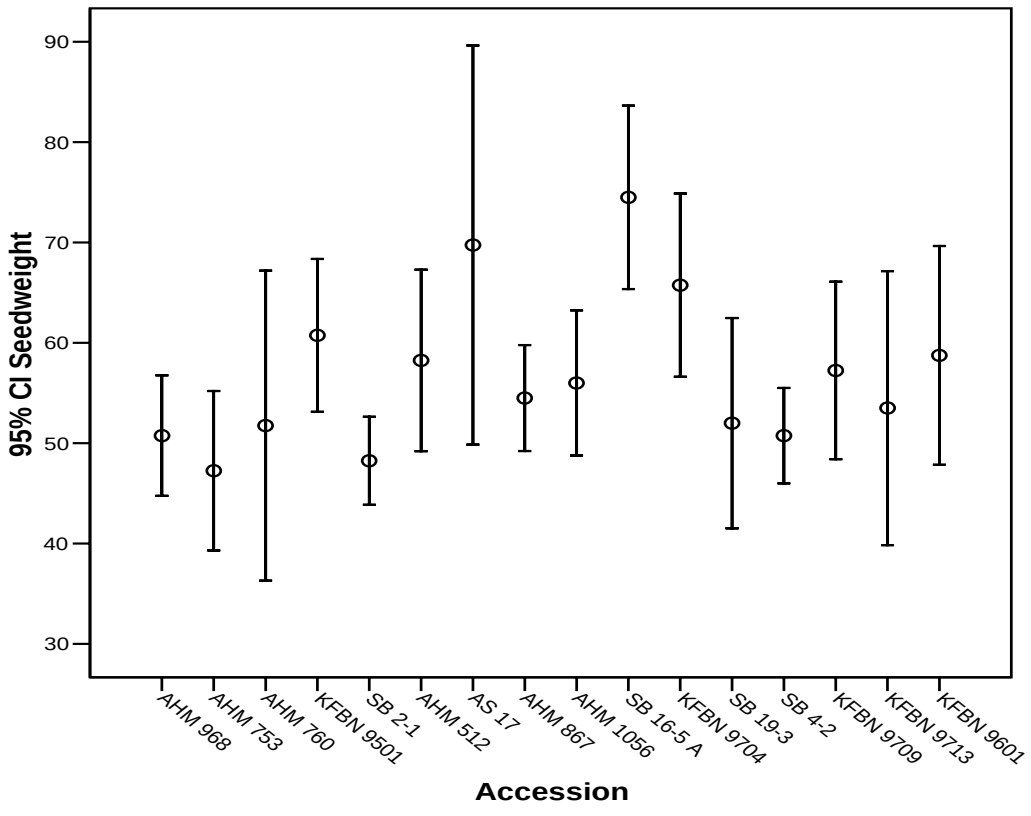
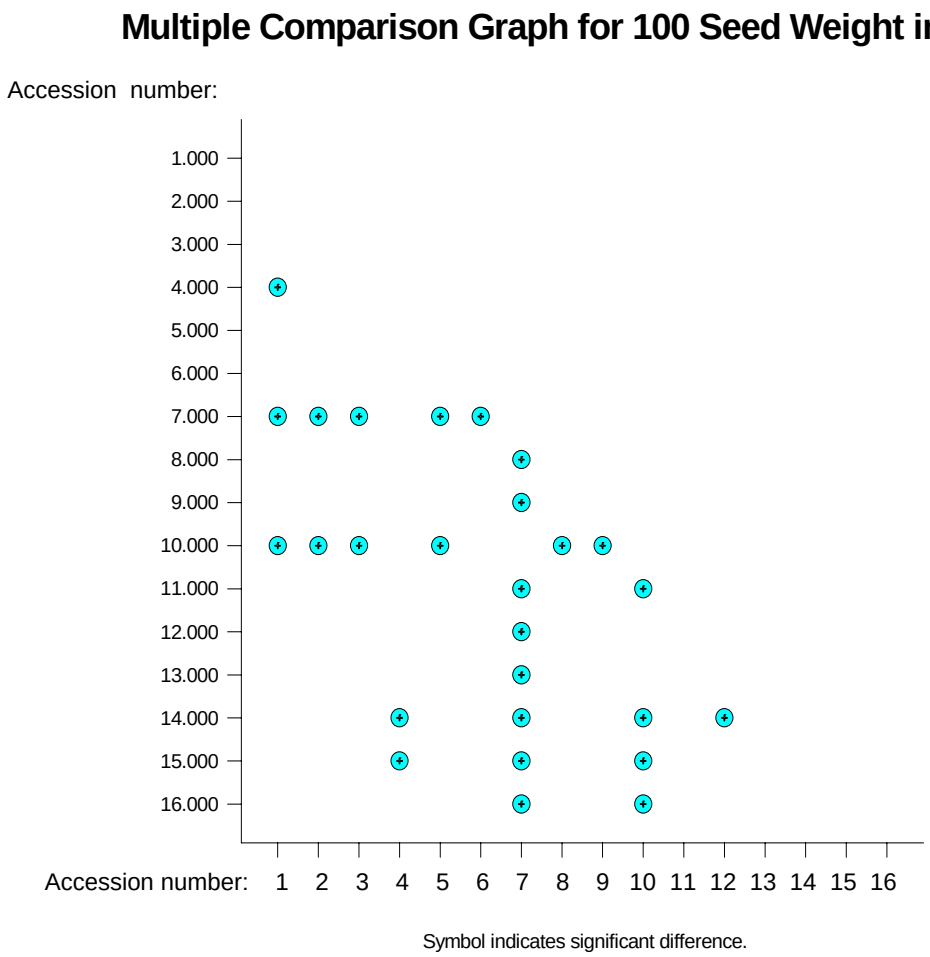


Figure 8. Error bar diagram with least significant difference of the mean (5%) for 100 seed weight of the 2000/2001 BLCT



However, one of the best ways to visualize the significant differences in 100 seed weight among entries in the BLCT was the "multiple comparison graph" feature of the SIGMA STAT statistical software package, of which an example is shown in the figure 9. Drawing a horizontal line from an entry number on the Y-axis and a vertical line from the same entry number on the X-axis, delivers the accessions (marked with symbols), which are significant different from that entry. In the graph entry b7 (AS 17), which had the highest 100 seed weight, had significant bigger seeds than all other entries except b4 and b10. Entry b10 was significant different from 10 other entries.

Figure 9. Multiple Comparison graph for 100 seed weight in the 1998/99 BLCT



3.3.3. Results of the third phase

The third phase generated over the three seasons, in which it was conducted (2000/01, 2001/02, 2002/03) an enormous amount of data, which have not all been analysed in Namibia. It was the most intensive agronomic evaluation, which has, due to the additional resources, so far been carried in Namibia. Parts of the data (especially from the developmental and growth analysis) were used for the modelling exercises conducted by the University of Nottingham. The focus of data analysis in Namibia was on the characteristics of the Bambara groundnut

ideotype as they have been defined through the producer and consumer surveys. The following chapter will give an overview of the data analysis that has been conducted in Namibia.

3.3.3.1. Agronomic traits

3.3.3.1.1. Yield potential of land races for contrasting environments

2000/01 season (1. year of phase 3)

After the collection of all relevant data from the experiment, the yield potential of the accessions and factors that had a possible influence on yield performance have been examined. The results have partly been presented at the BAMFOOD Mid-project Workshop in Swaziland by the project assistants KAULIHOWA and PHILANDER (2001). Average yield data for all entries, calculated to kg/ha at 90% dry matter are summarised in table 19. The average number of pods/plant is found in table 20. A comparison between yield ranking and rankings in yield related agronomic traits has been composed in table 21 and 22.

Table 19. Average yield per entry in kg/ha at 90% dry matter for Omahenene and Mashare in the 2000/01 season

Landraces	AS 17	AHM 968	AHM 753	Gab C	Dip C	OM 1	Swazi Red	Nyak C1	Nyak C2
Seed yield kg/ha at Omahenene	549	720	390	364	603	519	472	308	684
Av. No. of plants harvested	25	27	21	21	26	29	23	23	26
Seed yield kg/ha at Mashare	700	990	1055	968	1070	807	1166	1018	1270
Av. No. of plants harvested	**15**	21	23	24	22	**17**	26	25	26

Table 20. Average number of pods per plant

Landraces	AS 17	AHM 968	AHM 753	GAB C	DIP C	OM 1	SWA ZR	NYA K C1	NYA K C2
Average No.of pods per plant (Omahenene)	17	23	18	15	22	15	17	16	23
Average No.of pods per plant (Mashare)	30	26	49	35	32	29	29	33	44

The number of pods of 10 randomly selected plants from the net plot has been recorded at harvesting. Although differences in the mean values appear to be high, no significant difference between the land races could be found.

Table 21. Comparison of yield ranking with some agronomic trait rankings in Omahenene

Landrace	Yield	Disease tolerance	Number of plants harvested	Pods per plant	100 seed weight
AHM 968	1*	1	2	2	7
NYAK C2	2	3	3	1	3
DIP C	3	2	4	3	2
Significant differences	Yes	Yes	No	No.	Yes

*1 = best performer in the trait

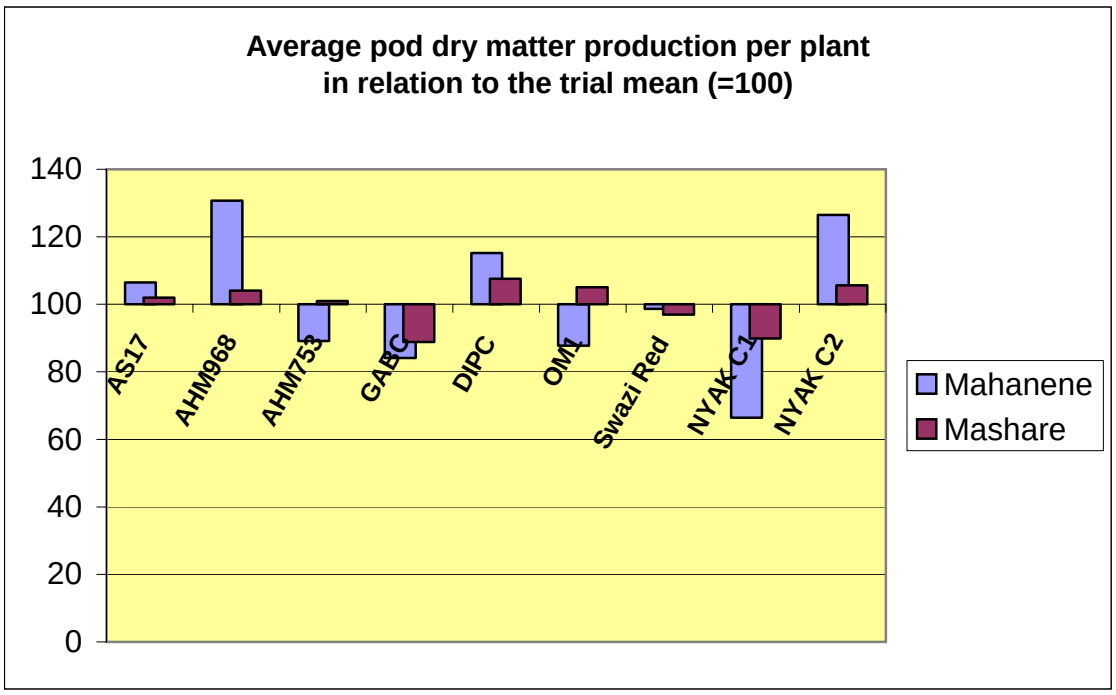
Notable was the relation between yield and a leaf disease scoring. In a statistical analysis it was found that there was indeed a statistically significant correlation between yield and the sum of two disease scorings, carried out during the growth period (see also chapter 3.6.5). Top yielder AHM 968 could compensate the lower 100 seed weight with a higher number of pods and number of plants harvested.

Table 22. Comparison of yield ranking with agronomic trait rankings in Mashare

Landrace	Yield	Disease tolerance	Number of plants harvested	Pods per plant	100 seed weight
NYAK C2	1	2	1	2	5
SWAZR	2	3	1	8	6
DIP C	3	2	5	5	2
Significant differences	Yes	Yes	**Yes**	No	Yes

As in Omahenene there was also a significant correlation between leaf disease scoring and yield in Mashare. A significant difference between entries was also found for the number of plants harvested and therefore disturbed the true yield performance of land races. The effect of plants harvested has been taken out by looking at the pod dry matter production per plant. Comparing pod dry matter production per plant over both locations, it emerges that four land races (AHM 968, Dip C, Nyak C2, AS 17) have been performing above average in both location. Two entries (Gab C, Nyak C1) performed twice below average (figure 10).

Figure 10. Average pod dry matter production per plant of all accessions in relation to the trial mean



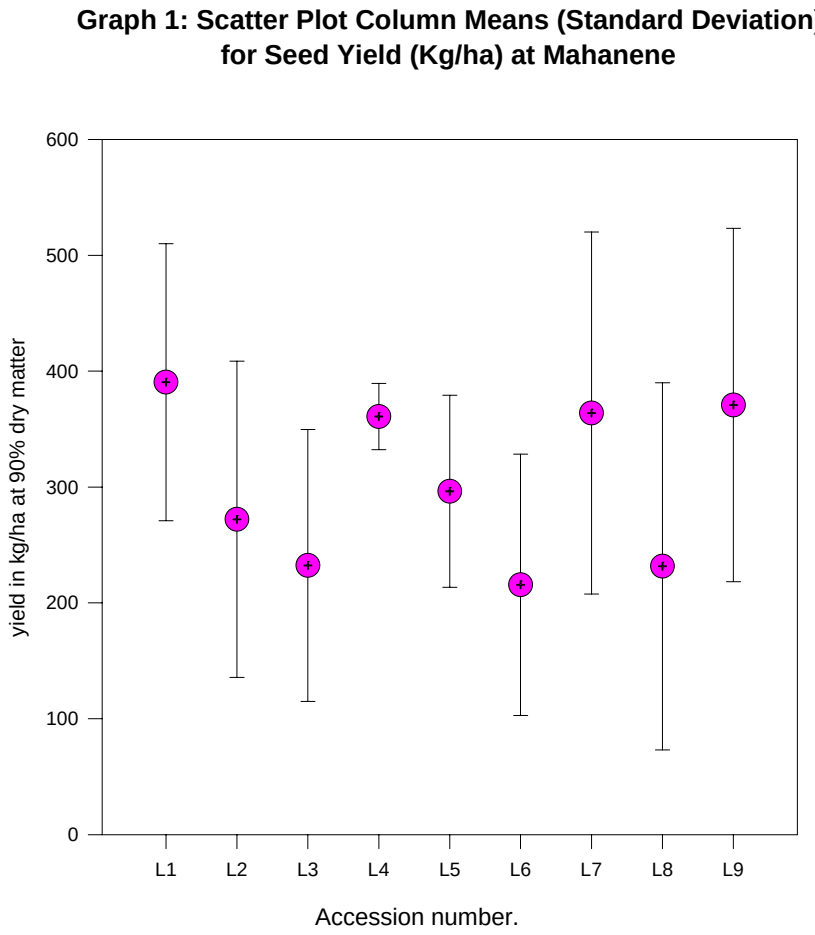
2001/02 season (2. Year of phase 3)

For the second year of phase 3, a serious drop in yield due to a below average rain fall season and an early end of the rains was observed. The trial average in Mashare dropped from 1005 to 215 kg/ha (79%), in Omahenene from 512 to 304 kg/ha (41%) (table 23). The enormous drop in Mashare resulted, however, also from some management mistakes. These results are nevertheless a good example for the seasonal yield fluctuation, which can be experienced in Bambara groundnut. The other issue, as observed many times in the BLCT trials, is the variation and inconsistence of production of accessions (see figure 11 below). No significant yield differences among entries could be found.

Table 23. Average yield per entry in kg/ha at 90% dry matter for Omahenene and Mashare in the 2001/02 season

Landraces	AS 17	AHM 968	AHM 753	Gab C	Dip C	OM 1	Uniswa red	Nyak C1	Nyakc C2
Seed yield kg/ha Omahenene	390.5	272.1	232.4	360.8	296.3	215.6	363.8	231.5	370.7
CV	30.6	50.1	50.5	7.9	28.0	52.3	42.9	68.4	41.1
Seed yield kg/ha Mashare	153.5	207.2	126.4	222.2	276.1	167.1	223.5	273.2	282.3
CV	55.6	33.0	41.7	25.5	28.1	25.9	63.1	32.1	65.8

Figure 11. Scatter plot column means with standard deviation for seed yield in Omahenene in 2001/02



2002/03 season (3. Year of phase 3)

The last season in this phase saw a recovery in rain fall as well as in yield of Bambara groundnut, especially in Omahenene, which had an above average rain season and even a higher average yield than in the first season. The yields in Mashare also recovered but not to the level of the 2000/01 season (table 24). Variation within the results for the same accession was, however, again high and therefore no statistically significant differences in yield could be found again for both locations after the data have been analysed with a two-factorial ANOVA (Tukey; factors: entry, replication)

Table 24. Average yield per entry for the 2002/03 season in kg/ha at 90% dry matter

Landraces	AS 17	AHM 968	AHM 753	GAB C	DIP C	OM 1	Uniswa red	Nyak C1	Nyakc C2
Seed yield kg/ha Omahenene	639.2	575.2	620.2	535.6	522.5	592.5	489.9	453.4	523.2
CV	36.4	19.0	32.7	44.2	30.5	20.0	24.5	40.2	51.1
Seed yield kg/ha Mashare	404.7	424.1	403.5	266.6	327.2	316.6	346.6	255.9	317.1
CV	52.8	32.9	25.3	40.9	39.1	67.9	24.5	18.6	60.2

3.3.3.1.2. Variation of agronomic traits in selected landraces

Germination and emergence

A crucial agronomic trait in crop production in general and for Bambara groundnut in special is germination and plant establishment. Therefore germination and emergence data have been analysed thoroughly in each season of the BAMFOOD experiment, especially in the first season. Before planting the 100 seed weight of each accession was determined. Table 25 shows the results for the 2000/01 experiment:

Table 25. 100 seed weight before planting of seed for accessions of the 2000/01 experiment

Accession	AS 17	AHM 753	AHM 968	Gab C	Dip C	OM 1	Nyak C1	Nyak C2	Uniswa Red
100 seed weight (in g)	75.8	38.7	43.8	63.4	65.5	78.1	56.1	52.3	58.0

For this first season, germination percentages at Omahenene were quite uniform between 75 and just above 90 % with very few significant differences between entries (see figures 12 and 13). At Mashare the picture was different (see figure 15). The two land races with the highest pre-planting 100 seed weight (AS 17, OM 1) had very poor germination percentages there, which resulted in poor plant establishment, a low number of plants harvested and consequently in a low average yield per hectare. Reason for the poor germination was at that time suspected to be insufficient soil moisture for the big seeded varieties OM 1 and AS 17 at planting and a subsequent dry spell.

The following is a detailed presentation of the germination and emergence results for the first season.

Omahenene results

Figure 12. Germination % for the 1.year at Omahenene

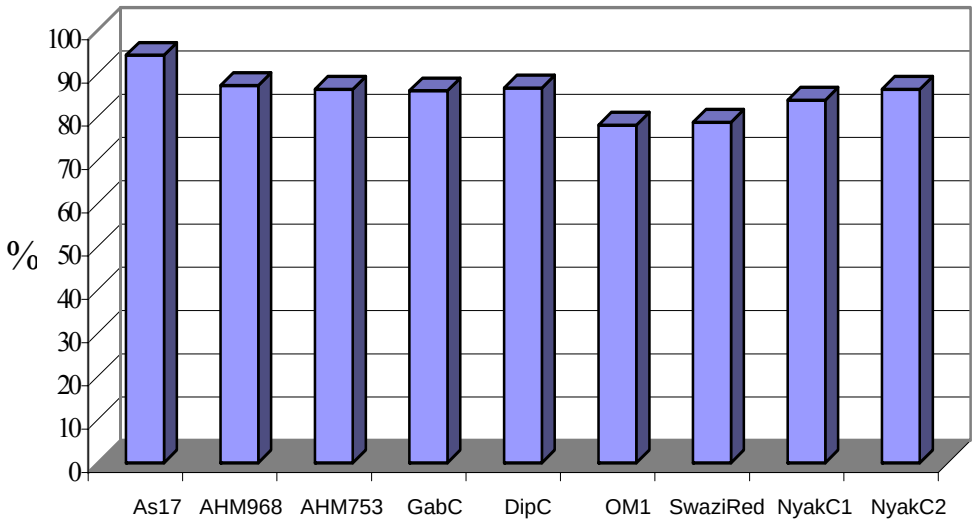
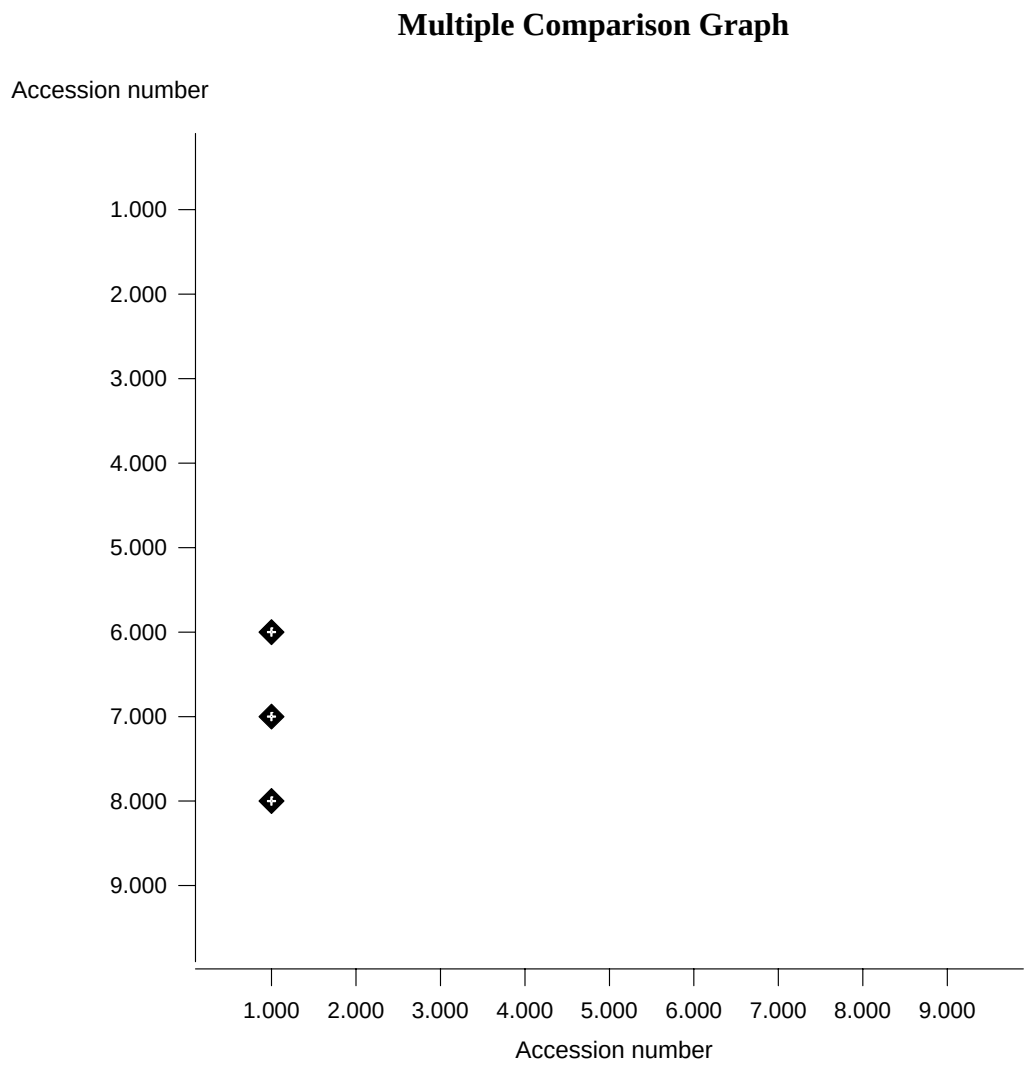


Table 26. Number of days to emergence at Omahenene

Landrace	Entry number	Average no. of days to emergence
AS 17	1	9.8
AHM 968	2	10.4
AHM 753	3	10.5
Gab C	4	9.8
Dip C	5	9.6
OM 1	6	10.3
Uniswa Red	7	10.4
Nyak C1	8	9.8
Nyak C2	9	10.1

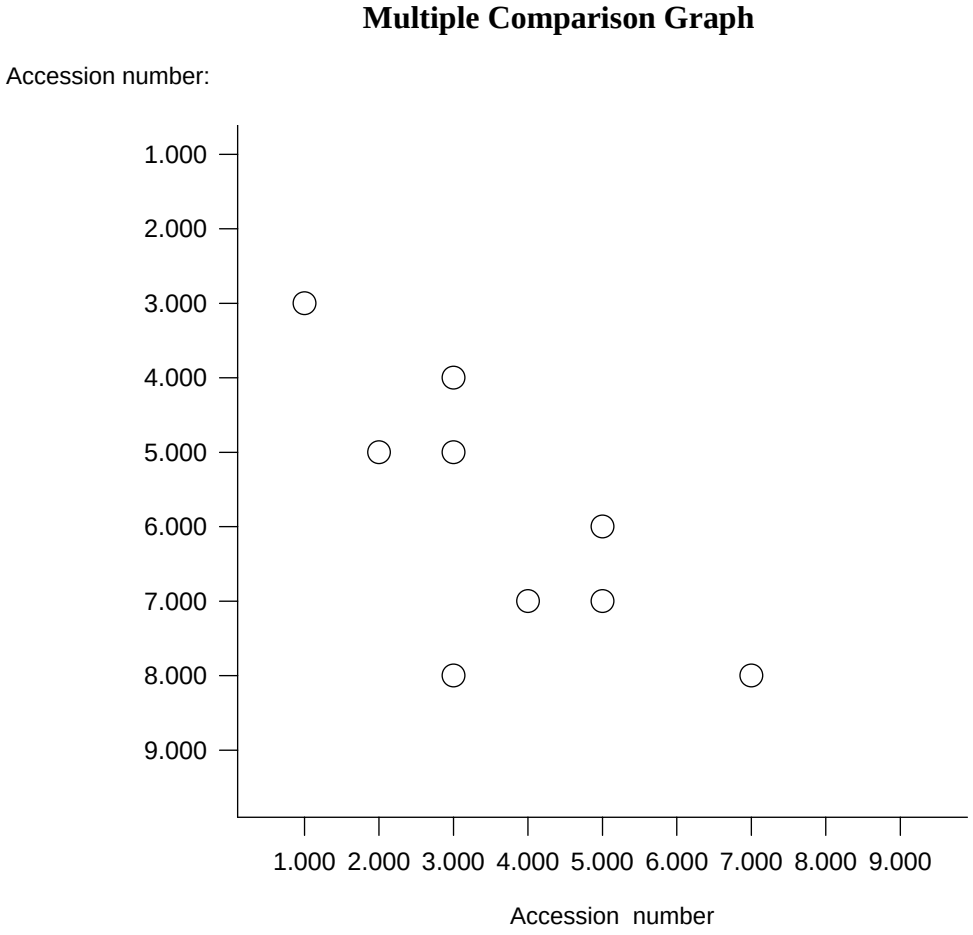
A two way factorial ANOVA has been carried out to determine the significance of the differences for germination percentage between the accessions. There was a statistically significant difference ($p = <0.001$). The multiple comparison graph in figure 13 reveals that only accession 1 (AS 17) had a significant higher germination percentage than accessions 6, 7 and 8.

Figure 13. Multiple Comparison graph for germination % at Omahenene



The average number of days to emergence at Omahenene varied between 9.6 and 10.5 days (see table 26). This is about the same dimension that has been observed in a germination pot experiment two years later. Despite this very narrow window, significant differences (accession $p < 0{,}001$) between entries could be detected with a two factorial (accession, replication) ANOVA. Significant different accessions are displayed in the multiple comparison graph in figure 14. The accession with the lowest average number of days to emergence (entry 5 = Dip C) is significant different from the four accessions (entries 2, 3, 6, and 7) with the longest emergence, while the highest value for entry 3 (= AHM 968) is significant different from the four lowest values (entries 1, 4, 5, and 8).

Figure 14. Multiple comparison graph for number of days to emergence at Omahenene



Mashare results

The summarized germination percentages for the first BAMFOOD season at Mashare have been summarized in Figure 15. As already mentioned, germination at Mashare was more variable and especially the big-seeded accessions AS 17 and OM 1 had a low germination percentage (figure 15). Emergence at Mashare took in average 5 days longer than in Omahenene. The results for the individual accessions were almost contrary to the results from Omahenene with Dip C, Gab C, AS 17 and Nyak C1, which were the fasted emerging accessions in Omahenene, being in Mashare among the slowest (see table 27).

Figure 15. Germination % for the 1. year in Mashare

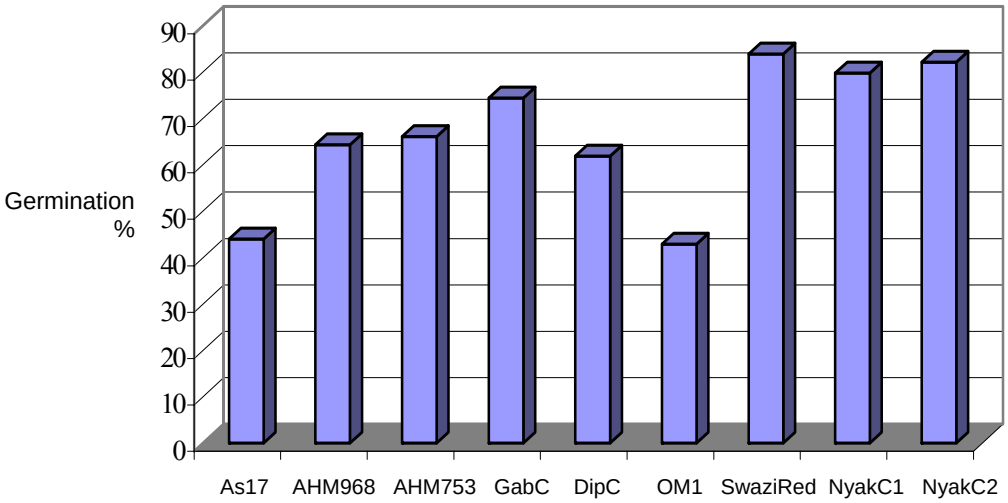
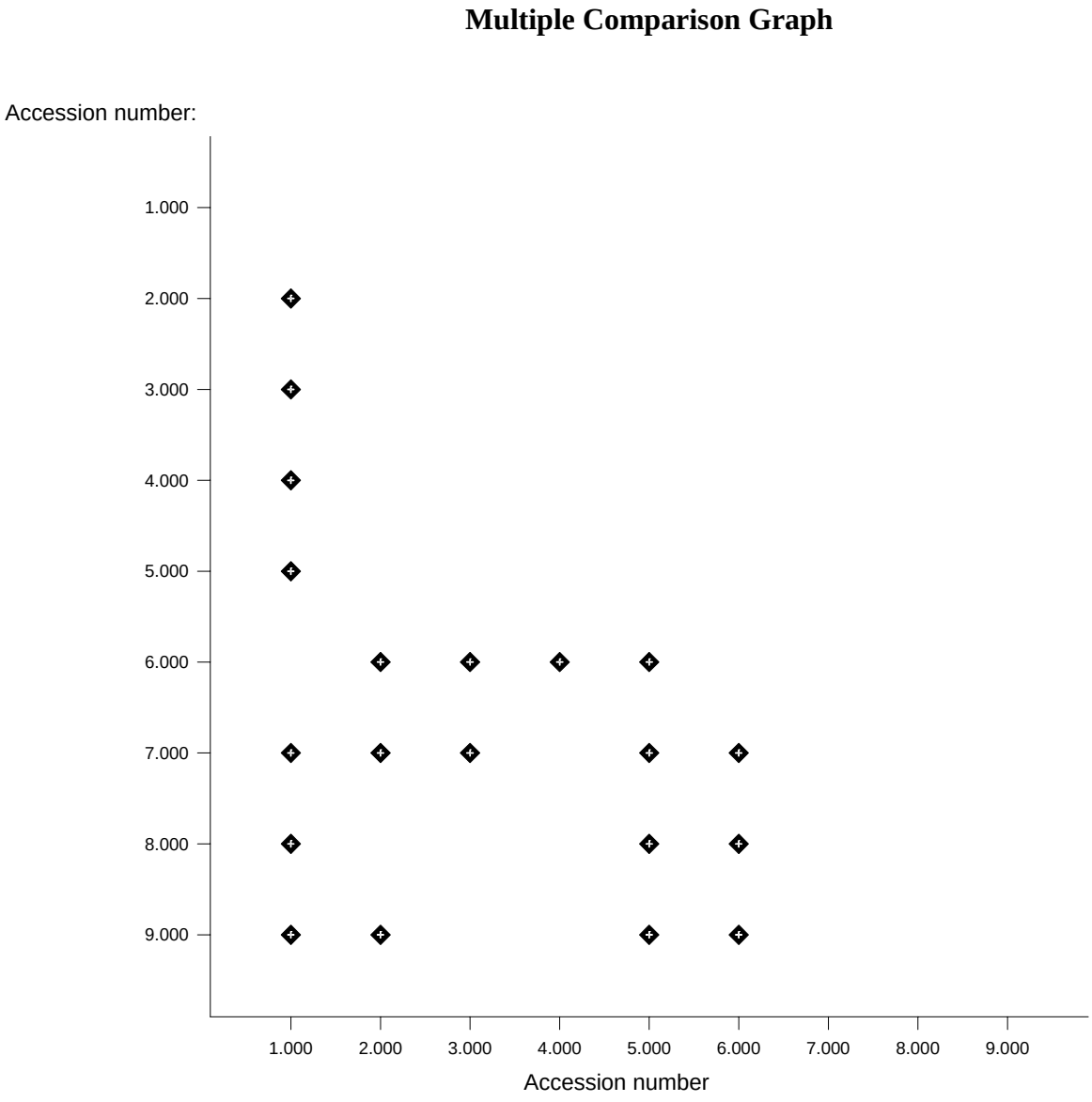


Table 27. Number of days to emergence for Mashare

Landraces	Entry number	Average no. of days to emergence
AS 17	1	15.9
AHM 968	2	14.5
AHM 753	3	15.1
Gab C	4	15.5
Dip C	5	15.5
OM 1	6	15.7
Uniswa R	7	16.3
Nyak C1	8	15.7
Nyak C2	9	14.0

A number of significant differences ($p < 0.001$) in germination percentage for the different accessions at Mashare were detected with a two-factorial (accession, replication) ANOVA and are shown in the multiple comparison graph in Figure 16. The statistical analysis for the days to emergence showed that there were no differences among accessions in regard to days to emergence.

Figure 16. Multiple comparison graph for germination % at Mashare.



Statistical analysis of the germination percentage for the **second season** of the third phase showed that the data were not normal distributed and equal variance testing also failed at both locations. However, despite that, a two-factorial ANOVA was conducted and statistically significant differences between entries (Tukey) occurred in Omahenene as well as Mashare. While in Omahenene only Dip C had a significant lower germination percentage than AHM 753, AHM 968 and Uniswa Red, in Mashare AHM 753 and Uniswa Red were significant better than five other land races (AS 17, Dip C, OM 1, Nyak C1, Nyak C2). However, at Mashare the influence of the replication and the interaction between entry and replication also had a highly significant influence on the germination percentage.

Emergence at Omahenene (9.8 days) was in average ca. 8 days faster than in Mashare (18.1 days). No statistically significant differences were observed between entries at Omahenene, while highly significant differences between entries occurred in Mashare. Uniswa Red and

Nyak C2 had significant faster emergence than AS 17, Dip C, OM 1, and Nyak C1. However, as with germination percentage, the replication and the interaction between replication and entry again had highly significant influence on the duration of emergence. Again data failed the equal variance test in both locations. However, data passed the normality test at Omahenene. It was also noted that replication 4 at Mashare had a significant longer duration of emergence than the other replications.

Statistical analysis of the germination percentages in the **third and last season** of this phase showed that there was not a statistically significant difference between the accessions at both locations in 2003. Germination percentage was lower at Omahenene (lowest for AHM 753 with 52.4 %, highest for Gab C with 63.7) than in Mashare (lowest for AS 17 with 68.9 %, highest again for Gab C with 83.5 %).

An analysis on how long entries needed to establish 50 % and 90 % of the total number of emerged plants showed that contrary to 2002, emergence took longer at Omahenene (19.5 days for 50 %, 22.5 days for 90 %) than at Mashare (13 days for 50 % and 16 days for 90 %). The accession, which reached 50 % at Omahenene the fastest, was Nyak C1, while AHM 968, AHM 753 and Uniswa Red were one day slower than the remaining entries. Nyak C2 and AHM 753 were slower than the rest to reach the 90 % mark. At Mashare AHM 753 and Dip C were slower than others at 50 %, while at 90 % AS 17 was fastest and Nyak C1 was slowest compared to the rest of the accessions. All differences between accessions were not statistically significant.

100 seed weight (oven dried)

Seed size (expressed in the 100 seed weight) was another important agronomic trait for the Bambara groundnut ideotype. 100 seed weight was according to the BAMFOOD protocol determined by oven drying a sample of 100 seed for 48-60hrs at 100°C. The mean values of accession for the 2000/01 season are summarized in table 28.

Table 28. 100 seed weight summary for the 2000/01 season

Landraces	AS 17	AHM 968	AHM 753	Gab C	Dip C	OM 1	Uniswa R	Nyak C1	Nyak C2
100 seed weight (g) Mashare	83.5	61.5	48.5	69.7	82.5	76.5	74.3	73.5	75
100 seed weight (g) Omahenene	68.5	47.9	46.7	56.1	63.1	60.1	63.4	55.2	63.4

Contrary to pervious experiences and surprisingly, the statistical analysis only delivered significant differences between accessions in Mashare, but not in Omahenene.

100 seed weight is usually a characteristic where significant differences between accessions can be expected, as variation in this characteristic is not as high as in yield. This was again confirmed in the second season, when results for 100 seed weight were analysed with a two factorial ANOVA (Tukey). Significant differences occurred at both locations, however

results where more impressive in Omahenene, where AS 17 managed to achieve a significant difference towards all other land races except Uniswa Red.

For the last season, 100 seed weight was increased to 200 seed weight. A three factorial ANOVA (Tukey) with the factors location (Omahenene, Mashare), entry and replication showed that AS 17 could achieve a statistically significant difference to all other entries except Uniswa Red. These results are in line with the results from 2002, where AS 17 was also the top performer regarding this characteristic. Uniswa Red was bigger than other entries except OM 1; the varieties with the smallest 200 pod weight were (as in previous years) AHM 968 and AHM 753.

Overall analysis of yield and seed size for phase 3

Because the trial was an identical replication for three years, an ANOVA with the four factors year, location, accession and replications could be performed for all seed yield and seed weight data that have been obtained over the three seasons. The results can be found in tables 29 and 30. As could be expected the only highly significant factor for seed yield was the influence of the experimental year. A minor, but significant influence has also been obtained for the locations in which the trial has been conducted. Seed weight was highly significant influenced by year and accession and not by location confirming previous experiences that seed size can be considered more an accession specific trait than yield performance.

Table 29. Results of all factors ANOVA for seed yield in phase 3

Dependent Variable: Seedyield

Source		Sum of squares typ III	df	Mean of sqares	F	Significance
Constant Term	Hypothesis	51377439,292	1	51377439,292	11,208	,079
	Error	9168147,288	2	4584073,644(a)		
Accession	Hypothesis	461765,550	8	57720,694	1,018	,424
	Error	11401979,780	201	56726,268(b)		
Replication	Hypothesis	180681,597	3	60227,199	1,062	,366
	Error	11401979,780	201	56726,268(b)		
Location	Hypothesis	225131,054	1	225131,054	3,969	,048
	Error	11401979,780	201	56726,268(b)		
Year	Hypothesis	9168147,288	2	4584073,644	80,810	,000
	Error	11401979,780	201	56726,268(b)		

a MS(Year)
b MS(Error)

Table 30. Results of all factors ANOVA for seed size in phase 3

Dependent Variable: Seedweight

Source		Sum of squares typ III	df	Mean od squares	F	Significance
Constant Term	Hypothesis	593692,156	1	593692,156	59,340	,016
	Error	20010,000	2	10005,000(a)		
Accession	Hypothesis	7569,010	8	946,126	9,814	,000
	Error	19377,426	201	96,405(b)		
Replication	Hypothesis	461,319	3	153,773	1,595	,192
	Error	19377,426	201	96,405(b)		
Location	Hypothesis	,409	1	,409	,004	,948
	Error	19377,426	201	96,405(b)		
Year	Hypothesis	20010,000	2	10005,000	103,781	,000
	Error	19377,426	201	96,405(b)		

a MS(Year)
b MS(Error)

3.3.3.2. Developmental analysis

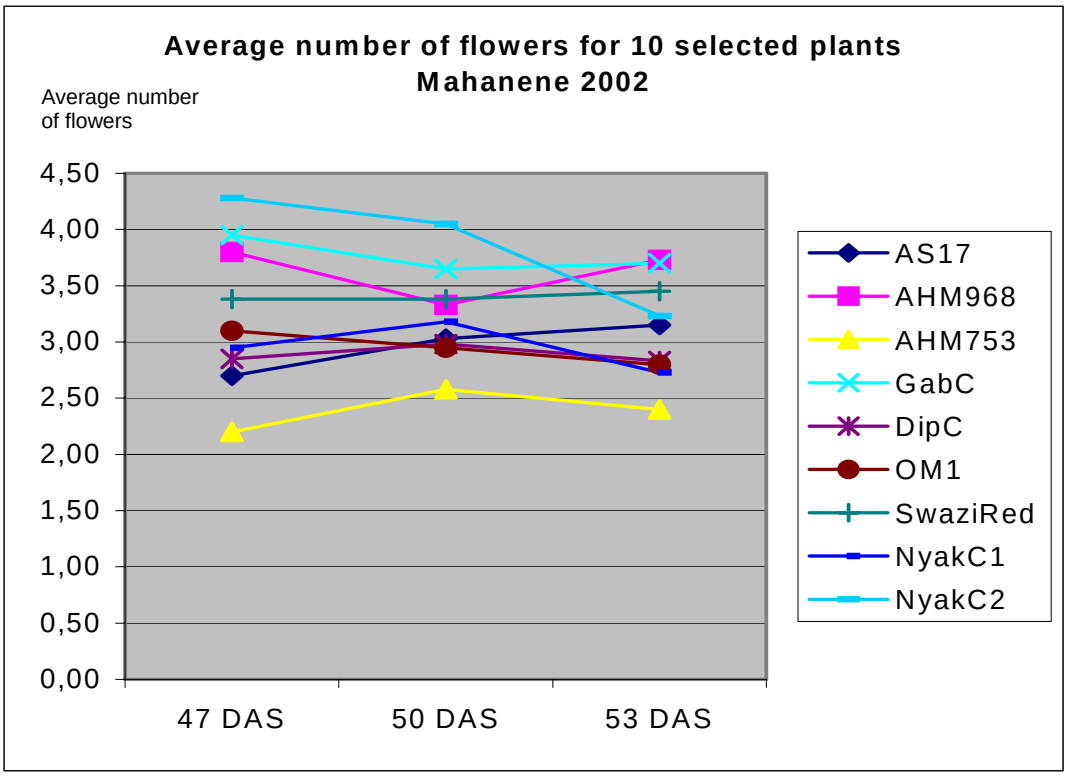
Developmental analysis and growth analysis (next chapter) data have been used to investigate the most important agronomic trait for farmers from the ideotype criteria: early maturity.

As Bambara groundnut is producing its seed below the soil surface, the visual determination of maturity is difficult. Farmers consider Bambara groundnut ready for harvest, once leaves turn yellow and start drying up. To find more objective parameters for maturity, some other, more quantitative assessable characteristics have been investigated e.g. start of flowering and pod dry matter content (which was available from the growth analysis).

Analysis of data from the developmental analysis only started in the second season of the BAMFOOD experiment. From the developmental analysis flower counts were used to make a comparison between accessions. Because of earthing-up, which was done shortly after flowering, only a limited number of dates (3 per season) have been available for analysis. Because of staff problems developmental analysis data from Mashare were of poor quality and have not been considered in the analysis.

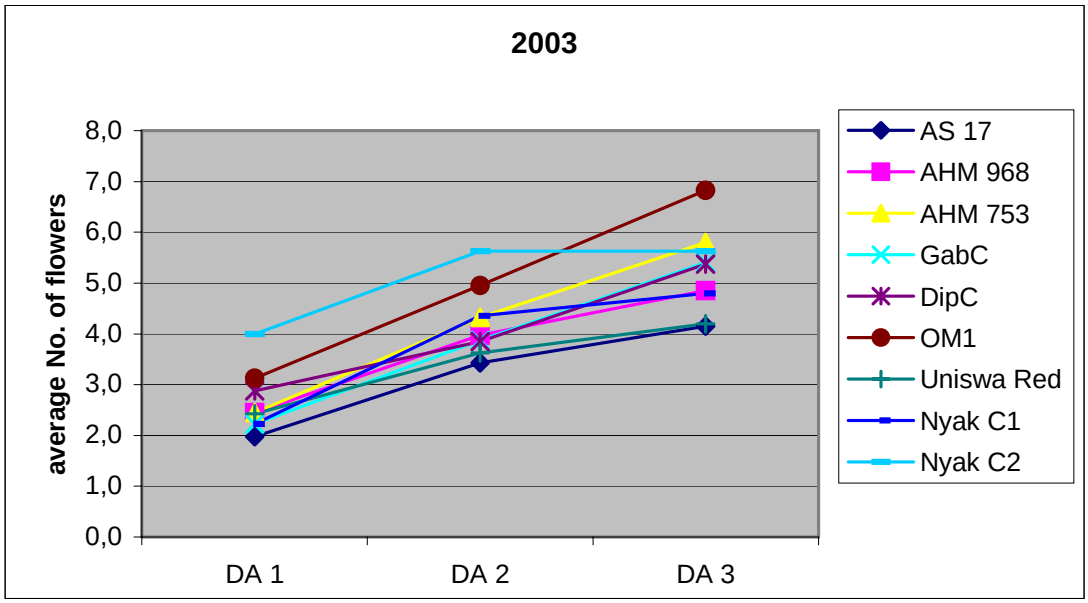
In 2001/02 flowering started quite uniform for all accessions between 43 to 47 days after sowing. However, the average number of flowers varied quite strongly with AHM 753 running at the lowest level, while Nyak C2, AHM 968 and Gab C produced the most flowers (see Figure 17).

Figure 17. Developmental analysis at Mahanene: number of flowers



In 2003 a developmental analysis was again only carried out in Omahenene because no project staff was based at Mashare. Data collection, however, appeared inaccurate (e.g. regarding days after planting) and data should therefore be regarded with caution. Nevertheless, the observation from 2002 that entries do not differ much in the onset and development of flowers seemed to be confirmed, but the number of flowers was higher for all entries. The highest number of flowers was this year recorded for OM 1, the lowest for AS 17. As in 2002, Nyak C2 again had a high number of flowers, but also AHM 753, which, however, had the lowest number of flowers in 2002 (figure 18).

Figure 18. Developmental analysis at Omahenene 2003: number of flowers



Growth Analysis

The growth analysis, which has been carried out during phase 3, gave an opportunity to examine pod development and pod dry matter content as indicators for maturity. Again only data from the second and third year have been used.

Begin of Pod development

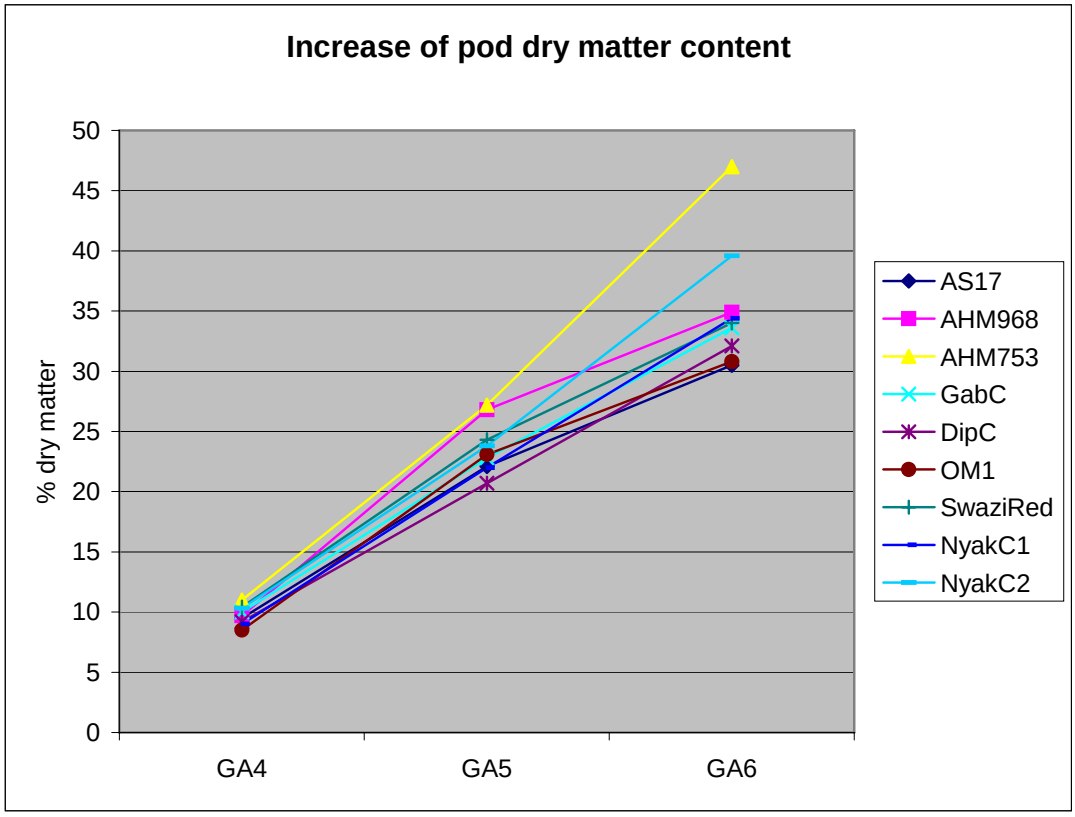
In the second season (2002) suitable data from the growth analysis were only available for the Omahenene experiment. All land races started pod development between growth analysis 3 (53 DAS) and GA 4 (67 DAS). The production of pods at GA 4 (as pod dry matter weight, see next paragraph) differed significantly between entries with OM 1 having the lowest and Swazi Red the highest production at that stage.

As in 2002, all entries were found at Growth analysis 3 (71/72 DAS at Omahenene/Mashare) of the third season to have started with pod production. Pod dry matter production at GA 4 did in this season not differ significantly between entries (see next paragraph).

Increase of pod dry matter content

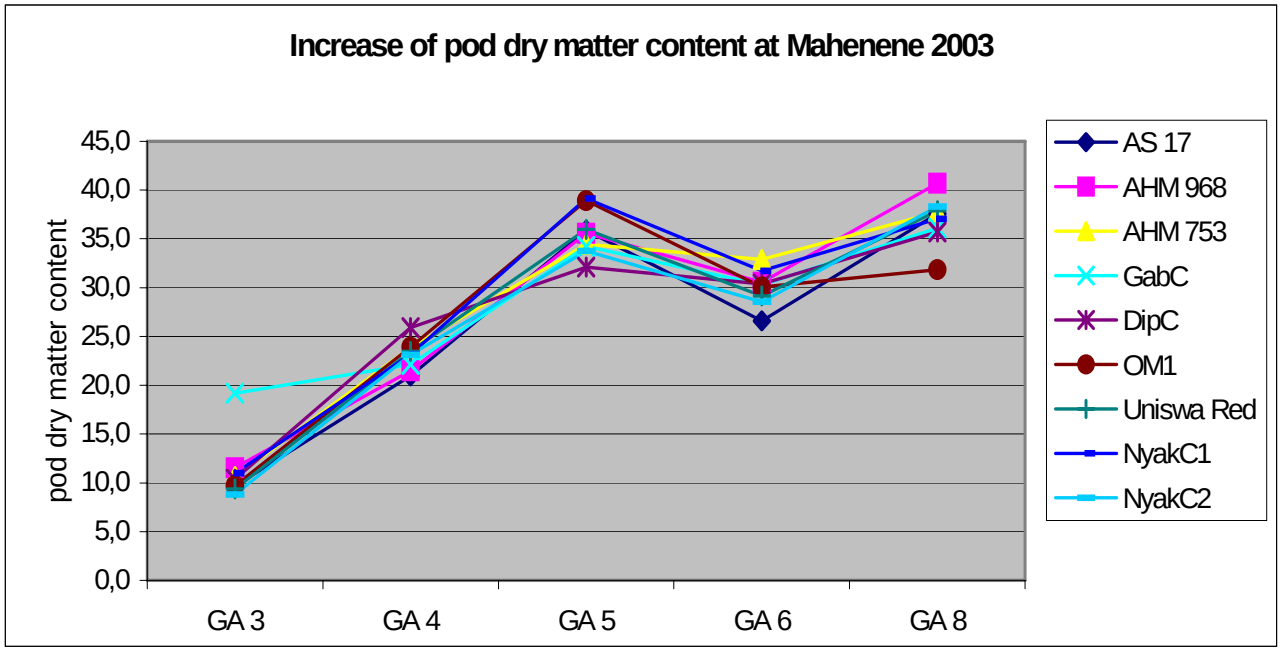
The increase of pod dry matter content with continuing growth has been chosen as another indicator for maturity. In 2002 pod dry matter content at three harvesting dates has been compared (Figure 19). Suitable data were, as for the developmental analysis, again only available for Omahenene. No significant differences between entries occurred at growth analysis 5 (81 DAS), however, at GA 4 (67 DAS) and GA 6 (95 DAS) the ANOVA generated a statistical significant difference ($p = 0.046$; $p = 0.043$). AHM 753 was always the accession with the highest pod dry matter content, while OM 1 had the lowest value at GA 4 and AS 17 at GA 6 (see also Graph 3).

Figure 19. Growth analysis at Omahenene in 2002: development of pod dry matter content



The records for pod dry matter content in 2003 (figure 20) showed that Gab C had the highest dry matter content at GA 3 (no statistically significant difference to other entries), while AHM 968 was the entry with the highest pod dry matter content pod dry matter content at GA 8. OM 1 was the entry with the lowest pod dry matter content at GA 8. Significant differences between the entries could, however, not be found.

Figure 20. Development of Pod dry matter content at Omahenene from GA 3 to GA 8 in year 3



3.3.4. Results of the fourth phase

The BAMFOOD project and the result of the ideotype identification initiated some changes in the last phase. Seed colour and early maturity were added to the existing evaluation criteria yield and seed size. Additionally some accessions from the nurseries and from the BAMFOOD experiment, which revealed potential in these characteristics, were included. Only 4 accessions from the 2000/01 BLCT "survived" this make-over and 11 accessions entered the BLCT for the first time. The characteristics of the four "reference" accessions were:

- KFBN 9709: above average yield and above average seed size during phase 2, early maturity, tan colour
- AS 17: above average yield, above average seed size (!), cream colour
- SB 16-5 A: above average seed size (!), tan colour
- AHM 968: tan colour, early maturity, good performance during phase 3

Due to the transfer of the BGIP leader to another duty station and a prolonged illness during 2003, the 2003/04 trial did not go very well. Staff problems and lack of supervision at Omahenene Research Station contributed to poor trial management. The trial was planted at the beginning of a 21 day dry spell and therefore germination was very poor and unequal. In 8 out of 60 plots no plants germinated, only 19 plots had more than 10 plants (from 32 planted seeds) at harvesting time. The consequences for statistical data analysis can be imagined.

Nevertheless, the results could help to identify accessions, which were able, even under extreme circumstances, to produce yield and therefore other ways of handling and analysing the data had to be found.

Table 31 shows the post-harvest results from the 2003/04 BLCT before and after they have been transformed. One way of transforming the data was by converting the mean values for seed yield of each entry to a percentage of the trial mean (mean for entry/average of trial x 100, column 3) as it has already been done for previous trials with a high variation in the data. This was also done for the 100 seed weight data. Another action was to calculate the seed yield per plant for each plot from the seed yield data and the number of harvested plants and from there a mean value for the accession (to compensate for the variable number of plants harvested). Again this was put in relation to the trial average. A third measure was to leave out the data of the three weakest accessions (TVSU 483, KFBN 0301, OM 1), who accounted for all empty plots, for data analysis.

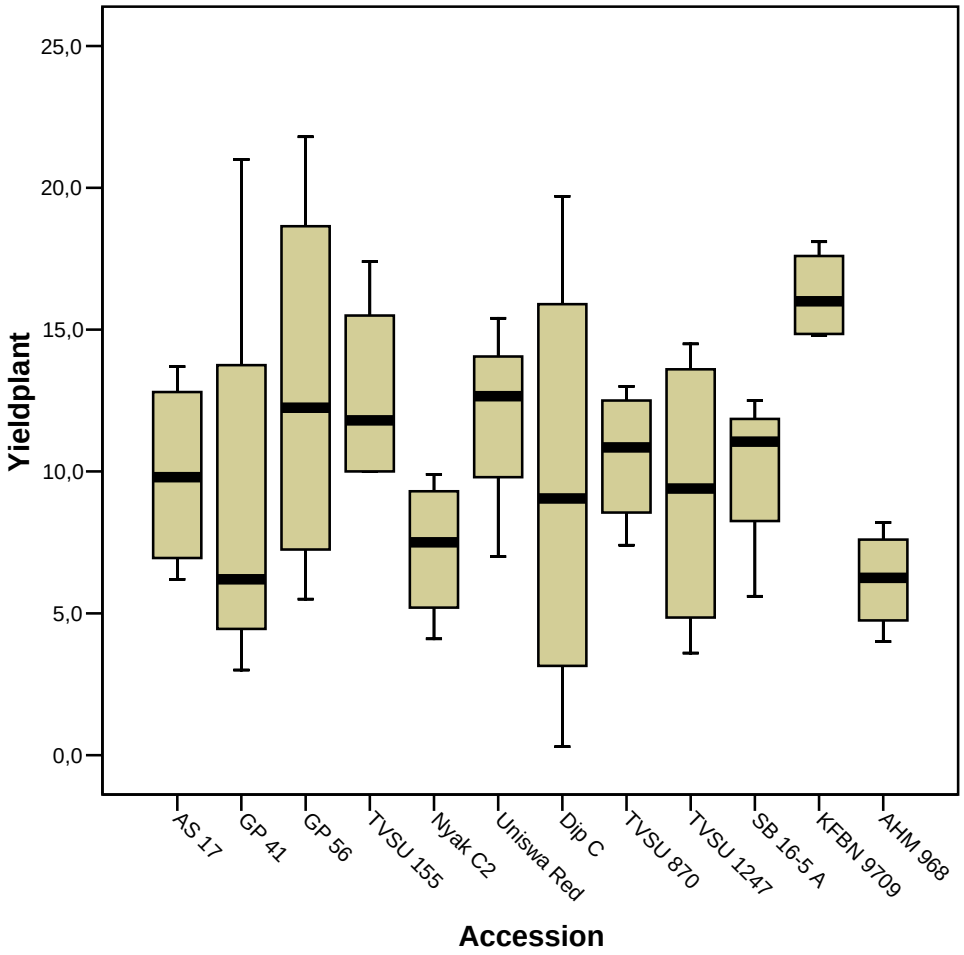
A box plot for yield/plant for the remaining 12 accessions can be found in Figure 21. A two-factorial ANOVA with the factors accession and replication did, however, despite obvious differences (e.g. between KFBN 9709 and AHM 968) not generate a statistical significant result for yield/plant ($p = 0.184$). After conducting another ANOVA with two more accessions excluded (GP 41 and Dip C with a CV >80), yield/plant between the remaining 10 accession (among them the six entries with the highest results for yield/plant), was significant different ($p = 0{,}037$). The results improved further (p for yield/plant = 0,000) after excluding two more accessions (GP 56 and TVSU 1247) with a CV >50).

Table 31. Post harvest data from the BLCT 2003/04

	mean seedyield/plot	% of trial mean	two worst acc. excluded	mean yield/plant	% of trial mean	two worst acc. excluded	100 seed weight	% of trial mean
AS 17	63,8	75,2	70,1	9,9	112,0	97,6	51,0	100,8
GP 41	83,1	97,9	91,3	9,1	103,4	90,1	56,4	111,4
GP 56	39,1	46,1	43,0	12,9	**147,1**	**128,1**	**57,0**	**112,6**
TVSU 483	23,0	27,1	25,3	5,8	65,4	56,9	52,1	102,9
TVSU 155	**121,4**	**143,0**	**133,3**	**12,7**	**144,9**	**126,2**	**56,6**	**111,8**
Nyak C2	66,1	77,9	72,6	7,2	82,1	71,5	37,4	73,9
Uniswa Red	**106,5**	**125,5**	**116,9**	**11,9**	**135,4**	**118,0**	**51,3**	**101,4**
Dip C	103,3	121,7	113,4	9,5	108,0	94,1	50,2	99,1
TVSU 870	**166,5**	**196,1**	**182,8**	**10,5**	**119,7**	**104,3**	**55,2**	**109,1**
TVSU 1247	63,7	75,0	69,9	9,2	104,6	91,2	50,0	98,8
SB 16-5 A	**134,4**	**158,3**	**147,6**	**10,1**	**114,3**	**99,6**	**52,0**	**102,8**
KFBN 0301		0,0		0,0	0,0		no 100 seed	
KFBN 9709	**178,4**	**210,1**	**195,8**	**16,2**	**184,4**	**160,6**	**55,4**	**109,4**
AHM 968	35,5	41,8	38,9	6,2	70,1	61,1	33,0	65,2
OM 1	4,3	5,0		1,4	16,1		no 100 seed	

Accessions in red have achieved above average results in all investigated traits (seed yield, yield/plant, 100 seed weight). The accession in blue was disadvantaged, because only 10 plants have been harvested from all four replication. Taking the yield/harvested plant into account; it belonged to the top-yielding entries. It should be noted that after the 2000/01 BLCT, KFBN 9709 was again the top-yielding accession in 2003/04. This accession was also found among the top-yielding accession of the progeny test trials for the first selection (see chapter 3.2.2.)

Figure 21. Box plot for yield/plant for 12 accessions of the 2003/04 BLCT



By far the top-yielding accession, also in regard to yield/plant was the accession KFBN 9709, which had an average of 16.2 g seed/plant with a low CV of 10.3, indicating a quite uniform performance.

For 100 seed weight only two accessions had a full set of data (4 replications) in the 2003/04 BLCT. 27 plots did not produce enough seeds for the determination of the 100 seed weight. The average of all available data for 100 seed weight was 50.6 gram; the two accessions with a complete data set were TVSU 870 and KFBN 9709. Both accessions were with 55.2 and 55.4 grams respectively about 10% above this average value. A statistical analysis was not carried out.

The 2004/05 BLCT, which will be the last BLCT that will be discussed here, was the largest BLCT ever planted. The two very weak accessions from the 2003/04 trial OM 1 and KFBN 0301 were omitted (they haven't even produced enough seed for another trial) and 11 new accessions from the second single plant selection were included. This brought the number of entries to 24.

This time the trial was planted under the supervision of the leading scientist of the BGIP on 18. January 2005. No dry spell affected the trial, on the contrary, a new record for rain fall in January and further good rains in February provided an excess amount of moisture. But instead of a perfect plant stand, extremely poor plant establishment was observed in many plots of the trial. The investigation of this phenomenon will be reported in chapter 3.6.2. For

the following data analysis all 9 cream seeded accessions have been excluded, because their germination percentage has been below 10% compared to 68% of the other accessions (see also chapter 3.6.2.) and their inclusion would have caused a distortion of the whole analysis. Table 32 therefore shows only the summary of results for the 15 pigmented accessions.

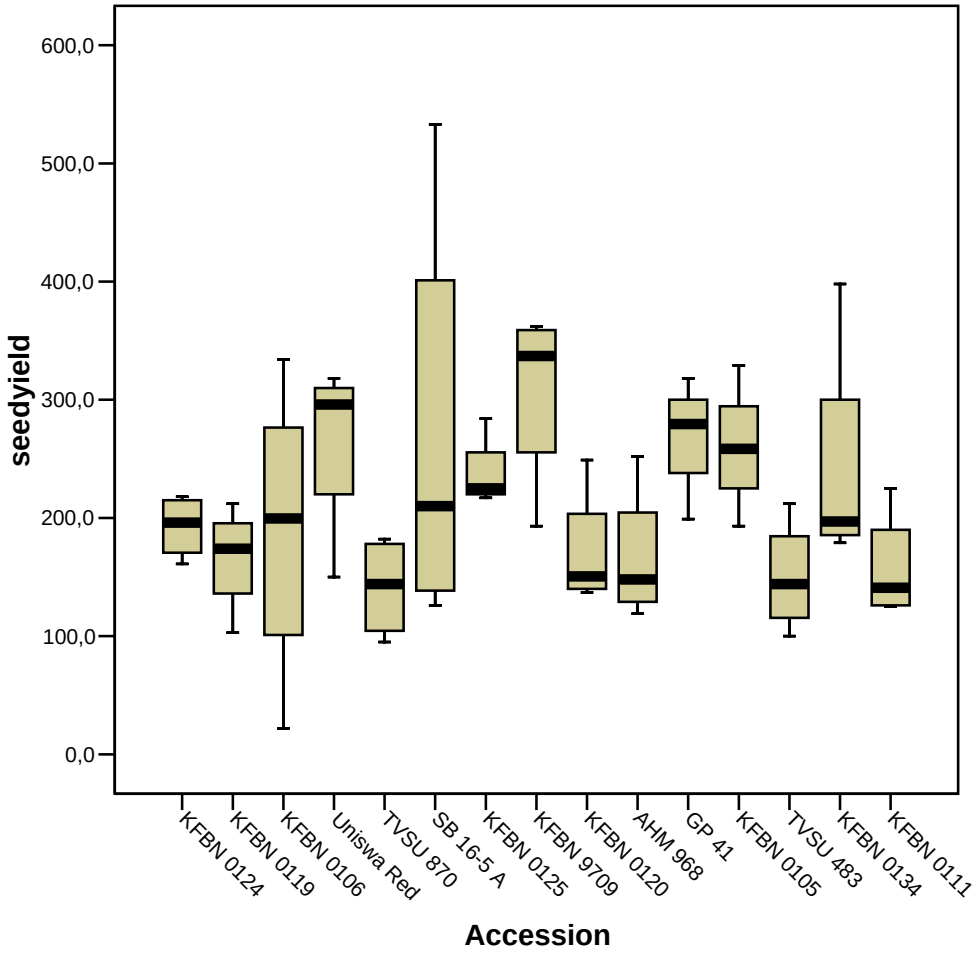
Table 32. Summary of results for 15 pigmented accessions of the 2004/05 BLCT

Accession	Seed yield (g/plot)	yield (kg/ha)	% of mean	CV for yield	100 seed weight	% of mean	CV
KFBN0124	192,8	481,9	90,7	14,0	74,3	95,2	10,5
KFBN0119	165,8	414,4	78,0	27,6	88,5	113,5	7,3
KFBN0106	188,8	471,9	88,9	68,3	82,8	106,1	9,9
UniswaRed	265,0	662,5	124,8	29,3	69,8	89,4	4,6
TVSU870	141,3	353,1	66,5	30,6	78,0	100,0	4,9
SB16-5A	**269,8**	**674,4**	**127,0**	**69,0**	**89,5**	**114,7**	5,5
KFBN0125	**237,8**	**594,4**	**111,9**	**13,1**	**91,0**	**116,7**	9,5
KFBN9709	**307,3**	**768,1**	**144,7**	**25,6**	72,5	92,9	4,1
KFBN0120	171,8	429,4	80,9	30,4	72,0	92,3	11,3
AHM968	166,8	416,9	78,5	35,3	57,8	74,0	10,5
GP41	**269,0**	**672,5**	**126,6**	**18,6**	**79,3**	**101,6**	18,2
KFBN0105	**259,8**	**649,4**	**122,3**	**21,4**	**84,3**	**108,0**	5,3
TVSU483	150,0	375,0	70,6	31,6	75,5	96,8	15,3
KFBN0134	242,8	606,9	114,3	42,8	73,5	94,2	3,2
KFBN0111	158,0	395,0	74,4	29,6	81,8	104,8	13,9
Mean	**212,4**	**531,0**	**100**		**78,0**	**100,0**	

Accessions, which have been marked in red, achieved an above average result in yield and seed size. Beside two original land races (GP 41, SB 16-5 A), two new breeding lines could perform above average. KFBN 9709 (in blue) was again the top performer for yield, but could due to the very high level in 100 seed weight of 78 gram only obtain a good, but below average result in this trait. Remarkable the fact that 4 out of the 5 top yielding accessions also had relatively low coefficients of variation for this trait.

Having a look at the box plot in Figure 22, one immediately discovers the skewness of the yield data of this trial. Only the accessions KFBN 0105 and KFBN 0106 had what could be considered as normal distributed data. However, this time it was not necessary to convert the data to yield/plant or exclude more varieties to receive some significant results, because the number of harvested plants for the pigmented accessions was quite similar. Even with two varieties included, which had a CV above 60 (KFBN 0106, SB 16-5 A), significant differences in yield could be detected through a two factorial ANOVA

Figure 22. Box plot for 15 accessions of the 2004/05 BLCT for seed yield



However, the two-factorial ANOVA with seed yield as dependent variable and accessions and replication as factors produced not only significant differences among accessions ($p = 0.011$), but also between replications ($p = 0.001$) (table 33). As it was already the case for some previous evaluation trials, the replications had a higher significance level than the accessions. This outcome could not even be improved with the elimination of the two entries with a high CV.

Table 33. Results of a two-factorial ANOVA for yield of the 2004/05 trial

Tests der Zwischensubjekteffekte

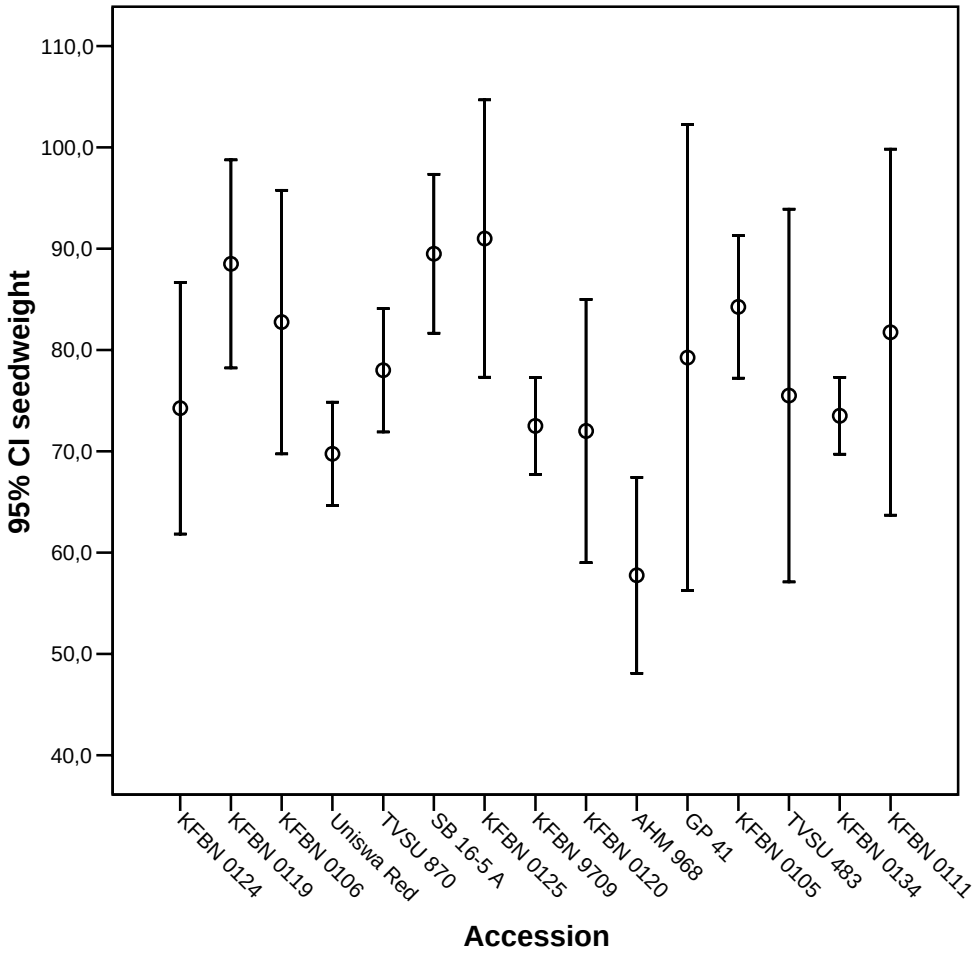
Dependent variable: seedyield

Source	Sum of squares typ III	df	Mean of squares	F	Significance
Corrected model	255735,850(a)	17	15043,285	3,220	,001
Constanter term	2707250,417	1	2707250,417	579,543	,000
Accession	163340,333	14	11667,167	2,498	,011
Replication	92395,517	3	30798,506	6,593	,001
Error	196196,733	42	4671,351		
Total	3159183,000	60			
Corrected total variation	451932,583	59			

a R-Square = ,566 (corrected R-Sqare = ,390)

The variation in the data for 100 seed weight was again low and most entries had a CV around 10 in this characteristic. Only three accession GP 41, TVSU 483 and KFBN 0111) had a CV >13 (maximum was 18.2). Significant differences (p = 0.000) between accessions could be found for this trait through a two factorial ANOVA. The replication had no significant influence (p = 0,572) for this trait.

Figure 23. Error plot diagram (means with standard error) for 100 seed weight



The trial had with 78g the highest overall average for 100 seed weight ever recorded in a BLCT. This was mainly due to the new accessions from the second selection, which entered the BLCT and had an average of 3.9% above the trial mean, while the average of the "old accessions" were 4.4% below the trial mean. The best entry with an average 100 seed weight of 91g was KFBN 0125, one of the new accessions from the second selection.

3.4. Agronomic Investigations

3.4.1. Germination pot experiment

The experiment was designed as an initial test to identify factors influencing germination and emergence of Bambara groundnut. The factors tested were accession, seed size, seed depth, and watering regime. Although 85% of the planted seeds emerged, the 22 missing values for the plants, which have not emerged, made it impossible to analyse the data statistically in a multifactorial ANOVA. However, the following statements could be drawn from the raw data:

- OM 1 and AS 17 needed in average approximately the same time for emergence, 11.1 and 11.2 days respectively, Nyak C2 emerged somewhat faster in 10.5 days (overall average)
- The accessions OM 1 and AS 17 with a poor field germination record achieved with 85.4% a higher germination percentage than Nyak C2 (83.3%)
- The fastest emergence (for all three accessions) happened with 3 cm seed depth, big seeds and daily watering (9.0 days)
- The slowest emergence was also for 3 cm seed depth and big seeds, but for weekly watering (13.9 days)
- The highest germination rate (100% for all three accessions) occurred with 6 cm seed depth, big seeds and daily watering
- The lowest germination rates were found for 3 cm seed depth and small seeds for both watering regimes
- The biggest influencing factor for the days to emergence as the watering regime
- Germination % seemed to be influenced by seed depth and seed size

Through clustering of all results for one factor, table 34 with all factor means for days to emergence and germination percentage could be compiled.

Table 34. Summary of mean values for factors of the germination pot experiment

Factors	Variables	
	Days to emergence	**Germination %**
Accession		
As 17	11.1	84.4
OM 1	11.2	84.4
Nyak C2	10.5	83.3
Seed depth		
3 cm	11.0	75.0
6 cm	10.5	87.5
9 cm	11.4	91.7
Seed size		
Small	10.5	**77.8**
Big	11.4	**91.7**
Watering regime		
daily	**10.3**	84.7
weekly	**11.6**	84.7

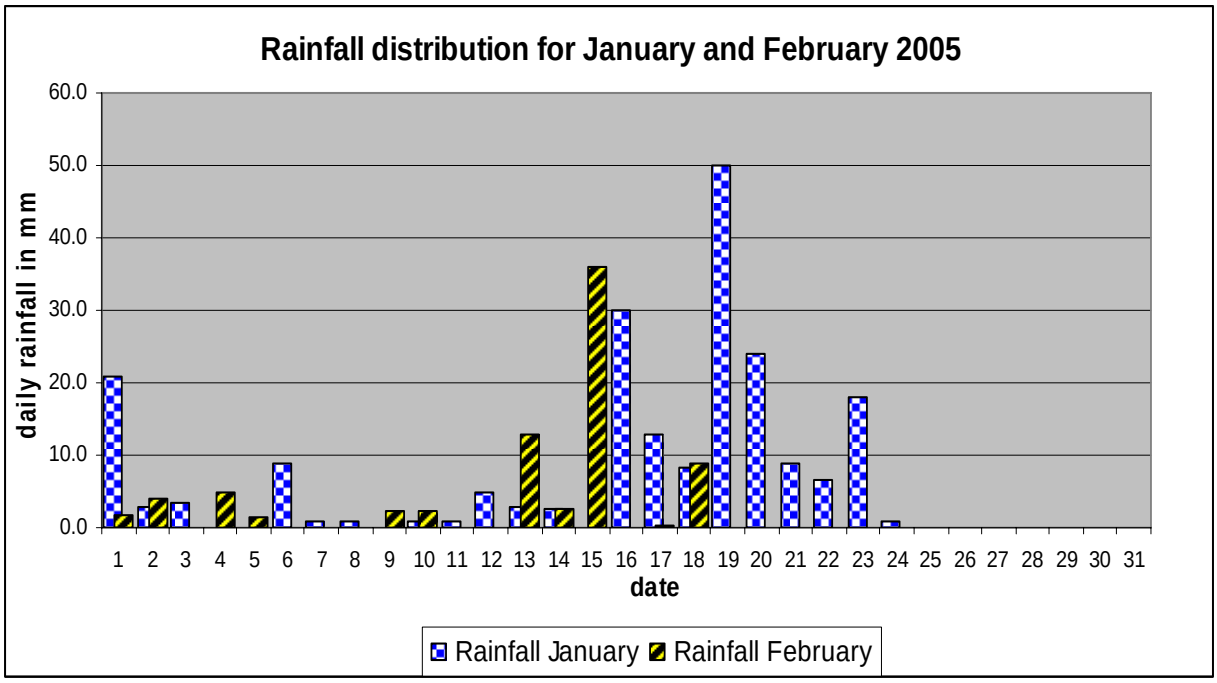
One-factorial ANOVAs were conducted for the mean values of each factor (as displayed in the table above) with the clustered data and significant influence (5% error probability) could be detected for watering regime on days to emergence (blue) and seed size on germination percentage (red), confirming two of the statements above.

3.4.2. Seed colour and germination

The 2004/05 BLCT trial was planted on 18 January 2005 during a period of excessive rainfall, which resulted in a record for this month since 1989. During a visit to the station on 24 February, it was observed that despite the good rainfall, plant establishment in some plots of the Bambara groundnut trial was extremely poor. Germination figures have been recorded for each plot individually and were analyzed to investigate this phenomenon. The rainfall

distribution for January and February 2005 at Omahenene Research Station is shown in Figure 24. The total rainfall for January was 210.7 mm, for February 77.3 mm.

Figure 24. Rainfall distribution for January and February 2005 at Omahenene Research Station



For the three days before planting (18. January) an amount of 51.3 mm rain was received. From planting until the visit to Omahenene on 24 February (36 days), when the germination figures have been recorded, rainfall was noted on 17 days with a total amount of 185.8 mm since the date of planting. The longest dry spell during that period was 7 days, during which the trial was irrigated once to prevent the soil surface from crust formation. It can therefore be concluded that sufficient moisture was available for germination and emergence at all stages. Table 35 and 36 summarize the germination records from the trial. Figure 25 compares the figures for the cream and tan/brown seeded accessions. As expected the difference in the number of emerged plants between cream and tan colored accessions was statistically highly significant.

Table 35. Germination records from the BLCT at Omahenene Research Station (No. of emerged plants out of 32 planted seeds)

Germination figures of BLCT 2004/05

	AS 17	GP 56	TVSU 155	KFBN 0138	KFBN 0116	KFBN 0118	Nyak C2
Rep. 1	4	1	0	1	2	1	1
Rep. 2	3	1	1	2	6	5	2
Rep. 3	3	0	0	2	2	1	2
Rep. 4	2	2	1	8	1	0	0
Average	**3**	**1**	**0.5**	**3.25**	**2.75**	**1.75**	**1.25**
seed colour:	cream	cream	cream	cream	cream	cream	cream

	Dip C	TVSU 1247
Rep. 1	2	1
Rep. 2	2	0
Rep. 3	2	1
Rep. 4	0	0
Average	**1.5**	**0.5**
seed colour:	cream	cream

	KFBN 0124	KFBN 0119	KFBN 0106	Uniswa Red	TVSU 870	SB 16-5 A	KFBN 0125
Rep. 1	19	19	12	18	22	23	23
Rep. 2	23	19	12	16	16	21	25
Rep. 3	20	20	17	28	22	26	29
Rep. 4	20	10	15	24	30	23	26
Average	**20.5**	**17**	**14**	**21.5**	**22.5**	**23.25**	**25.75**
seed colour:	tan	black	tan	red	red	brown	black

	KFBN 9709	KFBN 0120	AHM 968	GP 41	KFBN 0105	TVSU 483	KFBN 0134
Rep. 1	20	16	24	22	25	23	16
Rep. 2	21	17	16	21	25	19	21
Rep. 3	21	27	16	22	26	21	28
Rep. 4	22	17	24	25	27	27	26
Average	**21**	**19.25**	**20**	**22.5**	**25.75**	**22.5**	**22.75**
seed colour:	tan	tan	tan	red/tan	tan	dark red	tan

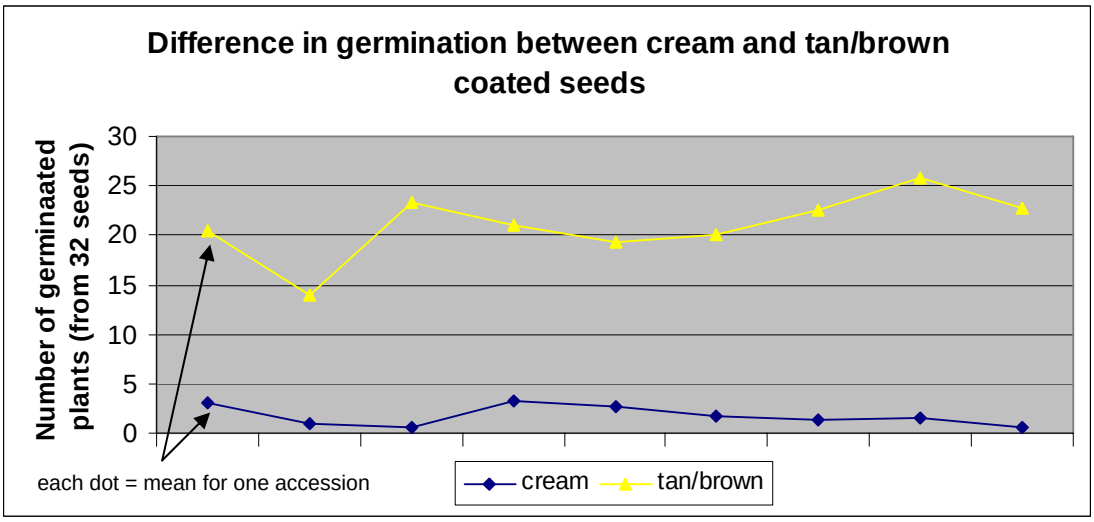
	KFBN 0111
Rep. 1	28
Rep. 2	22
Rep. 3	26
Rep. 4	22
Average	**24.5**
seed colour:	black

Table 36. Summary for emerged plants sorted according to seed colour

Comparison of emerged plants (out of 32 seeds) according to seed colour

Seed colour:	cream	tan/brown	black	red
	3.0	20.5	17.0	21.5
	1.0	14.0	25.75	22.5
	0.5	23.25	24.5	22.5
	3.25	21.0		
	2.75	19.25		
	1.75	20.0		
	1.25	22.5		
	1.5	25.75		
	0.5	22.75		
Average:	**1.7**	**21.0**	**22.4**	**22.2**

Figure 25. Comparison of emerged plants between the nine cream and tan/brown seeded accessions



3.4.3. Effect of sowing density on yield and yield components in two Bambara Groundnut land races in Namibia

Trial management records

After some showers during the mid of January 1998, the experiment was planted on 23rd January. Because no rain fell after sowing, 50 mm of irrigation were applied on 2nd February to support and enhance emergence. A second dry period occurred between end of February and end of March. Flowering was recorded 48 to 49 days after sowing. Earthing-up was done at the end of March. Harvesting started on 4th May and ended on the 29th of the same month. During the growing period the rainfall amounted to 147 mm, taking irrigation into account the total water supply was approx. 200 mm.

Kernel yield, 1000-kernel mass, seeds per plant, and single plant yield

Despite replanting, plant density at harvest differed slightly from sowing density (Tab. 37). This effect was negligible small and similar for both varieties, except for AS 17 at a seeding rate of 13.3 seeds m^{-2}. Plants harvested were only 11.4 plants m^{-2} as compared with 12.9 plants m^{-2} for AHM 1125. This difference proved to be statistically significant. It may be concluded, that AS 17 did not tolerate seeding rates above 12 kernels m^{-2}.

Table 37. Plant density (plants m^{-2}) at harvest for the Bambara groundnut varieties AS 17 and AHM 1125 at different seeding rates (kernel m-2)

seeding rate	4.3	5.3	6.7	8.7	13.3
AS 17	3.9	4.9	6.2	7.8	11.4
AHM 1125	4.0	4.9	6.4	7.9	12.9

Though statistically not significant, kernel yield of AS 17 continuously increased from 788 kg ha^{-1} in the lowest seeding rate up to 916 kg ha^{-1} in the highest seeding rate. AHM 1125 reached top yield at a medium seeding rate. However, kernel yield of AS 17 outperformed AHM 1125 at all plant densities. For AHM 1125 seeding rates below 6.7 clearly resulted in below average yields (table 38).

Average 1000-kernel mass was 732 g for AS 17, which was significantly higher than the corresponding value of AHM 1125 (table 38). This supremacy was observed for each planting density. AS 17 experienced a considerable drop in 1000 kernel weight at the highest seeding rate, while AHM 1125 maintained its (smaller) seed size almost at all seeding rates. In both land races highest values for 1000-kernel mass were measured in low to medium seeding rates (table 38, figure 26). A negative correlation between plant density at harvest and 1000-kernel mass was calculated for AS 17 ($r = -0.650$, $p=0.009$).

The relative decline of seeds per plant for the highest seeding rate compared to the lowest seeding rate (= 100) was with 49.4 % for AS 17 and 51.8 % for AHM 1125 quite similar for both accessions. However, the number of seeds per plant dropped considerable for AS 17 already at a seeding rate of 6.7 kernels m^{-2}, while AHM 1125 experienced the drop only at the highest seeding rate (table 38, figure 26).

The decline for the yield per plant from the lowest to the highest seeding rate was consistent and continuous for AS 17, while AHM 1125 experienced the most remarkable reduction at a seeding rate of 13.3 kernels m^{-2}. Both accessions were at the highest seeding rate with 40.9 % (AS 17) and 43.5 % (AHM 1125) of the values for yield/plant at the lowest rate very similar in their results (table 38, figure 27).

AHM 1125 lost its advantage of (in average) 11.6 % more seeds per plant compared to AS 17 through the significant higher 1000 kernel weight of AS 17 (+ 83.5 % in average), which reflected in a ca. 60 % higher average yield/plant for AS 17. However, comparing this yield advantage of AS 17 at the individual seeding rates, this advantage was highest at the two lowest rates (av. 87.7 %) then decreased for the two following densities (av. 32.9 %), before it increased again at the highest planting density to 66 %.

Table 38. Kernel yield, 1000-kernel mass, seeds per plant and single plant yield for the Bambara groundnut varieties AS 17 and AHM 1125 as affected by seeding rate

		seeding rate (kernels m^{-2})					
	variety	4.3	5.3	6.7	8.7	13.3	**mean**
kernel yield	AS 17	788	874	819	892	916	**858**
(kg ha^{-1})	AHM 1125	457	450	697	635	652	**578**
	p	*	*	n.s.	n.s.	n.s.	***
1000-kernel	AS 17	795	728	746	745	647	**732**
mass (g)	AHM 1125	389	427	414	393	373	**399**
	p	***	***	**	***	**	***
seeds per plant	AS 17	24,3	24.1	18,2	14,9	12,3	**18,7**
	AHM 1125	28.0	20,0	26,7	20,0	13,5	**21.6**
	p	n.s.	n.s.	n.s.	n.s.	n.s.	**n.s.**
single plant	AS 17	20,3	17.9	13,7	11,4	8,3	**14,3**
yield (g)	AHM 1125	11.5	9,0	10,9	8,1	5,0	**8,9**
	p	*	*	n.s.	n.s.	n.s.	**

Figure 26. Relative 1000 kernel weight (rTKM) and relative yield (rY) in relation to planting density (highest value = 100)

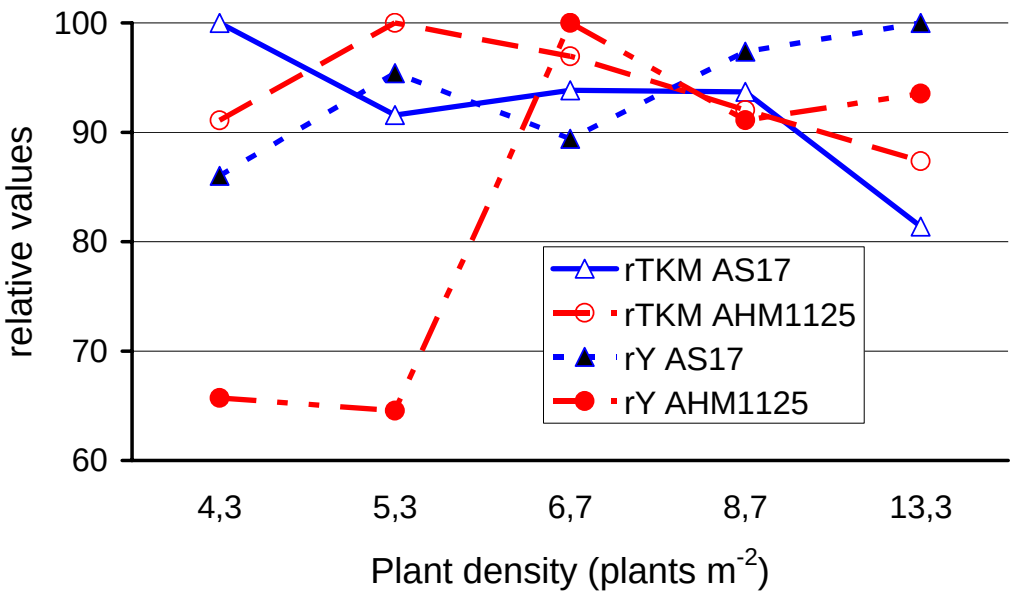
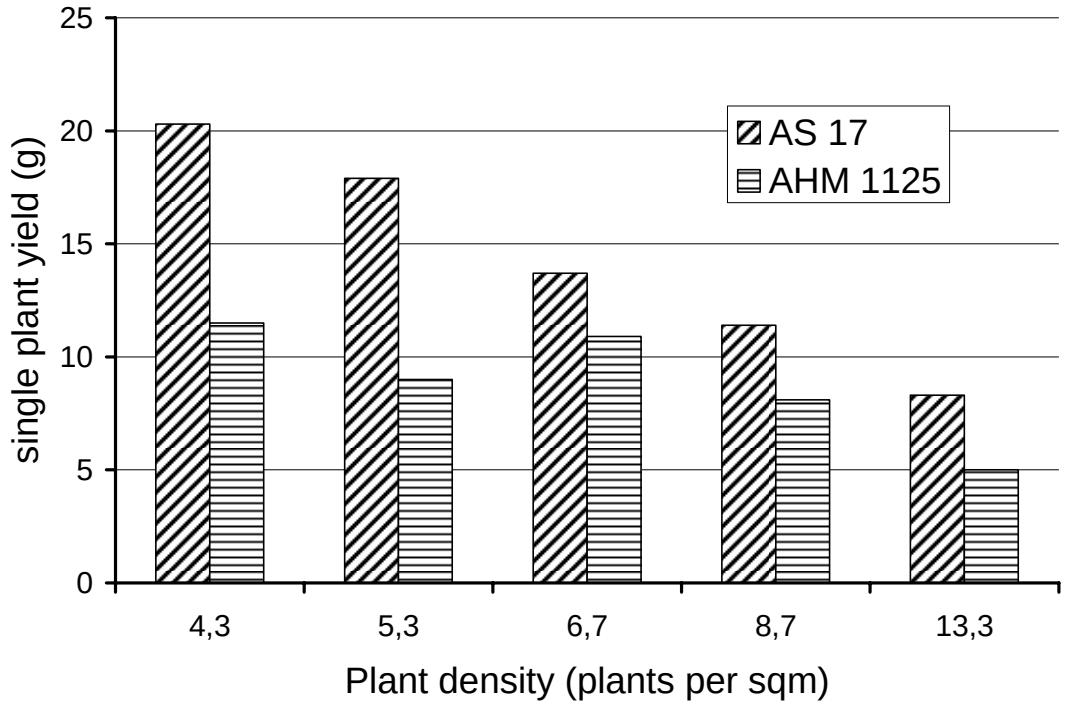


Figure 27. Relationship between planting density and single plant yield



Summarising the data presented above it becomes evident, that yield formation of AS 17 strongly depended on 1000-kernel mass. For AS 17 the coefficient of correlation for kernel yield and 1000-kernel mass was r = 0.459 (p=0.085), while no correlation could be found between seeding rate and yield. In contrast to this, yield formation in AHM 1125 was more depending on the number of seeds per plant (r = 0.489, p=0.065) and seeding rate (r = 0.389, p=0.152).

3.4.4. Earthing-up experiment

The results of the earthing-up experiment are summarized in table 39. Although the quality of the data is affected by the two missing values in the control, they clearly indicate varietal differences in the response of Bambara groundnut to earthing-up. While SB 16-5 A and the local accession appear to be highly responsive to this measure, AHM 753 acted indifferently or with a slight reduction in yield to earthing-up. The difference between earthing-up and the control was statistically not significant (except for the local accession alone).

Table 39. Total seed yield results for earthing-up experiment

Accession:	SB 16-5 B		AHM 753		Local	
	Earthed-up	Control	Earthed-up	Control	Earthed-up	Control
yield kg/ha	0,394	0,461	0,313	0,537	0,420	0,236
	0,643	0,111	0,695	0,635	0,354	
	1,000	0,265	0,508		0,657	0,149
average	**0,679**	**0,279**	**0,505**	**0,586**	**0,477**	**0,193**

3.4.5. Pests and diseases of Bambara groundnut in Namibia

3.4.5.1. Leaf disease and its influence on yield

A leaf disease has frequently been observed, especially in drought spells, on Bambara groundnut in Namibia (see pictures 9 and 10). The disease usually attacks mature leaves, which then become necrotic and start to dry up from the periphery, while new leaves still develop. In the final stage of the disease all leaves become necrotic and the plant can die. However, if rains reassume, the plants are able to recover. The cause for the disease has not yet been identified, but a correlation between the disease and yield has been established during the third phase of agronomic evaluation (see below). The disease has been observed during the first season of this phase in both locations and two disease scoring have been performed (0 to 5; 0 = no disease, 5 = all plants infected). The scorings were later put in correlation to the yield data. The results are shown in Figure 27 and 28. In Omahenene AHM 753 has been recorded with the highest disease scores and yielded below average. AHM 968 on the other hand was very tolerant to the disease in Omahenene with an average score of 0.38. This accession also achieved the highest yield in Omahenene. Similar influences could also be observed for the other entries. There was also a significant correlation between yield and leaf disease scoring in Mashare. It should be mentioned that the land races AS 17 and AHM 968 (!) had the highest disease scores at Mashare. Both varieties also had below average yield, with AS 17 yielding the lowest among all entries.

It may be concluded that since the disease has manifested late in the season, when plants were already in an advanced stage of pod formation, the disease did not have such devastating consequences on the overall yield as it could have been, if the crop had been attacked during the flowering stage

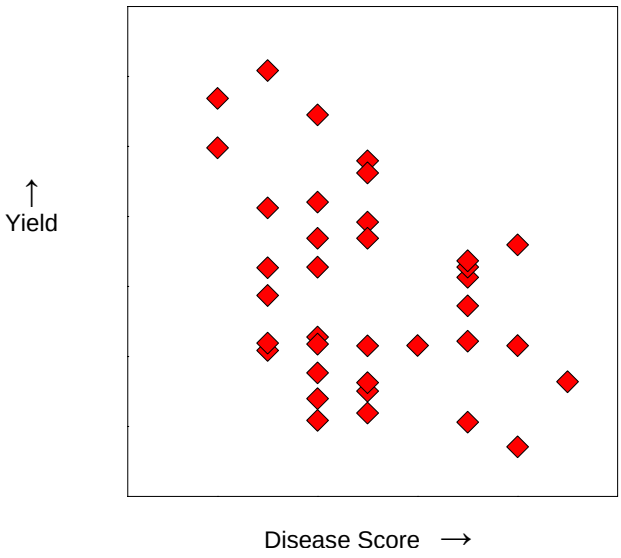
Picture 12. Leaf disease on Bambara groundnut (initial stage)

Picture 13. Leaf disease on Bambara groundnut (advanced stage)

Correlation between Disease Scoring and Yield

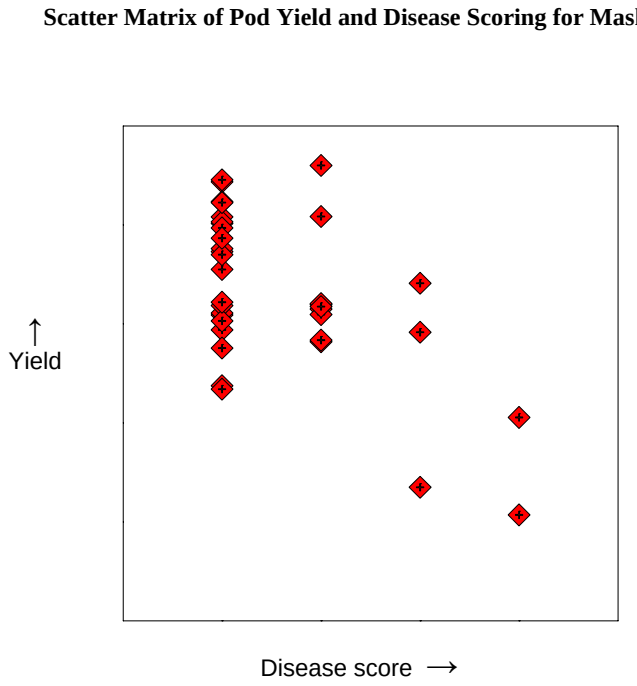
A significant correlation (Pearson; p = 0.0167) between pod yield and the sum of two scorings for a leaf spot disease could be found in the experiment at Omahenene (Figure 27). While the first scoring alone had no significant correlation to the pod yield, the second scoring alone was already significant correlated (p = 0.0336). The correlation coefficient increased by adding up both scorings (form r = - 0.355 to - 0.396). There is a statistically significant tendency that pods yield decreases with increasing disease scorings.

Figure 28. Correlation between pod yield and disease scoring in Omahenene (sum of scoring 1 + 2)



A significant correlation with r = - 0.586 between pod yield and the scoring for leaf disease could also be found in the experiment at Mashare (Figure 28). There were also significant differences between the accessions for the disease scoring.

Figure 29. Correlation between disease scoring and yield at Mashare ADI



3.4.5.2. Mildew

A disease, which only occurs in wet season with late rains, is mildew (see picture 11). Mildew infections are quite rare and only seem to occur late in the growth cycle. Mildew has not been observed to cause major damage in Bambara groundnut production.

Picture 14. Mildew infection on Bambara groundnut

3.4.5.3. Nematodes

Nematodes can have a devastating effect on Bambara groundnut and pose a real threat in production. The susceptibility of Bambara groundnut to nematodes is probably also the reason, why Bambara groundnut is planted in Swaziland only on "virgin" soils, which have previously not been under cultivation. Nematode pandemics have frequently been observed at Omahenene Research Station, especially during off-season crop production (with irrigation), but also (to a much lesser extend) on farmers' fields.

Picture 15. Off-season seed multiplication of Bambara groundnut at Omahenene Research Station affected by a nematode pandemic

Picture 16 and 17. Nematode galls on roots (left picture, healthy plant on the right) and pods (circle) of Bambara groundnut

3.4.5.4. Ombawa caterpillar (lesser army worm larvae?)

The caterpillar of a yet unidentified moth attacks young crops in Northern Namibia during dry spells within a few weeks after germination. Substantial damage can be observed, when the dry spells occurs with or after the first weeding and caterpillars move in droves from the dead weeds to cultivated crops.

Picture 18. Bambara groundnut plant damaged by ombawa catterpillars

3.4.5.5. Soil borne larvae

The larva of an unknown insect has been found feeding on the fruits of the Bambara groundnut. It usually erodes a small hole through the pod, then moves inside the pod and feeds on the seed inside. After that it leaves and moves on to the next pod.

Picture 19 and 20. Soil larva and damaged pods

3.4.5.6. Leaf miner

Bambara groundnut leaves are sometimes attacked by a leaf mining caterpillar, which exclusively feeds on the foliage. Because the pest normally attacks at an advanced growth stage, the damage that is caused does not have substantial consequences on production.

Picture 21. Leaf mining caterpillar on Bambara groundnut leaf

3.4.5.7. Harvester termite

Bambara groundnut plants can be completely defoliated around the nests of harvester termites, which carry the stems of the leaves inside the nest.

Picture 22. Bambara groundnut plants defoliated by harvester termites

Picture 23. Collected stems ready to be carried into the nest (entry hole in the middle)

3.4.6. Outlook for future agronomic investigations

Beside the issue of the genetic improvement of Bambara groundnut, further agronomic investigations will have to be carried out to optimize the genetic potential. Promotional measures for plant establishment and pod development should stand at the centre. The investigations carried out in this regard in Namibia showed the way forward and revealed the potential of improvements in the agronomic field, but also the discrepancy, which can been found. More intensive research is needed especially on the interactions between Bambara groundnut and soil factors (type, nutritional status, water holding capacity) and in regard to plant establishment and reproductive development. Other topics of interest include the influence of rain fall distribution and the effect of drought situations as well as the damage, prevention and control of pest and diseases.

Bambara groundnut is already an important crop for the indigenous Namibian farmer, but has also the potential to be assigned an increasing role in global agriculture in the light of an ever increasing need for food and a changing climate. The Namibian Bambara groundnut improvement program attempted to unlock this potential at a national level, and it is now up to the international research community to take this crop further.

3.5. Agronomic evaluation on-farm

3.5.1. Farmer managed participatory research trial

3.5.1.1. Results from the North Central FSRE Unit

Mid-Season Monitoring Summary

Establishment is known to be a problem of Bambara groundnut, when rain distribution is poor. This reflected in the very variable performance of the on-farm Bambara groundnut trials of the 1997/98 season. Poor emergence was found in Omhakoya and Eunda. Time of planting and rainfall distribution (sufficient rain after planting for germination and later for earthing up) was generally responsible for good or poor establishment of Bambara groundnut tests.

End-season Evaluation Summary

General Remarks

A serious handicap was that the records of the end-season evaluation meetings were not compiled in a proper way. The monthly reports of the technicians and the FSR/E unit also provided only very limited and general information. Details on legume trials and specific information on different varieties were therefore rare and originated in most cases from the incomplete notes and the memory of other attending group members.

Farmers' attendance in the evaluation meetings was good with women being always in a strong majority. Seed samples brought to some of the meetings made it easy for farmers to identify their variety and report on the test. In Omhakoya all host farmers for the legume tests were present. Discussions with farmers were lively and emphasised again the importance of legumes for rural households. While cowpeas are more considered a part of the household diet, Bambara groundnut and especially groundnut are seen also as cash crops. In general the feed back from farmers on the improved legume varieties was very positive.

Comments on the Bambara groundnut tests

The variable establishment of Bambara groundnut plots observed during the mid-season monitoring reflected also in the end-season evaluation. The test results were very variable and did not reflect a significant advantage of the improved material towards the traditional land races. Only one farmer in Elombe reported that AHM 1125 performed very well and produced a good yield. From farmers at Omhakoya and Onaanda it was reported that AHM 753 did not produce any pods.

3.5.1.2. On-farm experiments of the 2001/02 and 2002/03 seasons

The described on-farm protocol allowed generating some very promising and statistically analysable results from the on-farm experiments of the 2001/02 season. The number of complete and usable data sets was 4 for Ompundja, 6 for Okahao-Kangala and 3 for Iiviyongo. This constituted 50% of the participating farmers.

Picture 24. BAMFOOD research assistants collecting post harvest data on farm

Data analysis was done with the results for pod yield (total for 10 pre-determined plants, harvested by the host farmers). It could be observed that the means for the villages differed not much from each other (max. 15%), however averages for individual farmers had a variation of up to 400 % (see table 40).

Table 40. Summary of means (for all accessions) for farmers and villages

	Ompundja	% of mean	Okahao-Kangala	% of mean	Iiviyongo	% of mean
F1	143,4	40,2	435,4	143,4	245,4	69,3
F2	471,2	132,2	122,0	40,2	275,0	77,7
F3	230,2	64,6	488,0	160,8	541,2	152,9
F4	581,4	163,1	263,6	86,8		
F5			307,4	101,3		
F6			205,0	67,5		
Mean	**356,6**		**303,6**		**353,9**	

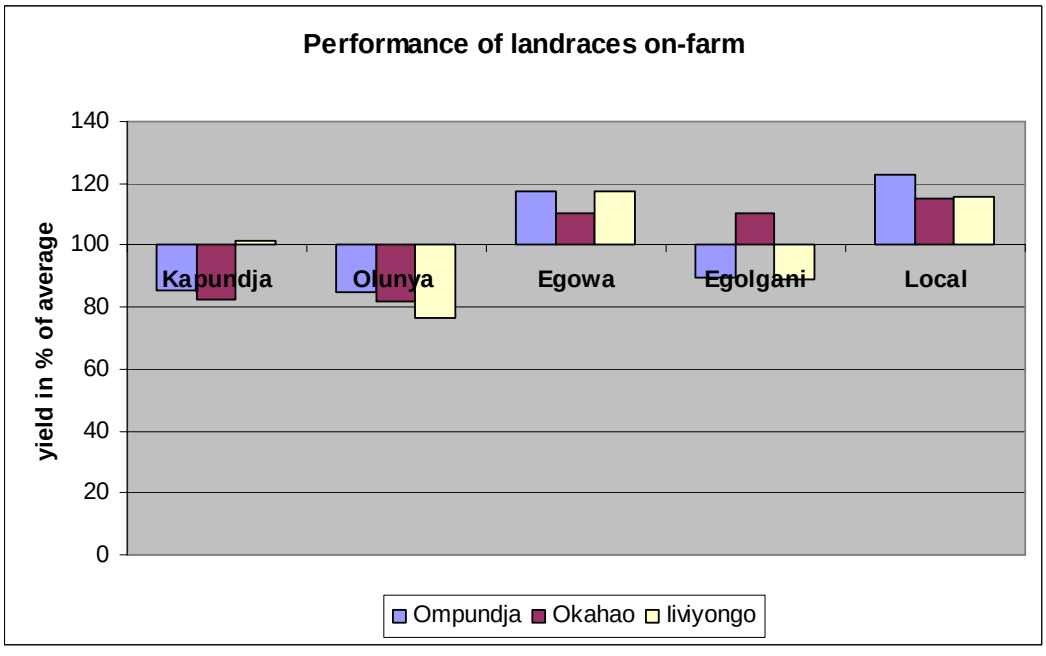
The big difference in the yield level between farmers is probably related to soil differences and/or application of crop management practices and could be seen as proof for the variable technical knowledge of the individual farmers for Bambara groundnut production. Through conversion of the accessions' raw pod yield data per farm to a % of the mean on that farm, the effects of farmer and village are taken out and a comparison between the accessions is possible. In the average of all 13 samples two accessions performed above average: Egowa AHM 968) and Local. Both accessions yielded on 10 farms above average, but also 3 times below average.

Table 41. Summary of the converted yield data for the 2001/02 on-farm trials

	Kapundja	Olunja	Egowa	Egolgani	Local
F 1	92,1	60,0	88,6	110,9	148,5
F 2	68,3	101,2	100,2	107,6	122,7
F 3	71,7	100,8	144,7	82,1	100,8
F 4	98,4	80,5	138,1	60,7	122,3
F 5	87,3	90,3	113,9	90,0	118,5
F 6	101,6	69,7	54,9	143,4	130,3
F 7	92,2	68,9	103,5	105,1	130,3
F 8	81,9	78,9	141,1	110,0	88,0
F 9	73,8	101,8	108,0	121,3	95,0
F 10	56,6	82,4	141,0	93,2	126,8
F 11	98,2	84,4	158,1	58,3	101,1
F 12	88,0	67,6	104,0	95,6	144,7
F 13	116,4	84,4	89,2	110,3	99,6
mean	**86,7**	**82,4**	**114,3**	**99,1**	**117,6**

Figure 29 shows a comparison of relative pod yield for each accession in the three villages (average of all farmers), where the on-farm test have been conducted. The local land race and Egowa (AHM 968) performed above average at all sites, while Olunya (Nyak C2), a strong performer on station, produced in each village below average. As a consequence farmers from two villages replaced this accession in the following season with a new one.

Figure 30. Summary of on-farm results for pod yield



The data for pod yield were also analysed with the SPSS statistical software package. First a three factorial ANOVA (for village, farmer and accession as factors) was performed with the raw data for pod yield as dependent variable (table 42), then the same ANOVA was done for the relativated pod yield data (table 43). While village and farmer had a highly significant influence on the raw data, their influence completely disappeared in the ANOVA for the relative values and had no longer a significant influence on yield. The influence of the accession on pod yield was in both ANOVAs significant.

Table 42. Results of a three factorial ANOVA for pod yield raw data

Dependent Variable: Podyield

Source	Sum of squares typ I	df	Mean of Sqares	F	Significance
Corrected model	1702374,985(a)	16	106398,437	19,774	,000
Constant term	6711796,446	1	6711796,446	1247,403	,000
Village	88042,671	2	44021,335	8,181	**,001**
FarmerID	1494394,683	10	149439,468	27,774	**,000**
Accession	119937,631	4	29984,408	5,573	,001
Error	258269,569	48	5380,616		
Total	8672441,000	65			
Corrected total variation	1960644,554	64			

a R-Sqare = ,868 (corrected R-Square = ,824)

Table 43. Results of a three factorial ANOVA for the relativated pod yield data

Tests der Zwischensubjekteffekte

Dependent Variable: Relativeyield

Source	Sum of sqares typ I	df	Mean of sqares	F	Significance
Corrected model	13024,273(a)	16	814,017	1,483	,146
Constant term	649960,001	1	649960,001	1184,036	,000
Village	,005	2	,003	,000	**1,000**
FarmerID	,010	10	,001	,000	**1,000**
Accession	13024,258	4	3256,064	5,932	,001
Error	26348,926	48	548,936		
Total	689333,200	65			
Corrected total variation	39373,199	64			

a R-Square = ,331 (corrected R-Sqare = ,108)

No data analysis has been carried for any other agronomic traits.

Data collection for the 2002/03 season was affected by the illness of the program leader, which did not allow extensive field work. Only 4 sets of complete data were obtained in one of the partner villages (Ompundja), which constituted, however, again 50% of the participating farmers in that village. The data are presented in table 44. Again pod yield for an accession (which was again the total yield of 10 pre-determined plants) has been set into relation to the mean of the farm (these can be found in column 2). Two new entries (Gab C, Uniswa Red) have been tested. They replaced on the request of farmers Olunya and Egolgani

from the previous year. Farmer 4 did not want to replace Egolgani, but due to missing values from other farms as comparison, it has not been included in the table. Data were too few for a meaningful statistical analysis, but some observation from the previous year found a repetition, such as the big variation of yield levels between farmers (column 2) and the good performance of the local accession.

Table 44. Data summary for the 2002/03 on-farm

	Pod yield average	Kapundja	Egowa	Gab C	Local	Uniswa Red
F 1	223,0 g	86,5	74,0	100,4	155,6	83,41
F 2	73,6 g	91,0	53,0	69,3	138,6	148,10
F 3	191,6 g	94,5	145,6	98,1	76,7	85,07
F 4	300,3 g	105,2	115,6	92,6	86,6	
mean		**94,3**	**97,0**	**90,1**	**114,4**	**105,5**

3.6. Breeding perspectives

One of the major challenges in the improvement of the Bambara groundnut remains the hybridization of Bambara groundnut. The second EU-funded Bambara groundnut project (BAMFOOD) therefore has included a separate objective to develop feasible techniques and physically conduct cross pollination of Bambara groundnut, which should pave the way for the development of Bambara groundnut ideotypes, as they have been described by Bambara groundnut producers in the different African partner countries of the project. Activities of BAMFOOD, which were linked to the hybridization were the work packages on molecular approach and RAPD technology as well as and the development of pure lines. However, the limited duration of BAMFOOD (36 months) was not sufficient to allow the completion of all deliverables that have been projected. While the theoretical parts could for the most part be completed, the practical applications were never realized due to the following reason:

- low success rate of the performed crosses (< 2%) and the subsequent shortage of seed for further activities
- seed of the core collection could not be obtained from IITA and therefore the core collection could never be planted under field conditions in the African partner countries

Nevertheless, the molecular investigations carried out under the BAMFOOD Project together with some previous work on the characterization and differentiation of Bambara groundnut have opened the door for the next phase in the improvement of Bambara groundnut. BAMLINK, the third EU-funded Bambara groundnut project, in which the capacity of 10 scientific institutions from 8 countries has been pooled together, will attempt in the coming years to achieve advances in the “molecular, environmental and nutritional evaluation of Bambara Groundnut for food production in semi-arid Africa and India”.

3.6.1. Differentiation and clustering of Bambara groundnut

FRANK BEGEMANN (1988) was the first scientist, who conducted an eco-geographic differentiation/clustering of Bambara groundnut with all 1378 accessions that were at that time available in the germ plasm collection of the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria. Due to the unavailability of molecular approaches during that time, Begemann's work focused on the description and comparison of the available germ plasm with data about ten qualitative and twenty-five quantitative characteristics, which were collected through physical field work. Through the differences in the expression of these traits, the accessions could then be clustered with the Ward's minimum variance cluster analysis into 8 major cluster (or "families") of Bambara groundnut in Africa. However, the IITA collection only contained accessions from 19 predominantly West and East African countries. Accessions from countries like Botswana, Democratic Republic of Congo Democratic Republic of Congo, Mozambique or Namibia, in which Bambara groundnut is also an important crop, were not represented.

3.6.2. Developing a core collection of Bambara groundnut through comparative analysis of descriptive data

In 2001, SCHENKEL *et al* revisited Begemann's data base, which then consisted of 1463 characterized accessions and has meanwhile been made available via the International Bambara groundnut data base (BEGEMANN *et al.*, 2000), with improved statistical software. For 1013 accessions a complete data set of 33 morphological descriptors could be found and they could therefore be included in the analysis. The objective of this work was to identify a core collection of Bambara groundnut – a collection with a minimal number of accessions representing a maximal degree of genotypic diversity – which could easily be handled and used as a baseline for future evaluation and improvement activities.

A core collection has in 1984 defined by FRANKEL as a limited set of accessions representing, with a minimum of repetitiveness, the genetic diversity of a crop species and its wild relatives. Since, as in this case, only the genetic diversity of a specific gene bank (IITA) has been addressed, in which, as already mentioned, a considerable number of countries was not represented, the more specific definition of BROWN (1995) that "a core collection consists of a limited number of the accessions in an existing collection, chosen to represent the genetic spectrum of the whole collection" seems to be more appropriate. Core collections based on this definition are also called "core subsets" (VAN HINTUM *et al.*, 2000).

SCHENKEL *et al* identified five cluster levels with 8, 16, 32, 70 and 102 clusters, which were selected based on stability and distance between levels. At each level the most typical accession from each cluster was chosen as an entry for the core collection. Five core collections (consisting of 8, 16, 32, 70 and 102 accessions) were defined with all accessions representing one level being also part of the next higher level (e.g. all accessions from the 8 cluster level were also taken to the 16 cluster level and so on). The resulting set of core collections is called a hierarchical nested core collection. This type of core collection allows the size of the collection to be adjusted to a given enquiry. A clear link between the core collection and the main collection (with all available accessions) will enhance the use of all accessions in the collection

3.6.3. Developing a core collection through genetic fingerprinting of Bambara groundnut with molecular markers

Fifteen years after Begemann, SINGRÜN AND SCHENKEL (2003) used meanwhile developed molecular approaches, to describe the inter-landrace genetic diversity and relationship of 223 accessions from 13 African countries (now including accessions from Botswana, Swaziland and Namibia) and Indonesia, but also the intra-landrace diversity of 10 accessions. The original idea to compare the "new" accessions with the large core collection (102 entries) from the IITA gene bank could unfortunately not be carried out, because the accessions for this core collection could not be obtained from IITA.

There are very few studies that have been conducted to determine the genetic diversity of Bambara groundnut with genetic markers. Since it is a self-pollinating crop, intra-landrace diversity could be expected to be low. The use of isoenzyme markers showed a low diversity among domesticated accessions, but a comparatively high diversity within landraces (PASQUET *et al.*, 1999), whereas AMADOU *et al.* (2001) reported a considerably high diversity among accessions on the basis of RAPD markers. The use of the AFLP marker technique resulted in such a high level of polymorphism that it was possible to reveal the non-existence of genetically identical landraces, whereas the intra diversity was found to be negligible (MASSAWE *et al.*, 2002).

AFLP is a universal multi-locus marker technique that can be applied to genomes of any source or complexity. The method is based on the selective PCR amplification of restriction fragments from a double-digest of genomic DNA under stringency conditions. Due to its capacity to reveal many polymorphic bands in a single reaction, AFLP provides an ideal tool for estimating genetic variation of both cultivated and natural populations (TRAVIS *et al.*, 1996; BARRETT and KIDWELL, 1998).

SSR or microsatellite loci consist of varying numbers of tandemly repeated di-, tri-, or tetra-nucleoide DNA motifs. They are a very powerful marker system, because of their high variability and have been employed in many diversity studies (PLASCHKE *et al.*, 1997; BRYAN *et al.*, 1997; DONINI *et al.*, 1998). SSR primers are very specific for the species where they have been identified (DIWAN *et al.*, 1997; ZANE *et al.*, 2002), but cross-species amplification is possible for closely related taxa such as species belonging to the same genus or to recently separated genera (PEAKALL *et al.*, 1998; SCRIBNER and PEARCE, 2000).

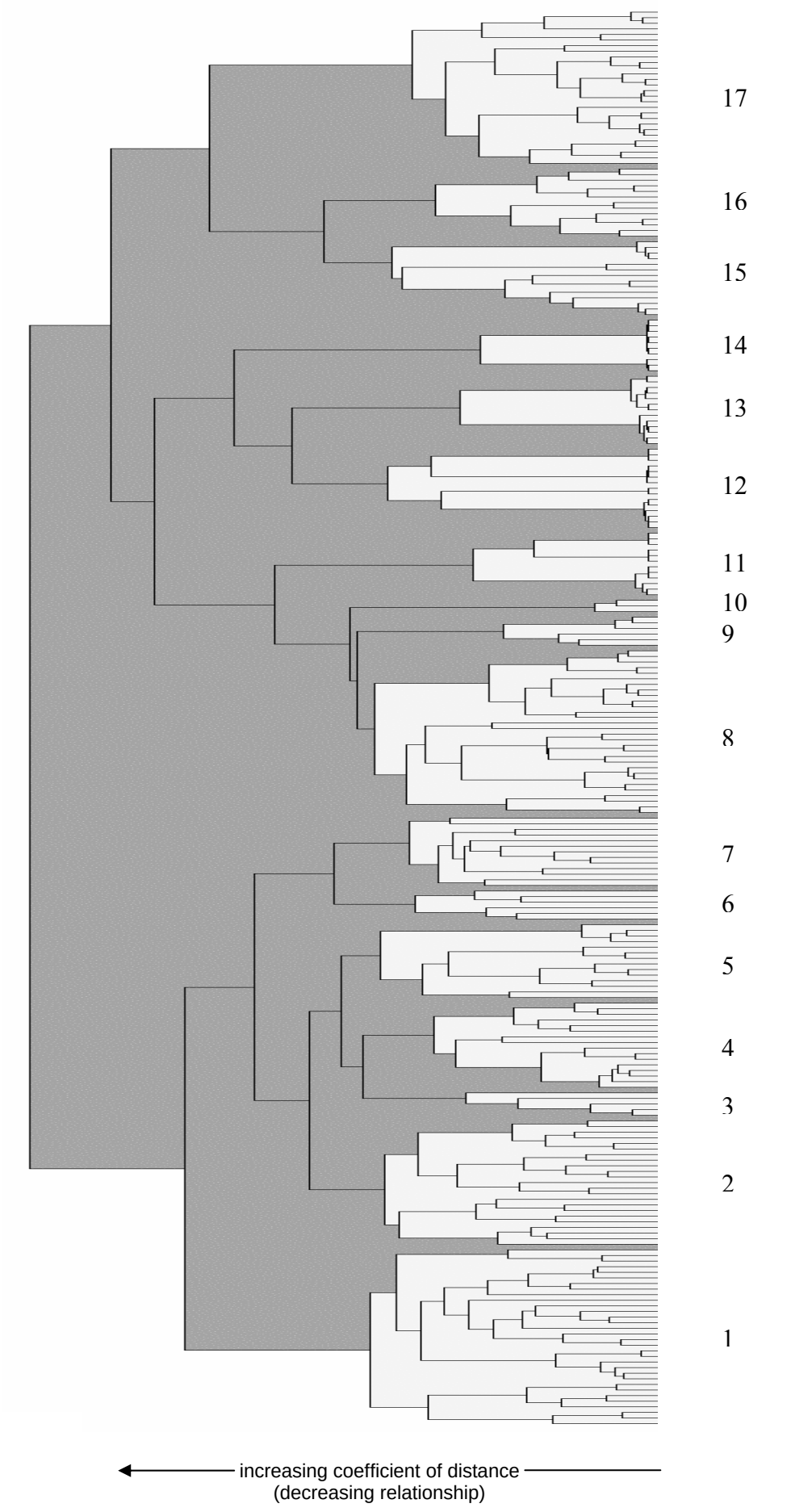
Investigations on the genetic diversity and genetic relationship of Bambara groundnut were conducted among 223 accession from the IITA gene bank, Botswana, Namibia and Swaziland using enzyme system *Eco*RI/*Mse*I amplified fragment length polymorphism (AFLP) and the simple sequence repeat (SSR) marker techniques. In the AFLP approach, profiles were generated with 10 primer combinations, namely: E32M47, E32M49, E33M49, E35M48, E38M53, E39M47, E40M47, E41M58, E44M49, and E46M49. Due to the non-availability of SSR primers specific for Bambara groundnut, amplification was done using 14 heterologous primer pairs that are specific for other legume species (soybean, cowpea, mung bean and common bean). In order to investigate the intra-landrace diversity 10 to 15 individual plants of some of the land races (Botswana: Gab C, Dip C, OM 1; Swaziland: Nyak C 1, Nyak C 2, Uniswa Red; Namibia: AHM 753, AHM 968; South Africa: AS 17; Indonesia: Cibadak) were included in the molecular marker analysis. Similarities between samples were calculated using the Nei and Li algorithms. Based on the genetic similarities matrices, dendrogrammes were constructed using the clustering methods of the unweighted pair group method or arithmetic averages (UPGMA) and Ward's method.

The dendrogramme resulting from a cluster analysis (see figure 30), showed that the 223 landraces under investigation belonged to 17 distinct clusters (for detailed results see Annex 9) There are different levels of relationship, and depending on the level, the accessions can be grouped into three to eight major different genotypes. As Begemann (he found a differentiation of accessions between West and East Africa), Singün and Schenkel also found that accessions from neighbouring countries (= similar agro-ecological environments) tended to cluster together, supporting the idea of adaptive natural or induced selection that has taken place for Bambara groundnut.

With the molecular approach and the genetic fingerprint of Bambara groundnut germ plasm it was possible to ultimately confirm genetic diversity in the examined germ plasm, which was a major pre-condition for successful breeding and hybridization. Another application was the development of a database on molecular markers for the core collection and selected land races. The Bambara groundnut core collection, which has been identified, represents not only the genetic diversity but also the future potential of the crop. A seed multiplication of the relevant accessions and distribution thereof to all countries with an interest in Bambara groundnut improvement would be an important achievement and step forward. With the introduction of the RAPD technology in research institutions of African countries, successful hybridization of Bambara groundnut, achieved through the cross pollination of pure, genetically different lines, could be verified.

An important step for the future would be an improvement of the IITA germ plasm collection through the collection of more accessions (especially from Southern Africa and Asia) and a better maintenance of this largest Bambara groundnut collection in the world. Especially all 102 accessions of the largest core collection need to be multiplied and maintained in order to enable everybody interested in an improvement of the crop to have access to this collection and make use of it. It is discontenting that despite the availability of newest technologies for plant breeding they can not be applied in a satisfactory extent because of simple management problems in a gene bank. Handing over the responsibility for the Bambara groundnut germ plasm collection to the International Plant Genetic Resources Institute (IPGRI) would be one of the options that can be considered.

Figure 31. Dendrogramme for 223 Bambara groundnut accessions



3.6.4. Artificial hybridization

As it has been correctly expressed by MASSAWE *et al* (2003) "the potential of pure line selection breeding in self-pollinated crop such as Bambara groundnut" (and as performed in the Namibian Bambara groundnut improvement program) "is limited by the available genetic variability between and within landraces. In any Bambara groundnut improvement aimed at developing improved cultivars with desirable traits, artificial hybridization is essential".

During the BAMFOOD period a successful protocol for the artificial hybridization in Bambara groundnut could be developed and has also been applied in Namibia. However none of the performed crosses yielded mature and fertile seeds. The hybridization efforts in the green houses of Nottingham and Weihenstephan were more successful and yielded (especially in Nottingham, where the 272 performed crosses resulted in 5 harvested F_1 hybrid seeds) some mature seeds. Hybridism could be confirmed through phenotypic comparison of the hybrid descendant with the parent material and through molecular markers. No reports are available from succeeding generations, but through personal communication with Dr. Schenkel, it could be confirmed that the hybrid seeds harvested in Weihenstephan only produced a degenerated progeny, which could not be used further.

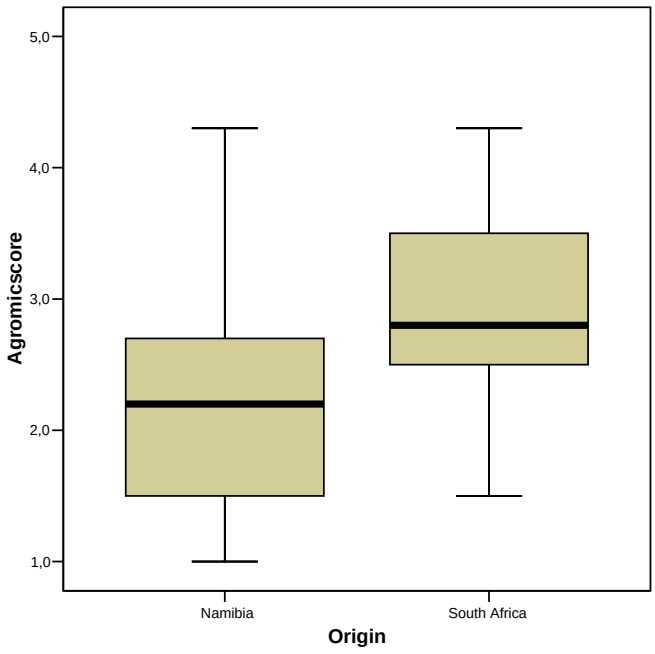
The future success in artificial hybridization of Bambara groundnut will depend on further investigation of a number of factors, including a clear understanding of the floral biology, development and adoption of an appropriate hybridisation protocol, and investigation and careful control of environmental factors during and after pollination.

4. DISCUSSION

4.1. Collection and characterization of germ plasm

The first Bambara groundnut observation nursery proved successfully the potential of the crop in a semi-arid environment like Namibia. Accessions indicated a yield potential of above 800 kg/ha in a below average rain fall season, with more than 20 accessions yielding an average of more than 10 g seed per harvested plant and with the best accession yielding over 20g. Results for individual plants reached even up to 77.9 g seed. The range of data for yield per plant is similar to the one reported from a yield trial with 72 Bambara groundnut accessions from IITA's germ plasm collection (BEGEMANN, 1988). Notable is the strong yield performance of the Namibian germ plasm: 9 out of the seventeen Namibian accessions (the 4 accessions from the market have not been included, because their origin was not known and could probably be Angola) could be found under the top 15 yielding entries. Only 3 Namibian accessions were found in the lower yielding half, which mostly comprised of the South African material. However, as proven through statistical analysis, this superior performance in (total) yield is based to a large extent on the significant higher number of plants that could be harvested from the Namibian accessions. Taking the higher number of harvested plants as an expression for better crop establishment, this result, together with the higher average number of pods per plant for the Namibian accessions, can also be interpreted as a better adaptation of the Namibian material to their "home ground" and its quite harsh climatic conditions. It can also be seen as proof that Namibian farmer's selected their accessions over the centuries according to their adaptability to these local conditions. Another indicator for a better adaptation is the better average agronomic scoring of the Namibian accessions as expression for phenotypic appearance and plant vigour (see figure 31).

Figure 32. Comparison of the average agronomic score between Namibian and South African accessions



An important function of the germ plasm screening nurseries was, beside the agronomic characterization, also the detection of variation. Genotypic variation is a pre-condition for successful breeding programmes (KUCKUCK *et al*, 1985), no matter if for selection or cross breeding, and can for example be detected through the variation of the available material in phenotypic and agronomic characteristics in the same agro-ecological environment. The phenotypic and agronomic characterization of germ plasm can therefore give a first indication of the available genotypic variation in a population, but can on the other hand also be used for clustering and relationship dendrograms (BEGEMANN, 1988). Because only certain, adapted genotypes manifest themselves over time in a defined agro-ecological zone (through natural or induced selection), a genotypic depletion usually takes place in that area. The inclusion of germ plasm from other agro-ecological environments can therefore contribute to increase genotypic variation and diversity in the available test material.

While the 16 Namibian accessions had an average coefficient of variation of 29.4% for six agronomic traits with available quantitative and objective data, the average CV for the 39 South African accessions was 35.3%. If shelling percentage (with a CV of 2.0 for Namibian and 2.4 for South African material) is discarded, the figures change to 34.9 and 41.8% respectively. The average coefficient of variation for all accessions (Namibian and South African together) is with shelling percentage 35.7, without 42.4%. The reduction of genetic variation in an isolated agro-ecological zone can either be attributed to natural selection or selection activities of the indigenous farming community. Proof that selection has taken place in Namibia should be also the fact that almost all native Namibian Bambara groundnut accessions have, despite an enormous diversity in seed pigmentation, tan or black seed colour – a wise and logical measure as will be shown later.

The germ plasm screening nurseries proved that variation in agronomic traits of Bambara groundnut existed and could be increased through the number of characterized accessions and the introduction of germ plasm from other agro-ecological zones. The prevalence of genotypic variability has meanwhile been confirmed through genetic finger printing of Bambara groundnut with molecular markers (SINGRÜN and SCHENKEL, 2003). The characterization of local and the continuous introduction of "exotic" germ plasm is therefore an important activity in each crop improvement program.

Another application of phenotypic and genotypic characterization is the possibility to cluster the available germ plasm into genotypic "families". This is important, because crossings within members of the same family (in-breeding) will be in general less effective for agronomic crop improvement (except in the case of hybrids, where in-bred lines play an important role) than crossings between partners with a different genotype (BEGEMANN, 1988; SINGRÜN and SCHENKEL, 2003).

Screening nurseries for new germ plasm were therefore a regular feature in the Namibian Bambara groundnut improvement program and increased the diversity of the available material. Although data collection was less intensive for the succeeding nurseries, accessions with promising results for yield and seed size were always fed from these nurseries into agronomic evaluation trials. Seed colour played also a role in the later phases of the program.

4.2. Single plant selection as breeding strategy and means for genotype purification

Every breeder should in his choice for a suitable breeding strategy not be influenced by considerations regarding the novelty of the approach, but merely by its usefulness and efficiency. The applied breeding strategy depends in particular on the defined breeding objectives, the available breeding material, the general state of breeding in the respective country, the available technical and scientific resources and finally on the qualification of the breeder himself (KUCKUCK *et* al, 1985).

"One of the oldest breeding procedures and the basis of all crop improvement is selection. Two methods of selection are practiced in breeding new varieties of self-pollinated crops – mass selection and pure line selection. If a group of similarly appearing plants is selected and harvested together, the resulting mixture is known as mass selection. Mass selection can rapidly produce improvement in land races, but may still contain some genetic variation. When single plants, assumed to be homozygous, are selected from a population and each individual plant gives rise to a new line, this is referred to as pure line selection.

A variety developed by pure line selection is therefore more uniform than a variety developed by mass selection. Mass selection in a self-pollinated population with homozygous plants is connected with great difficulties to distinguish between hereditary and environmental factors. Pure line selection followed by progeny test is much more efficient in this respect. Selection within a pure line will certainly give no progress" (SVALÖV WEIBULL, 2001).

Single plant or pure line selection has also the advantage of genotype purification, as the term "pure line" already indicates. Pure lines are important and a pre-condition for controlled and targeted cross-breeding and hybridization.

Considering all available information, external and internal factors as well as the available resources, it was therefore decided to work for the Bambara groundnut improvement program with pure line selection (or single plant selection as it was called in the program). Another reason was that the origin of the germ plasm material and its genetic purity was in most cases not known. The objective of the single plant selection was to obtain homozygous lines with a clear expression of desired traits such as yield and seed size. Additionally it could be an advantage at a later stage to have pure lines available for potential cross-breeding.

Support for this choice has been found in Ben-Erik VAN WYK's and Nigel GERICKE's book "People's plants" (2000), who were of the opinion that "simple selection" (in Bambara groundnut) "may result in drastic improvement of up to 300 percent in terms of seed size within a single rotation. It is thought that large seed have traditionally been selected for eating, while small seeds have been kept as seed for the next year's sowing, so that there may well have been a form of selection against seed size".

4.2.1. First selection

The selection criteria, which have been set in consultation with farmers and traders, proved to be appropriate. With 3.5 % of the test population the selection yielded a reasonable number of pure lines (54) for grade I and II. The selected lines originated from 25 parent lines (out of 60), of which 12 were of Namibian origin, 13 from South Africa. The selected pure lines therefore could be considered satisfactory, regarding quantity, quality and diversity.

The quality of the selected material could be verified in the succeeding progeny tests. Because of the non-replicated layout of the first progeny test, no statistical analysis of the results could be conducted, the average (calculated) improvement indices (advantage of selected lines vs. parent material in %) of 127% for yield and 110% for seed size indicated a reasonable level of improvement. Higher potential for improvement through selection could therefore be found for yield than for seed size. Improvement of 300% for seed size as suggested by VAN WYK and GERICKE could not be found, but individual results reached up to 230% improvement towards the parent material. Almost half of the selected lines (26) showed improvement in both, yield and seed size, and only 4 lines had neither better yield nor bigger seeds than the parent material. To achieve the breeding objectives of an improvement in yield and seed size, only the lines with an improvement in both traits were considered in the replicated progeny testing.

The evaluation of 15 top breeding lines (average improvement index 171.5% for yield, 139.5% for seed size) against 5 parent lines in replicated trials for two seasons delivered due to poor rainfall and planting mistakes not the desired, statistically significant results. However, the replication of results with the same three pure lines, KFBN 9704, KFBN 9709 and KFBN 9713, among the five top-yielding entries for two consecutive years and the considerable yield advantage of two of these lines over their parent line (46.8 and 19.6% as average of two years) proved the success of the selection. The results for seed size were, as previously observed, less obvious and not conclusive. With the observed results, sufficient evidence was obtained that these three pure lines are qualified to participate in the landraces comparison trials.

While VAN WYK and GERICKE (2000) assumed that selection would bring considerable improvement in seed size, it was proven with the progeny tests that the potential for improvement could predominantly be found in other yield components. Unfortunately pod counts were not carried out, but due to the similarities in seed size between pure line and parent line and the fact that significant differences in the number of harvested plants were not detected, it can be assumed that the improvement of yield can most likely be attributed to a higher number of pods produced by the superior pure lines (pods per plant, seed size and number of plants harvested have been identified through the germ plasm screening nurseries as yield components with significant influence on yield).

4.2.2. Second selection

The second selection, which was carried out from the progeny trials for the first selection, did not generate such significant improvements as the first selection. It was a result that could be expected, because the second selection originated to 75% from pure lines from the first selection. The non-replicated progeny test for the second selection revealed that both improvement indices for yield and seed size dropped significantly, which can be interpreted as a proof for an increased genotypic purification, but on the other hand also as evidence for the selection potential that has been prevalent in the source material. This statement gains more ground by looking at the improvement indices for seed size for the new lines from original material and from the first selection. The selected lines from original germ plasm were in average 4.7% better than the parent material, while the selected lines originating from the first selection held an average value of only 1.2%.

Nevertheless, 11 individual selections showed good results for yield and seed size (average improvement index 150% for yield, 112% for seed size) and it was decided to include them in a replicated comparison against the top performers of the Bambara groundnut land races

comparison trial in the 2004/05 season, because they could also be considered (after two single plant selections) as truly purified genotypes.

4.3. Agronomic evaluation of land races on-station

The agronomic evaluation of Bambara groundnut in Namibia was characterized throughout by the so-called "temper" of the crop, a term, which is often used to describe the inconsistent yield performance of Bambara groundnut under field conditions. These fluctuations in yield have not only been observed in Namibia, but are also an issue in other publications (AZAM-ALI, 1992, KARIKARI, 1996). The consequences of this inconsistency could be experienced in almost each season of agronomic evaluation in Namibia and resulted in explicit yield differences for the same entry in the replications of agronomic trials. This resulted in most cases in high standard errors for means and non-significant differences among entries especially for yield performance. The extent of the yield variation for an accession can also be expressed in the coefficient of variation (CV), a mean-relativated measurement for the variation of data. Because the yield differences were in most cases unspecific to a certain replication, soil differences or management practices can be ruled out as influencing factors. In a trial with non-significant differences among replications, the individual CVs of entries in a trial can then be used as an indicator for stability and consistence of performance of that entry in certain agronomic traits. A thorough and comprehensive investigation into the yield fluctuations of Bambara groundnut has not yet been carried out, but they can certainly be attributed to factors influencing germination and plant establishment as well as fertilization of flowers and pod development. To compensate high variations in yield, raw yield data have been transformed in many ways (especially when significant differences in the number of harvested plants existed) to unleash the performance of Bambara groundnut accessions and identify lines, which could contribute to achieve the objectives of the program. Transformations, which proved very useful in this regard, were the use of relativated figures (yield of accessions as a percentage of the trial mean) or the calculation of raw yield data to a yield per harvested plant figure.

4.3.1. The first phase

The first BLCT in the 1995/96 season delivered, despite high CVs for some accessions, a clear message: seed, which is kept by farmers or scientific institutions (such as gene banks), the so-called "inside" seed, is of higher quality than seed available on markets. This implies that in times of seed shortages, a purchase of market grain as seed for planting bears a risk of poor production results. The same is the case for the introduction and distribution of locally non-evaluated and un-tested seeds, like the accession from Botswana distributed and sold by the Namibian Extension Services. This "outside" seed will not only frustrate farmers at the end of a season of hard work, but will also question the credibility of the distributing institution. The results of the trial are a good example for the importance of high quality and locally adapted seed material for sustainable crop production.

4.3.2. The second phase

The results of the second agronomic evaluation phase focused mainly on yield performance and seed size. Yield performance was characterized by the already mentioned yield fluctuations and the subsequent lack of significant differences among entries. Seed size, however, generated less variable data and significant differences between accessions could be

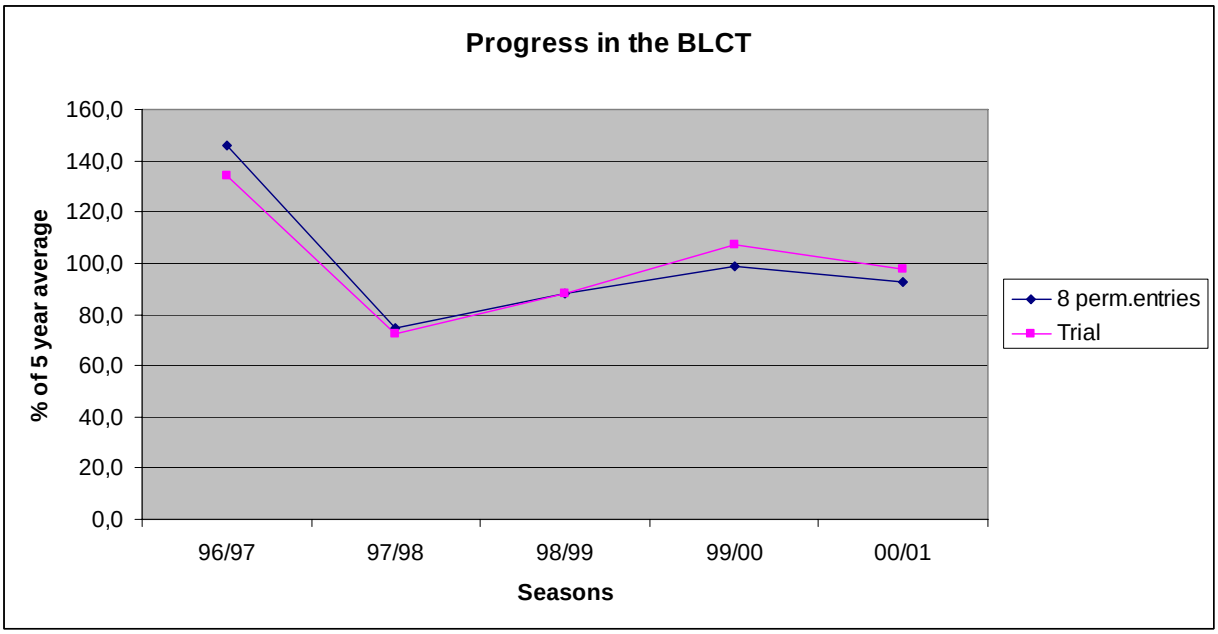
detected. At the end of the second phase three accessions could be identified, which had combined advantages in yield and seed size:

From the Namibian germ plasm collection: AHM 512
From the South African material: AS 17
From the Namibian breeding program: KFBN 9709

Some accessions showed very good yield performance e.g. AHM 867, SB 19-3, but could not enter the top ranks on seed size, others produced very big seeds e.g. SB 16-5 A, KFBN 9704, KFBN 9713, but revealed deficits in yield performance.

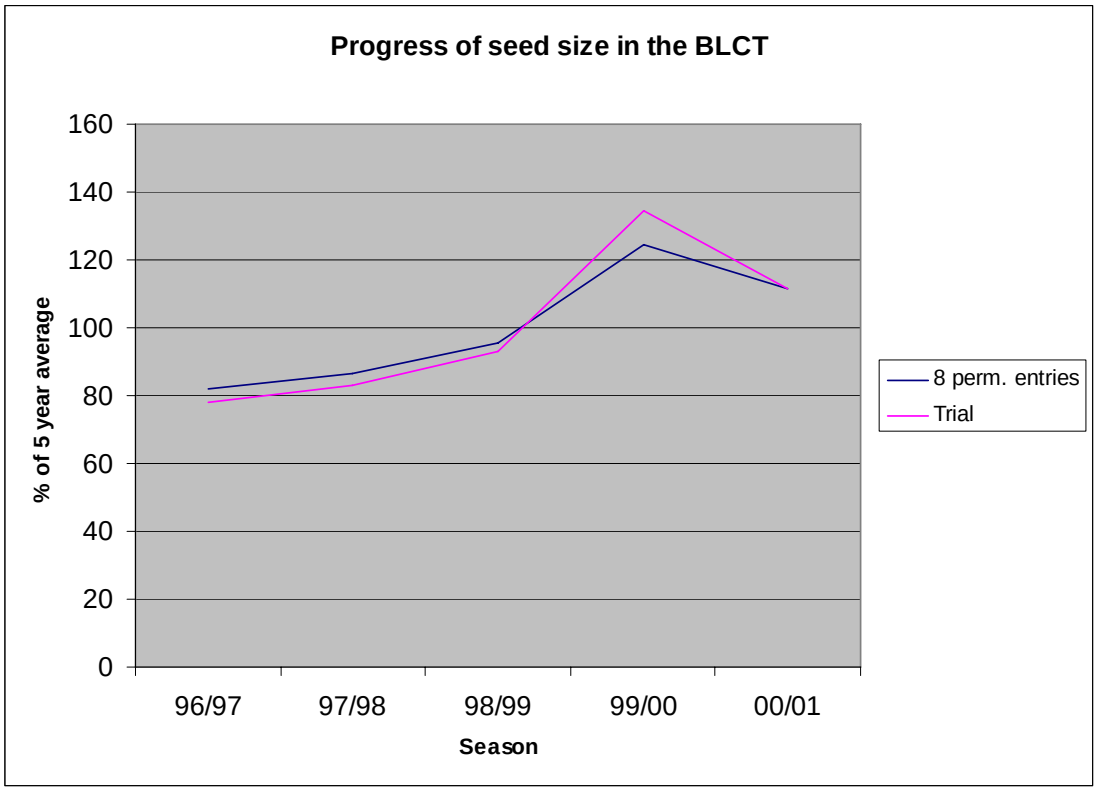
A comparison of the average yield of eight permanent entries, which were included continuously in the BLCT from the 1996/97 to 2000/01 season (the 5 seasons of the second phase), against the trial average of each year (as a percentage of the 5 year overall average) visualizes the progress for the improvement of yield, which was made in the BLCT (see figure 32).

Figure 33. Progressive development of yield in the BLCT



While the eight reference accessions in the beginning were above the yield average of the trial, this picture changed over the years by continuously replacing weak performers with new accessions from the screening and breeding components of the program. The same development can be found for the 100 seed weight (= seed size) (see figure 33).

Figure 34. Progressive development of 100 seed weight in the BLCT



These figures provide evidence that the Namibian Bambara groundnut program worked successfully and was on the right track to improve yield level and seed size of Bambara groundnut in Namibia.

4.3.3. The third phase

Agronomic evaluation could be broadened in the third evaluation phase due to the availability of additional resources and support from other scientific institutions. This phase also allowed a comparison of accessions from the Namibian program with some new accessions from Botswana and Swaziland. For Namibia, yield performance was not the major focus of this evaluation phase and the aim was to gain more knowledge in regard to other agronomic traits.

4.3.3.1. Yield and 100 seed weight

Significant differences for yield among the accessions could only be found in the first season of phase three, probably because beside the already known yield influencing factors (numbers of plants harvested, number of pods per plant and 100 seed weight), yield performance was during that season significantly influenced by a leaf disease. While the Namibian accession performed top in the semi-arid and sandy environment of Omahenene, the foreign accessions dominated in the more humid climate and on the loamy soils of Mashare. Calculating the raw yield data to pod dry matter production per plant (because a significant difference in the number of plants harvested per entry was detected at Mashare), the picture changed with two Namibian and two foreign accessions performing above average at both locations. Only foreign accessions performed below average in both locations thus confirming an advantage of local material on their home ground. The second and third season of phase three were

characterized by lower yields and non-significant yield differences among entries. The four-factorial ANOVA for all three season superbly provides the statistical evidence and summarizes the observations made over the years with the agronomic evaluation of Bambara groundnut: the biggest influencing factor for yield in Bambara groundnut was the season, in which the evaluation was conducted, followed by the location of the experiment. The influence of the accessions was lowest among all factors investigated and not significant.

The picture was different for 100 seed weight, where significant differences between accessions regularly occurred. Accession and season therefore had a highly significant influence in the four-factorial ANOVA. 100 seed weight was independent from the location and can be considered as a "trade mark" trait for an accession. The seasonal influence can most likely be attributed to varying soil moisture conditions. A significant influence of drought conditions on 100 seed weight has been established by MWALE *et al* (2003)

The challenge for Bambara groundnut improvement became very clear from the results of phase three: to find high yielding accessions with a consistent yield performance, which does not predominantly depend from the production season.

The inconsistence of yield performance became more and more a key issue in the improvement program and was a major target of the agronomic investigations.

4.3.3.2. Germination

Germination as one of the possible influencing factors for inconsistent yield performance was investigated for the first time during the third phase. Despite the occurrence of some statistical significant differences between accessions for the duration of emergence and the final germination percentage, no obvious trends could be found. For the germination percentage only this statement can be made: two accessions (OM 1, Dip C) were never reported with a notably high germination percentage, while two other accessions (AHM 968, Gab C) have never been observed with a low germination percentage. The days to 90% germination varied considerably for the three seasons and also between the two locations, but to a much lesser extent among the accessions. The range of data recorded over three seasons for the duration of emergence was 9 to 23 days, with a mean of 11.7 days for the fastest and 19.0 days for the slowest emergence records.

The conclusions, which could be made from the germination records, led to some thoughts, which factors could have an influence on the germination and emergence of Bambara groundnut. The poor germination percentages of OM 1 and AS 17 at Mashare in the first season suggested an influence of seed size, because these two accessions had by far the highest 100 seed weight among all accessions. The influence of soil moisture (as a result of rain fall quantity and distribution) was obvious through the strong seasonal influence. As a consequence an initial germination experiment, which investigated the factors seed size, watering regime and seed depth, was conducted with three accessions. The results of this experiment have been reported on under the agronomic investigations and will be discussed at a later stage.

4.3.3.3. Flowering and pod dry matter content

Results from the developmental analysis (number of flowers) and growth analysis (pod dry matter content) should shed some light on the most important ideotype criteria that farmers have identified – maturity characteristics of Bambara groundnut.

In the first germ plasm screening nursery, the percentage of plants flowering at a certain number of days after planting, was used to get some idea of the onset of the reproductive phase and ultimately on maturity. Data collection during the third evaluation period was much more sophisticated with regular flower counts on fixed days two times per week. These flower counts had, however, to be terminated after the plants were earthed up at 100% flowering. For the observed nine accessions it was found that flowering started very uniform with no notable differences between the accessions. This was surprising, because from the Namibian material it was known that AHM 968 and AHM 753 have been considered as early to medium maturing accessions, while AS 17 was late maturing. The suspicion evolved that maturity was not determined through the onset of flowering, but with the period necessary for the development of pods. The number of flowers, however, differed quite largely between the accessions and also between seasons. During the 2001/02 season with below average rainfall the overall average for all nine accessions over three counts was 3.1 flowers per plant, while in the good season of 2002/03 this average value reached 3.9 flowers per plant, which is 25% higher. The average yield during this season was 80% higher than the yield level of the 2001/02 season. It seemed as if the number of flowers could possibly be used as forecast indicator for the yield level (low/medium/high) in a specific season. Due to the few years available this statement is purely speculative, but should encourage further investigations. Looking at the individual accessions it can be noted that only the Swaziland accession Nyak C2 had in both season an above average number of flowers.

The progression of pod dry matter content revealed more expressiveness in regard to maturity than the flower counts. The phenotypic observations made for the maturity categories of the Namibian accessions (AHM 753 = early, AHM 968 = medium, AS 17 = late) clearly reflected in the increase of pod dry matter content. While AHM 753 and AHM 968 belonged in both seasons to the three accessions with the highest pod dry matter content at the last growth analysis (GA 6 in 2002, GA 8 in 2003), AS 17 always belonged to the accessions with the lowest dry matter content. While the accessions still were at close range at growth analysis 3 (GA 3), except for Gab C in 2003, the differences progressively increased from growth analysis to growth analysis. Among the foreign accessions OM 1 was another land race with slow increases in pod dry matter, while Nyak C2 belonged to the group with a higher pod dry matter content at the last growth analysis.

An interesting phenomenon could be observed in the growth analysis of 2003. Pod dry matter content first increased as expected for all accessions from GA 3 to GA 5. At GA 6 the dry matter content of pods, however, decreased, and reached the level of GA 5 only at GA 8 again. The reason suspected for this is that on the date of GA 5 and the following two days, heavy rainfall was experienced at Omahenene. The pods, still not mature, obviously absorbed moisture from the soil and probably continued growth until the next growth analysis, which led to a decrease of pod dry matter. The decrease was less expressed in early maturing accessions like AHM 753 (-1.6%) than in late maturing accessions such as OM 1 (-8.8%) and AS 17 (-9.3%), which can probably be attributed to an advanced maturity state of AHM 753. OM 1 and AS 17 were also the accessions with the biggest seed size. To achieve this superior seed size pod development obviously is protracted in these accessions through the ability to absorb moisture at an advanced maturity state and continue growth.

In summary, the results of the third phase did not generate significant new findings in regard to yield and seed size. They were more or less a confirmation of the results from the second phase. However, some very useful information could be generated on physiological processes

like germination, flowering and pod development of Bambara groundnut, which ultimately led to a better understanding of the crop.

4.3.4. The fourth phase

Only four accessions from the second phase progressed to this phase of agronomic evaluation. AS 17 and KFBN 9709 came with good records from the second phase, while AHM 968 gained merits during the third phase. SB 16-5 A has been identified as a superior accession for seed size. Because the single plant selection did not result in significant and consistent achievements in regard to seed size, it was decided to keep this accession in the trial as a second reference for seed size beside AS 17. Another four accessions (two from Swaziland, two from Botswana) were included from the third phase. With these, six accessions (out of nine) from the third phase were included in the fourth phase. Three accessions from phase three, which did not reveal a major potential in ideotype traits, were left out. The other seven accessions for the 2003/04 trial came with promising records (in regard to the ideotype characteristics) out of the screening nurseries. Four of these originated from the IITA material, three were Namibian land races. Considering the origin of the accessions, this was the most diverse Bambara groundnut trial, which has been planted up to date in Namibia.

At harvesting it looked as if the trial ended up with disastrous results. However, after conversion of the absolute yield data to a calculated figure for yield per plant and leaving out three accessions, which accounted for all plots, in which no plants have emerged, the results gained some expressiveness. After discarding two more accessions with a coefficient of variation of more than 80%, the data analysis even produced significant yield differences among the accessions. KFBN 9709, a breeding line from the first selection could generate an overwhelming advantage in yield over all other accessions. In seed size this accession could also achieve an above average result and occupied third rank. The consequences of data conversion was most obvious for GP 56, a Namibian land race, which occupied 11th rank in total yield with all accessions included, but jumped to second rank behind KFBN 9709 after conversion to yield/plant harvested. GP 56 was also the top performer in seed size. It was obvious that the potential of GP 56 would have gone lost without the transformation of data. The performance of KFBN 9709 gains more merit considering the lowest coefficient of variation of 10.3% for yield/plant among all accessions. The average results for each replication varied only between 14.8 and 17.1 g seed/plant for this accession thus indicating a very consistence performance under very difficult circumstances. KFBN 0301, which could not establish a single plant in this trial and OM 1 were the weakest accessions in the trial and were due to their poor performance removed from further evaluation trials.

For the next and last season of this phase the 13 remaining accessions from the 2003/04 trial were supplemented with 11 new breeding lines from the second selection. The number of participating entries reached now 24, which meant the largest evaluation trial ever. The establishment of the trial suggested another setback, when very unsatisfactory germination was observed in many plots despite a record rainfall and personal involvement of the leading scientist during planting. However, analysis of the germination records resulted in one of the most important observations made so far during the work with Bambara groundnut in Namibia – the obvious relation between seed colour and germination capacity, an issue which will be discussed in detail at a later stage.

Evaluation of yield performance and seed size therefore focused only on the 15 pigmented (black, tan and red seeded) accessions in the trial and did not include the 9 cream seeded entries. The most important finding was that KFBN 9709 reached again the top spot for yield

among the entries, which strengthened the record for this accession to three consecutive top performances in four evaluation seasons. Although the result for 100 seed weight was about 7% below the trial average, it was nevertheless the best result that has ever been recorded for KFBN 9709. The 11 new breeding lines pushed 100 seed weight to a never before recorded 78 g as average for the trial. This result, compared to the 100 seed weight averages from the second evaluation phase, should be regarded as another step in the progressive improvement of seed size.

Two pure lines from the second selection, KFBN 0105 and KFN 0125 entered the top ranks with above average performances in yield and 100 seed weight. As KFBN 9709 they could with low coefficients of variation also convince in regard to yield consistency. However, this performance still was a single season event. Future trials, especially in below average rain fall seasons, will yet have to proof the potential of these two accessions.

The parent line of KFBN 0105, SB 16-5 A was also found among the top performing accession and could even overtrump its breeding line in both agronomic traits. With these results SB 16-5 A could justify its selection as reference accession for the Bambara groundnut land races comparison trial, although it is anticipated that the climatic conditions during the season were very favourable for this genotype. GP 41, a Namibian land race, was only slightly above average for 100 seed weight, but ranked third on yield with almost 27% above the trial average. With the above average performance in 100 seed weight and near average results for yield in the previous season, GP 41 is an accession, which needs to be observed further before drawing final conclusion.

Final statement for the agronomic evaluation

The agronomic evaluation of land races on station produced, despite a considerable inconsistence of yield data with few significant differences among accession, useful findings. The transformation and conversion of raw yield data was in many seasons inevitable to obtain conclusive results that could be used to evaluate the test material. However, 100 seed weight could be identified as a trade mark trait with clear differences between accessions. Nevertheless, progress could be established, after ten seasons of evaluation trials, in the two major evaluation parameters, yield and 100 seed weight, and through this in the improvement of Bambara groundnut. Investigations into growth parameters such as germination, flowering and pod development contributed in the identification of critical areas of concern in the production of Bambara groundnut. Breeding lines from the first and second selection could achieve a remarkable performance in the evaluation trials. It could be established that KFBN 9709, a pure line from the first selection, had superior performance in the following ideotype traits:

- early maturity
- big seeds
- drought tolerance
- high yield
- tan colour

Early maturity, high yield and big seed could be confirmed through quantitative results from the trials. Drought tolerance was not physically measured, but KFBN 9709 achieved always top-rankings during below average and average seasonal rain fall seasons. The worst performance for this accession (yield below trial average, ranked 10th from 16 accessions) resulted from the high rainfall season 1999/2000 (31.3% above average), probably not as a result of poor performance of KFBN 9709, but due to a better yield of the other accessions (highest trial average for the land races comparison trial with 759.5 kg/ha). Tan colour was

one of the three pigmentation types that farmers mentioned in the ideotype exercise. Tan colour was the second most popular and it is obvious that a variety can only belong to one colour type. Two ideotype characteristics, cooking time and taste, can be considered as subjective qualitative, objectively not measurable data, which can only be assessed through participatory evaluation methods (e.g. matrix ranking), because they probably differ on the basis of individual perception. Therefore, an accession, which combined all identified quantitative and objective ideotype characteristics, could be found through a simple selection strategy. It can be noted that selection can still be considered as an appropriate breeding tool for under-utilized, self-pollinating crops, especially in resource poor countries. As a conclusion from all evaluations that have been carried out, KFBN 9709 was identified as a superior breeding line and before the 2005/06 cropping season breeder seed of this accession was handed over to the formal seed sector in Namibia for foundation seed production.

4.4. Agronomic investigations

As it emanated from the evaluation trials, agronomic issues emerged as a critical area of concern in the improvement of Bambara groundnut production and could belong to the reasons behind the observed inconsistent performance of the crop. Two major issues could be identified and have been investigated:

- Plant establishment (germination and emergence)
- Pod development

4.4.1. Germination pot experiment

Little information could be found about investigations into factors influencing germination and emergence of Bambara groundnut. However, it was reported that farmers in Botswana preferred big seeds for planting, because they would produce more vigorous plants (RAMOLEMANA *et al*, 2003). The Namibian pot experiment therefore produced some groundbreaking information, which can be used in future for more thorough investigations.

The first surprising statement, which could be made from the data of the experiment, is that no significant differences between the three test accession in regard to germination percentage and duration of emergence could be found, although AS 17 and OM 1 came with worse germination records from the phase 3 evaluation trials than Nyak C1. Therefore a varietal effect for the recorded data could be excluded. Another general statement, which can be made, is that Bambara groundnut probably needs at least 9 days for emergence, because no faster emergence could be found even in the individual records. This very long germination and emergence process makes the germ buds of Bambara groundnut susceptible to soil borne pathogens and therefore requires special defence mechanisms - an issue, which will still be discussed at a later stage.

The opinion of the Botswana farmers that big seeds are better for planting could somehow be confirmed, because big seeds could achieve a significant higher germination percentage than small seeds (which was contrary to the assumptions made from the results of the phase three evaluation), needed, however, in average one day longer for emergence. Overall germination percentage also increased continuously with seed depth, the watering regime had no influence. Surprisingly the category “big seeds” included both, the fastest as well as the slowest emergence records for all three test accessions. Surprising again that the slowest and fastest emergence also fell both in the same seed depth category (3cm). The difference

between fastest and slowest emergence was found in the watering regime, where daily watering resulted in significant faster emergence than weekly watering. It is suspected that with weekly watering the upper soil layer turned dry, causing a delay in the germination process. This water deficiency prolonged the emergence of big seeds through the alternation between water uptake and dehydration of the seeds, but did not affect their viability, while it reduced the germination percentage of small seeds, probably because the germinating seeds were ultimately damaged through the temporary water shortage. The shortest emergence records, which were found for big seeds at 3 cm seed depth and daily watering, can possibly be attributed to a stronger vigour of the germ bud and less soil ahead before it reached the surface. Duration for emergence was longest for the deepest planting (9cm), most likely due to a longer growth period, which was needed to reach the surface. However, this seed depth achieved the highest germination percentage, probably as a result of the more stable moisture conditions in this depth. Overall, a seed depth of 6 cm achieved the fastest and most constant duration of emergence with a coefficient of variation of 9.5% compared to CVs of 17.8% for 3 cm and 10.6% for 9 cm respectively.

Considering all available data it can be concluded that the best germination results should be obtained through the use of big seeds, a seed depth of 6 cm and daily watering. As daily watering is quite unlikely under field conditions and the watering regime did not have a significant influence on germination percentage, the tendency should in praxis rather go to deeper than to too shallow planting. However, this recommendation will have to be adapted to the prevailing conditions and in the end it must be left to the farmer to trade off between high germination percentages and fast emergence

The obtained results still need to be confirmed through further experiments, as there is still some controversy in the obtained data e.g. regarding the significant varietal differences that have, contrary to this experiment, been detected in the phase three evaluation trials. However, these varietal differences may only occur under specific conditions for example through uneven planting and non-uniform seed size. For the future, the influence of the soil type on germination and emergence through differences in soil moisture content and water holding capacity is one of the topics, which urgently needs to be investigated.

4.4.2. Seed colour and germination

No investigations have yet been carried out, which investigated the influence of seed colour on germination and plant establishment of Bambara groundnut. The relevance of the issue was discovered in Namibia only by chance. Considering the available data from the 2004/05 Bambara ground land races comparison trial the relationship between seed colour and germination appeared obvious, but could in the beginning not be interpreted. Through consultation with other scientists the prevailing opinion was found that the differences in germination between white and dark coloured Bambara groundnut should most likely be attributed to chemical effects on damping-off organisms. Dark seeds contain more polyphenols and these substances are able to protect the plants from soil borne pathogens, as they are able to inactivate poisonous substances from attacking Fungi and Bacteria. The excessive rainfall probably caused an increased activity of soil borne pathogens and the cream seeded accessions were in a higher extent susceptible to these and could not germinate, because tannins and other substances in dark seeds probably act as a natural seed dressing.

During the First International Edible Legume Conference in Durban in April 2005, the idea behind these thoughts gained more ground through a poster presentation of NIOGU *et al*. (2005) from Botswana, who investigated the anti-nutritional components (trypsin inhibitor

activity and condensed tannin content) of Bambara groundnut grown in Southern Africa. For their work they used accessions from the BAMFOOD project, which were also planted in Namibia. Nyakeni C1 and OM1 were cream seeded varieties from Botswana and Swaziland origin, while AHM 753 (a Namibian germ plasm accession) was red seeded. The findings of Niogu *et al* read as follows:

"The condensed tannin content was determined using the Butanol-HCl method. It ranged from 0.02% (for Nyakeni C1 and OM1…) to 0.49% for AHM 753 cultivated in Namibia."

As can be seen from this investigation, the tannin content of the cream seeded varieties is about 25 times lower than the one of the red-seeded variety. In the "Tannin Handbook" of Prof. HAGERMAN (1998) tannins are described as plant compounds that belong to a chemical group of polyphenols called polymeric flavanoids. They do not function in primary plant metabolism such as biosynthesis, but are having diverse biological activities ranging from toxicity to hormonal mimicry and "may play a role in protecting plants from herbivory and disease".

The word "tannin" originates from the ancient Celtic word for oak, a typical source for tannins for leather making, a process that is called tanning and goes back to one attribute that separates tannins from all other phenolics: the ability to precipitate proteins. Other effects on biological systems include the potential action as metal ion chelators and biological antioxidants.

The protective characteristics of tannins in regard to micro-biological activities, which have been used by man for thousands of years in the preservation of animal skins, have obviously also an influence on the germination on Bambara groundnut in Northern Namibia. The preference of consumers for cream seeded Bambara groundnut can now also be better understood, as tannins are responsible for a bitter taste and some anti-nutritional effects. Therefore only a maximum tannin content of 0.10% is allowed in food (NIOGU *et al*., 2005).

It can be concluded that despite being the favoured type of seed, cream seeded Bambara groundnut varieties could not establish (or have disappeared over time) in Northern Namibia due to their low tannin content and the subsequent susceptibility to soil borne pathogens, which probably have an increased activity in Namibian soils during years with excessive and prolonged rainfall and then attack Bambara groundnut during its long emergence process.

4.4.3. Effect of sowing density on yield and yield components in two Bambara Groundnut land races in Namibia

This investigation together with the earthing-up experiment, which will be discussed at a later stage, aimed at possible factors influencing pod production, which is one of the major yield components of Bambara groundnut.

A wide range of data is available regarding optimal sowing rates and plant density of Bambara groundnut. An early study from FAO (1961) indicates sowing rates from 25 up to 75 kg ha^{-1}. More recent studies talk about an average plant population of 9,75 plants m^{-2} in pure stands in Sierra Leone (SESAY *et al*. 1996). BRINK *et al*. (1995) found plant densities from 0.25 to 16.7 plants m^{-2} in Botswana. In Cameroon planting density in mixed stands is reported to be 25 to 38 seeds per m^{-2} for sowing on ridges, 8 to 16 seeds m^{-2} for sowing on mounds, and 13 seeds m^{-2} in pure stands (NGUY-NTAMAG, 1995). In Togo planting densities varied from 6 to 13 seeds m^{-2} (NAMBOU, 1995), which is similar to values from Zimbabwe (8

to 12 plants m^{-2}, MABIKA and MAFONGOYA, 1995). In Namibia plant densities between 2.4 and 25 plants m^{-2} have been reported, but with the majority of farmers in a range between 6 and 8 plants m^{-2} (FLEISSNER, 2001). This considerable variation is probably due to the wide range of environmental and other factors that Bambara groundnut is exposed to. In order to assess the optimum plant density for specific combinations of landrace x environment plant density trials were conducted by SESAY and YARMAH (1996) and KARIKARI *et al.* (1996). The authors claimed higher seed densities for high yielding conditions. A recent investigation on the response of Bambara groundnut to planting density (EDJE *et al*, 2003), which was, however, only conducted with a single land race, found a reduction in pod quality and a significant decrease in the number of pods per plant with increasing plant density, but no significant influence of plant density on seed yield and 100 seed weight (seed size). They, like previously SESAY, YARMAH and KARIKARI, also reported a tendency of increasing total yield with increasing plant density. Yield may, however, not be the only important characteristic that Bambara groundnut producers aim at, especially when it comes to the marketing of the crop (FLEISSNER, 2001) and except the investigation of EDJE *et al* (2003) little meaningful information is available on the effect of plant density on seed quality.

From the results of the plant density trial, it was found that AS 17 proved to be superior to AHM 1125 in regard to yield as well as seed size. Only for the number of pods per plant, AHM 1125 could establish an advantage over AS 17. These differences might be due to the origin of the accessions: while AHM 1125 was a raw, unsorted land race from the Namibian germ plasm collection, AS 17 originated from a small sample of seed, which has been received from a scientific research institution in South Africa and held a high degree of uniformity. This is supported by the observation that lower values for the coefficient of variation were obtained for the yield components of AS 17 than for AHM 1125. Beside a possible greater genetic potential, the yield performance of AS 17 may also have benefited from this uniformity. According to SALIH (1999) graded seeds proved to be beneficial in faba beans, an observation which could also be confirmed for Bambara groundnut through the germination pot experiment.

Analysis of the data suggested that the two accessions, which were included in the trial reacted quite differently to increasing plant density. In respect of total yield the highest plant density resulted for AS 17 also in the highest yield. The threefold higher number of plants in the highest seeding rate could fully compensate for the (relatively smaller) decreases in 1000 kernel weight (- 19 %), seeds per plant (- 49.4 %) and the resulting yield/plant (- 59 %) towards the lowest seeding rate. This was not the case for AHM 1125, which achieved top yield at a seeding rate of 6.7 kernels m^{-2} through the combination of the second highest 1000 kernel weight and the second highest number of seeds per plant at this rate. The twofold higher number of plants at the highest seeding rate (13.3 kernels m^{-2}) could in this case not compensate for a 55 % lower yield per plant at this rate compared to the 6.7 kernels m^{-2} rate.

It can therefore be concluded that for AHM 1125 the optimal seeding rate in regard to yield and seed size would be noted at 6.7 kernels m^{-2}. Considering for AS 17 the negligible lower total yield (-2.6 %) of the second highest towards the highest planting density, but the considerable decrease of -13.2 % for the quality trait 1000 kernel weight, it can be suggested that not the highest seeding rate, but a seeding rate of 8.7 kernel m^{-2} can be regarded as an optimum for this accession.

These observations confirm the growth type differences between AS 17 and AHM 1125 that have previously been observed and suggest that different kinds of yield formation exist for Bambara groundnut landraces. The different yield components of the land races reacted

differently to increasing seeding rates. AS 17 started from a high level at the lowest seeding rate and experienced from the first increase of the seeding rate on a continuous decrease in individual yield components such a seeds per plant and yield per plant, which reached, however, never the extent of the increase in the plant population and therefore resulted always in a higher total seed yield. The positive yield trend with increasing seeding rate for AS 17 was only stopped at the highest seeding rate with the considerable decrease in the quality trait seed size (1000 kernel weight) and the significant drop in the number of harvested plants compared to the lower seeding rates. This can also be interpreted in the way that the yield increase of AS 17 through an increase in plant density has been fully exhausted with the highest seeding rate and that further increases in plant density would most likely neither be beneficial for yield nor quality (seed size). Increasing seed rates had through the increase of the plant population also a positive effect on the total seed yield of AHM 1125, however, contrary to AS 17, major yield components of this accession remained more or less unchanged up to a seeding rate of 6.7 kernel m^{-2}, which resulted in a yield maximum at this rate. AHM 1125 could even close the yield gap to AS 17 considerably and only with the two highest seeding rates, AHM 1125 followed the trend of AS 17.

It can therefore be concluded that land races differ in their optimum seeding rate and plant density and recommendations have to consider beside management (e.g. row width) and environmental (e.g. rain fall, soil type) factors also the specific requirements of these land races. The statements from previous publications (STICKSEL *et* al, 2003, EDJE *et al*, 2003) that pods per plant decrease with increasing seeding rate and that planting density has no significant influence on seed size may apply to one land race, but can as well be disproved through another one (e.g. AS 17 had a statistically significant (negative) correlation between seeding rate and seed size, but not AHM 1125). More investigations into the relationship between plant density and yield components of different land races are therefore needed for a further improvement of the productivity of Bambara groundnut.

4.4.4. Earthing-up experiment

Earthing-up is not only in Namibia believed to be an indispensable measure for the production of Bambara groundnut regarding yield as well as quality aspects (FLEISSNER, 2001; BRINK *et al*, 1995). For farmers in Namibia this management practice is usually determined by two factors, the developmental stage of the crop and soil moisture conditions. The developmental stage for earthing-up is flowering with a number of fully developed flowers present and open (at this stage the flowers have already been fertilized). Flowering of Bambara groundnut in Namibia happens usually in batches (probably related to periods of rain) and therefore there can be more than one earthing-up period. According to Namibian farmers, soil moisture conditions decisively determine the success of this management practice. When carried out after heavy rains with too wet soil, the (fertilized) flowers will "rot" and not produce any yield, while dry and hot soil will burn the flowers with the same consequence for pod production. Farmers in Namibia may delay earthing-up until soil moisture conditions are optimal, but never bring it forward to an earlier developmental stage. In most cases, soil is not only ridged around the plant, but also put on top (see picture 22).

The reasons behind earthing-up, which have been identified, included the enhancement of pod formation, an easier penetration of pods into the soil and a positive influence on yield (BRINK *et* al, 1995; FLEISSNER, 2001). A protection of the developing pods from pests (BEGEMANN, 1988) and an improvement of pod quality (BALOLE *et al*, 2003) were also mentioned.

Picture 25. Earthed-up plants of Bambara groundnut in Northern Namibia

In literature, reports on both, increases and decreases of yield through earthing-up can be found (MALAWI AGRICULTURAL COUNCIL (ARC), 1975; MALAWI GOVERNMENT 1977). Yield reductions have also been accompanied by increased incidences of disease (VAN DER WOLK 1915; MALAWI ARC 1972), which point towards the fear of Namibian farmers for earthing-up with too wet soil. Varietal effects have so far not been mentioned and were also not an issue in the most recent study of BALOLE *et al* (2003) in Botswana with nine landraces, in which the positive effects of earthing-up on seed yield and quality have been generalized for all accessions. Comparing, however, the results of the little Namibian experiment with the trial of BALOLE *et al* (2003) one observation can be made. As in the Namibian experiment (-13.8 %), AHM 753 showed also in the Botswana trial a reduction of yield (-17.6 %). The yield reduction in Botswana seemed to have resulted from the lower number of pods for the earthed-up treatment (-21.1 %), while other yield components remained more or less stable. Unfortunately comparable data for the Namibian experiment are not available.

It can therefore be suggested that earthing-up may not be beneficial for each and every land race. As for the seeding rate, it must be cautioned to generalize statements on the benefit of earthing-up.

4.4.5. Overview of important pest and diseases of Bambara groundnut

Despite the reputation of being a crop with little pest and disease problem (BEGEMANN, 1988), a number of pests and diseases have repeatedly been observed on Bambara groundnut. Fungal leaf diseases have previously been reported from Botswana, Madagascar, Malawi, Swaziland, Tanzania and Uganda and have been attributed to *Cercospora sp.* (BEGEMANN, 1988; KARIKARI, 1996; KHONGA and KWEREPE, 2003; MAGAGULA *et al*, 2003). This is most

likely also the organism behind the leaf disease that was found in Namibia. Another fungal disease that occurs in Namibia during periods of excessive rain fall, is mildew. It is, however, due to the usually dry weather conditions in Namibian quite rare and no major losses have ever been reported. Damages of mildew have rather been reported from higher rainfall areas like Swaziland (KHONGA and KWEREPE, 2003; MAGAGULA *et al*, 2003).

The susceptibility of Bambara groundnut to nematodes is well documented (BEGEMANN, 1988; KARIKARI, 1996; KHONGA and KWEREPE, 2003; MAGAGULA *et* al, 2003) and the devastating effects of a nematode pandemic could be experienced at first hand in Namibia during an off-season seed multiplication at Omahenene Research Station. The type of nematode could not be identified, but sources suggest *Meloidogyne sp*. (root knot nematode) as one of the major culprits (BEGEMANN, 1988; KARIKARI, 1996; KHONGA and KWEREPE, 2003; MAGAGULA *et* al, 2003).

Several insect larvae have been found on Bambara groundnut in Namibia, feeding on foliage as well as on pods. Like for diseases the identification of the correct species was problematic because a qualified entomologist is only available at the Namibia National Museum and usually overloaded with work. One of the most damaging larvae, because it usually attacks in great numbers on juvenile plants during stress situation (e.g. drought) and can wipe out a whole field over night, is suspected to be the lesser army worm (*Spodoptera exigua*). The pest has not been properly entomologically identified yet, but is known in the Oshiwambo language of North Central Namibia as *ombawa* and can also cause severe damage to other crops like pearl millet (*Pennisetum glaucum*). The larvae of another moth, *Helicoverpa armigera* (American bollworm) has been reported to be one of the most damaging pests in Swaziland (MAGAGULA *et al*, 2003), but was not yet found on Bambara groundnut in Namibia. The imago of a leaf miner can probably also be found within the *Lepidoptera*. Unknown is the origin of a soil borne larvae, which feeds on the immature seeds inside the pods of Bambara groundnut. No other reference for this pest could be found.

Harvester termites (*Hodotermes mossambicus*), which can become a serious pest in semi-arid grass lands, have been observed in Namibia to cut off the leaves of Bambara groundnut and carry the stems into their nests under the soil surface. No other similar reports could be found.

The problem with the identification of major pests and diseases of Bambara groundnut in Namibia lies with the entomological back-up. No qualified entomologist is employed in the Ministry of Agriculture, Water and Forestry although several attempts have been made to secure the services of such a specialist. The situation in Namibia suggests the deployment of a pest and disease identification mission with foreign specialists, because other crops also suffer from unidentified pests and diseases.

4.5. Agronomic evaluation on-farm

4.5.1. NCD FSRE unit

After a collective discussion among the members of the Legume Working Group of the North Central division's FSRE Unit, the following conclusions were drawn from the farmer participatory legume tests in the NCD FSRE focus communities in the 1997/98 season. Three critical areas were identified.

Results:

- Only few concrete and substantial results were obtained from the tests
- FSRE reports (monthly, quarterly, monitoring) contained few/no substantial/ concrete information
- Difficulties in compiling final report due to the lack of detailed information

Methodology:

- Introduction of legume tests was successful
- Farmer's management was successful
- But: follow-up visits did not happen in the required extent and intensity
- Good participation of farmers in the legume tests
- Procedure of the mid-season monitoring did not allow in-depth discussions with farmers ("farm-hopping")
- End-season evaluation: good for general evaluation, but not enough time to evaluate all trials and tests properly, due to the combination of topics (use of PRA tools like Matrix Ranking require more time)

Legumes and the farmer:

- Feeling of farmers towards legume tests has been positive
- Bambara groundnut: the tested material was not superior to farmer's landrace

Despite the good cooperation and positive feedback from the participating farmers, the participatory on-farm evaluation of Bambara groundnut with the NCD FSRE unit did not produce any results which had an impact for the Namibian Bambara groundnut improvement program (beside some information collected during visits to farmers' fields). The only statement with value from the final evaluation was that the tested material Bambara groundnut material was not superior to farmer's landrace. This was, however, not surprising, because the tested material did (at that stage) not belong to the top-performing accessions, but should only provide (as a first step) a sample of the available diversity and help to identify preferences. The problem of the NCD FSRE unit was lying with the working method of the unit. Especially the final evaluation was too superficial and unspecific, probably as a result of the big group of officials, which participated and who all had a different background. This and the high number of evaluation topics that needed to be discussed during a single day did not allow an in-depth discussion of results for any crop. A collection of quantitative data did also not take place. The approach of the NCD FSRE unit has also been the subject of a publication, which compared different methodologies for participatory cowpea evaluation (FLEISSNER and BAGNALL-OAKELEY, 2001). The findings can be transferred without changes to the Bambara groundnut evaluation. In this publication it was concluded that only "highly accurate or highly focused activities resulted in a good client focus and the proper documentation of results. This is the crucial point in the effectiveness of methodologies. Due to its direct effect on time (and through that on resources and costs) and its dependency from appropriate resource input and management, accuracy is the factor, which needs to be optimized". The limitation, however, is that highly focused and accurate approaches often needed an unsustainable amount of resources. It was also concluded that for the success of low resource approaches, like the NCD FSRE approach, an "improvement in qualitative and quantitative data collection will be crucial". Although the activities of the NCD FSRE unit still continued for some seasons, the NCD FSRE unit was dissolved during 2003, probably also as a result of the few accurate outputs, it generated.

4.5.2. On-farm experiment during the BAMFOOD period

With the experiences of the NCD FSRE unit in mind and through the availability of an accurate research protocol and additional, specifically for Bambara groundnut allocated resources, a new protocol could be designed for the on-farm experiments during the BAMFOOD period. As described in the previous paragraph, accuracy was the factor that needed to be optimized. The additional resources were decisive in the development of a very intensive approach, which in the end generated accurate and statistically analysable results. The intensive preliminary phase consisted of producer and consumer/trader surveys, in which a lot of relevant information could be gathered. The identification and involvement of farmers, which had a mutual interest in Bambara groundnut production, proved extremely helpful in the process. With the generated knowledge an appropriate approach for the realisation of successful on-farm evaluation trials could be developed. The new approach, which also gave the participating farmer some responsibilities in data collection, proved to be extremely successful and for the first time, a statistical analysis for yield data received from on-farm experiments could be conducted and statistically significant yield differences between the tested accessions could be found. Unfortunately the on-farm experiments could be conducted in a larger scale only for one season.

The only valuable experience from the NCD FSRE on-farm trials could this time be confirmed with real figures. The local check outperformed the test accessions in yield at all locations. Only Egowa (AHM 968) performed also above average in all locations and could even achieve a slightly higher yield average than the local check in one location. However, AHM 968 is also an accession from the Namibian germ plasm collection. Therefore the already discussed superiority of local land races on their "home ground" towards foreign accessions could once again be observed. Beside the selection advantage of the local material, the management practices applied by the farmers probably also favoured the local material, because they have over time been perfectly adjusted to the needs and requirement of the local seed types. Differences in the response of land races to management practices have already been confirmed through the agronomic investigations. Due to time and personnel limitations, no other agronomic traits could be investigated, although it would have been possible to collect and analyse also their results.

In the second season the on-farm experiments were only conducted in one location with usable data received from four farmers only. The sample was too small to conduct a statistical analysis, but the local check took again the lead in the average values, took, however, the top yielding rank only at one farm. AHM 968 took the top spot twice and the new test accession Uniswa Red once.

The major importance of participatory approaches lies, however, not in the generation of quantitative data, but in the evaluation of qualitative and subjective data like taste or cooking time (two of the ideotype criteria), which can otherwise not be assessed. Matrix rankings proved to be very useful in Namibia in the evaluation of qualitative characteristics in cowpea, pearl millet or sorghum. They could, however, not yet be applied during the evaluation of Bambara groundnut, because the available resources were unfortunately not sufficient and the duration of the BAMFOOD project too short - a shortcoming that created frustration and endangers the development of the real ideotype.

With a feasible and accurate approach in place the farmer participatory on-farm evaluation of Bambara groundnut will also generate significant results in the future and will, if the

necessary resources can be secured, remain a crucial part of the Namibian Bambara groundnut improvement program.

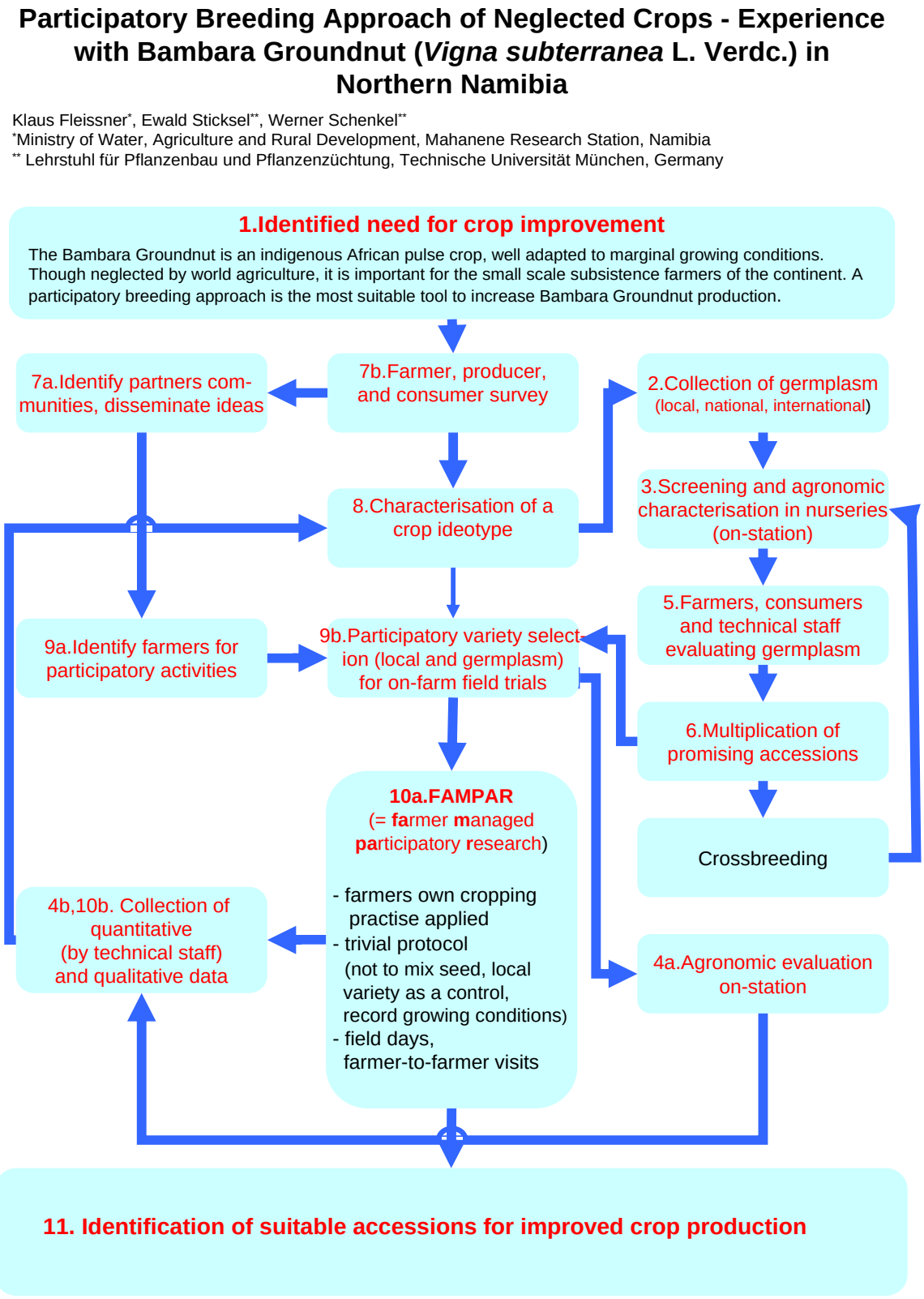
4.6. A model approach for Participatory Plant Breeding of under-utilized crops

The ultimate outcome of the Namibian Bambara groundnut improvement program would have been achieved if the scientific and participatory activities that have been performed, could be combined to model approach that would not only summarize the participatory improvement of Bambara groundnut but could also be applied for other self-pollinated under-utilized crops.

The PVS/PPB/COB approaches, in which the Namibian Bambara groundnut improvement program is embedded, have so far not been worked out in a kind of step by step guideline or been visualized in a generally applicable model (blueprint). The reason for this could be that this participatory approach depends heavily on one independent role-player outside the scientific community, who is difficult to predict – the farmer. Scientific strategies are in general not very flexible and the spirit of participation could easily get lost by a too schematic scientific model. However, a successful model approach with sufficient flexibility to react to changing parameters could also be useful for the improvement of other under-utilized crops. This created the challenge: to merge basic plant science activities with a socio-economic and anthropological component.

Against this background and in an attempt to develop a blue print model, a model approach for the participatory breeding of under-utilized crop was developed in 2002. Fortunately, this model could be based on 7 years of practical experiences made so far with the Namibian program and then also incorporated the activities that have been carried out and were still planned with BAMFOOD. Because the model was developed parallel to on-going activities, there was another important advantage: while it was designed, it could at the same time be tested for its appropriateness and still be adjusted, as the need arose. The “ideal” model in figure 34 was presented at the 2002 Deutscher Tropentag (Fleissner *et al*, 2002). Only numbers to indicate the order of implementing the different steps in the model in Namibia have been added for the purpose of this thesis. All steps in red have physically been performed in Namibia and can be found more or less in the same wording as chapters in this thesis. The crossbreeding activity was also performed in Namibia, but did not yield any mature hybrid seeds. Successful crossbreeding has been performed in greenhouses in Nottingham and Munich-Weihenstephan, however, none of these hybrid seeds were ever tested under field conditions in Namibia. Therefore crossbreeding has not been a major subject of this thesis.

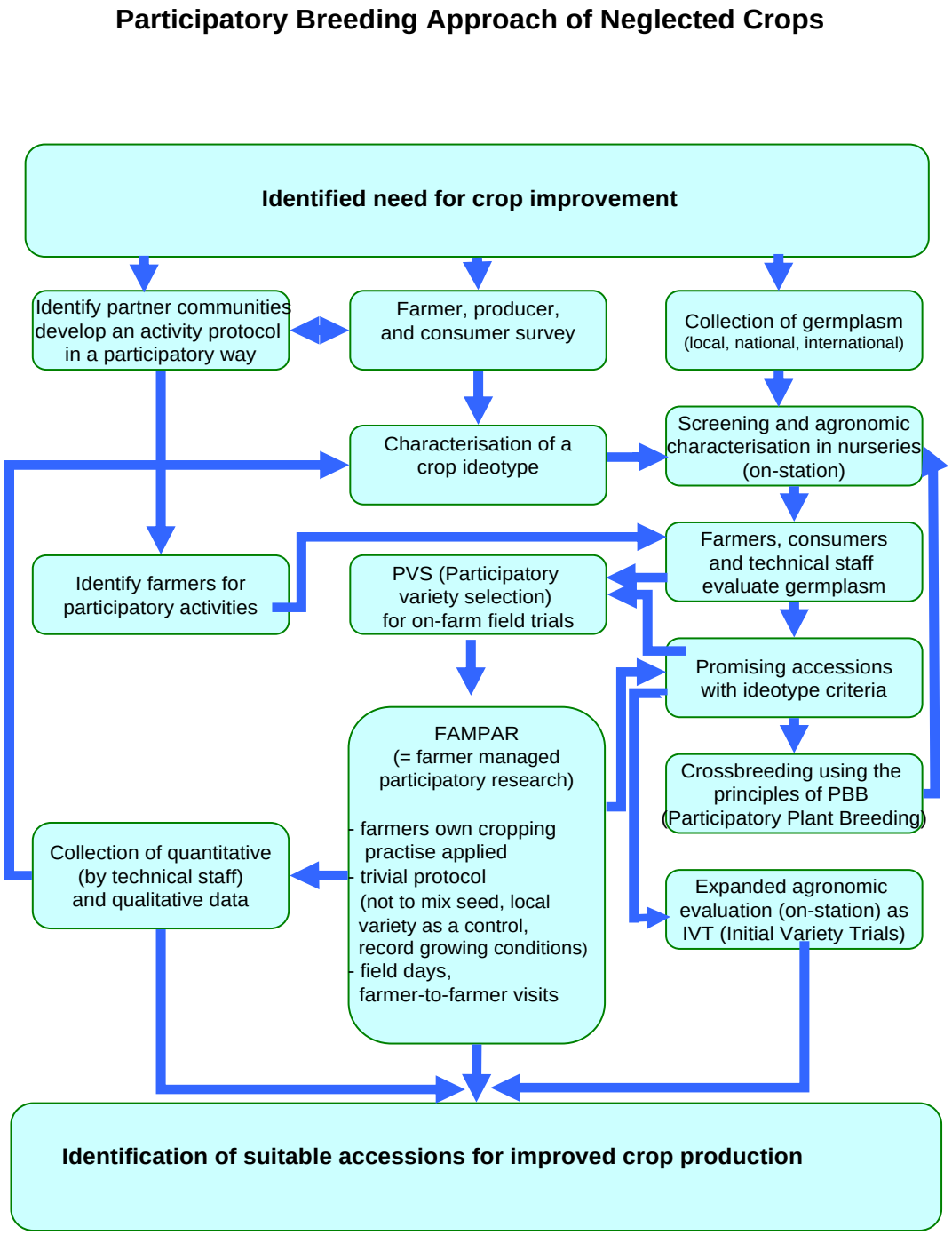
Figure 35. Poster of the model participatory breeding approach as presented at the 2002 Deutscher Tropentag



It should be noted that only the starting point and the output of the model should be considered fixed and that the activities of the model (in the boxes) are more important than the order in which the activities are conducted (described by the arrows). This order should

be considered flexible and can/should be changed according to the circumstances, although a certain logical sequence always results from the activities e.g. multiplication of promising accessions can not happen before the agronomic evaluation on-station and the collection of quantitative and qualitative data. An example for the possible adaptation of the model caused for example by a change in the available time frame or the available funds is shown in figure 35.

Figure 36. Possible adaptation of the model (e.g. in the case of the availability of additional resources and the need to speed up the process)



5. Summary

Crop production in the Northern Regions of Namibia is characterized by traditional, small-scale, subsistence farming, which is dominated by cereals with *Pennisetum glaucum* (pearl millet) being the most important crop. Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is after cowpea (*Vigna unguiculata*) the second most important legume. Both crops are drought tolerant and can cope with the extreme agro-ecological conditions in Northern Namibia.

A Namibian National Bambara Groundnut Improvement Programme was launched in 1995. No distinct or improved varieties of Bambara groundnut existed in Namibia and farmers only used seed of their traditional land races for planting. Through natural and induced selection the genetic diversity of the Namibian germ plasm was, however, reduced over the centuries (which has been confirmed through genetic finger printing) and needed to be increased through the introduction of foreign germ plasm for a successful breeding and improvement programme. Through the strict self pollination and the difficulties in artificial hybridization of Bambara groundnut single plant selection with progeny testing was chosen as the most suitable breeding strategy for Bambara groundnut improvement. Furthermore an alternative breeding model, which belongs to the field of participatory breeding approaches, was developed. The direct involvement of the farmer is an integral part of this approach and ensures the participation of the most important stakeholder in the breeding activities, which are determined and directed through the use of participatory tools. This approach also ensures focused and efficient work with an optimal use of scarce resources. Beside the breeding components (germ plasm screening, single plant selection) agronomic evaluation on-station and on-farm and some agronomic investigations were performed.

The characterization of germ plasm from Namibia and South Africa revealed the potential of Bambara groundnut. In a below-average rainfall season yields of more than 800 kg/ha and 20 g/plant were found, seed weight in the predominantly single-seeded pods reached 0.8 g and above. Number of pods per plant and seed weight could be identified as the major factors, which determine the yield per plant. It was found that the Namibian germ plasm had advantages in total yield (through a higher number of established plants and pods per plant) and agronomic scoring over the South African material, which can be interpreted as a better adaptation of the Namibian germ plasm. Advantages of the South African accessions were found in yield per plant and seed size supporting the necessity for the introduction of new germ plasm in the breeding programme.

The first single plant selection was carried out in 1996. Selection parameters were determined through a fixed yield target of 1000 kg/ha and the average seed size from a market sample (0.8 g seed per pod). All plants were graded in categories, which were fixed according to compliance with the selection parameters. 54 Grade I and II plants (3.5 % of the test population) were selected for progeny testing. From the first (non-replicated) progeny test of the selected lines against their parents, the 15 best performers advanced to (replicated) progeny trials, which were conducted for two seasons. Three promising pure lines could be identified and entered in the 1999/2000 season the agronomic comparison trials. A second single plant selection was carried out from the replicated progeny trials for the first selection to further purify the material and look if further improvement would be possible. As expected, the non-replicated progeny test of the second selection produced lower improvement indices than the first selection. Nevertheless, 11 pure lines from the second selection have since the 2004/05 season been included in the agronomic comparison trials.

The agronomic evaluation of land races and breeding lines was based on information received from Bambara groundnut producer and consumers. For the first and second evaluation phase the focus of evaluation was only on yield and seed size. With a survey of Bambara groundnut producers, traders and consumers during the third phase, characteristics for an ideotype Bambara groundnut were determined. Three objectively measurable quantitative traits (early maturity, high yield, big seeds), two objectively assessable qualitative traits (seed colour, drought tolerance) and two subjective qualitative traits (sweet taste, fast cooking) were identified and the evaluation was extended to include traits like early maturity, drought tolerance and seed colour. Especially evaluation of yield was characterized by a statistically significant seasonal influence and a highly inconsistent performance of the trial entries (over the years as well as within the same year). In 11 agronomic trials conducted over ten season only two years produced statistically significant differences in the yield performance of entries and a meaningful evaluation could in most cases only be conducted through the transformation of data to yield/plant and omission of entries with extreme high coefficients of variation. Seed size, although also influenced by seasonal effects, proved as a trade mark traits for Bambara groundnut and consistent and meaningful results were obtained. Through comparison of the averages of some permanent entries with the trial averages, progress in the improvement of yield level and seed size could be established. Agronomic evaluation in regard to germination, flowering, pod development and pod dry matter content was conducted during the intensive third agronomic evaluation phase. One breeding line from the first single plant selection, KFBN 9709, could be identified as a variety, which matched with all quantitative and objective ideotype criteria.

Through cluster analysis, based on 33 morphological descriptors, nested core collections with 8, 26, 32, 70, and 102 clusters representing different degrees of relationship, could be developed from 1013 accession of the IITA Bambara groundnut collection. Genetic fingerprinting of 223 Bambara groundnut accessions with molecular markers provided beside the proof of intra-landrace and inter-landrace genotypic diversity, also the proof for the existence of 17 genotypic similar clusters (or families) in the examined material, which are to a large extent based on their geographic occurrence.

The agronomic investigations targeted the inconsistent yield performance of Bambara groundnut. Factors influencing germination and pod development were suspected to contribute a big deal to this reputation. A germination pot experiment provided some groundbreaking results. The duration of emergence of Bambara groundnut was significantly influenced by the watering regime. A significant influence of seed size on germination percentage has been established, with big seeds having a better germination percentage than small seeds. The best germination results were obtained with a seed depth of 6 cm, big seeds and daily watering. Under field conditions, where the watering regime can not be controlled, the tendency should rather go to deeper than to shallower planting (better germination percentage). Through a plant density experiment it could be established, that, contrary to previous findings, optimal plant density is depending on the accession. An experiment with a high yielding, big seeded accession and an accession, which used to produce a high number of small pods, produced different optimal plant densities for the two accessions. The different yield components reacted differently to increasing seeding rates. The big seeded accession started at the lowest seeding rate with high levels for individual yield components such a seeds per plant and yield per plant, and experienced from the first increase of the seeding rate on a continuous decrease thereof, which, however, never reached the extent of the increase in the plant population and therefore always resulted in a higher total seed yield. The positive yield trend with increasing seeding rate was only stopped at the highest seeding rate with a considerable decrease in seed size and the significant drop in the number of harvested plants

compared to the lower seeding rates. Increasing seed rates had through the increase of the plant population also a positive effect on the total seed yield of the small seeded accession. However, major yield components of this accession remained up to a medium seed rate more or less unchanged, which resulted in a yield maximum at this rate. The small seeded accession only followed the trend of the big seed accession at the higher seed rates.

Some additional results from agronomic investigations:

1. A significant influence of a leaf disease on Bambara groundnut yield was noted in Namibia. Other pests and diseases of Bambara groundnut that have been observed in Namibia were mildew, nematodes, caterpillars, larvae and harvester termites.
2. Cream seeded varieties are in periods of excessive rainfall due to their lower tannin content more susceptible to soil borne pathogens than varieties with tan, red or black seed colour, what resulted in reduced emergence figures for cream seeded accessions.
3. In a small earthing-up experiment varietal differences on the effects of this widely used management measure were found. As in a similar experiment in Botswana, a reduction in yield through earthing-up was observed for the Namibian germ plasm accession AHM 753, while other accessions showed a clear increase in yield.

A newly developed protocol for agronomic on-farm evaluation, which involved the farmer in data collection, generated meaningful and statistically analysable results for Bambara groundnut. The results of the on-farm experiments established a good performance of the farmers own land races and the Namibian germ plasm compared to accessions from other countries.

From the experiences made with the activities of the Namibian Bambara groundnut improvement program a participatory breeding model could be developed that can be used as a blueprint model for the improvement of other under-utilised crops.

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7. Annexes

Annex 1 A. **Republic of Namibia-Ministry of Agriculture, Water and Rural Development**
Division of Agricultural Research- Crop/ Agronomy Trial Field Record

Trial: Location: Season: Ref. No:
Responsible Technician: Plot size: Net plot size: Sowing Date:

Plot no.	Entry no.	75% emergence (Date)	Plants establishment (Net-Plot)	75% Flowering (Date)	Plant count (Net-Plot)	Harvest (Date)			Pests/ Diseases Observed	Remarks
						1	**2**	**3**		

Annex 1 B.

Republic of Namibia- Ministry of Agriculture, Water and Rural Development
Division of Agricultural Research- Crop/ Agronomy Trial Post Harvest Record

Trial: Location: Season:
Ref. No.:
Responsible Technician: Net Plot Size: Data's required:

Plot No.	Rep No.	Entry No.	Pod yield (g/plot) **A**	No. of pods in 100 g sample **B**	Seed mass in sample **C**	Total seed mass (g/plot) **D**	100 g seed weight **E**	Moisture content % **F**	Foliage Fresh Mass **G**	Foliage Dry Mass **H**	**I**	**J**	**K**	**L**

Annex 2.

BAMFOOD Survey Planning Workshop

- Duration: Ca. 30 Min. per Interview
- Sample size per community: minimum of 4
- For Bambara groundnut producers

Checklist for topics to be covered:

Varieties

- No. and type
- Characteristics: Advantages → Preferences
  Disadvantages
- Origin

Agronomic Practices

- status as crop (role of BN in farming system)
- what are the factors to decide where to grow BN (site selection)
- when is BN planted? (planting time: first rain or later)
- inter-cropping
- spacing
- seed rate
- earthing up/ covering (when, how)
- weeding pattern
- pests/ diseases (control?)
- manure/ fertilizer
- rotation
- area planted (size, ha)
- harvesting (how do they know the right time; individually, parts of plot, whole plot harvested at a time

Uses

- consumption versus sale
- storage
- cultural trade
- seed selection
- seed availability

Final's question

If you could make a BN, how would you want it to be?

Annex 3.

Accession Code	Plot-No.	No. of Plants harvested	Seed Yield/Plot [g}	av. Pod Weight per Plant [g]	av. Seed Weight per Plant [g]
AHM 1104	101	7	62,7	11,0	9,0
AHM 201 B	102	23	107,5	11,3	4,7
Mahenene Local	103	20	80,7	9,8	4,0
AHM 449	104	9	112,8	18,8	12,5
AHM 867	105	21	208,2	24,3	9,9
AHM 780	106	23	226,8	25,3	9,9
AHM 260	107	5	53,6	19,6	10,7
AHM 968	108	18	235,8	30,4	13,1
AHM 1064	109	21	130,4	14,9	6,2
AHM 787	110	22	250,1	22,2	11,4
AHM 1125	111	19	214,6	29,5	11,3
KFBN 9502	112	20	108,7	10,7	5,4
KFBN 9504	113	10	33,5	7,0	3,4
KFBN 9501	114	19	222,6	21,2	11,7
KFBN 9506	115	10	77,7	13,9	7,8
AHM 760	116	19	243,5	38,3	12,8
KFBN 9505	117	16	132,0	18,6	8,3
KFBN 9503	118	9	90,9	17,7	9,1
AHM 1056	119	16	179,4	26,8	11,2
AHM 753	120	19	77,8	9,4	4,1
AHM 512	121	21	181,6	20,7	8,6
Brown Ex Zim.	122	12	92,0	13,6	7,7
AS 18	123	0	0,0	0,0	0,0
AS 17	124	14	188,1	20,4	13,4
SB 4-2	125	15	134,9	20,2	9,0
AS 9	126	10	29,9	9,7	3,0
S 3	127	12	47,4	8,5	4,0
SB 11-1 A	128	14	55,5	8,3	4,0
SB 16-5 B	129	12	76,5	11,3	6,4
S 4	130	4	14,1	8,8	3,5
SB 7-1 B	131	8	67,5	15,8	8,4
SB 11-5	132	6	47,1	9,5	7,9
SB 17-1 A	133	8	85,5	24,8	10,7
SB 4-4 C	134	14	166,4	26,9	11,9
SB 2-1	135	15	257,6	34,3	17,2
SB 10-2	136	15	181,5	23,1	12,1
SB 7-2	137	0	0,0	0,0	0,0
SB 10-1 B	138	12	78,6	15,7	6,6
SB 17-1 B	139	10	104,5	13,1	10,5
SB 13-4 B	140	4	86,3	23,5	12,2
SB 11-1	141	12	133,7	16,8	11,1
SB 16-5 A	142	12	212,2	27,9	17,7
SB 9-1	143	14	131,6	12,2	9,4
AS 19	144	7	66,4	20,3	9,5
Swazi VSA	145	10	157,9	28,9	15,8
SB 19-3	146	9	188,8	32,3	21,0
SB 4-4 A	147	7	90,7	24,9	13,0
S 13	148	10	156,2	25,0	15,6
AS 13	149	6	22,8	7,3	3,8
SB 19-3 B	150	8	79,1	20,3	9,9

SB 4-4 E	151	10	32,8	7,8	3,3
SB 20-2	152	8	73,2	15,8	9,2
As 12	153	7	37,8	8,1	5,4
K 2	154	9	49,0	14,1	5,4
SB 10-1 A	155	8	62,6	15,9	7,8
SB 20-1	156	15	106,0	15,5	7,1
SB 17-1	157	18	141,6	17,1	7,9
AS 7	158	6	20,3	7,2	3,4
Potgietersrus 3	159	4	22,7	16,5	5,7
SB 10-1	160	13	109,3	15,7	8,4

Annex 3 (cont.)

Accession Code	Plot-No.	av. Seed Weight per pod [g]	calc. Yield [kg/ha]	av. Agronomic Score	Flowering %
AHM 1104	101	0,81	209	4,3	0
AHM 201 B	102	0,41	358	2,2	10
Mahenene Local	103	0,41	269	2,5	10
AHM 449	104	0,68	376	3,3	10
AHM 867	105	0,41	694	1,2	50
AHM 780	106	0,39	756	1,0	50
AHM 260	107	0,54	179	2,2	30
AHM 968	108	0,43	786	2,0	15
AHM 1064	109	0,42	435	3,2	10
AHM 787	110	0,51	834	2,0	40
AHM 1125	111	0,38	715	2,3	40
KFBN 9502	112	0,51	362	3,0	5
KFBN 9504	113	0,48	112	3,0	0
KFBN 9501	114	0,55	742	2,7	5
KFBN 9506	115	0,56	259	2,3	40
AHM 760	116	0,33	812	1,5	25
KFBN 9505	117	0,44	440	1,0	25
KFBN 9503	118	0,52	273	1,8	25
AHM 1056	119	0,42	598	1,0	10
AHM 753	120	0,44	259	2,5	25
AHM 512	121	0,42	605	1,0	40
Brown Ex Zimbabwe	122	0,56	307	2,5	0
AS 18	123	0,00	0	2,3	0
AS 17	124	0,66	627	2,0	25
SB 4-2	125	0,45	450	3,5	35
AS 9	126	0,31	100	3,3	0
S 3	127	0,46	158	3,0	40
SB 11-1 A	128	0,48	185	3,7	50
SB 16-5 B	129	0,57	255	2,8	10
S 4	130	0,40	47	2,5	15
SB 7-1 B	131	0,53	225	3,7	0
SB 11-5	132	0,83	157	3,0	0
SB 17-1 A	133	0,43	285	3,5	15
SB 4-4 C	134	0,44	555	1,8	30
SB 2-1	135	0,50	859	1,5	70
SB 10-2	136	0,52	607	3,2	50
SB 7-2	137	0,00	0	4,3	0

SB 10-1 B	138	0,42	262	3,0	10
SB 17-1 B	139	0,80	348	2,8	10
SB 13-4 B	140	0,52	162	4,3	5
SB 11-1	141	0,66	446	3,3	10
SB 16-5 A	142	0,63	707	1,7	40
SB 9-1	143	0,64	439	3,0	30
AS 19	144	0,47	221	3,7	5
Swazi VSA	145	0,55	526	2,2	0
SB 19-3	146	0,65	629	2,7	35
SB 4-4 A	147	0,52	302	4,0	0
S 13	148	0,62	521	2,7	25
AS 13	149	0,52	76	4,2	10
SB 19-3 B	150	0,49	264	3,5	5
SB 4-4 E	151	0,42	109	2,5	30
SB 20-2	152	0,58	244	4,0	30
As 12	153	0,66	126	2,8	15
K 2	154	0,38	163	2,0	40
SB 10-1 A	155	0,49	209	2,8	15
SB 20-1	156	0,45	353	1,8	50
SB 17-1	157	0,46	472	2,7	20
AS 7	158	0,47	68	3,0	5
Potgietersrus 3	159	0,34	76	2,8	15
SB 10-1	160	0,54	364	2,2	50

Annex 4.

Explorative data analysis for 1995/96 screening nursery

	Origin	Fälle					
		Gültig		Fehlend		Gesamt	
		N	Prozent	N	Prozent	N	Prozent
Yield	Namibia	17	100,0%	0	,0%	17	100,0%
	South Africa	37	100,0%	0	,0%	37	100,0%
Plantsharvested	Namibia	17	100,0%	0	,0%	17	100,0%
	South Africa	37	100,0%	0	,0%	37	100,0%
Yieldplant	Namibia	17	100,0%	0	,0%	17	100,0%
	South Africa	37	100,0%	0	,0%	37	100,0%
Seedweight	Namibia	17	100,0%	0	,0%	17	100,0%
	South Africa	37	100,0%	0	,0%	37	100,0%
Podplant	Namibia	17	100,0%	0	,0%	17	100,0%
	South Africa	37	100,0%	0	,0%	37	100,0%

Univariate Statistiken

	Origin			Statistik	Standard fehler
Yield	Namibia	Mittelwert		158,635	16,8970
		95% Konfidenzintervall des Mittelwerts	Untergrenze	122,815	
			Obergrenze	194,455	
		5% getrimmtes Mittel		159,389	
		Median		179,400	
		Varianz		4853,630	
		Standardabweichung		69,6680	
		Minimum		53,6	
		Maximum		250,1	
		Spannweite		196,5	
		Interquartilbereich		130,6	
		Schiefe		-,144	,550
		Kurtosis		-1,662	1,063
	South Africa	Mittelwert		95,022	9,6418
		95% Konfidenzintervall des Mittelwerts	Untergrenze	75,467	
			Obergrenze	114,576	
		5% getrimmtes Mittel		91,486	
		Median		85,500	
		Varianz		3439,651	
		Standardabweichung		58,6485	
		Minimum		14,1	
		Maximum		257,6	
		Spannweite		243,5	
		Interquartilbereich		86,1	
		Schiefe		,839	,388
		Kurtosis		,336	,759

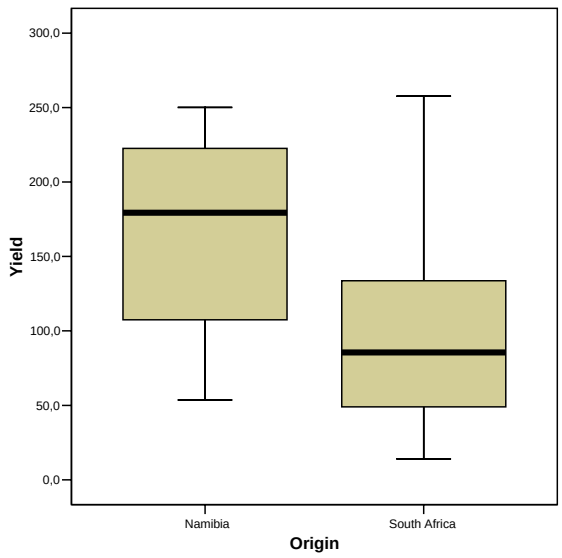
Plantsharvested	Namibia	Mittelwert		17,76	1,327
		95% Konfidenzintervall des Mittelwerts	Untergrenze	14,95	
			Obergrenze	20,58	
		5% getrimmtes Mittel		18,18	
		Median		19,00	
		Varianz		29,941	
		Standardabweichung		5,472	
		Minimum		5	
		Maximum		23	
		Spannweite		18	
		Interquartilbereich		4	
		Schiefe		-1,518	,550
		Kurtosis		1,229	1,063
	South Africa	Mittelwert		10,22	,590
		95% Konfidenzintervall des Mittelwerts	Untergrenze	9,02	
			Obergrenze	11,41	
		5% getrimmtes Mittel		10,21	
		Median		10,00	
		Varianz		12,896	
		Standardabweichung		3,591	
		Minimum		4	
		Maximum		18	
		Spannweite		14	
		Interquartilbereich		6	
		Schiefe		,050	,388
		Kurtosis		-,785	,759

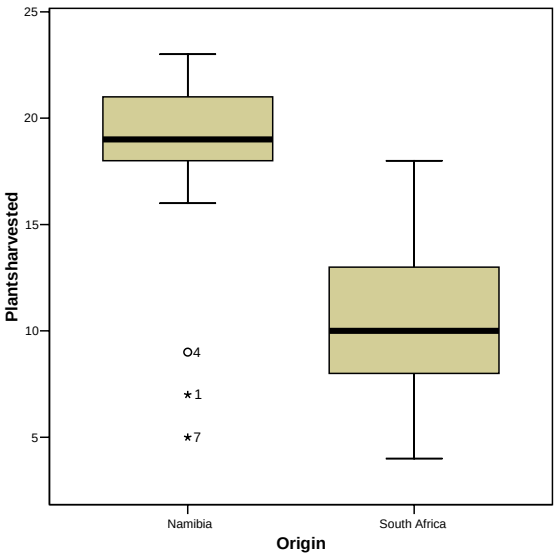
Yieldplant	Namibia	Mittelwert		9,206	,7644
		95% Konfidenzintervall des Mittelwerts	Untergrenze	7,585	
			Obergrenze	10,826	
		5% getrimmtes Mittel		9,279	
		Median		9,900	
		Varianz		9,933	
		Standardabweichung		3,1517	
		Minimum		4,0	
		Maximum		13,1	
		Spannweite		9,1	
		Interquartilbereich		5,8	
		Schiefe		-,588	,550
		Kurtosis		-1,133	1,063

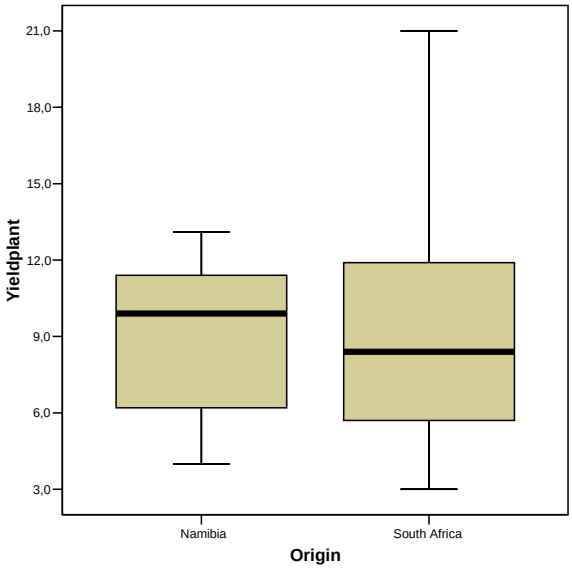
	South Africa	Mittelwert		9,159	,7335
		95% Konfidenzintervall des Mittelwerts	Untergrenze	7,672	
			Obergrenze	10,647	
		5% getrimmtes Mittel		8,920	
		Median		8,400	
		Varianz		19,905	
		Standardabweichung		4,4615	
		Minimum		3,0	
		Maximum		21,0	
		Spannweite		18,0	
		Interquartilbereich		6,5	
		Schiefe		,709	,388
		Kurtosis		,151	,759

Seedweight	Namibia	Mittelwert		,4741	,02900
		95% Konfidenzintervall des Mittelwerts	Untergrenze	,4126	
			Obergrenze	,5356	
		5% getrimmtes Mittel		,4635	
		Median		,4200	
		Varianz		,014	
		Standardabweichung		,11959	
		Minimum		,33	
		Maximum		,81	
		Spannweite		,48	
		Interquartilbereich		,12	
		Schiefe		1,724	,550
		Kurtosis		3,121	1,063
	South Africa	Mittelwert		,5249	,01870
		95% Konfidenzintervall des Mittelwerts	Untergrenze	,4869	
			Obergrenze	,5628	
		5% getrimmtes Mittel		,5198	
		Median		,5200	
		Varianz		,013	
		Standardabweichung		,11374	
		Minimum		,31	
		Maximum		,83	
		Spannweite		,52	
		Interquartilbereich		,15	
		Schiefe		,710	,388
		Kurtosis		,757	,759

Podplant	Namibia	Mittelwert		20,224	2,0295
		95% Konfidenzintervall des Mittelwerts	Untergrenze	15,921	
			Obergrenze	24,526	
		5% getrimmtes Mittel		19,821	
		Median		20,700	
		Varianz		70,022	
		Standardabweichung		8,3679	
		Minimum		9,4	
		Maximum		38,3	
		Spannweite		28,9	
		Interquartilbereich		14,9	
		Schiefe		,403	,550
		Kurtosis		-,390	1,063
	South Africa	Mittelwert		17,219	1,2191
		95% Konfidenzintervall des Mittelwerts	Untergrenze	14,746	
			Obergrenze	19,691	
		5% getrimmtes Mittel		16,875	
		Median		15,800	
		Varianz		54,993	
		Standardabweichung		7,4157	
		Minimum		7,2	
		Maximum		34,3	
		Spannweite		27,1	
		Interquartilbereich		12,8	
		Schiefe		,513	,388
		Kurtosis		-,536	,759



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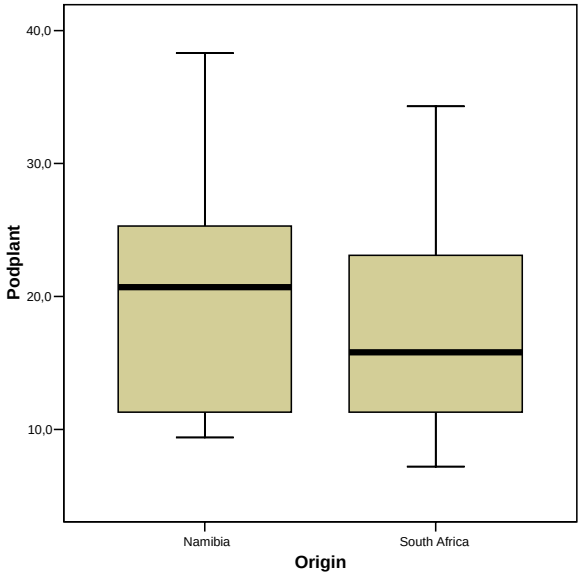
Namibia
South Africa
Origin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10,0
Podplant
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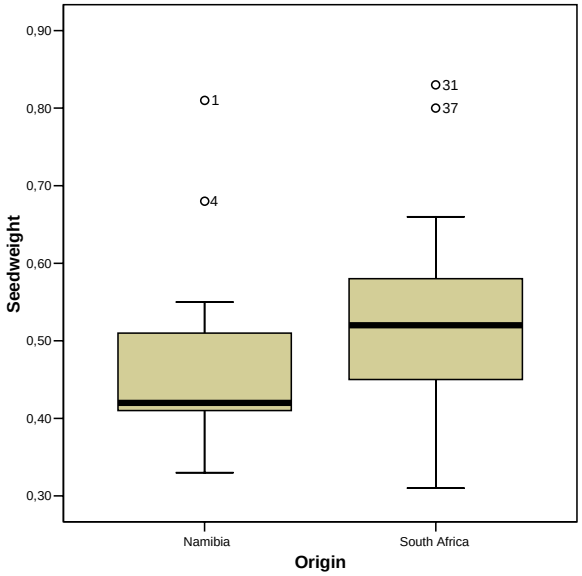
South Africa
Origin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1
4
31
37
Seedweight
Namibia
South Africa
Origin

Annex 5.

Accession ID	Pod Yield [g]	Index (% of Parent)	No. of Pods	av. Seed Weight per pod [g]
Parent 1 (101)	**362,3**	**100**	**159**	**0,54**
102	593,4	164	92	0,93
103	443,6	122	137	0,61
104	661,3	183	95	0,86
Parent 2 (105)	**209,8**	**100**	**193**	**0,44**
106	359,3	171	167	0,52
107	412,3	197	150	0,58
108	450,0	214	176	0,47
109	434,1	207	128	0,65
110	485,7	232	119	0,73
111	429,2	205	158	0,54
112	432,5	206	176	0,49
Parent 3 (113)	**240,5**	**100**	**159**	**0,55**
114	457,9	190	174	0,47
115	16,5	one plant		
116	45,6	four plants		
Parent 4 (117)	**236,5**	**100**	**185**	**0,49**
118	312,3	132	178	0,50
119	240,9	102	215	0,41
120	261,2	110	195	0,45
Parent 5 (123)	**313,6**	**100**	**166**	**0,53**
121	232,7	74	154	0,46
122	360,1	115	190	0,58
Parent 6 (128)	**209,4**	**100**	**140**	**0,62**
124	331,4	158	156	0,55
125	338,7	162	86	0,98
126	371,6	177	161	0,58
127	455,2	218	117	0,73
Parent 7 (130)	**276,5**	**100**	**260**	**0,35**
129	370,2	134	164	0,58
Parent 8 (132)	**192,9**	**138**	**100**	**0,63**
131	373,1	179	193	0,45
Parent 9 (134)	**371,9**	**100**	**220**	**0,39**
133	319,6	86	164	0,54
Parent 10(136)	**329,6**	**100**	**130**	**0,64**
135	333,5	102	156	0,52
Parent 11 (138)	**231,9**	**100**	**184**	**0,46**
137	259,4	112	194	0,44
Parent 12 (140)	**477,9**	**100**	**170**	**0,49**
139	502,0	105	167	0,53

Annex 5 (cont.).

Parent 13 (141)	**409,6**	**100**	**111**	**0,74**
142	477,8	117	159	0,51
143	323,6	79	161	0,52
144	399,7	98	164	0,49
Parent 14 (145)	**329,8**	**100**	**170**	**0,51**
146	364,0	110	193	0,43
Parent 15 (147)	**249,3**	**100**	**228**	**0,39**
148	306,2	123	205	0,42
Parent 16 (149)	**214,6**	**100**	**148**	**0,56**
150	237,3	111	156	0,56
151	279,8	130	149	0,58
Parent 17 (152)	**180,0**	**100**	**200**	**0,42**
153	337,4	187	144	0,60
154	421,5	234	169	0,51
Parent 17 (155)	**272,4**	**100**	**219**	**0,40**
156	496,4	182	94	0,92
157	381,5	140	130	0,68
Parent 19 (158)	**314,7**	**100**	**212**	**0,40**
159	283,6	90	136	0,64
160	311,5	99	191	0,51
Parent 20 (164)	**224,4**	**100**	**200**	**0,48**
162	196,8	88	193	0,46
163	207,2	92	142	0,61
Parent 21 (166)	**345,2**	**100**	**196**	**0,44**
165	291,2	84	279	0,31
Parent 22 (168)	**232,7**	**100**	**186**	**0,46**
167	289,6	124	179	0,48
Parent 23 (170)	**295,8**	**100**	**161**	**0,53**
169	149,4	51	150	0,58
Parent 24 (175)	**397,7**	**100**	**175**	**0,50**
171	589,4	148	151	0,57
172	544,8	137	150	0,57
173	473,5	119	168	0,55
174	327,3	82	144	0,60
Parent 25 (180)	**329,0**	**100**	**130**	**0,60**
176	399,3	121	145	0,61
177	431,4	131	121	0,73
178	289,0	88	133	0,69
179	360,7	110	167	0,52

Annex 6. Progeny trial 1997/98

Entry 1 = KFBN 9701
Entry 2 = KFBN 9702
Entry 3 = KFBN 9703
Entry 4 = KFBN 9704
Entry 5 = KFBN 9705
Entry 6 = KFBN 9706
Entry 7 = KFBN 9707
Entry 8 = KFBN 9708
Entry 9 = KFBN 9709
Entry 10 = KFBN 9710
Entry 11 = KFBN 9711
Entry 12 = KFBN 9712
Entry 13 = KFBN 9713
Entry 14 = KFBN 9714
Entry 15 = KFBN 9715

Parents:

Entry 16 = AS 17
Entry 17 = KFBN 9501
Entry 18 = SB 16-5 A
Entry 19 = AHM 201 B
Entry 20 = KFBN 9505

Entry	Plot No.	Yield [g/plot]
1	101	179,9
1	217	52,7
1	313	25,3
2	102	99,9
2	215	58,9
2	310	72,0
3	103	262,7
3	213	61,3
3	309	30,6
4	105	211,5
4	211	207,8
4	318	81,6
5	106	139,6
5	214	44,5
5	315	33,8

Entry	Plot No.	Yield [g/plot]
6	107	84,0
6	201	71,8
6	317	45,1
7	109	148,4
7	203	165,1
7	314	48,3
8	110	107,3
8	206	74,5
8	301	70,9
9	111	301,4
9	218	196,5
9	306	79,8
10	113	163,8
10	219	81,3
10	302	73,2

Entry	Plot No.	Yield [g/plot]
11	114	39,6
11	207	61,7
11	319	12,5
12	115	46,8
12	209	65,8
12	303	20,1
13	117	174,3
13	202	168,0
13	305	153,3
14	118	91,6
14	210	49,6
14	307	66,6
15	119	19,7
15	205	0,0
15	311	199,4

Entry	Plot No.	Yield [g/plot]
16	104	400,0
16	216	62,0
16	308	97,3
17	109	190,1
17	212	92,0
17	320	91,0
18	112	32,9
18	204	283,8
18	316	36,7
19	116	106,2
19	220	117,3
19	312	139,1
20	120	47,9
20	208	20,5
20	304	101,9

Annex 7. Progeny trial 1998/99

Entry 1 = KFBN 9701
Entry 2 = KFBN 9702
Entry 3 = KFBN 9703
Entry 4 = KFBN 9704
Entry 5 = KFBN 9705
Entry 6 = KFBN 9706
Entry 7 = KFBN 9707
Entry 8 = KFBN 9708
Entry 9 = KFBN 9709
Entry 10 = KFBN 9710
Entry 11 = KFBN 9711
Entry 12 = KFBN 9712
Entry 13 = KFBN 9713
Entry 14 = KFBN 9714
Entry 15 = KFBN 9715

Parents:

Entry 16 = AS 17
Entry 17 = KFBN 9501
Entry 18 = SB 16-5 A
Entry 19 = AHM 201 B
Entry 20 = KFBN 9505

Entry	Plot No.	Yield [g/plot]
1	101	256,0
1	217	83,8
1	313	350,3
2	102	307,8
2	215	144,4
2	310	344,4
3	103	336,4
3	213	249,6
3	309	272,3
4	105	231,7
4	211	473,4
4	318	239,6
5	106	183,1
5	214	139,2
5	315	234,5

Entry	Plot No.	Yield [g/plot]
6	107	166,1
6	201	247,9
6	317	113,2
7	109	312,7
7	203	305,9
7	314	220,8
8	110	257,4
8	206	292,5
8	301	237,4
9	111	375,1
9	218	160,6
9	306	404,7
10	113	212,8
10	219	107,4
10	302	395,7

Entry	Plot No.	Yield [g/plot]
11	114	116,6
11	207	211,8
11	319	97,1
12	115	131,4
12	209	166,7
12	303	237,8
13	117	200,7
13	202	444,5
13	305	402,3
14	118	220,3
14	210	277,5
14	307	314,6
15	119	130,6
15	205	243,6
15	311	314,6

Entry	Plot No.	Yield [g/plot]
16	104	164,0
16	216	203,9
16	308	352,0
17	109	269,4
17	212	232,4
17	320	327,1
18	112	234,8
18	204	354,5
18	316	147,8
19	116	177,9
19	220	234,7
19	312	338,4
20	120	129,7
20	208	153,5
20	304	305,9

Annex 8.

2. Single Plant Selection from 1997/98 Progeny Trial

Plant ID	Seed Weight [g]	Pod Count	av. Seed Weight per Pod [g]
215/B1	19,4	32	0,61
103/A1	22,1	31	0,71
105/B4	25,2	28	0,90
105/B3	20,4	31	0,66
103/A2	25,1	43	0,58
211/B1	21,0	32	0,66
211/B2	19,8	30	0,66
203/B1	18,3	16	1,14
110/A1	35,5	45	0,79
111/A2	22,1	27	0,82
111/B3	28,6	23	1,24
218/A2	27,3	46	0,59
113/A4	26,6	40	0,67
207/A1	21,2	16	1,33
202/B2	18,2	22	0,83
118/B1	22,6	29	0,78
210/B1	21,8	34	0,64
311/A1	23,6	22	1,07
311/A3	26,3	25	1,05
104/B1	29,3	43	0,68
104/B3	24,1	36	0,67
104/B4	39,5	56	0,71
204/B1	56,6	92	0,62
116/B1	48,2	67	0,72
220/A1	21,5	24	0,90

Entries in red advanced to progeny testing

Annex 8 (cont.)

2.Single Plant Selection from 1998/99 Progeny Trial

Plant ID	Seed Weight [g]	Pod Count	av. Seed Weight per Pod [g]
101/B1	25,4	29	0,88
102/A1	21,0	25	0,84
102/A2	19,1	24	0,80
103/B1	21,1	32	0,66
105/B3	20,3	26	0,78
110/B1	19,3	21	0,92
110/B3	22,7	18	1,26
111/A4	24,0	27	0,89
111/A5	23,0	29	0,79
112/A2	18,4	16	1,15
113/A1	18,8	24	0,78
118/B1	20,4	23	0,89
201/B1	19,5	23	0,85
202/B2	20,5	32	0,64
202/B3	20,3	25	0,81
204/B1	36,9	41	0,90
210/B2	22,3	18	1,24
210/B3	22,6	26	0,87
211/A3	27,2	29	0,94
216/A1	28,9	40	0,72
218/A1	18,6	21	0,89
220/B1	21,1	23	0,92
220/B2	20,7	26	0,80
301/A1	27,1	28	0,97
304/A1	23,4	29	0,81
305/B1	25,0	35	0,71
306/A1	35,2	40	0,88
306/B1	22,8	27	0,84
307/A1	19,3	17	1,14
308/B1	23,2	30	0,77
308/B2	22,7	21	1,08
308/B3	23,5	23	1,02
310/B1	21,0	28	0,75
311/B1	29,8	30	0,99
312/A1	19,7	27	0,73
313/B2	19,7	22	0,90
313/B3	20,7	25	0,83
315/A2	19,4	33	0,59
320/B1	19,5	22	0,89
320/B3	28,2	33	0,85

Annex 9

Cluster 1:	**Cluster 2 (cont.):**	**Cluster 6:**	**Cluster 8 (cont.):**
BEN TVsu193	ZIM TVsu992	ZIM TVsu1052	IDN Parung brown
NGA TVsu620	ZMB TVsu735	ZIM TVsu1072	NAM 1749/3
GHA TVsu142	MDG TVsu817	NGA Tvsu610	NAM 1143/2
ZMB TVsu850	ZMB Tvsu787	ZIM TVsu1056	
ZMB Tvsu712	ZMB TVsu791	NGA Tvsu573	**Cluster 9:**
GHA TVsu150	ZIM TVsu1060	ZMB Tvsu740	NAM 1691/2
ZMB TVsu922	ZIM TVsu1061		NAM 426/3
ZIM TVsu972		**Cluster 7:**	NAM 235/3
TZA TVsu183	**Cluster 3:**	ZMB Tvsu747	NAM 1749/3
GHA TVsu139	BEN TVsu189	ZMB TVsu788	NAM 481/3
NAM Sb2-1	NGA TVsu614	ZIM TVsu1064	NAM 235/3
IDN Parung black	CMR TVsu551	ZIM TVsu974	
IDN Ramayana black	NGA TVsu581	ZIM TVsu1017	**Cluster 10:**
IDN Parung red	NGA TVsu841	ZMB TVsu955	ZMB TVsu866
TZA Dodoma red		ZMB TVsu854	ZMB TVsu927
SWZ Manzini tan	**Cluster 4:**	ZMB TVsu884	ZMB TVsu784
SWZ Manzini black	GHA TVsu164	MDG TVsu815	
ZMB TVsu932	BEN Tvsu207	ZIM TVsu1025	**Cluster 11:**
SWZ Manzini butterfly	GHA Tvsu216	ZIM TVsu1034	NAM AHM 753
ZMB Tvsu730	NGA Tvsu586	NGA TVsu590	NAM AHM 753
ZMB Tvsu742	NGA Tvsu577	ZIM TVsu1008	NAM AHM 753
ZMB Tvsu712	GHA Tvsu215		NAM AHM 753
ZMB TVsu935	GHA Tvsu220	**Cluster 8:**	NAM AHM 753
MDG TVsu814	NGA Tvsu631	ZMB TVsu852	NAM AHM 753
SWZ Manzini star	GHA Tvsu210	NAM 1761/3	NAM AHM 968
SWZ Manzini shade star	NGA Tvsu673	NAM 1603/2	NAM AHM 968
SWZ Manzini shade eye	GHA Tvsu221	NAM 1689/2	NAM AHM 968
SWZ Manzini black ring	NGA Tvsu608	NAM 1756/3	ZAF AS17
ZMB TVsu986	NGA Tvsu653	NAM 1143/2	ZAF AS17
ZIM TVsu1024	CMR Tvsu541	NAM 1689/2	ZAF AS17
NAM Sb16-5a	CMR Tvsu569	NAM 1690/2	
MDG TVsu822	NGA Tvsu597	NAM 1690/2	**Cluster 12:**
		NAM 1756/3	BWA Dip C
Cluster 2:	**Cluster 5:**	NAM 1144/3	BWA Dip C
GHA TVsu157	KEN TVsu793	NAM 1144/3	BWA Dip C
TZA Dodoma cream	ZIM Tvsu1011	NAM 1690/2	BWA Dip C
ZMB TVsu733	ZIM TVsu1050	NAM 481/3	BWA Dip C
ZMB TVsu762	ZMB TVsu875	NAM 1144/3	BWA Dip C
ZMB TVsu790	ZMB Tvsu692	NAM 1689/2	MDG TVsu801
ZMB TVsu892	ZMB Tvsu739	NAM 1143/2	ZIM TVsu1049
NGA Tvsu588	ZMB Tvsu695	NGA TVsu130	BWA Gab C
ZMB TVsu927	ZMB Tvsu686	NAM Sb2-1	BWA Gab C
MDG TVsu810	ZMB Tvsu691	ZIM TVsu1026	BWA Gab C
CMR Tvsu560	ZMB Tvsu688	ZIM TVsu1013	BWA Gab C
NGA TVsu838	ZIM TVsu1016	NAM Sb4-2	BWA OM 1
NGA Tvsu599	ZIM TVsu1029	MDGTVsu829	BWA OM 1
ZIM TVsu1035	ZIM TVsu1032	NAM Sb19-3	BWA OM 1
ZIM TVsu1006	ZIM TVsu1033	NAM 235/3	
ZMB TVsu857		NAM Sb16-5a	
ZIM TVsu1000		NAM KFBN 9501	

Annex 9 (cont.)

Cluster 13:	**Cluster 14 (cont.):**	**Cluster 16:**	**Cluster 17(cont.):**
SWZ Nyakeni C1	IDN Cibadak	TZA TVsu184	ZIM TVsu988
SWZ Nyakeni C2	IDN Cibadak	TZA TVsu379	ZIM TVsu989
SWZ Nyakeni C1	IDN Cibadak	MDG TVsu811	ZIM TVsu1009
SWZ Nyakeni C1		ZMB TVsu889	ZIM TVsu1038
SWZ Nyakeni C1	**Cluster 15:**	ZMB TVsu853	ZMB TVsu891
SWZ Nyakeni C1	GHA TVsu134	ZMB TVsu736	ZIM TVsu996
SWZ Nyakeni C2	GHA TVsu160	ZMB TVsu743	ZIM TVsu1015
SWZ Nyakeni C2	GHA TVsu158	ZMB TVsu716	ZMB TVsu950
SWZ Nyakeni C2	ZMB TVsu845	ZMB TVsu721	ZMB TVsu954
SWZ Nyakeni C2	ZMB TVsu846	ZMB TVsu881	ZIM TVsu1004
SWZ Nyakeni C2	GHA TVsu166	ZMB TVsu719	ZIM TVsu1005
SWZ Nyakeni C2	NGA TVsu591	ZMB TVsu727	ZIM TVsu1023
SWZ Nyakeni C2	NGA TVsu601	MDG TVsu796	ZIM TVsu1014
	NGA TVsu173		ZMB TVsu930
Cluster 14:	NGA TVsu174	**Cluster 17:**	ZMB TVsu948
SWZ Swazi red	GHA TVsu136	GHA TVsu161	ZMB TVsu896
SWZ Swazi red	GHA TVsu140	ZMB TVsu942	ZIM TVsu1043
SWZ Swazi red	GHA TVsu138	ZIM TVsu999	ZMB TVsu921
IDN Cibadak	GHA TVsu144	ZIM TVsu1018	ZMB TVsu925
IDN Cibadak		ZIM TVsu1045	ZMB TVsu934
IDN Cibadak		ZIM TVsu966	ZMB TVsu941
IDN Cibadak		ZIM TVsu990	

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Curriculum Vitae

Personal Data:

Name:	Klaus Werner Emil Fleissner
Date of Birth:	06.03.1960
Place of Birth:	Schweinfurt/Main, Germany
Marital status:	married

Education:

1966 – 1970	Primary Education in Grundschule Neumühlweg in Nürnberg
1970 – 1978	Secondary Education in Hardenberg Gymnasium in Fürth/Bay.
1978 – 1979	Military Service, Air force bases Roth and Feuchtwangen
1980 – 1986	University study of Agricultural Sciences at the Technical University of Munich in Freising – Weihenstephan, Faculty of Agricultural Sciences and Horticulture
	Obtain University Degree: Diplom-Agraringenieur (Univ.)

Professional Career:

1986 – 1987	Farm assistant, Farm Ojtisororindi, Omitara, Namibia
1987 – 1990	Farm manager, Farmverwaltung Franken, Kamanjab, Namibia
1990 – 1991	Farm manager, Farmverwaltung Gemsbokpan, Grootfontein, Namibia
1991 – 1995	Roads Superintendent, Ministry of Works, Transport and Communication, Namibia
Since 1995	Senior Agricultural Research Officer, Ministry of Agriculture, Water and Forestry, Namibia