Response to Selection for Downy Mildew (*Peronosclerospora sorghi*) and Maize Streak Virus Resistance in three Quality Protein Maize Populations in Mozambique

By

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General abstract

Quality protein maize (QPM) has high nutritional value, but production is threatened by downy mildew (DM) and maize streak virus disease (MSVD) among other constraints. There are few studies of DM and MSVD resistance in QPM cultivars. The objective of this study was to improve resistance to DM and MSVD in three QPM populations. This was realized through ascertaining farmers' key production constraints and special preferences for cultivars; determining the utility of recurrent selection method for improvement of three QPM populations (SussumaS2, ZM521Q and Pop62SRQ); and determining grain yield potential. The study was conducted in Mozambique for DM and in Zimbabwe for MSV, during 2003 to 2006.

Surveys were conducted in Manica and Angonia districts in Mozambique to ascertain farmers' perceptions and preferences for maize varieties, especially QPM. Participatory rural appraisal tools that included semi-structured questionnaires and focus group discussions were used to collect data. Results showed that farmers predominantly grew open pollinated varieties and fewer normal maize hybrids (non-QPM), and grain yield was estimated to be very low (0.2 to 0.6 t ha^{-1}). Results showed that drought and insect pests were the dominant constraints to maize productivity in Mozambique, while diseases were ranked third. Downy mildew disease and MSVD were considered to be the most important diseases reducing maize productivity. Farmers also showed high preference for high yielding and early maturity cultivars in all areas. Predominantly, farmers were still using their local landraces because of sweet taste, particularly for home consumption and flint grain for storage. Farmers' access to improved cultivars was limited due to high seed prices on the local market. Research priorities as perceived by the farmers included breeding for resistance to drought, grain weevils and diseases and sweetness. Generally, farmers showed little knowledge of QPM varieties and the importance of this trait, but they observed that the few QPM varieties they knew had some weaknesses such as poor storability and susceptibility to DM and MSVD which required improvement. These results should be considered in breeding new cultivars, both normal and QPM.

To improve DM and MSV disease resistance in QPM varieties, S1 recurrent selection was conducted in three QPM populations, Sussuma, ZM521Q and Pop62SRQ at Umbeluzi Research Station in Mozambique and at CIMMYT-Harare Research

Station in Zimbabwe during 2003 to 2006. Two selection cycles were formed and evaluated. Selection intensity was 50%, and 25% in cycle1 (C1) and cycle2 (C2), respectively. Results indicated significant improvement in DM resistance from C1 to C2, with scores of 4.6-3.9 in Sussuma, 3.0-2.3 in ZM521Q and 4.0-3.3 in Pop62SRQ, respectively. This was associated with an increase in yield of about 4.67% in Sussuma, 4.68% in ZM521Q and 4.47% in Pop62SRQ. Results indicated also increases in genetic variances (σ^2_G) for DM and MSVD from C1 to C2. Similarly, broad sense heritability (H^2) estimates ranged from moderate to high and increased from C1 to C2 in all populations. There was also an improvement in flintiness of the grain with texture scores of 2.7-1.4 in Sussuma, 2.9-1.8 in ZM521Q and 2.5-1.7 in Pop62SRQ. Maize streak virus disease results showed significant improvement in MSVD resistance from C1 to C2, with scores of 3.4-2.9 in Sussuma, 2.7-2.1 in ZM521Q and 3.47-3.0 in Pop62SRQ, respectively. This was associated with an increase in yield of about 4.57% in Sussuma, 4.62% in ZM521Q and 4.37%) in Pop62SRQ. There was also an improvement in flintiness of the grain with texture scores of 2.7-1.5 in Sussuma, 2.9-1.9 in ZM521Q and 2.5-1.7 in Pop62SRQ.

In conclusion, the study indicated that farmers' preferences would be greatly influenced by the major prevailing constraints, and thus should be included in the breeding programmes. Two cycles of S1 recurrent selection significantly improved DM and MSVD resistance in the three QPM populations although the basic levels of resistance differed. Therefore, farmers in the southern zones of Mozambique where DM is predominant would be encouraged to plant the new DM resistant versions of Sussumma, ZM521Q and Pop62SRQ, while those in the north and central medium to high altitude areas, where MSV is the major constraint, would be advised to plant the MSV resistant versions of these populations. Future improvement would still be viable because the genetic variances for both yield and disease resistance were not compromised during the two cycles of recurrent selection.

Declaration

The thesis study was carried out in the African Centre for Crop Improvement (ACCI), in the School of Biochemistry, Genetics, Microbiology and Plant Pathology, University of KwaZulu-Natal, Pietermaritzburg Campus, under the supervision of Prof. P. Tongoona and Dr. John Derera

Research presented in this thesis represents original work by the author and has not been otherwise submitted in any form for degree or diploma to any university. Where use has been made of the work of others it is duly acknowledged in the text.

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Dedication

To my father, Mariote Dastane (1914-1989) and my mother, Flecitasse Gabriel Machila (1930-2005), who lie in the cold soils of Lichinga, Niassa Province.

Their counsel and vision remain my greatest inspiration to go for the stars.

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Introduction to thesis

1. Importance of Maize in Africa

Maize (*Zea mays L.*) is among the three leading cereal crops worldwide. Global production amounted to 130 million ha with output of 574 million MT (Ito, 1998). The other two are wheat and rice. It is an important staple food crop for millions of people in developing countries, and in developed countries it is used as feed for livestock and other industrial uses. Maize is the main source of calories (20%) and proteins (17-60%) for the majority of the people in Africa (FAO, 1992). Therefore, adequate production of maize is required to feed both the urban and the rural people. However, production still fails to match the high demand for maize in most countries in sub-Saharan Africa including Mozambique.

Production varies among the African countries (Table 1). South Africa is the leading producer of maize in the continent. Nigeria produces most of the maize in West Africa while in East Africa Tanzania produces the bulk of the crop. Generally, grain yield is below 2 t ha^{-1} in most countries in sub-Saharan Africa (Table 1). The exceptions being Burkina Fasso with just over 2 t ha^{-1} in West Africa, and South Africa with more than 3 t ha^{-1} in southern Africa. In Mozambique, maize is produced on 1.2 million ha and the average yield almost 1 t ha$^{-1.}$

Although a lot of maize is consumed in Africa, the crop produces proteins of low biological quality hence it has low nutritional quality. This is because maize is deficient in two essential amino acids namely, lysine and tryptophan (Bathia and Robinson, 1987). The potential to improve nutritional quality of maize was realised after Mertz et al. (1964) discovered the genetic effects of the opaque-2 (*o2)* gene on maize endosperm protein. According to Vasal et al. (1997) this led to the breeding of quality protein maize (QPM), which is based on the (*o2)* mutation with selection for improved kernel types.

Quality protein maize breeding has been initiated in Mozambique to alleviate the malnutrition pandemic. In the last 15 years Mozambique has been facing serious of natural disasters such as cyclic floods and drought that have displaced many families. Due to lack of food, malnutrition and poverty are increasing in the country. In 2002 the level of malnutrition in the country was around 40% (DINA, 1995). Maize is the staple food for the majority of the Mozambican population and QPM with its high quality protein can contribute to alleviate the malnutrition problems. There is a strong view that introduction of QPM could be a viable solution especially for feeding young babies. Unfortunately, the QPM varieties are susceptible to DM and MSVD that lower their grain yield potential and also affect their production in the country. For this reason the existing varieties need to be improved for resistance to DM and MSVD.

Table.1: Maize production data for selected sub-Sahara African countries

Name of the Country	Total Area (million ha)	Total Production (Metric Ton)	Average Yield t/ha
Ghana	732.95	1157.62	1.58
Nigeria	3592.97	5957.00	1.66
Mali	424.85	634.46	1.50
Burkina Fasso	380.13	999.05	2.10
Guinea	90.01	90.00	1.00
Cameron	549.88	1023.11	1.90
Benin	755.42	864.70	1.14
Togo	380.00	485.00	1.28
Malawi	1817.07	1253.00	1.70
Mozambique	1230.01	1403.00	1.14
South Africa	3222.16	11749.00	3.65
Ethiopia	1950.00	3342.84	1.71
Uganda	780.00	1170.00	1.50
Tanzania	1998.31	3288.00	1.65
Kenya	1771.12	2905.56	1.64

Source: FAO, 1992

Downy mildew was reported among the dominant constraints to maize production in Mozambique (Pingali and Pandey, 2001). Unfortunately, a significant number of QPM varieties grown by small scale farmers in coastal Mozambique still lack effective tolerance to DM. These varieties include Sussuma, ZM521Q and Pop62SRQ. As a result farmers face a huge yield “penalty” when these susceptible varieties are grown in environments where DM is prevalent, or during the seasons which favour DM development. Downy mildew is considered the major threat to maize production mainly in lowland areas and southern regions. On the other hand, the MSVD is prevalent in all production areas, even during the drought years which do not favour DM development, in both low and high yield potential environments throughout the country. Special attention is therefore being given to breeding DM and MSVD resistance in these QPM varieties, which are already being grown by farmers. However, no studies have been conducted on the response to selection for DM and MSVD resistance in these QPM varieties.

3. Downy Mildew

Denic et al. (2001) reported that downy mildew disease, caused by *Perenosclerospora sorghi*, was the most destructive disease of maize in the lowland areas in central and southern Mozambique. Some widely grown maize varieties were withdrawn from the market due to their susceptibility to DM. There is therefore need to breed for resistance to DM in QPM. Deployment of resistant varieties was long ago identified as one of the viable options for controlling DM in maize (Singh *et al.,* 1977). Resistance in local populations can be improved through selection to accumulate the resistance alleles in QPM populations (Vasal *et al., 1997*). In Mozambique, good progress in breeding for DM resistance and other traits in normal maize was realised through selection, therefore, it is expected that similar gains can be obtained in QPM populations (Denic *et al.,* 2001).

4 Maize Streak Virus Disease

Bosque-Pérez (2000) reported that MSVD was among the most devastating diseases of maize in Africa. The disease has been reported to be most prevalent in mid altitude and subtropical areas throughout Africa (Pingali, 2001). Huge grain yield losses of up to 100% are incurred when a young maize crop is attacked by the MSVD (Grahan *et al.,* 1990; Bosque-Pérez, 2000). In Zimbabwe, Mzira (1984) reported 54% yield reduction when a two weeks old crop was subjected to MSV, while only 0.8% yield loss was incurred in a crop that was infested at 12 weeks after emergence. Similar results were reported by Ampong-Nyarko et al. (1998). Therefore, heavy losses can be prevented if the crop is adequately protected at the young stage. It has been observed in Mozambique that early planted maize crop can escape MSVD because the disease intensifies late during the season. Denic et al. *(*2001) reported that the crop “reaches a safe age after the seven leaf stage before populations of the leafhoppers which transmit MSVD build up”.

Use of the escape mechanism is not always reliable because the leaf hoppers might over winter in irrigation schemes and still attack the early planted crop; hence breeding for MSVD resistance in varieties would be the most reliable in controlling the MSVD in Mozambique (Denic *et al.,* 2001).

5 Farmers' Preferences in Quality Protein Maize

Farmers' preferences should be considered during the improvement of existing popular varieties and during development of new QPM populations in Mozambique. This will increase the chances of their adoption by farmers. Breeders alone may not be capable of identifying all the preferences of small-scale farmers. It has been reported that some superior varieties were not adopted because they were not meeting farmers' preferences (Banziger and Cooper, 2001). In many areas of Mozambique, farmers are still using local varieties that are not improved for resistance to DM and MSVD, and that might be contributing to the significantly low yield and thus furthering the yield gap between actual yield and yield potential of the existing varieties. There is also need to investigate small-scale farmers' perception on QPM varieties and also to identify the key factors they would consider in selecting a suitable QPM variety. Prior studies indicated that farmers in Mozambique have little knowledge about QPM varieties and their perceived nutritional value. However, they do recognize that the QPM varieties are highly preferred by grain weevils compared to the normal maize they are currently growing. There is a need of promoting the nutritional importance of QPM varieties in the smallholder farming sector and that they could contribute significantly to alleviate malnutrition in Mozambique.

6 Objectives of the study

The main objective of this study was to enhance productivity of QPM varieties in the small-holder and commercial sector in Mozambique by improving QPM cultivars for resistance to DM and MSVD. This was realised through ascertaining farmers' key production constraints, special preferences and perceptions on QPM cultivars, and determining the utility of recurrent selection method to improve three QPM populations Sussuma, ZM521Q and Pop62SRQ for DM and MSVD resistance. The information generated was used to devise appropriate breeding strategies to enhance QPM germplasm for high yielding ability, tolerance to DM and MSVD in Mozambique national programme.

Specific Objectives

The specific objectives of the study were as follows:

a) to determine the farmers' preferences for maize cultivars, using a PRA- study in two regions of Mozambique;
b) to determine the selection gains for DM and MSVD resistance and yield in three QPM populations: Sussuma S_2, ZM521/SWA8075DMR//QSRDMR and Pop62SR using recurrent selection procedures, and
c) to determine correlated responses of other important agronomic traits.

7 Research Hypotheses

The following research hypotheses were tested in the dissertation:

a) there is adequate genetic variation and high levels of resistance to DM and MSVD which are highly heritable and are exploitable in a breeding programme to generate disease resistant materials; and
b) there is simultaneous improvement of other agronomic traits through selection for DM and MSVD resistance.

8 Thesis structure

The thesis structure is as follows:

Thesis structure

General Introduction	
Chapter One	Literature Review
Chapter Two	Participatory Rural Appraisal (PRA)
Chapter Three	Recurrent Selection for Downy Mildew Resistance in three
Quality	Protein Maize populations in Mozambique
Chapter Four	Recurrent Selection for MSV Resistance in three QPM population originated from Mozambique in Zimbabwe
Chapter Five	Research Overview

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Chapter 1: Literature Review

1.1 The spread of maize into Mozambique

Maize originated from Mexico in Mesoamerica because its closest relatives are found in this region (Doebley, 1994). Maize is now widely distributed in the American continent (Crosby, 1972) and worldwide. A large body of the literature indicates that the Portuguese were involved in moving maize to Brazil and several other destinations including Africa and Asia during the 16th century (Boxer, 1969). Whereas the actual dates of maize introduction into Africa are not known, Boxer (1969) reported that maize was cultivated in Africa around the middle of 1500s. The Portuguese writer Valentim Fernandes made reference to maize in West Africa during 1502, while on the east coast of Africa maize was first reported around the island of Mozambique. The Mozambican island was used as a major station for the Portuguese during their travel to and from Lisbon (Portugal) and Goa in India. By 1561 maize had become a staple food for the Portuguese settlers in Mozambique. Today, maize is the major staple crop throughout the country, and in east and southern Africa, and provides much of the protein and calories to consumers in the region (Table 1.1).

1.2 Quality protein maize

The nutritional value of maize is similar to other cereal grains, but it is superior to wheat flour. However, it is inferior to rice (Vasal *et al.,* 1997). Breeding and improvement of protein quality in maize started after the discovery of maize mutants with *opaque-2* gene during mid1960s (Mertz *et al.,* 1964). This gene enhances lysine and tryptophan content in the maize endosperm protein. However, these mutants have been linked with several undesirable traits which include opaque and chalk grain texture, low grain yield, higher levels of ear rot, slow drying down and high susceptibility to grain weevils. Improvement of QPM germplasm for these traits involved multi-disciplinary teams of breeders, biochemists and other scientists at CIMMYT (Vasal *et al.,* 1997). As a result of these improvements, Cordova and Pandey (1999) reported that QPM germplasm now has similar quality traits as normal maize such as grain texture, taste and colour, but the QPM has almost double the levels of lysine and tryptophan compared to normal maize, in addition to high grain yield potential and stress tolerance. Superiority of QPM nutrition both as human food and animal feed for pigs and poultry has been widely demonstrated worldwide (Vasal *et al.,* 1997).

Advances have been made in improving maize for yield and for nutritional value, but the problem of malnutrition is still prevalent in developing countries (Vasal et *al.,* 1997; Cordova and Pandey, 1999). The problem of malnutrition affects about 200 million children below five years worldwide (Cordova and Pandey, 1999). The problem results in stunted growth, weakened resistance to disease infection and reduced intellectual development in children. Therefore development of quality protein maize varieties might be a viable solution to reduce cases of malnutrition among the poor in Mozambique, who obtain 30% of their protein requirements from maize (Table 1.1). Quality protein maize, which contains high levels of essential amino acids, lysine and tryptophan, has more protein than normal maize, thus QPM can be used to alleviate problems of human malnutrition and to feed the livestock (FAO, 1992; Vasal et al., 1980).). The QPM is more valuable than normal maize with biological value of 80% and 40-50%, respectively (Bressani, 1992). Use of QPM can also reduce the costs of livestock feed. Studies in the US indicated reductions of 2.6% to 3.4% in costs of poultry and pig feed when QPM was used when compared to traditional formulas containing soybean, sorghum and synthetic lysine and methionine (Lopez-Pereira 1993). Nyanamba et al. (2003) also reported a 5% reduction in cost when QPM was used to make poultry feed in Kenya.

Table 1.1 Importance of maize in the diet of individuals in selected countries with respect to the percentage of calories and protein in the total diet

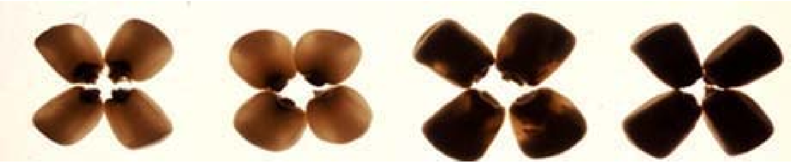
	Maize as:	
Country	% Total Calories	% Total Protein
Lesotho	58%	55%
Zambia	57%	60%
Malawi	54%	55%
Zimbabwe	38%	46%
Kenya	36%	34%
Tanzania	33%	33%
South Africa	33%	33%
Togo	25%	29%
Cape Verde	24%	26%
Swaziland	23%	24%
Mozambique	22%	31%
Ethiopia	21%	17%

Estimates calculated from FAO food balance sheets; FAOSTAT

1.3 Genetics and Breeding Strategies of QPM

Breeding of QPM entails manipulation of three distinct genetic systems comprising opaque-2 mutant alleles, endosperm modifiers and the amino acid modifiers.
The first step is manipulation of the recessive mutant allele of the opaque-2 (o2) gene, which is the most important. These genes have been found to encode a transcription factor in the zein synthesis (Cordova and Pandey, 1999). The zeins, especially alpha-zein, have been found to be abundant in the maize endosperm (Gibbon *et al.,* 2005). However, the zein has low levels of essential amino acids such as lysine and tryptophan. The homozygous o2 mutant reduces production of the zein proteins, which results in the increased level of proteins containing lysine and tryptophan (Gibbon *et al.,* 2005).

A QPM breeding programme also manages the alleles of endosperm hardness modifier genes, the “en-modifiers” Gibbon et al. (2005). These endosperm-modifiers convert the soft or opaque mutant endosperm to hard endosperm with minimum loss of protein quality. The high levels of gamma zein protein has been shown to contribute to the recovery of a hard endosperm because QPM grains have two-fold levels gamma zein in the endosperm compared to the o2 mutant (Gibbon *et al.,* 2005). During QPM breeding the en-modifiers and the o2 mutant allele are identified using rapid and cheap selection methods. Selection is then based on light projection through the vitreous grains or the light is blocked by opaque grains. The grain endosperm opaqueness is then rated using a scale of 1 -5, where 1 = completely hard/vitreous to 5 = soft or opaque grain (See Fig 1.1, by Gibbon *et al.,* 2005). The grains with a rating score of 1 and 5 are homozygous for the o2 allele, but scores 2 and 3 have sufficiently modified hard endosperm and therefore qualify to be selected as QPM grains.



2- Completely hard/vitreous 5- Soft/opaque

Fig 1.1 Grains showing different levels of modification as viewed from the light table (source: Gibbon et al., 2005)

Bjarnason and Vasal (1992) reported the presence of a set of amino acid modifier genes (”aa-modifiers”). These genes influence the lysine and tryptophan content in maize grain endosperm, such that lysine level is about 2% of total protein in normal maize and about 4% in the QPM flour. Variation for the levels of these amino acids have been found to range from 1.6-2.6% in normal maize and from 2.7-4.5% in the QPM (o2) converted counterpart germplasm in different genetic backgrounds (Vassal *et al.,* 1997) (Table 1. 2), indicating the scope for improvement of maize for the QPM trait. The lysine and tryptophan levels have been reported to be highly correlated (Bjarnason and Vasal, 1992), suggesting that only one amino acid can be measured depending on cost of the process. Generally, breeders evaluate tryptophan content and use the results to predict the lysine content.

Table1.2: Percentage of lysine and tryptophan levels of total protein in whole grain of maize flour

Amino acid	Normal maize (%)	QPM (%)	Requirement (%) for 2–5 year old children
Lysine	1.6-2.6 (avg 2.0)	2.7-4.5 (avg 4.0)	5.8
Tryptophan	0.2-0.5 (avg 0.4)	0.5-1.1 (avg 0.8	1.1

Source: FAO guideline requirements for children; FAO 1995, Energy and protein requirements. FAO, Rome;

1.4 Production Constraints of Maize

The main production constraints of maize were identified in all agro-ecological zones in Mozambique (Nunes *et al.,* 1985). In southern Mozambique the main constraints were reported to be drought, maize streak virus disease (MSVD), downy mildew disease (DM), stalk borers and grain storage pests. In central and northern parts of the country, the main constraints were reported as low soil fertility, periodic drought in lowland areas; stem rots, ear rots, leaf blights and leaf rust diseases at higher altitude; the MSVD and DM were prevalent in Manica and Sofala provinces, and grain weevils were also important in all areas. Much of the existing and available QPM germplasm is only adapted to the higher altitude areas which are the most productive environments, which account for 15 to 20% of total production, but this germplasm, is susceptible to DM and MSVD (Denic, 1994). Based on these identified constraints to QPM production, there is a need of selecting genotypes resistant to both DM and MSVD, which are limiting production in these principal maize production areas. Therefore, in this study the focus is on improving QPM germplasm for resistance to DM and MSVD.

1.5 Downy Mildew

Downy mildews are a distinct fungal group with similar morphology and epidemic characteristics, and most of them cause devastating grain yield losses in many economic crops including maize and most grasses (van der Westthuizen, 1977). There are ten species belonging to three genera in the downy mildew group that affect maize (De Leon *et al.,* 1993). The *Peronosclerospora sorghi*, which causes sorghum downy mildew (SDM), has been reported to cause the most widespread damage in maize and is prevalent in all maize growing areas, worldwide. The alternative hosts of *P. sorghi* are sorghum spp, teosinte, millet and panicum spp and common grass weeds in maize production (Kenneth, 1981).

The *P. sorghi* is dispersed primarily through oospores and to a small extent through conidia (Frederiksen, 1980). The oospores, which are resting spores are dispersed by wind and infected maize debris. The conidia are produced on systemically infected plants and can be spread within a field. However, the *P. sorghi* produces few spores on maize, but produces most of its spores on sorghum (*Sorghum bicolour*) and the weed, Johnson grass, (*Sorghum halapense*) (Frederiksen and Renfro, 1977). Therefore management of both the plant debris or stovers and alternative host plants is important for the effective control of DM disease.

The distribution of DM is on the increase globally. In Nigeria, DM has been widespread because of continuous cultivation of maize throughout the year (Kim *et al.,* 1994). Bigirwa et al. (2001) reported SDM in 11 of 22 districts in Uganda and estimated the yield loss to be 4% in both 1994 and 1995. In the USA, SDM was long ago reported to be present from the North to Illinois and Kentucky, but it was found to be only important in Texas (Frederiksen and Renfro, 1977).

1.5.1 Epidemiology of Downy Mildews

Initially, DM distribution is sporadic in the field depending on existence of an active inoculum and environmental conditions (van der Westhuizen, 1977). Craig and Frederinsen (1989) reported that infection may start with a single plant. The infection sources could be from germination of a conidium or oospores, or mycelium contained in the seed or it arise from a latent state in some perennial organ of the plant. During the second phase the disease spreads throughout the field and the epidemic becomes apparent.

Changes in relative humidity cause the conidia to be detached and are spread by the wind. Conidial germination, which occurs over a range of temperatures, is not as important as the sporulation for disease occurrence. Craig and Frederiksen (1983) reported that sporulation was greatest in darkness and continuous wetness at 10-25oC. The other major sources of inoculum, soil-borne oospores, were favoured by temperatures of 15-32oC (Smith and Renfro, 1999). Although the oospores can survive for five years, they are vulnerable to attack by some hyperparasites (Craig and Frederiksen 1983). The factors that provide optimum conditions for DM epidemics to develop in tropical areas include soil temperatures up to 32oC, wet and warm nights, and a wetness period at ambient temperature up to 30oC during daytime (van der Westhuizen, 1977). These conditions are common in southern Mozambique, where DM is a major problem.

The fungus can over-winter as oospores in the soil, in plant debris (Kim *et al.,* 1994) and in perennial grasses (Kenneth, 1981). Both local and systemic infection occurs in maize. The systemic infection can occur when the oospores germinate and invade the roots, especially under low soil moisture and low temperature conditions (Frederiksen *et al.,* 1969). The fungal mycelia are found in seed embryos, but can lose viability when seed moisture is less than 20%, but the mycelium spreads internally from the roots to the leaf tissues (Frederiksen *et al.,* 1969). The conidia which are produced on the leaves from the systemic infection can be spread by wind to other plants in the field, resulting in secondary local infection (Smith and Renfro, 1999).

1.5.2 Disease symptoms

The DM symptoms on infected plants may be in the form of leaf chlorosis or white stripes on the leaves. Usually the infected leaves are narrower and more upright than the non-infected leaves. Symptoms develop from the first leaf and spread to the young leaves. There is a distinct margin between the diseased basal portion of the leaf and non-diseased area towards the tip (Craig and Frederiksen, 1983). At greater than 95% relative humidity and 20-22oC there is massive asexual sporulation on the infected abaxial surface of leaves resulting in a downy appearance (Frederiksen *et al.,* 1969). Systemically infected seedlings become chlorotic and growth is stunted. Leaf chlorosis is more noticeable on the lower half of the leaf (Frederiksen *et al.,* 1969) and the infected young plants can die prematurely. Frederiksen et al. *(*1969) and Craig and Frederiksen (1983) reported that under cool and humid conditions a white downy growth, as a result of conidia and conidiophores growth, was observed on the lower surface of leaves. The conidia are mainly produced at night because they require a layer of moisture on the leaf for spore production to occur. The leaf symptoms usually are more pronounced as the plants grow (Smith and Renfro, 1999) and the old leaves often display some alternating parallel stripes of green and yellowish-green to white tissue.

1.5.3 Control of DM

Several methods can be used to control DM disease in maize. Cultural and chemical controls can be utilised to control the disease. Cultural methods involve removal of the alternative host species and deep ploughing to bury the maize debris to reduce the inoculums sources. The time of planting can also be adjusted so that the crops will escape the high disease pressure during the growing season. For example, Frederiksen and Renfro (1977) reported that young plants out-grew DM when they were not infected at the seedling stage. While the seed treatments with fungicides have been effective, they are not readily available in remote areas in Mozambique. Bigirwa et al. (2001) also reported that planting maize in well-drained soils could be effective in reducing infection by oospores. It appears that breeding QPM for resistance would be most effective and economical means of controlling SDM for small-scale farmers in Mozambique.

1.5.4 Source of resistance to Downy Mildew and Breeding Progress

A survey of literature indicates that DM resistance has not been reported in QPM germplasm. However, DM resistance has been reported in normal maize. Resistance to DM has also been reported in CIMMYT lines and populations which were adaptable to tropical conditions (Pratt and Gordon, 2006). Pratt and Gordon (2006) also reported several tropical and temperate inbred lines that were resistant to DM. The temperate lines with resistance included Mo17, NC248, T250, T254, Tx61M, Tx403, Tx601, Tx5855, and Tx6252 (Darrah, 1985, as reported in Pratt and Gordon, 2006). This germplasm would not be very useful for the breeding programme in Mozambique, because they are not adapted. In most cases the temperate germplasm has yellow endosperm which is not preferred by small-scale farmers in Africa. The resistant sources developed under lowland tropical conditions at IITA in Nigeria would be more adaptable to lowland conditions in southern Mozambique. In addition, germplasm from Thailand was reported to be highly resistant to DM under the tropical African conditions (Brewbaker *et al.,* 1989; Adipala *et al.,* 1999). For example, materials that were derived from Suwan-1 have been used in develping the QPM population ZM521QSR in Mozambique. The Asian materials from the Phillipines were also reported to be useful sources of DM resistance in the IITA breeding programme in Nigeria.

High breeding progress was reported to be associated with improvements in inoculation techniques (Caldwell et al., 1997; Kim *et al.,* 1994). Previously, repeatability of DM screening trials had been very low due to high rate of germplasm escaping the disease during screening experiments. The new techniques included the use of spreader rows which is not labour intensive. Spreader rows have also been used in screening maize germplasm in the Mozambican programme at Umbeluzi Research Station near Maputo (Denic et al., 2001). With this method labour requirements were reduced because germplasm could be rated once without compromising selection efficiency (Ajala et al*.,* 2003). Rapid progress in DM resistance has not been associated with reduction in grain yield and other important agronomic traits in normal maize (De Leon et al*.,* 1993; Ajala et al., 2003), suggesting that DM resistance was not negatively correlated with grain yield in normal maize. Similar breeding progress would be expected in selecting for DM resistance in QPM. Although there are few reports of breeding for DM resistance in QPM, Denic et al. (2001) reported significant gains for DM resistance in both normal and QPM germplasm in Mozambique using full-sib recurrent selection.

1.6 The Maize Streak Virus in Africa

Maize streak disease (MSVD) is caused by a geminivirus that is transmitted by viruliferous leafhoppers (*Cicadulina mbila*) in Africa (van Rensburg *et al.,* 1991; Welz, 1998; Pratt and Gordon, 2006). This disease has not been reported anywhere else in the world. It is a single-stranded DNA virus and different strains have been reported in Africa (Bosque-Pérez *et al.,* 1999). There were also differences in the pathogenicity of the different subtypes of MSV (Bosque-Pérez et al., 1999; Pernet *et al.,* 1999). This suggested that the most virulent and predominant pathotype should be identified and used to screen QPM germplasm in Mozambique.

A detailed review of the MSVD in maize was presented by Pratt and Gordon (2006). A large body of the literature has suggested that the maize streak virus disease is the most important disease that compromises maize grain production in many countries in sub-Saharan Africa (Bosque-Perez, 2000). The disease causes devastating grain yield reduction especially in the mid altitude areas (800-1600 masl) and throughout the sub-tropical regions in Africa (Pingali and Pandey, 2001). In east and southern Africa, the MSVD has been reported to be devastating in Mozambique (Denic *et al.,* 2001), Zimbabwe (Mzira, 1984), and Kenya (Pingali and Pandey, 2001). It appears that control strategies which target the vector *Cicadulina* species would be effective in controlling this disease. The MSVD is strongly associated with occurrence of Cicadulina species which act as vectors (Pham, 1992). In Mozambique, surveys conducted during 2002-2003 showed that MSVD was most severe in mid-altitude and highland areas (Denic *et al.,* 2001) where the vector was prevalent. The disease was very severe and inflicted heavy grain yield losses when young plants were infested (van Rensburg *et al.,* 1991; Kyetere *et al.,* 1999; Bosque-Pérez, 2000). Studies conducted in Zimbabwe showed that proper timing of planting would be effective in reducing yield losses that were attributed to MSVD. Under natural infection, Mzira (1984) reported 54% yield losses when young plants were attacked compared to 0.8% when old plants were infested in Zimbabwe. Denic (1997) reported that there were few leaf hoppers to transmit the disease at the beginning of the season in Mozambique suggesting that early sowing might be used in managing the disease. This strategy may not be sustainable because all farmers might not use the same planting date or they may grow winter crops which can serve as alternative hosts for the leaf hoppers (DeVries and Toenniessen, 2001). The beginning of the rainy season is also difficult to predict, which poses problems in timing the planting

(Bosque-Pérez, 2000). The early rains were associated with high incidences of *Cicadulina* leaf hoppers in West Africa which provided early hosts before the maize crop was established. Use of chemicals to control the vector might not be viable due to cost and limited availability in remote areas in Mozambique. Seemingly, breeding for host plant resistance in maize cultivars would be preferred and has been widely recommended (Bosque-Pérez, 1999; DeVries and Toenniessen, 2001) and might be more sustainable in QPM varieties that would predominantly be grown by small-scale farmers in Mozambique

1.6.1 Epidemiology of maize streak virus

The MSVD causes high grain yield losses in maize especially under irrigated conditions (Engelbrecht, 1975). Several grass species which grow under these irrigated conditions act as alternative hosts and provide favourable conditions for development of the vectors during the off-season. The disease first appears on young plant leaves as pale and small circular spots (van Rensburg *et al.,* 1991). The numbers of spots then increase and expand in length, and form chlorotic areas between narrow broken stripes along leaf veins (van Rensburg *et al.,* 1991). According to Barrow (1992), the secondary and tertiary veins are more affected than primary veins resulting in five to seven groups of parallel streaks on maize leaves. The symptoms are observed on the young leaves while the old leaves remain green which can be used to estimate the time of infection. Early infection of young plants results in stunted growth and production of small cobs, which causes low yield. The loss of chloroplasts which is reflected by chlorosis of the leaves reduces photosynthesis in relation to respiration, which compromises leaf size and plant height leading to stunted growth (Pernet *et al.,* 1999). Number of leaves with disease symptoms has been reported to be closely associated with single plant yield (Efro *et al.*, 1989).

1.6.2 Sources of Resistance

There are few sources of MSVD resistance identified in QPM but many sources have been reported in normal maize. Denic et al. (2001) reported resistance in the QPM population Pool I5 and the QPM inbred line E-5Q from Ghana. Both at CIMMYT and at the International Institute of Tropical Agricultural (IITA) have reported some resistance sources in normal maize germplasm (Barrow, 1992), which can be used in breeding for MSVD resistance in QPM. The MSVD resistance has been reported in germplasm that were derived from Tuxpeño and yellow germplasm from East Africa (Efron *et al.*, 1989; Bjarnason, 1986). Bjarnason (1986) also reported some MSVD resistance in the population “La Revolution”, from Réunion Island and in Tuxpeño x Ilonga composite from Tanzania. Earlier, Storey (1967) reported that resistance from the sources was incorporated into regional populations that were used as base germplasm throughout sub-Saharan Africa. Conventional breeding efforts in national maize programmes have also made significant progress in breeding and releasing MSVD resistant varieties, but most of them are normal maize. This has been mainly realised through collaborative efforts between national programmes with CIMMYT and IITA (Tang and Bjarnason 1993).

Use of both field and screen-house screening has led to development of resistant germplasm at IITA in Nigeria and CIMMYT in Zimbabwe (Mzira, 1984; Kim *et al.,* 1994; Efron *et al.,* 1989). In a comprehensive review, Pratt and Gordon (2006) reported many lines and populations with high levels of resistance to MSVD. The following inbred lines have been released at IITA in Nigeria Tzi3, Tzi4, Tzi15, and Tzi17 (Brewbaker *et al.,* 1989). Resistant lines have also been derived from the Pop 49-SR at CIMMYT in Zimbabwe. The CIMMYT lines CML217-238, CML195-CML215, CML442 and the population ZM607 are resistant to MSVD (Pratt and Gordon, 2006). In the same review, it was indicated that CVR3-C3 (Bjarnason, 1986), CIRAD 390 (Barrow, 1992), D211 (Pernet, 1999), MSIRI 3B (Bjarnason, 1986), and population IRAT297 (Caulfield *et al.,* 1997) were resistant to MSVD. In southern Africa, MSVD resistance has also been bred in both yellow and white commercial hybrids in Zimbabwe and South Africa (Barrow, 1992; van Rensburg *et al.,* 1991). Various sources of resistance can therefore be utilised to bread for resistance to MSVD in Mozambique and in the region.

1.6.3 Progress on breeding maize streak virus in QPM

Both population improvement and pedigree breeding procedures have been successful in developing MSVD resistant germplasm (Tang and Bjarnason, 1996) in both normal and QPM. A survey of the literature seems to indicate that yield has not been significantly compromised in the process of breeding for MSVD resistance. Development of QPM varieties started in 1988 at the Research Institute of Agriculture in Mozambique. New QPM germplasm was developed by crossing Pool 15Q and E-5Q inbred lines which are resistant to MSV to the adapted normal lines from populations Matuba and Rampur 8075 DMR. The S1 and Full-sib (FS) recurrent selection methods were used to develop early white-flint QPM varieties resistant to maize streak virus and downy mildew. Early generation QPM materials were crossed with Obatanpa, Pop 62Q and Pop 63Q, SIW91Q and Pool 15Q to create five QPM interpolpulations to start other FS recurrent selections. All materials were subjected to heavy MSVD infection in the nurseries. The method of spreader rows was used to infest many breeding materials as recommended by William (1984), with modifications but it was modified by including combinations of late and continuous planting to ensure adequate MSV pressure as recommended by Caldwell *et al.* (1997) and Denic (1994).

1.7 Recurrent Selection in maize

Recurrent selection (RS) is a process of cyclical selection in a breeding population to increase the frequency of favourable alleles. These populations can then be used to extract new and superior inbred lines and prevent development of a possible genetic ceiling for future hybrid improvement (Duvick, 1992; Kannenberg and Falk, 1995). There are several methods of RS; but when there is no over dominance gene action, Self progeny selection using either S1 or S2 lines was reported to be superior to other methods for maize population improvement (Lamkey, 1993). During S RS alleles are fixed rapidly and deleterious, homozygous alleles are exposed and eliminated early in selection (Weyhrich *et al.,* 1998). Population improvement through S selection is the result of direct selection favouring additive genetic effects because there are no masking effects of a tester.

Development of QPM using recurrent selection to improve the population has been done in Mozambique since 1998. Extensive programme on screening for disease resistance and endosperm modification in QPM has been carried out. Three cycles of selection for MSVD resistance, grain texture and endosperm modification, and one cycle of DM resistance were completed in 2000 in Mozambique (Denic *et al.,* 2001). After three cycles of selection 419 S1 and S2 lines with MSVD resistance from four populations were formed but susceptibility to DM was still high. In cycle one of DM resistance screening, 38 experimental populations with 933 progenies were included and they showed some distinctive classes of DM resistance with class intervals of 10 % (Denic *et al*., 2001). Denic et al. (2001) reported that the differences between MSVD and DM resistance in the same germplasm were largely due to number of cycles of selection for MSVD (C3) than for DM (C1) resulting in, and the differences allele frequencies for resistance to the two diseases. Similar to observations in normal maize populations In Mozambique, reported by Denic et al. (2001), the study concluded that screening for DM and MSVD resistance did not compromise the genetic variation within populations which remained large. This variation makes selection for both MSV and DM disease resistance more efficient.

1.8 Participatory Rural Appraisal

Farmer participatory research approaches have previously been used in plant breeding. Derera et al. (2006) investigated the preferences of cultivars by farmers in eastern Zimbabwe using PRA tools such as focus groups. They reported that farmers unanimously preferred the old hybrids that were developed in the 1970s to new hybrids because they were more tolerant to stress than the new hybrids. A local landrace was also found to be preferred by farmers because of its superior taste and flint grain texture than the new hybrids. There were specific preferences in terms of cultivars according to the agro-ecological conditions of each district. Farmers living in the more productive areas showed high preference for grain-weevil resistant cultivars, while those living in less productive zones preferred cultivars with drought tolerance among other traits. This indicated that farmers' requirements were quite different in this region hence it would not be viable to breed for broad adaptation in cultivars. The PRA results from Zimbabwe might be applicable to some parts of Mozambique because the farmers in eastern Zimbabwe share a similar culture to farmers in Mozambique. They are most likely to behave in a similar manner. In fact

Derera et al. (2006) reported that farmers in Zimbabwe were also growing some landraces from Mozambique.

In all the surveyed districts farmers still relied on their landraces instead of improved varieties because of their early maturity, taste and flint texture of the grain that is thought to prevent losses in storage. Langyintuo et al. (2005) also reported that adoption of new cultivars was very low in Mozambique. They suggested that low adoption was as result of poor performance of improved varieties, unavailability of preferred improved seed, and limited resources to purchase new seed. However, some improved cultitivars were popular among a few farmers. These included Matuba (OPV), and hybrids SC513 and PAN64, and the QPM OPV “Sussuma”.

In Ghana, participatory breeding (PB) programme was reported in developing cassava cultivars (Manu-Aduening *et al*. (2006). A trend similar to that observed in maize was observed as farmers preferred landraces to new cultivars. Similar reasons such as superior taste and poundability of landraces were given for the trends (Manu-Aduening *et al*., 2006). The farmers also preferred early maturing cultivars, with high yield potential and high quality traits for cooking and marketing. According to Manu-Aduening et al. (2006) the PB approach resulted in development of cultivars with large storage roots and high yield potential which were among the most preferred traits.

These cases indicated the importance of encouraging the breeder-farmer interactions during variety development. Similar approaches should be considered in improving QPM germplasm for the farmer preferred traits. This would increase adoption of new QPM varieties in Mozambique.

1.9 Summary

This review showed that there is very little published information on research in breeding for disease resistance especially DM and MSVD in QPM populations despite the demonstrated importance and potential of QPM in alleviating malnutrition in sub-Sahara Africa. A huge gap still exists between grain yield potential and actual yield because the yielding ability of QPM can be increased through breeding for resistance to DM and MSVD which cause heavy yield losses in Mozambique, especially if these diseases affect the young crop i.e., before flowering. Genetic variation for DM and MSVD has been reported in QPM populations in Mozambique. This genetic variation allows for further improvement of the populations through RS which was shown to be effective in improving the resistance to diseases and yield. In addition, there are several sources of DM and MSVD resistance which can be exploited in improving MSVD resistance in populations and inbred lines in Mozambique in the future.

The review on participatory rural appraisal revealed that for farmers to adopt the variety, it must meet their preferences. Farmers still rely on their landraces because their varieties meet their preferences. In Mozambique, besides the variety not meeting farmers' preferences there were other problems that influence adoption of improved varieties such as unsatisfactory performance, unavailability of preferred improved seed and lack of cash to purchase improved seed. The review also revealed that farmers' preferences were generally determined by environmental conditions under which they grew their crops, suggesting that breeders should have a thorough understanding of these conditions in order to design suitable products for small scale farmers especially in marginal areas.

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Chapter 2: Farmer perceptions on maize production constraints and the status of DM and MSV in two districts of Mozambique

Abstract

Agriculture in Mozambique is primarily small-scale, subsistence level and it is characterized by low productivity. The objective of this study was to determine maize production constraints, assess the status of downy mildew (DM) and maize streak virus disease (MSVD), and to determine farmers' preferences and varietals selection criteria. Participatory rural appraisal (PRA) was conducted in Manica and Angonia districts in Mozambique during 2005 and 2006. To guide the group discussion and individual interview of selected farmers, semi-structured questionnaires and surveys were used. Problems listing, analysis and ranking by farmers and other key informants were tools employed in conducting the PRA study. Results showed that farmer's predominantly grew open pollinated varieties (OPVs) and a few hybrids. Grain yield of maize grown by smallholder farmers was very low and ranged from 0.2 to 0.6 t ha^{-1}. Results showed that drought and insect pests were the dominant constraints to maize productivity in Mozambique. Diseases were ranked the third most important production constraint, and DM and MSVD were considered the most important threats of maize productivity. Angonia and Manica districts are located in different agro-ecological zones in the country, and production constraints differed between districts. Angonia is located in the highland zone and is a more productive region than Manica. Farmers in both regions preferred weevil resistant cultivars. Manica is located in the intermediate zone. Farmers preferred high yielding and early maturing cultivars. Farmers are still using their local landraces because of sweet taste, particularly for home consumption and flint grain for storage. In all districts farmers showed common preference for high yielding, white coloured kernels, and early maturing cultivars. Research priorities as perceived by the farmers included combination of high yield potential, disease resistance and early maturity in all districts, and weevil resistance in the relatively more productive areas. Farmers in both districts had little knowledge about QPM cultivars and their nutritional advantage. The few farmers who were aware, however, recognized that QPM varieties were more susceptible to insect pests and diseases. It was concluded that breeders needed to develop cultivars combining these traits and promote QPM and its nutritional superiorities to the farmers.

2.1 Introduction

In Southern Africa, the small-scale and subsistence farmers dominate in maize production. The productivity of maize is low (below 1.0 t ha-1), because the crop is grown under marginal conditions of low soil fertility, drought, disease and pests (Banziger and de Meyer, 2002). Under these conditions, farmers devote a lot of their effort to minimise risks of crop failure (Kieft, 1993). These farmers have limited access to essential inputs such as water, fertilisers and pesticides. Landraces are mostly (about 63%) grown by farmers, even when improved varieties are available (Sthapit *et al.,* 1996). Perhaps the available varieties do not meet farmers' requirements in the marginal environments. Breeders may not be able to identify farmers' preferences and perceptions that influence their variety selection criteria without engaging farmers during the variety development process (Toomey, 1999; Banziger and Cooper, 2001; Pingali, 2001; Derera, 2005).

The farmers' requirements are not uniform and depend on their niches, yet breeders normally select cultivars for broad adaptation (Sthapit *et al*., 1996). Appropriate maize breeding strategy should take care of requirements of the small-scale farmers in the marginal environments. This requires proper identification of their perceptions on production constraints and factors that influence variety selection (Derera, 2005). According to Witcombe et al. (1996) this can be achieved by interacting with farmers in the varietal development process at the beginning so that the right breeding objectives are set and appropriate breeding germplasm is identified.

The farmers' perceptions on QPM varieties have not been established in Mozambique, which may affect rapid adoption of QPM varieties. In addition to the QPM trait, farmers would be interested in the agronomic quality of the varieties, and its tolerance to stress in the marginal environments. It has been previously shown that farmer participation in variety development can help the breeders to get information on cultivar design which includes plant type, grain qualities, taste, stress resistance and market qualities (Sthapit *et al.,* 1996; Derera, 2005). Although QPM varieties have been introduced in Mozambique, it has not been established whether farmers know the advantage of these varieties over their normal maize landraces. Therefore, it is important that the objectives of the national maize breeding programme in Mozambique should be based on the understanding of the small-scale farmers' preferences and perceptions on both normal and QPM varieties if productivity is to be improved in the country.

2.2 Objectives and Research hypothesis of the study

The main objective of the study was to identify farmers' needs and preferences and to establish the importance of two major maize diseases (DM and MSV) among other production constraints.

The specific objectives of the study were:

a) to understand farmer's preferences and selection criteria for future varietal development,
b) to assess the current status of downy mildew and maize streak virus diseases, and the status of the QPM varieties, and
c) to identify farmers maize production constraints.

2.3 Material and Methods

2.3.1 Study Area

In order to understand the farmers' needs with regard to maize varieties the Participatory Rural Appraisal (PRA) technique was used in two districts of Mozambique. The study was conducted in Manica and Angonia districts in Central region of Mozambique during the wet season of 2005 and 2006. The selected areas are among the leading regions in maize production in Mozambique and represent different agro-ecologies. As the environmental factors influencing downy mildew and maize streak virus disease epidemic the selection of these agro-ecologies was extremely important for the outcomes. Another reason was that the rainfall amount and pattern is modified by altitude, such that high elevation (Angonia) receives the highest and most reliable rainfall, while Manica (mid-altitude) receives the least amount of rainfall which is erratic and poorly distributed over the season. Manica district lies at range of 600 m above sea level (masl) (mid-altitude), while Angonia lies at range of 1550 masl (high-altitude). In Manica district crop production is to a great extent dominated by small-scale farmers. Angonia district with the most reliable rainfall is dominated by small maize production commercial companies and small-scale farmers. Diallo (1999) noted that in recent years DM and MSVD epidemics cover all areas ranging from lowlands to highlands of Mozambique.

2.3.2 Selection of farmers

The selection of districts for the study was based on the importance of the area under maize cultivation, and represent mid-altitude and highlands of Mozambique. Fifty farmers were selected from each of the districts. Two villages in each district were selected and 25 farmers including male and female were selected. The selected farmers formed focus group discussions from each district. The choice of farmers from each village was done by the area leader and the district extension officer based on the following criteria: respectability in the community, maize production capacity, and recommendation by traditional leaders. The selection was done in such way that all socio-economic classes of farmers were represented adequately in the study. From Manica district the study took place in Machipanda and Zonoue village, while in Angonia district the study covered Lisulo and Matwere villages. Two parishes in each village were selected.

2.3.4 Data collection

Data were collected using different PRA techniques. Formal and informal approaches were employed in data collection in order to enhance precision. According to Mergeai et al. (2001, cited by Derera, 2005) informal PRA approach enhances evidential value by taking into account relevant situational local knowledge and identifying key elements, while greater precision is obtained from formal surveys. Village leaders and extension staff facilitated the survey by creating good atmosphere, by mobilizing farmers for the focus group discussion and provided lists of farmers to be sampled for the formal survey. A combination of three data collection techniques was employed: a) semi-structured interviews for focus group discussion; b) transect walks for field observations with the groups; and c) formal survey with questionnaires for individual interviews.

The PRA involved three focus group discussions and interviews with key informants such as local teachers, businessmen, school headmasters. The techniques employed consisted of problem listing, analyses and ranking by important informants using semi-structured questionnaires (Appendixes 2.1 and 2.2). Group discussions were held with a selected sample of 15 farmers to confirm results from questionnaires for individual farmer interviews including a key informant.

The important informants were designed to guide the discussions yet provided the group sufficient opportunity to bring up their own issues. Discussion in the groups started by farmers listing uses of maize in the area, and identifying important cereals and other crops they grew. During discussions, farmers were asked to list and rank the major constraints to maize production in the area. Constraints were ranked by drawn rank matrices.

Farmers ranked independently the constraints, and the highest score was considered the most important. Observations in the farmers fields were made during the transect walks. Selection of different traits and plant characters that were considered important by farmers were recorded. Special requirements such as consumption, marketing and improved maize seed availability were discussed as the way to increase the productivity.

2.3.5 Data analyses

Data collected from questionnaires and interviews were analyzed using SPSS computer package (SPSS Inc., 2002). Average scores and ranks were calculated from both quantitative and qualitative data. Descriptive statistics, analysis of variances and mean comparisons were computed for data collected in each district followed by mean comparisons between districts

2.4 Results

2.4.1 Maize consumption

Survey conducted indicated that on average 65% of maize was consumed and 30% sold for cash or exchanged for labour at weeding time and 5% donated to extended members of the family in need. Almost all the sorghum produced by the average household was consumed in the household. Only 5% was estimated to be sold (Table 2.1).

Table 2.1: Average percentage of crop utilization in the Districts of Angonia and Manica

Crop	Own consumption	Sales	Donation
Maize	65	30	5
Sorghum	90	5	5
Cowpeas	50	50	0
Beans	15	85	0
Cotton	0	100	0

Note: Donation refers to gratuitous transfer of part of the harvest to family members living outside the household (urban areas or areas affected by poor rainfall).

2.4.2 Household Characteristics

In 90% of the cases, the household head was male. The average age of the household head was 47 years. The level of education was low, averaging 3.5 years of schooling for all adults. There were five adults per household. The maximum area under cultivation was 5.5 ha. The dominant crop in the area was maize. Other crops included sorghum, beans, cowpeas, cotton, tobacco, sunflower and horticultural crops in the lowlands.

Most of the interviewed farmers in Manica district were former refugees in Zimbabwe for years during the Mozambican civil war. While in Zimbabwe most of these small scale farmers were introduced to high input intensive farming techniques. This may explain the higher percentage of input use in Manica district compared to Angonia. Another possible reason is the lower costs of inputs in Zimbabwe. Interviewed farmers near the border said that they bought most of their inputs, from the neighbouring city of Mutare in Zimbabwe, 7 km across the Machipanda border.

Data taken from the two districts under study showed that maize was a significant staple food in both districts. Maize was ranked first followed by sorghum (Table 2.2). The main uses of maize were as food (Nsima), brewing and as a snack (fresh and dry grain). Household sizes were smaller in Manica district than Angonia district. The average land holding differed significantly between districts, ranking from 0.8 ha in Manica to 2.0 ha in Angonia.

Table 2.2 Rank of crops as preferred by farmers in Zoonue and Machipanda in Manica district

Crop	Zoonue	Machipanda
Maize	1	1
Sorghum	2	2
Beans	4	3
Pearl-millet	3	4
Groundnut	5	5

Scores: 1 = best and 5 = least preferred crop for the area

Table 2.3 Rank of crops as preferred by farmers in Lusulo and Matwere of Angonia district

Crop	Lusulo	Matwere
Maize	2	3
Sorghum	1	1
Beans	4	2
Pearl-millet	5	5
Groundnut	3	4

Scores: 1 = best and 5 = least preferred crop for the area

2.4.3 Maize Production

Although the majority of the farmers still grew local varieties, there was a substantial use of inputs such as seeds of new improved cultivars. On average, twenty three percent said they used improved cultivars in the previous season. The highest proportion of improved cultivar users were found in Manica district, with 40% using new maize cultivars, compared to 23% for Angonia. Most of the new cultivars were open pollinated varieties (OPVs), which were being reused. Seed and fertilizer have been introduced to maize farmers in Manica and Angonia through public and private extension services. Open pollinated varieties, hybrids, and fertilizer have been introduced by government extension and seed company demonstration plots as well as on on-farm trials. A number of farmers have had access to these new inputs through emergency programs or through development programs such as SG2000, PAN (National Action Programme) action and others. Other practices being promoted include conservation tillage and herbicide use. Several white, open pollinated cultivars and hybrids developed by public and private institutions are available to farmers including quality protein maize (QPM), but the adoption of all of them is still limited. Twenty eight percent of the interviewed farmers in the two districts planted both traditional and an improved cultivar in the previous cropping season (2004/05) (Table 2.4). No single farmer interviewed planted only the improved cultivar. Farmers planted both traditional and new improved cultivars. The average area planted to an improved maize cultivar, among those planting the new cultivars was 0.5 ha while the traditional cultivars were planted by all on an average of 2.3 ha.

Table 2.4 Farmers who planted at least one improved maize variety in 2005/06.

District	Number of farmers (Sample out of 100)	Number of farmers using improved seed	% of users
Manica	10	4	40.0
Angonia	22	5	22.7
Total	32	9	28.1

Improved cultivars in the region were early, intermediate and late maturing. Early maturing cultivars such Matuba, were planted. Among the intermediate to late cultivars grown in Manica were the hybrid PANNAR 67 (PAN 67) and QPM Sussuma. Fertilizers were not commonly used in the food crop sector in Manica. Most of the interviewed households said that the same land is repeatedly sown with the same crops, and they were aware of soil quality deterioration and therefore the need of fertilizer to improve soil fertility. Fertilizer was, however, used primarily on cash crops such as cotton and tobacco. In case of these crops the processors usually supplied inputs on credit against the crop delivery. The assurance of repayments allowed the creditors to offer the farmers relatively favourable interest rates, thus explaining the greater use of capital in these enterprises relative to food crops such as maize.

Farmers, especially in the district of Manica, close to the border with Zimbabwe, bought maize hybrids and OPV seeds in the neighbouring Zimbabwe. The local varieties included a group of varieties that have been locally adapted or selected. The local varieties' seeds were obtained from other farmers and passed from generation to generation. The local varieties commonly used in the surveyed area included Chimanica, La Posta, Kangere, Chinyamwana, Macolo and Chingenda. All local varieties were tall with long season maturity, white large grain and of good poundability. Improved cultivars included hybrids and OPVs. The most used improved maize OPVs were Matuba, Sussuma and Manica. Farmers surveyed reported that they obtained seed from markets, home saved seed, donations and purchase from shops (Table 2.8).

Agro-climatic conditions of the two districts are different; hence the maize grain production differed significantly between locations during 2005 and 2006 period, with Angonia having reliable rainfall during the season, and consequently highest yield, Manica and cyclic years of drought and erratic rainfall. This affected strongly the maize grain production during 2005/06 season. Data from family unit survey revealed that in both districts farmers predominantly grew open pollinated varieties (OPVs), and few hybrids from: Seed Co (SC), Qualita (QL) and Pannar (PAN). In Manica district, although farmers have accepted the new early maturing OPVs, they showed very high regard for their local varieties. The general perception was that improved varieties were not as drought tolerant as their local varieties. Related to other agronomic traits, in both districts farmers were less concerned about them, while grain texture preference was the trait for their concern. Most farmers, consistently preferred flint grain texture to the dent. In all districts, farmers were of the opinion that flint grain texture conferred high storability, and better taste (Table 2.5).

Table 2.5 Mean rank values for preferred traits of stress tolerant cultivars from formal survey in each district

Characteristic	District		Overall
	Angonia	Manica	
Drought tolerance	2.9	2.7	2.8
Low soil fertility	3.0	3.4	3.2
Disease and pests	2.8	2.6	2.7
Grain weevils	2.7	3.6	3.2
Maturity	3.7	2.9	3.3
High yield	1.8	1.5	1.7
Cob size	3.5	2.8	3.2
Grain texture	2.6	2.5	2.5
Ear per plant	2.5	2.0	2.2

Scores were: 1 = most important and 5 = least important

2.4.6 Production Constraints

Drought was ranked the most important factor among others that hampered maize production in both districts, followed by lack of improved seed. In addition, weevils (storage pests) were ranked highly due to the damage that they caused to maize rain during post-harvest storage. Diseases were ranked in third, just after the seed availability (Tables 2.6 and 2.7).

Table 2.6 Mean rank for perceived production constraints in focus group discussion in Manica district

	Manica District	
Constraint	Zonue	Machipanda
Drought tolerance	1.0	1.0
Seed availability	1.5	2.0
Disease and Pests	3.0	2.5
Low soil fertility	2.5	3.0

Scores were: 1 = most important and 5 = least important

Table 2.7 Mean rank for perceived production constraints in focus group discussion in Angonia district

	Angonia District	
Constraint	Lusulo	Matwere
Drought tolerance	2.5	2.0
Seed availability	1.0	1.0
Disease and Pests	3.0	3.0
Low soil fertility	2.0	2.5

Scores were: 1 = most important and 5 = least important

The survey revealed that farmers did not have the best approaches for controlling diseases and pests. More that 50% of the farmers mentioned that they would pluck and burn the affected plants and 25% said they had no solution to control disease and insect pests problem. The use of unimproved seed contributed to the reduction on maize grain yield in both locations.Only 15.7% purchased seeds from the market (Table 2.8).

Table 2.8 Source of seed for farmers in two districts

	District			
Seed source	Angonia	Manica	Total Frequency	Percentage
Market	12	10	22	15.7
Own home saved	18	19	37	26.2
Donations	26	23	49	34.8
Purchase from shops	15	18	33	23.4
Total	71	70	141	100

2.4.7 Importance of downy mildew and maize streak virus disease.

There were different opinions in terms of disease prevalence between the two districts (Table 2.9). Farmers described disease symptoms that devastated their crops and were able to identify them from photographs that extension officers presented. Twenty five percent of the farmers interviewed in Angonia district reported that maize streak virus (MSV) was the most important disease followed by gray leaf spot (GLS). In Manica district, 23 % of the farmers reported that downy mildew (DM) was the most important disease followed by MSV.

Table 2.9 Importance of DM and MSV and their ranking in two districts: Percent of farmers reporting a particular disease

	District		
Disease	Angonia (%)	Manica (%)	Total Frequency (%)
Rust	1	1	2
GLS	12	9	21
Turcicum	5	3	8
MSV	25	16	41
DM	5	23	28
Total	48	52	100

2.5 Discussion

The Participatory Rural Appraisal study indicated that farmers were still using own saved seed. They grew unimproved cultivars for stress tolerance and therefore these varieties succumbed to disease and insect pest damages. This finding is in conformity with those reported by Gibbon et al. (2005) who observed that most farmers selected seeds for planting from the best plants in their fields. Due to occasional droughts, some farmers in Manica district obtained their seeds from donations (NGO's and Projects). These are improved seeds that help farmers to get higher maize grain yields. In Angonia, farmers reported higher grain yield than Manica district. These farmers were able to sell part of their produce, indicating that Angonia has the potential to produce surplus grain.

During the survey, some special farmers' preferences were identified in both districts. They included large white kernels and high density for marketing and sweet taste for home consumption. These attributes were also reported from a survey in Uganda and Tanzania (Gibbon *et al.,* 2005). These attributes have not been addressed by breeders

In Angonia farmers acknowledged MSV as an important constraint in maize production.

In Manica farmers mentioned DM as a major constraint of maize, especially if infection occurs in the early stages of plant development. In other studies downy mildew was reported as a destructive disease of maize in the lowland and especially for southern part of Mozambique (Denic 1994). Manica district which receives lower rainfall and high humidity than Angonia provided favourable conditions for DM development. Pingali (2001) reported that DM was considered as one of the major constraints contributing to yield gap in sub-Sahara Africa. Since most improved maize cultivars grown by farmers were not improved for DM resistance, an epidemic could cause a great losse in farmers' fields. The National Maize Programme in Mozambique has begum improving the existing maize cultivars for resistance to DM.

From the survey findings, control measures for DM and MSVD employed by farmers consisted of early planting and removal of growing tip of young affected plants, a pratice similar to rouging. Early planting could help crops escape DM and MSVD, which is better than what farmers were doing because removal of growing tip kills the plants before producing any ear. Early planting could also help avoid leafhopper population build-up, thus reducing MSVD severity; however farmers delayed land preparation thus encouraging leafhopper population build-up during the season. Some farmers rotated cultivars in each season and planted some cultivars in one or the other season which was only effective where MSVD occurrence was sporadic but did not work where continuous occurrence of MSVD was prevalent.

Nevertheless, the effectiveness of these control methods as described by farmers depended on season, crop growth stage at which the infection occurred and the genetic make up of the plant cultivar in question. According to Pingali (2001) the most commonly used practice by farmers to control yield losses were timely planting and treatment of seed with systemic insecticides. DeVries and Toenniessen (2001), reported that for subsistence farmers a more effective and practical solution for yield losses is high yielding maize cultivars that are resistant to DM and MSVD. In both districts, there were few farmers who grew improved seed, due to the influence of the neighbouring countries (Zimbabwe with Manica and Malawi with Angonia) (DINA, 1995). These farmers, although they grew hybrids, still mentioned that those hybrids suffered DM and MSV damages, causing yield losses.

2.6 Conclusions

The survey revealed that farmers in Angonia and Manica districts obtain most of their food and cash from the crops they raise mainly maize, sorghum, cowpeas and beans.

The survey also revealed that drought, seed unavailability and diseases and insect pests (DM, MSVD, stalk borers and weevils) were the four dominant factors as maize production constraints in the two districts. Declining soil fertility was other factors identified as maize production constraints. Among the diseases DM was the most important in Manica district while MSVD was the most important in Angonia district.

Results of the study showed that farmers still have a basic preference for high yielding and early maturity maize cultivars with large, white and high density kernels and sweet tastes. Priorities for crop improvement as perceived by farmers therefore should address resistance to drought, insect pests and disease.

In both districts surveyed few farmers have knowledge about QPM cultivars and those few they recognized that QPM cultivars were more susceptible to insect pests and diseases compare to the normal maize.

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Appendices

Appendix. 2.1 Informal questionnaire on constraints and preferences for QPM cultivars in two districts of Mozambique.

Farmers' Key Constraints & P
references for QPM Cultivars

Informal questionnaire for the preliminary PRA study at Angonia and Manica districts of Mozambique

By David Mariote

Objective: To obtain the overview of key constraints and farmers' preferences for quality protein maize resistant cultivars.

Hypothesis: Farmers recognise key production constraints and have special preferences for cultivars

Research Question 1: Do farmers recognise Quality Protein Maize?
Research Question 2: Do farmers recognise the maize production constraints?
Research Question 3: What are the farmers' preferred plant traits?

a) Importance of Maize

1. What are the uses of maize in your area? List the uses.
2. Which maize varieties do you grow in your area? List them
3. What are the other important cereals in your district? List them
4. What other crops do you grow? List them and give the reasons why you grow them.

b) Major Maize Production Constraints

1. What are the major production constraints of maize in your area? [e.g. disease; drought; seed viability; fertility (soil type); low yield; insect pests including storage pests] a) Name them ; b) Rank them
2. Which measures do farmers use to overcome the constraints? List them.

c) Cultivar and Plant Trait Preferences

1. Which QPM cultivars have you planted in recent years? List the cultivars.
2. Which QPM cultivar you did not like to grow again? Name and give the reasons.

3. Which QPM cultivar do you like to grow again in your farm? Name the cultivar & state the reason.
4. Which plant traits do you prefer? List them.

d) Sources of Seed

1. Where do you obtain QPM seed for planting ever year? Name.
2. How many seed dealers are in your district and which do you know that commercialize QPM varieties? List them
3. How many seed companies are operating in your district? List.

Appendix 2.2 Formal Survey on Key Constraints and Preferences of Disease Tolerant Maize Cultivars

District: ______________ Village: _________________________
Questionnaire Number: __________
Enumerator: __________________________________

Household details

1. Name of household head: …………………………………………………..
2. State the gender --------------------------------------(male/female)
3. What is the composition of the household?

Gender Group	Number in household	Number with formal education
Male adults		
Female adults		
Male children		
Female children		

4. How many animals do you own?

Livestock	Number
Cattle	
Chickens	
Goats	
Sheep	
Donkeys	
Pigs	
Others (specify) …………………………..	

5. Which assets do you own?

Asset	Number
a) Motor vehicles	
b) Television sets	
c) Radio set	
d) Tractor	
e) Plough	
f) Harrow	
g) Water pump	
h) Modern house (brick and asbestos sheets)	

Production Constraints Data

1. Name and rank the production constraints in your district?

Constraint	Rank (1 Worst, 5 least problematic)

Options:,Diseases and insect pests seed availability cultivar problems, and poor fertility

7. Biotic Constraints (List and rank them)

Constraint	Rank

Options: Diseases, insects, weeds, and others

8. How much fertiliser did you apply last season?

Fertiliser Type	Quantity (No. of bags)
Manure	
Basal Maize Fertiliser	
Top Dressing	
Lime	
Others (Specify) -----------------------------	

c) If No, explain why you did not apply fertiliser

____

____

____

Options: Expensive, not available

9. How do you apply fertiliser/Manure?

Fertiliser Type	Method Of Application
Manure	
Basal Maize Fertiliser	
Top Dressing	
Others (Specify) -----------------------------	

Options: a) Drilling, b) Broadcast, c) Other method

Seed

10. What type and how much seed did you buy?

Year	Cultivar Name/Brand	Place	Quantity
2005/6			
2004/5			
2003/4			
2002/3			

Rains

11. Commend on the rainfall in your district

Year	Quantity
2005/6	
2004/5	
2003/4	
2002/3	

1. *Options: Quantity: Little, moderate*
2. *sufficient or insufficient for the maize crop*.

Grain Yield

12. How many bags of grain did you produce during the past years?

Year	Number of Bags Produced	Comment
2006		
2005		
2004		
2003		
2002		

13. How many bags of grain did you sell over the past years?

Year	Number of Bags Sold	Where did you sell the grain?
2006		
2005		
2004		
2003		
2002		

Options: a) Less than 5 bags, b) 6 to 10 bags, c) More than 10 bags, d) zero

14. How many bags do you require for the family consumption every year? -------------------

a) Less than 5 bags
b) 6 to 10 bags
c) More than 10 bags

15. List the factors that you consider when selecting maize varieties?

Factor	Reasons

Options:

1. *High yielding*
2. *Tolerance to disease/pest*
3. *Drought stress tolerance*
4. *Resistance to storage pests (e.g. grain weevils)*
5. *Maturity period*
6. *Grain texture*
7. *Cob coverage*
8. *Number of cobs per plant*
9. *Cob size*

16. Which of these factors are most important? Rank them

Factor	Rank
High yielding	
Tolerance to disease/pest	
Drought stress tolerance	
Resistance to storage pests (e.g. grain weevils	
Maturity period	
Cob coverage	
Grain texture	
Number of cobs per plant	
Cob size	

17. Which maize variety have you planted in recent years? Give reasons.

Year	Cultivar	Reasons
2005/6		
2004/5		
2003/4		
2002/3		

Name the variety you would like to grow next year, and give the reasons.

Variety: ---

Reasons: ---

18. Which the most popular maize varieties according to performance.

Cultivar	Rank

19. Which of the following grain texture does the farmer prefer? (Show ear samples of each type). Indicate the preferred texture with a cross (X).

Grain texture	Preferred	Reasons
Flint		
Intermediate		
Dent		

Chapter 3: Response to selection for downy mildew resistance, grain yield, and secondary traits in three quality protein maize populations in Mozambique

Abstract

Downy mildew (DM) is a major problem in quality protein maize (QPM) varieties under cultivation in Mozambique. Recurrent selection was therefore initiated to improve DM resistance in three QPM populations, mainly Sussuma, ZM521Q and Pop62SRQ at Umbeluzi Research Station in Mozambique, during 2003-2006 seasons. Downy mildew disease incidence and severity were rated at four and eight weeks after infection (WAI) based on visual assessment of the whole plot. Selfed S1 progenies were selected based on FS progeny performance. Two selection cycles were formed and evaluated. Selection intensity was 50%, and 25% in cycle 1 (C1) and cycle 2 (C2), respectively. The C1 and C2 were evaluated in a randomized complete block design with three replications in 2005/6 season. Results indicated significant improvement in DM resistance from C1 to C2, with scores of 4.6-3.9 in Sussuma, 3.0-2.3 in ZM521Q and 4.0-3.3 in Pop62SRQ, respectively. Results also indicated increase in genetic variances (σ^2_G) for DM from 0.069 in C1 to 0.119 in C2 in Sussuma; 0.054 in C1 to 0.1442 in C2 in ZM521Q, and from 0.097 in C1 to 0.313 in C2 in Pop62SRQ. Broad sense heritability (H^2) estimates ranged from moderate to high and increased from C1 to C2 in all populations. The H^2 estimates were 0.63-0.76 in Sussuma; 0.60-0.63 in ZM521Q and 0.60-0.63 in Pop62SRQ. These changes were associated with an increase in yield of about 4.67% in Sussuma, 4.68% in ZM521Q and 4.47% in Pop62SRQ. There was also an improvement in flint nature of the grain with texture scores of 2.7-1.4 in Sussuma, 2.9-1.8 in ZM521Q and 2.5-1.7 in Pop62SRQ. There were no significant changes in anthesis-silking interval, plant height and number of ears plant^{-1}. This study showed that S1 recurrent selection was effective in improving QPM populations for DM resistance, increasing genetic variances and broad sense heritability estimates without compromising grain yield, texture, and other important characteristics.

3.1 Introduction

The objective of QPM breeding is to improve the nutritional value of proteins in maize grain, which is only 40% of that of milk (Bressani, 1991). Maize is therefore recommended and consumed with other balancing proteins from legumes and animal products, which are not readily available to small-scall farmers. Most people in sub-Saharan Africa rely on a predominantly maize based diet hence cases of malnutrition abound. In Africa for example, maize contributes 20% of total daily calories and accounts for 17 to 60% protein FAO (1995) requirements, yet it lacks in essential amino acids. QPM varieties would therefore address such inadequacy in maize.

Although the grain yield potential of QPM varieties has been improved, the varieties in Mozambique are still highly susceptible to many diseases. The disease pressure is high on QPM varieties because the varieties were presumably developed from germplasn with little resistance to prevalent pathogens in Mozambique. Downy mildew is one of the most serious diseases that compromise yield. Downy mildew, which is caused by *Peronosclerospora sorghi* reduces grain yield when it attacks the maize crop during the early growth stages and development (Denic *et al.,* 2001). In Africa, this disease is prevalent in East Africa (Weston and Uppal, 1932), southern Nigeria in West Africa, Abedon and Tracy (1988) and Mozambique in Southern Africa (Plumb-Dhindsa and Mondjane, 1984; Denic, 1994).

Rana et al. (1982) reported that Indian inbred maize lines were resistant to DM pathogens (*Peronosclerospora sorghi* (*SDM) and Perenosclerospora heteropogoni; (RDM*). They also reported that resistance was polygenically inherited and that resistance was dominant over susceptibility in that germplasm. In a later study, Nair et al. (2004) found that resistance was partially dominant when lines were subjected to SDM infection, but was complete in lines infected with RDM. However, they concluded that additive genetic variance was more important than the non-additive genetic variance in controlling resistance to SDM and RDM, (Nair *et al.,* 2004), suggesting that resistance could be improved by selection. In Mozambique, the SDM is the predominant pathogen that has been associated with DM in maize.

Recurrent selection (RS) methods have been widely used to improve yield and agronomic performance of maize populations (Ceballos *et al.,* 1991). During recurrent selection it is desired to improve mean performance for the desirable attributes without compromising the genetic variation which is required to ensure continued selection gains. Thus the RS which has been proven to be efficient in exploiting additive effects (Moll and Smith, 1981) would be used to improve three QPM populations for resistance to DM in Mozambique. A survey of available literature showed that very little RS, if any, has been conducted to improve QPM especially for DM resistance. However, some progress on DM resistance has been reported in normal maize (CIMMYT, 2001), especially when S1 selection was used in combination with full-sib selection (Ajala, 1992). The QPM populations under cultivation in Mozambique have not been studied for genetic variability for DM resistance and their response to selection for DM resistance. This study was, therefore, based on the premise that DM resistance is polygenically controlled by predominantly additive gene action, and can be improved by recurrent selection.

3.2 Objectives and Research hypothesis

The specific objectives of the study were:

a) To study the response to recurrent selection for DM resistance and other important traits using selfed progenies (S1) in combination with full-sib evaluation of three QPM populations,

b) To determine correlated responses of the three populations for yield, ASI, grain texture, grain moisture and other important agronomic characteristics after two cycles of recurrent selection.

The hypothesis tested was:

a) Resistance to DM in QPM populations can be improved by using recurrent selection, and genetic variability for DM and other important traits remains high after cycles of recurrent selection.

3.3 Materials and methods

3.3.1 Location of the study

The experiment was conducted at Umbeluzi Research Station, which is located 30 km south of Maputo, with a mean altitude of 15m above sea level (a.s.l). The research station area is located in the Boane district in the Maputo province, Mozambique, between the latitude 26°02' – 26°04' south and the longitude 32°17' – 32°19' west. The climate is subtropical, with a monomodal rainfall pattern. The average rainfall per annum is 678 mm. January is the wettest month and August the driest month of the year. The rainy season runs from October to April and the dry season from May to September. The annual average temperature is 22.9°C. The highest average temperature is in January (25.6°C) and the lowest in July (17.8°C). The relative humidity does not vary markedly during the year with values ranging between 65% during August/September to 72% in March/April.

3.3.2 Germplasm

The three quality protein maize populations Sussuma (S_2 generation), ZM521Q, and Pop62SRQ (Table 3.1) used in this study were obtained from CIMMYT. They are high grain yielding but highly susceptible to downy mildew. These populations were designated Sussuma, ZM521Q and Pop62SRQ, respectively, in this study. All three populations were originally developed at the International Maize and Wheat Improvement Centre (CIMMYT) Mexico and Harare. All the populations are adapted to tropical environments in East and Southern Africa. They were converted to QPM at Instituto de Investigação Agrária de Moçambique (IIAM), in Mozambique. The characteristics of these populations are summarized in Table 3.1.

Table 3.1: Characteristics of three QPM populations subjected to recurrent selection for downy mildew resistance in Mozambique

Designate Name	Source Population	Characteristics
ZM 521Q	[ZM521/SW8075DMR//QSRDMR] F2	● Intermediate to late maturing; high-yielding white grain, flint grain type. Improved for quality protein Adapted to tropical environments. Grown at sea level to 1500m in Mozambique.
SUSSUMA	Sussuma S2	● Has Obatanpa GH background, derived from Pop63SR, originated from CIMMYT, Mexico. Intermediate to Late maturing; high-yielding white grain; semi- dent grain type. Improved for high quality maize protein, grain texture and drought tolerance at ex-INIA, IIAM. Adapted to tropical environments. Grown at sea level to 1500m in Mozambique.
POP 62 SRQ	Pop 62 SR	● QPM early maturing; high-yielding white grain, flint grain type. Adapted to tropical environment. Grown at sea level to 1500m in Mozambique.

3.3.3 Establishment of screening nurseries and artificial inoculation of spreader rows for downy mildew

Downy mildew nurseries were established three seasons to screen the progenies at Umbeluzi Research Station, (URS) in December 2003, November 2004, and November 2005. Selected ears from selfed (S1) seeds of each population were planted for screening for DM resistance. The population size of about 5,316 plants for each population was established. Screening nurseries were laid out in three blocks for each population on one row plots of 5 m long. The blocks were made up of 275 rows. Field layout involved planting four rows of spreaders (susceptible checks) at the beginning of each block, followed by five rows of the population to be screened, and at the end of the block. The progenies of the selected plants from the selfed generation (S1) were planted in an ear-to-row method in which progenies of each plant were planted in one 5 m long row only. Agronomic practices included fertilizer application at the rate of 375 kg ha-1 compound (12N:24P:12K) at planting; herbicide application with glyphosate before planting followed by weeding and top dressing with urea (46% N) at the rate of 150 kg ha-1 during the vegetative stage. Stalk borer control was done by spraying with insecticide Decis (pyrethroid) at regular intervals to reduce crop loss. A combination of night-time infection techniques developed in Thailand (Caldwell *et al.,* 1997), and a modified inoculation procedure (Caldwell *et al.,* 1997) were used to inoculate trials. Seeds of a susceptible variety were selected, and treated with 5% savlon (desinfectant) for 1 min, and then washed with tap water, and left to pre-germinate for 72 hrs. Downy mildew diseased leaves were harvested late afternoon and used to make a layer in a plastic box. The layer of seedlings was placed over the layer of diseased leaves and left to sporulate over night, in a controlled chamber at 20 oC. The infected seedlings were then planted in the field as spreader rows and the S1 progeny rows were planted 14 days later. The pathogen was already sporulating on the spreader plants by the time the test materials were planted.

3.3.4 Formation of the cycles

During the test period, all selected plants had their ear shoots covered with cellophane bags at flowering time. The ears of the selected progenies were self-pollinated to provide S1 seed. Pollen from selfed plants was used to pollinate ears from other randomly selected plants to form full-sib seed. Full-sib families were harvested and evaluated and the results used as base to select the S1 progenies The formation of cycles is illustrated in Figure 3.1. Selfed progenies based on the best FS progenies were selected for quality protein content using light tables (Pixley and Bjarnason, 2002). To confirm the results of light table selection, enzyme-linked immunosorbent assay (Elisa) test was conducted in the laboratory for selected grain, and only those that met QPM protein requirement levels were selected. The selected S1 seeds were planted in an isolated plot to allow them to inter-mate and then the seed was bulked to form C1. The process was repeated using C1 seed as base to form C2 seed Although FS and S1 progenies from an equal number of plants in each of the three populations were sought, the proportion of plants obtained was 50% (2658 plants), 25% (665 plants) and 25% (166 plants) for the populations Sussuma, ZM521Q and Pop62SRQ, respectively. The rational of choosing this selection intensity was to maintain the variability within populations for future selections. These were plants with adequate FS seed with resistance to DM used to form the base population referred to herein as cycle 1.

In 2005/06, a trial was planted for evaluation of the two cycles of each population. A simple lattice was used. Selected high yielding progenies of full-sib families were randomly assigned to each block. Planting density was 53,333 plants ha^{-1}. Plot size was one row of 5 m length, 80 cm between and 25 cm within rows. The hills were over planted and thinned to one plant per hill. Additional variables, such as days to 50% anthesis, plant height and ear height were recorded for each plot. Plots were hand harvested and shelled grain weight recorded. Grain moisture at harvest was determined and plot yields adjusted to 13.5% moisture level. Data were analyzed on a per block basis and individual analyses of variance pooled over blocks for a trial. Selection was based on FS performance within blocks. Only those FS that yielded above their respective blocks means and were equal to or below the average grain moisture at harvest and with desirable quality protein content were selected. Selfed (S1) progenies based on superior FS families were advanced to the next generation.

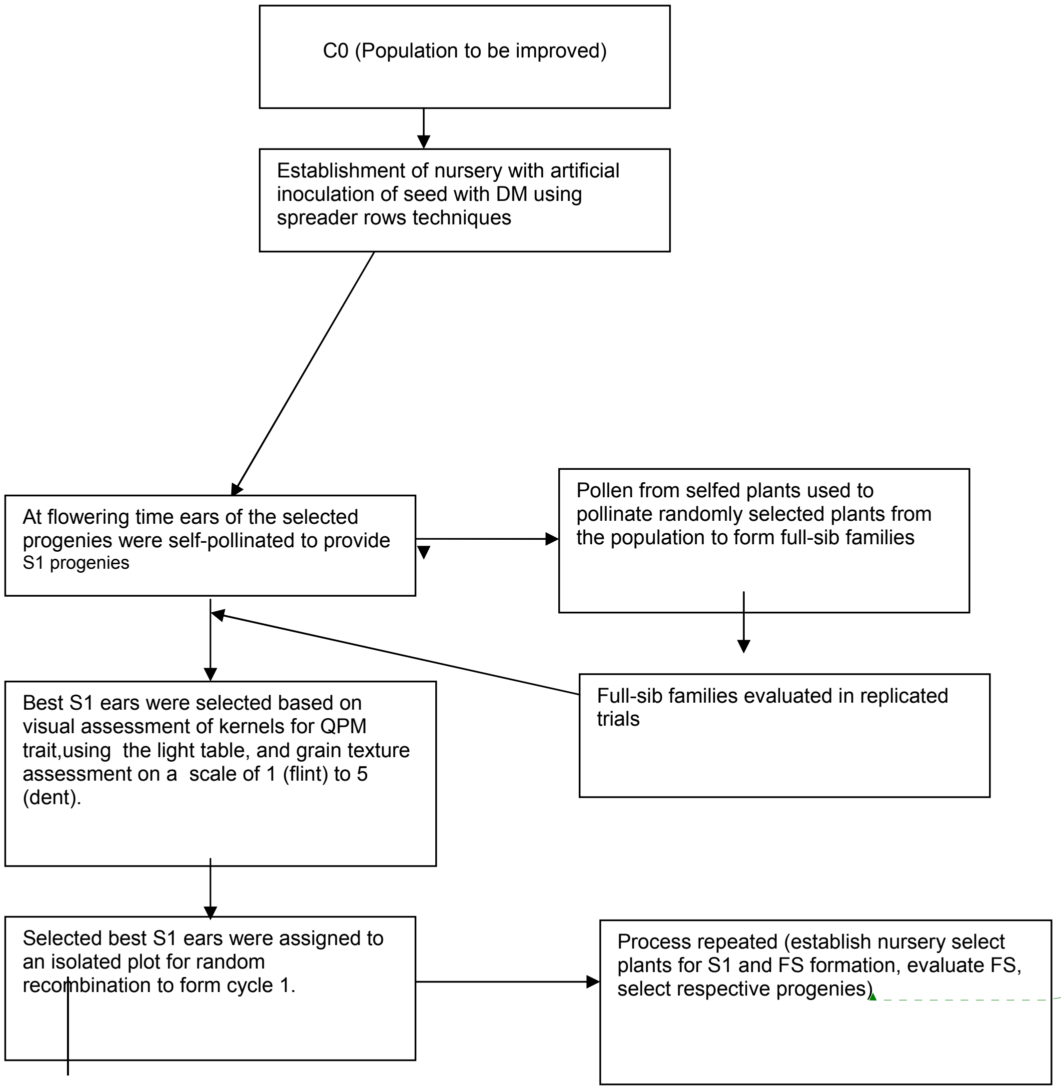

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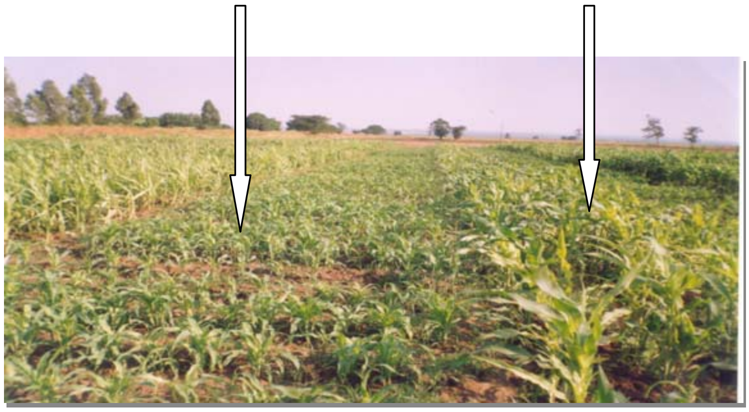
Fig. 3.1 Formation of cycles using S1 and full-sib families in QPM populations

3.3.5 Selection method

The selection method for DM was based on single plant selection. This was done just before flowering stage (because of the need for cross and self pollination). The best rows were selected and in each row the best five plants were selected. The best plants were those that showed resistance to downy mildew. The selected plants were hand self-pollinated to generate selfed progenies, and cross pollination was carried out for full-sib progenies formation using randomly selected plants from the population. The full-sib families were also selected at harvest for yield and other environmental responses. Selection of plants for advancement to the next generation was conducted in stages: First, based on DM disease severity scores. Plants with zero (0) severities scores were not selected because they could not be differentiated from escapes. Only plants that showed symptoms with severity scores of 2 and 3 indicating high resistance were selected. About 10% (510/5,316) of the plants with scores of 2 to 3 (rating scale 0 to 5) were selected, equivalent to selection intensity of 1.74 (Falconer, 1981). Second, the self-pollinated progenies of each population were again selected during harvest time and taken to the laboratory for the final analysis of tryptophan content to keep the protein quality of the selected progenies for the next generation of selection. Selected progenies with resistance to DM were also selected on the basis of grain texture. Selection for grain texture was based on levels of flintiness of the grain, and was done after harvest. In each population best ears were selected for flintiness using the scale of 1 (flint) to 5 (completely dent). Only plants showing grain texture scores between 1.9 and 2.8 indicating high levels of flintiness were selected and advanced to the next cycle of selection.

3.3.6 Experimental layout of yield trial

For yield evaluation and other agronomic characteristics, full-sib families were formed by cross pollinating and the selected plants were used. Trials were laid out as a randomized complete block design with three replications. Each entry was planted in two rows, 5m long with spacing of 80cm between rows and 25cm between hills within rows.



Progenies under evaluation

Spreader rows (infested material)

Fig. 3.2 Downy mildew nursery planted at Umbeluzi Research Station in December 2005

3.3.7 Data collection

Disease development was monitored throughout the growth cycle, and the data was recorded. Downy mildew disease incidence and severity were scored twice after planting as infection takes place about three weeks after planting, based on visual assessment of the whole plot. Disease incidence was scored by recording the number of plants in each population showing DM symptoms and expressing that as a percentage of total plant population. Disease severity was scored on the whole plant as a proportion of total leaf area diseased using a rating scale of 1 to 5 where 1= no disease on leaves, 2 = lesions on lower leaves and no lesions on leaves above the ear, 3 = disease on most leaves and some lower leaves dead, 4 = dead lower leaves and many lesions on all leaves and ear, and 5 = nearly all the leaves are dead (CIMMYT, 2001). The number of days to mid-silking (DMS) and anthesis (DMP) were estimated as number of days from planting to 50% plants with silks emerged and tassels shedding pollen, respectively. Plant and ear height were measured as the distance from the base of the plant to the height of the first tassel branch and the height of the node bearing the uppermost ear, respectively. Grain weight and moisture content per plot were obtained at harvest and values obtained were used to estimate grain yield (t ha^{-1}) adjusted to 13.5% moisture content.

3.4 Data analysis

Quantitative data generated from 2006 infected trials were each subjected to a separate ANOVA using REML tool in Field book. Data were analyzed using the following model: $Y_{ijk} = \mu + \beta_i + g_j + e_{ijk}$, where μ is the general mean, β_i the effect of $_i$the blocks, g_j the effect of $_j$the genotype and e_{ij} the error associated with particular measurement

Table 3.2 Skeleton analysis of variance when *g* genotypes are raised in RCBD with *r* replications

Source	Df	S.S	MS	Expected Mean square
Replications	(r-1)			
Among genotypes	(g-1)	$r\Sigma(yi-y..)^2$	M1	$\Sigma^2e + \sigma^2g$
Within genotypes	(r-1)(g-1)	$\Sigma(yij-yi.)^2$	M2	Σ^2e
Total	(rg-1)			

Response to selection was determined using the following formula: $R = iH^2\sigma^2_P$ (Falconer, 1961), where i = selection intensity of 50 and 25%; H^2 = broad sense heritability; and σ^2_P = phenotypic variance. Response to selection per cycle-1 was also calculated as the difference between cycles where appropriate (C2-C1). Broad-sense heritability estimates were calculated using the following formula: $H^2 = \sigma^2g/\sigma^2P$ x 100 (Falconer, 1961). Genetic covariance between FS was estimated as: *Covg (FS) = t (1/2VA + 1/4VD + VEc*) (Lonnquist *et al., 1967)* ; genetic coefficient of variation for DM and yield were obtained using the following formula: *GCV = √σ/X x 100 (*Eberhart *et al.,1973)*; and the correlations for the FS were obtained using the following formula *t = (1/2VA + 1/4VD + VEc)/VP* (Falconer, 1961).

3.5 Results

Responses to selection per cycle^{-1} in C1 and C2 for all three QPM populations are presented in Table 3.3 as the difference between two cycles (C2-C1. Variances associated with differences among FS families in three QPM populations were highly significant (3.4, 3.5, and 3.6). Seed availability of C0 was not adequate to be included during evaluation of C1 and C2. it was include in Table 3.3 to show DM values of the original population.

Table 3.3 Means and response to selection for DM rating, yield and agronomic traits of different cycles of selection in three QPM populations

	SUSSUMA					ZM 521Q					Pop 62 SR Q				
Trait	C0	C1	C2	+Resp cycle^{-1}	LSD	C0	C1	C2	+Resp cycle^{-1}	LSD	C0	C1	C2	+Resp Cycle^{-1}	LSD
DM rating (1-5)	4.60	4.25	3.9	-0.35	1.2	3.0	2.75	2.30	-0.45	0.7	4.40	3.50	2.95	-0.55	0.6
Yield (t ha^{-1})	3.36	3.49	3.67	0.18	1.08	3.05	3.15	3.30	0.15	1.80	1.65	1.89	2.0	0.18	0.67
Plant height (cm)	147.2	145.6	145.1	-0.50	34.0	165.3	164.7	163.9	-0.70	44.7	152.1	150.9	150	-0.9	22.0
Ear height (cm)	64.3	63.7	62.8	-0.90	0.15	82.6	81.5	80.8	-0.70	0.44	76.2	75.4	74.9	-0.50	0.29
Days to 50% silking	64.6	62.2	60.3	-2.15	0.11	66.0	63.7	61.2	-2.50	0.13	71.0	68.8	65.8	-3.0	0.17
Days to 50% pollen shed	61.5	59.6	58.1	-1.5	0.09	62.5	60.6	59.7	-0.9	1.2	67.3	65.4	63.3	-2.1	0.12
Anth-Silk Interval (ASI)	3.1	2.6	2.2	-0.40	1.3	3.5	3.1	2.1	-1.0	2.0	3.7	3.4	2.5	-0.90	1.6
Ear per plant	1.07	1.11	1.15	0.04	1.1	0.88	0.93	1.06	0.13	0.9	1.06	1.08	1.16	0.08	1.3.
Grain moisture (%)	15.60	17.40	14.90	-2.50	1.4	15.20	17.30	14.90	-2.40	5.9	15.50	15.70	14.87	-0.83	1.5
Grain Texture (1-5)	2.7	2.1	1.4	-0.70	0.8	2.9	2.1	1.8	-0.30	0.8	2.5	2.1	1.7	-0.40	0.5

+ Response to selection cycle^{-1} = C2-C1

3.5.1 Downy Mildew

Downy mildew ratings for resistance showed a reduction in disease severity of 0.35 in Sussuma, 0.45 in ZM521Q, and 0.55 in Pop62SRQ per cycle (Table 3.3).

The change from C1 to C2 had had reduced the infection rate from 4.60 to 3.90 in Sussuma, from 3.00 to 2.10 in ZM521Q, and from 4.40 to 3.30 in Pop62SRQ (Table 3.3).

Table 3.4 Estimated variance components of the SUSSUMA population related to the different agronomic traits in cycles C1 and C2

Mean squares for downy mildew rating revealed highly significant variation ($P \le 0.01$) among full-sib families in all QPM populations (Appendices 3.1, 3.2, and 3.3). Genetic variances for DM resistance increased from C1 to C2 from 0.069 to 0.119 in Sussuma; from 0.054 to 0.1442 in ZM521Q; and from 0.097 to 0.313 in Pop62SRQ (Tables 3.4, 3.5 and 3.6). Comparatively, higher heritability estimates were observed for DM resistance in C1 in Pop62SRQ (0.70) than Sussuma population (0.63) and ZM521Q (0.60) (Tables 3.4, 3.5 and 3.6).

		C1			C2	
Traits	σ^2_g	Se	H^2	σ^2_g	Se	H^2
Downy Mildew	0.069	0.046	0.63	0.119	0.051	0.76
Yield	0.561	0.131	0.69	0.667	0.135	0.72
Plant height	206.9	30.10	0.91	361.8	31.30	0.94
Anthesis-silking Interval (ASI)	0.443	0.054	0.72	0.559	0.260	0.85
Grain moisture	1.965	0.876	0.60	3.504	1.250	0.86

In C2, higher heritability estimates for DM resistance were observed in Sussuma (0.76), followed by Pop 62SRQ (0.71), and ZM521Q (0.63) (Tables 3.4, 3.5, and 3.6).

Table 3.5 Estimated variance components of the ZM 521 Q populations related to the different agronomic traits in cycles C1 and C2

		C1			C2	
Traits	σ^2_g	Se	H^2	σ^2_g	Se	H^2
Downy Mildew	0.054	0.032	0.60	0.1442	0.1019	0.63
Yield	0.337	0.179	0.78	1.790	0.184	0.90
Plant height	96.73	34.70	0.79	176.1	36.93	0.84
Anthesis-silking Interval (ASI)	0.158	0.118	0.66	0.561	0.090	0.89
Grain moisture	2.210	1.480	0.71	2.258	3.140	0.79

Genetic coefficients of variation (GCV) for DM resistance changed less in Sussuma than in Pop62SRQ with advances in selection. The increase in genetic covariance (Covg (FS-S1) for yield from C1 to C2 was more pronounced in ZM521Q and Pop 62SRQ (Table 3.7).

Table 3.6 Estimated variance components of the Pop62SRQ population related to the different agronomic traits in cycles C1 and C2

			Pop 62 SRQ			
		C1			C2	
Traits	σ^2_g	Se	H^2	σ^2_g	Se	H^2
Downy Mildew	0.097	0.135	0.70	0.313	0.046	0.71
Yield	0.944	0.618	0.68	2.699	0.610	0.81
Plant height	185.6	55.00	0.74	581.3	89.80	0.92
Anthesis-silking Interval (ASI)	2.120	1.040	0.55	2.466	0.407	0.69
Grain moisture	0.725	0.537	0.65	5.986	0.731	0.76

3.5.2 Grain yield

The gain per cycle was 180 kg in Sussuma, 150 kg in ZM521Q and 180 kg in Pop62SRQ (Table 3.3). Mean squares for grain yield among full-sib families were highly significant ($P \leq 0.01$) in C2 of all populations (Appendices 3.1, 3.2, and 3.3). Similarly heritability estimates were highest in ZM521Q (0.90) in C1, and lowest in Sussuma (0.72) (Table 3.4, 3.5 and 3.6). Genetic variances for grain yield increased from 0.561 to 0.667 in Sussuma; from 0.337 to 1.790 in ZM521Q; and from 0.944 to 2.699 in Pop62SRQ (Tables 3.4, 3.5, and 3.6) with selection. Genetic coefficients of variation (GCV) for yield changed very little from C1 to C2 in Sussuma whereas in Pop62SRQ GCV were approximately four times higher in C2 compared to values in C1 (Tables 3.7). More pronounced increase in genetic covariance (Covg (FS-S1) for yield was found in ZM521Q and Pop62SRQ from C1 to C2 (Table 3.7). Using a selection of intensity of 50 % in C1 and 25 % in C2 the response to selection was 0.50 in C1 and 0.88 in C2 for Sussuma, 0.41 in C1 and 1.61 in ZM521Q and 0.64 in C1 and 1.87 in C2 for Pop62SRQ population (Table 3.8).

Table 3.7 Genetic parameter estimates for FS families of the three QPM populations on cycles C1 and C2

3.5.3 Plant height

			YIELD			
	SUSSUMA		ZM521Q		Pop62SRQ	
	C1	C2	C1	C2	C1	C2
Parameter	FS	FS	FS	FS	FS	FS
GCV	21.46	22.25	18.43	40.54	52.51	82.14
σ^2_G	0.561	0.667	0.337	1.79	0.944	2.699
Covg(FS-S1)	34.89	38.43	15.88	59.45	60.36	116.2
H^2	0.69	0.72	0.78	0.9	0.68	0.81

GCV = Genetic coefient of variation; Covg = genetic covariance; σ^2G = genetic variance; H^2 = broad-sense heritability;

The gains per cycle were negligible in all their populations, Sussuma, ZM521Q and in Pop62SRQ (Table 3.3). Mean squares (Appendices 3.1, 3.2 and 3.3) were significant ($P \leq 0.01$) for plant height in all three QPM populations.. Mean square for C2 was significant ($P \leq 0.01$) in ZM521Q but not significant in Sussuma and Pop62SRQ (Appendices 3.1, 3.2 and 3.3. Heritability estimates were 0.91 in C1 and 0.94 in C2 for Sussuma, 0.74 in C1 and 0.92 in C2 for Pop62SRQ, and 0.79 in C1 and 0.89 in C2 in ZM521Q. Genetic variances for plant height showed an increase from C1 to C2 from 206.9 to 361.8 in Sussuma, from 96.37 to 176.1 in ZM521Q, and from 185.6 to 581.3 in Pop62SRQ (Tables 3.4, 3.5 and 3.6).

3.5.4 Anthesis-Silking Interval (ASI)

The gain per cycle for ASI reduced by 3.5% in Sussuma, 3.0% in ZM521Q and 3.4% in Pop62SRQ (Table 3.3). Mean square among full-sib families for ASI was significant in Sussuma but not in ZM521Q and Pop62SRQ (Appendices 3.1, 3.2, and 3.3). Heritability estimate for Sussuma were 0.72 in C1 and 0.85 in C2, 0.66 in C1 and 0.89 in C2 in ZM521Q, and 0.55 in C1 and 0.69 in Pop62SRQ (Tables 3.4, 3.5, and 3.6). The invcreas in genetic variances for ASI was small in Sussuma but was large in ZM521Q (Tables 3.4, 3.5, and 3.6).

Table 3.8 Response to selection for yield in three QPM populations in C1 and C2

			Yield			
	Sussuma		ZM521Q		Pop62SRQ	
	C1	C2	C1	C2	C1	C2
I	0.798	1.271	0.798	1.271	0.798	1.271
H^2	0.69	0.72	0.78	0.90	0.68	0.81
σ_P	0.9018	0.9638	0.6555	1.4071	1.1778	1.8209
RS	0.50	0.88	0.41	1.61	0.64	1.87

RS = response to selection; i= selection intensity
H^2 = broad-sense heritability; σ_P = standard error of phenotypic variance

Table 3.9 Genetic parameter estimates for FS families of the three QPM populations

				Downy Mildew				
	SUSSUMA			ZM 521 Q			Pop 62 SRQ	
	C1	C2		C1	C2		C1	C2
Parameter	FS	FS		FS	FS		FS	FS
GCV	6.21	8.83		8.78	16.51		8.55	16.96
σ^2_G	0.069	0.118		0.054	0.144		0.097	0.313
Covg(FS-S1)	5.26	5.96		4.36	10.9		5.64	18.81
H^2	0.63	0.76		0.6	0.63		0.7	0.71

GCV = Genetic coefient of variation; Covg = genetic covariance; $\sigma^2 G$ = genetic variance; H^2 = broad-sense heritability

3.5.5 Grain Moisture

Selection reduced grain moisture by 4.78 % in Sussuma, 4.90 % in ZM521Q and 4.79 % in Pop62SRQ (Table 3.3). Mean squares for grain moisture among full-sib families was significant in all populations (Appendices 3.1, 3.2 and 3.3). Heritability estimates were 0.60 in C1 and 0.86 in C2 for Sussuma, 0.71 in C1 and 0.79 in C2 for ZM521Q, and 0.65 in C1 and 0.76 for C2 Pop62SRQ (Tables 3.4, 3.5 and 3.6). Genetic variances for grain moisture increased from 1.965 in C1 to 3.504 in C2 for Sussuma, from 2.210 in C1 to 2.258 in C2 for ZM521Q; and from 0.725 in C1 to 5.986 in C2 for Pop62SRQ (Tables 3.4, 3.5 and 3.6).

Table 3.10 Response to selection in Downy Mildew on three QPM populations in C1 and C2

RS = response to selection; i= selection intensity
H2 = broad-sense heritability; σP = standard error of phenotypic variance

	Sussuma		ZM 521Q		Pop 62 SR	
	C1	C2	C1	C2	C1	C2
i	0.798	1.271	0.798	1.271	0.798	1.271
H^2	0.63	0.76	0.6	0.63	0.7	0.71
σ_P	0.334	0.394	0.299	0.48	0.37	0.668
RS	0.17	0.38	0.14	0.38	0.21	0.6

3.5.6 Correlation Coefficients

In Sussuma significant correlations were observed between DM and ASI, and grain yield with ears per plant and grain moisture. Plant height was also significantly correlated with ears per plant and grain moisture. Grain texture exhibited high correlation with grain moisture (Table 3.11).

Table 3.11 Correlations coefficients among measured parameters of Sussuma population in C 2

	ASI	Downy Mildew	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Downy Mildew	0.357*						
Ear per Plant	-0.06	0.043					
Grain Moisture	0.113	-0.295	0.229*				
Grain Texture	0.099	0.015	-0.113	0.1730*			
Grain Yield	-0.19	-0.533	0.287*	0.4380**	-0.196		
Plant Height	0.068	0.209	0.222*	0.2510*	-0.157	0.181	

In ZM521Q correlations were shown between DM with ear per plant and plant height with grain yield (Table 3.12).

Table 3.12 Correlations coefficients among measured parameters of ZM521Q population in C 2

	ASI	Downy Mildew	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Downy Mildew	-0.1100						
Ear per Plant	-0.0800	0.2020*					
Grain Moisture	0.0180	-0.1210	-0.2440				
Grain Texture	0.0550	0.2610*	-0.0350	-0.0180			
Grain Yield	0.0690	-0.1640	-0.1200	-0.0420	0.0740		
Plant Height	0.1000*	-0.1440	0.0460	0.0350	0.0090	0.3440*	

In Pop62SRQ, DM exhibited high correlation with ASI, and grain texture was correlated with grain moisture. Grain yield showed high correlation with grain texture (Table 3.13).

Table 3.13 Correlations coefficients among measured parameters of Pop62SR1Q population in C 2

	ASI	Downy Mildew	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Downy Mildew	0.275*						
Ear per Plant	-0.060	-0.143					
Grain Moisture	0.186	-0.145	-0.0100				
Grain Texture	0.026	-0.304	-0.0230	0.2810*			
Grain Yield	0.102	-0.491	0.1540	0.1230	0.2330*		
Plant Height	0.003	-0.014	0.0650	0.0250	0.1000	-0.0130	

3.7 Discussion

3.7. 1 Sussuma

Analyses of variance of FS in Sussuma population indicated highly significant variations among progenies.These variations could be useful for effective selection against DM resistance. A survey of the literature indicates that there are few previous studies of recurrent selection for DM resistance in QPM, most of the previous studies were conducted with normal maize. In the current study, two cycles of recurrent selection for DM resistance significantly reduced the infection rates from 4.6 to 3.9 (1.0 to 5.0 scale) in Sussuma. Moderate temperature (15-32oC) and high humidity favour infection of DM (Denic *et al.,* 2001). The incidence of this disease is always high in southern part of Mozambique where such conditions are prevalent (Denic, 1994). An increase in genetic variance and heritability estimates for DM from C1 to C2 were observed in this population. This was probably due to the large number of S1 progenies advanced to the next cycle. The more than 500 S1s advanced for inter-mating could have mimicked panmixis. This is consistent with the finding of Denic et al. (1997) who observed that DM was highly heritable and not very complex to score. These authors concluded that screening of advanced lines should be sufficient to identify DM resistance in a maize breeding programme. Previously, Ajala (1992) found additive gene action being important in controlling resistance against DM. Nair et al. (2004) also reported that DM resistance is multi-genic and controlled by many partially dominant genes.

Data on disease spread indicated that after two cycles of recurrent selection, the reduction in disease severity per cycle was 4.24 % in Sussuma. These findings are in conformity with those reported by De Leon et al. (1993) who observed reduction in the severity of downy mildew infection in advanced cycles of recurrent selection in maize populations. He also documented significant progress in levels of downy mildew resistance (-1.1.0 %) with correspondent increase in grain yield (507 kg ha^{-1}) in four maize populations after conducting three cycles of S1 recurrent selection.

Mean square values for grain yield were highly significant ($P \leq 0.01$) for cycles and high correlation was observed between DM and number of ears per plant. It could be argued that improvement in grain yield was related to increased resistance to DM. Ceballos et al. (1991) reported a similar relationship between disease resistance and higher grain yield. Heritability estimates for grain yield were high indicating that an improvement would be achieved from field selection for grain yield. These results were similar to those of Abedon and Tracy (1998), who reported very close correspondence of expected and observed responses (446 vs. 421 kg ha^{-1}) after two cycles of S1 recurrent selection in a high yielding maize synthetic variety. Recurrent selection significantly ($P \leq 0.01$) increased grain yield in Sussuma from 3.49 to 3.67 t ha^{-1}. This response of Sussuma population could be a possible manifestation of its increased resistance to DM as observed in the present study.

Grain yield increased by 180 kg ha^{-1} (4.73 %) per cycle in Sussuma. Highly significant increase in grain yield (507 kg $cycle^{-1}$) in four populations was revealed by De Leon et al. (1993), after three cycles of S1 recurrent selection for downy mildew resistance. Ceballos et al. (1991) reported 19 % gain $cycle^{-1}$ in early and 7 % gain $cycle^{-1}$ in intermediate populations for grain yield under disease pressure. Similarly, Weyhrich et al. (1998) experienced significant increase in grain yield in the BS 11 maize population. They reported selection gains of 110 and 220 kg ha^{-1} gains $cycle^{-1}$ after four cycles of progeny selection with 10 % and 30 % selection intensity, respectively.

Analysis of variance of full-sib progenies indicated the presence of highly significant ($P \leq 0.01$) genetic variation in Sussuma for days to tasseling, silking and pollen shedding. These results suggested that despite high genetic variability among S1 lines, they were indeed highly consistent in performance over the two cycles of S1 line recurrent selection. These results are in agreement with those of De Leon et al. (1993), who reported significant differences for maturity in four tropical maize populations implementing S1-S2 line recurrent selection for downy mildew resistance. Abedon and Tracy (1998), observed significant variations for mid-silking and mid-pollen shedding using recurrent selection for rust resistance in three sweet corn populations. Using full-sib recurrent selection for northern corn leaf blight disease resistance in subtropical maize populations, Ceballos et al. (1991) reported a significant decrease in maturity parameters. The reduction in days to silking and pollen shed per cycles in Sussuma were 3.1 to 2.2d. Johnson et al. (1986) reported early flowering with a 4.4% increase in grain yield cycle^{-1} after conducting 15 cycles of full-sib recurrent selection in one lowland tropical maize population, Tuxpeno Crema1.

3.7.2 ZM521Q and Pop62SRQ

Populations ZM521Q and Pop62SRQ showed similar responses as Sussuma population. Populations ZM521Q and Pop62SRQ showed highly significant variations among progenies. Downy mildew (DM) resistance rating was significantly reduced from 3.0 to 2.1 after two cycles of recurrent selection, while in Pop62SRQ the DM infection rate was reduced from 4.40 to 3.30. In both populations increases in genetic variances and heritability estimates were observed for DM from C1 to C2. These findings are in conformity with those reported by Ajala (1992). The reduction in disease severity per cycle was 3.5 % in ZM521Q, and 3.75 %, in Pop62SRQ after two cycles. De Leon et al. (1993) also observed reduction in the severity of downy mildew infection in advanced cycles of recurrent selection in maize populations.

Highly significant correlations coefficients between grain yield and grain moisture; grain yield and ASI were observed in Pop62SRQ, while in ZM521Q highly significant correlations were detected among DM and plant height. These findings are in conformity with those reported by Ceballos et al. (1991) who observed similar association between disease resistance and higher grain yield. The grain yield increase after two cycles of recurrent selection was from 3.05 to 3.30 t ha^{-1} for ZM521Q, and from 1.65 to 2.0 t ha^{-1}. The increase in yield cycle^{-1} was 150 kg ha^{-1} in ZM521Q and 180 kg ha^{-1} in Pop62SRQ. Ceballos et al. (1991) reported 19 % gain cycle^{-1} in early and 7 % gain cycle^{-1} under intermediate disease pressure trials for grain yield in maize populations.

For silking and pollen shedding in Pop62SRQ the days were reduced from 3.7 to 2.5, while in ZM521Q days were reduced from 3.5 to 2.1. Johnson et al. (1986) reported early flowering with a 4.4% increase in grain yield cycle^{-1} after conducting 15 cycles of full-sib recurrent selection in one lowland tropical maize population, Tuxpeno Crema1.

3.8 Conclusions

Two cycles of S1 recurrent selection significantly improved DM resistance in the three QPM populations although the basic levels differed.

There was concurrent improvement in grain yield performance, ASI, grain texture, grain moisture, ears per plant and other desirable characteristics.

Genetic variances and heritability estimates for DM resistance and other important characteristics generally increased or remained unchanged which was important for future continued selection within these populations.

The objective of the Mozambican maize programme is to improve the nutritionally enhanced populations for DM resistance and other desirable characteristics. The germplasm generated so far in this work lays a firm foundation to achieve this objective.

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Appendices

Appendix 3.1 Means of DM, grain yield and secondary traits of Full-Sib families of Sussuma population in cycle two

Entry Sussuma C 2	Downy Midew	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
	(1-5)	t ha^{-1}	Rank	D	Cm	#	%
		Bottom Ten					
15	2.3	1.70	30	3.4	130.4	1.11	14.3
6	3.4	2.70	29	2.4	130.1	1.01	14.0
9	1.5	2.83	28	3.3	125.2	1.07	14.3
14	2.3	3.03	27	4.3	132.0	1.05	16.2
27	3.8	3.13	26	2.7	129.7	1.03	13.8
26	3.1	3.15	25	2.9	156.6	1.02	17.1
8	1.1	3.16	24	2.6	130.3	1.00	14.0
22	2.6	3.20	23	2.9	119.7	1.01	13.6
22	1.8	3.20	23	2.9	119.7	1.01	13.6
2	3.2	3.27	22	2.6	147.6	1.01	15.0
		Top Ten					
17	2.8	5.07	1	2.1	174.7	1.06	15.4
4	1.9	4.78	2	3.9	155.5	1.14	14.0
12	2.1	4.75	3	4.2	148.8	0.96	14.0
19	2.0	4.58	4	2.6	151.1	0.97	14.6
3	1.8	4.57	5	2.9	172.8	1.12	13.7
13	2.1	4.33	6	2.0	155.6	1.10	14.6
25	3.8	4.30	7	3.7	145.8	1.05	13.6
30	1.5	4.28	8	2.9	150.0	1.04	15.3
29	3.0	4.02	9	3.4	141.2	1.07	14.7
28	1.7	3.80	10	2.7	159.3	0.86	14.7
Mean	3.9	3.67		2.2	145.1	1.15	14.9
LSD (0.05)	3.3	1.08		1.3		0.15	1.4
Mse	4.3	0.58		0.7	195.3	0.01	0.8
CV	3.6	20.75		27.2	9.6	8.94	6
P	3.2	0		0.045		0.17	0
P	2.9	***		*	Ns	Ns	***
Min	2.5	1.7	1	2	119.7	0.86	13.4
Max	2.9	5.07	30	4.3	174.7	1.14	17.1
StandardError	0.6	0.53		0.7	9.6	0.07	0.7

Appendix 3.2 Means of DM, grain yield and secondary traits of full-sib families of ZM521Q population in cycle two

Entry	Downy Mildew	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
ZM 521 Q C 2							
	(1-5)	t ha^{-1}	Rank	d	Cm	#	%
		Bottom ten					
12	4.1	1.55	142	1.9	163.0	0.48	23.2
30	3.8	1.58	141	2.0	150.2	0.93	21.7
38	3.6	1.13	145	2.8	127.4	0.54	22.7
44	3.5	0.80	146	1.5	154.5	1.45	23.1
49	3.4	1.72	139	2.6	165.4	0.79	25.4
83	3.4	1.25	144	2.1	160.8	0.86	18.7
102	3.3	1.79	138	3.0	159.5	1.16	17.6
121	3.2	1.66	140	2.5	153.0	0.86	26.7
122	3.1	1.52	143	2.7	133.5	0.81	21.1
2	3.0	1.81	136	2.5	186.3	0.73	20.6
		Top ten					
32	2.3	5.05	5	3.1	177.3	1.07	20.9
123	2.4	5.16	4	2.5	174.6	1.17	22.8
133	2.4	5.34	3	2.4	156.5	0.88	23.7
134	2.5	4.98	7	3.5	161.5	0.98	27.1
135	2.5	5.03	6	2.5	199.6	0.91	25.6
136	2.6	4.90	10	2.0	182.3	0.91	23.0
138	2.7	4.95	8	2.0	142.2	0.95	24.7
142	2.8	5.37	2	3.0	141.3	0.93	26.9
145	2.9	4.91	9	1.3	186.6	0.99	21.6
148	2.9	6.05	1	2.0	120.2	0.94	19.6
Mean	2.30	3.30	73	2.1	153.9	1.06	14.90
LSD (0.05)	0.7	1.80	42	2.0	44.7	0.44	5.9
Mse	0.2	0.83		1.1	557.2	0.05	8.6
CV	14.6	27.63		42.9	14.4	23.08	12.9
P	0.005	0.000		0.883	0.013	0.303	0.015
P	**	***		ns	*	Ns	*
Min	2.3	0.80	1	-2.0	120.2	0.48	15.0
Max	4.1	6.05	146	4.0	210.5	1.45	28.6
StandardError	0.3	0.91		1.0	22.6	0.22	3.0

Appendix 3.3 Means of DM, grain yield and secondary traits of full-sib families of Pop62SRQ population in cycle two

Entry	Downy Mildew	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
Pop 62SRC 2							
	(1-5)	t ha^{-1}	Rank	D	Cm	#	%
		Bottom Ten					
15	2.7	1.10	30	3.7	154.0	1.30	25.8
21	3.2	1.31	29	2.2	142.9	1.06	20.7
30	3.5	1.34	28	3.3	141.9	0.99	24.9
17	4.0	1.45	27	1.4	142.5	1.19	25.2
6	4.2	1.57	26	3.4	145.9	1.15	20.4
2	2.9	1.75	25	3.0	146.5	1.14	23.1
10	3.3	1.76	24	2.0	143.6	1.31	23.3
24	4.6	1.76	23	2.4	159.4	0.98	27.4
9	3.2	1.78	22	2.0	156.5	1.37	22.6
12	3.7	1.91	21	2.6	160.7	1.10	26.2
		Top Ten					
22	0.7	2.77	1	2.3	164.1	1.23	21.3
29	1.7	2.72	2	1.7	161.7	1.44	20.4
14	1.9	2.70	3	3.3	151.3	1.07	27.5
18	1.6	2.49	4	2.4	162.6	0.96	26.3
16	2.2	2.40	5	2.3	148.6	1.15	28.1
11	1.8	2.33	6	2.3	126.4	1.03	25.8
8	2.3	2.28	7	2.0	145.2	1.10	23.1
7	2.1	2.28	8	2.3	153.9	0.93	20.3
27	1.8	2.28	9	2.7	143.1	1.29	23.2
23	1.9	2.20	10	2.3	156.9	1.21	25.6
Mean	2.95	2.00		2.5	150.0	1.16	14.87
LSD (0.05)	0.6	0.67	9	1.6	22.0	0.29	
MSe	0.1	0.25		0.9	273.6	0.03	5.7
CV	13.5	25.05		38.4	11.0	15.64	9.9
P	0.000	0.000		0.329	0.067	0.084	
P	***	***		Ns	+	+	Ns
Min	0.7	1.10	1	1.4	126.4	0.93	20.3
Max	4.6	2.77	30	3.7	164.1	1.44	28.1
StandardError	0.3	0.33		0.8	10.7	0.14	2.0

Appendix 3.4 Means of DM, grain yield and secondary traits of Full-Sib families of Sussuma population in cycle one

Entry	Downy Mildew	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
SUSSUMA C1	(1-5)	t ha^{-1}	Rank	d	Cm	#	%
		Bottom ten					
12	4.8	1.97	18	2.6	150.7	1.07	18.5
30	4..6	2.37	25	3.2	158.3	1.08	18.3
38	4.5	2.46	22	3.6	156.4	1.00	18.3
44	4.0	2.66	13	2.0	155.5	1.01	17.9
49	4.4	2.73	19	2.2	157.3	1.00	17.8
83	4.2	2.74	10	2.3	158.8	1.19	17.6
102	4.3	2.76	27	2.7	153.9	1.07	17.3
121	4.5	2.77	21	2.4	161.4	1.00	17.1
122	4.1	3.05	11	3.6	156.5	1.00	17.0
2	4.3	3.07	24	3.0	161.5	1.05	16.9
		Top Ten					
32	3.8	3.35	15	1.9	161.5	1.09	17.5
123	3.6	3.37	14	3.0	153.5	1.00	17.6
133	3.7	3.48	7	2.2	155.1	1.10	17.8
134	3.7	3.49	26	2.8	153.0	1.08	17.6
135	3.8	3.52	29	1.2	148.2	1.00	17.5
136	3.6	3.60	17	1.5	156.3	1.11	16.9
138	3.8	3.62	28	3.3	151.3	1.00	16.8
142	3.7	3.66	23	2.8	160.5	1.04	17.0
145	3.6	3.77	8	3.4	162.9	1.03	16.9
148	3.7	4.17	30	1.9	156.9	1.01	17.2
Mean	4.25	3.49		2.6	145.6	1.11	17.40
LSD (0.05)	3.3	1.00		2.9	16.0	0.14	27.2
Mse	4.3	0.45		3.8	150.4	1.00	24.3
CV	22.5	21.27	6	3.2	7.9	1.05	24.7
P	3.2	0.005	12	2.1	0.449	1.22	29.2
P	2.9	**	2	3.5	ns	1.01	26.7
Min	3.6	1.97	4	2.0	144.0		24.1
Max	4.9	4.17	3	1.9	164.1	1.05	
StandardError		3.14			155.6	0.14	24.9

Appendix 3.5 Means of DM, grain yield and secondary traits of Full-Sib families of ZM521Q population in cycle one

Entry	Downy Mildew	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
ZM521Q C1							
	(1-5)	t ha^{-1}	Rank	d	Cm	#	%
		Botton ten					
12	3.8	0.97	30	2.6	114141	1.01	16.1
28	3.5	1.01	29	2.1	145.9	1.12	17.5
38	3.5	1.01	28	1.7	145.9	1.03	17.8
39	3.4	1.12	27	3.0	140.2	0.97	17.8
42	3.3	1.16	26	2.3	153.0	1.01	18.6
57	3.3	1.23	25	2.4	158.8	1.01	16.5
88	2.9	1.29	24	1.8	147.8	0.97	17.1
123	2.8	1.39	23	2.0	160.2	1.05	18.7
135	2.7	1.42	22	1.5	152.8	1.00	18.6
144	2.6	1.58	21	2.7	160.0	1.03	18.9
32	2.8	2.47	1	1.7	147.5	0.94	18.6
96	2.9	2.46	2	2.3	160.8	1.13	16.8
113	2.5	2.19	3	1.8	154.5	1.08	16.3
124	2.3	2.15	4	1.6	155.0	1.10	19.1
129	2.5	2.15	5	2.6	166.6	1.03	18.5
135	2.4	2.08	6	2.7	152.9	0.98	21.4
138	2,5	2.02	7	2.4	163.7	0.98	17.2
141	2.6	2.01	8	2.1	164.3	1.08	16.9
143	2.3	1.89	9	2.4	166.7	1.30	16.5
145	2.7	1.87	10	2.2	148.4	1.17	17.0
Mean	2.75	3.15	37	3.1	146..7	0.93	17.30
LSD (0.05)	3.0	0.78	38	2.7	2.3	1.03	15.7
Mse	3.1	0.25	42	2.9	2.0	1.03	16.5
CV	2.8	28.82	41	2.3	60.2	1.11	16.5
P	2.9	0.003	30	2.5	0.716	0.97	19.0
P	2.7	**	22	**	ns	0.99	18.6
Min	2.3	0.97	31	0.97	0.7	0.99	20.0
Max	3.0	2.47	36	2.47	3.8	0.96	24.2
StandardError	3.0	1.73	14	1.73	2.4	1.20	17.0

Appendix 3.6 Means of DM, grain yield and secondary traits of Full-Sib families of Pop62SRQ population in cycle one

Entry	Downy Mildew	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
Pop62SRQC1	(1-5)	t ha^{-1}	Rank	d	Cm	#	%
		Botton ten					
15	4.7	1.10	30	3.7	154.5	1.00	17.1
21	4.6	1.31	29	2.2	160.8	1.18	16.0
30	4.3	1.34	28	3.3	166.0	0.87	17.4
17	4.3	1.45	27	1.4	147.5	1.02	16.9
6	4.1	1.57	26	3.4	152.9	1.00	18.1
2	4.0	1.75	25	3.0	154.5	0.97	16.8
10	4.0	1.76	24	2.0	151.9	1.31	14.4
24	4.0	1.76	23	2.4	156.1	1.12	18.1
9	3.8	1.78	22	2.0	152.8	1.14	16.2
12	3.6	1.91	21	2.6	149.1	1.22	15.0
22	2.5	2.77	1	2.3	159.7	1.20	15.5
29	2.6	2.72	2	1.7	155.0	0.97	15.8
14	2.8	2.70	3	3.3	136.6	0.93	14.8
18	2.9	2.49	4	2.4	164.3	1.31	15.1
16	3.0	2.40	5	2.3	157.6	1.21	19.6
11	3.0	2.33	6	2.3	161.1	0.93	17.4
8	3.1	2.28	7	2.0	149.8	1.08	15.1
7	3.2	2.28	8	2.3	153.0	1.12	14.0
27	3.3	2.28	9	2.7	148.4	0.95	15.0
23	3.5	2.20	10	2.3	163.7	1.38	15.4
Mean	3.50	1.89	16	3.4	150.9	1.08	15.70
LSD (0.05)	1.3	0.67	9	2.3	13.1	0.42	4.5
Mse	0.6	0.25		2.0	68.6	0.06	8.2
CV	33.5	25.05		60.2	5.3	22.86	10.6
P	0.118	0.000		0.716	0.000	0.273	0.153
P	ns	***		ns	***	ns	Ns
Min	1.1	1.10	1	0.7	136.6	0.87	24.0
Max	3.5	2.77	30	3.8	166.7	1.49	29.8
StandardError		2.00		2.4	2.5		

Appendix 3.7 Correlations coefficients among measured parameters of Sussuma population in C 1

	ASI	Downy Mildew	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Downy Mildew	-0.1200						
Ear per Plant	-0.0700	-0.0220					
Grain Moisture	0.0380	-0.1280	-0.4330				
Grain Texture	0.0430	0.02860	-0.2350	0.2800*			
Grain Yield	0.0690	-0.1454	0.1200*	-0.4200	0.0540		
Plant Height	0.0750	-0.1360	0.0460	0.3500	0.0190	0.0440	

Appendix 3.8 Correlations coefficients among measured parameters of ZM521Q population in C 1

	ASI	Downy Mildew	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Downy Mildew	0.247*						
Ear per Plant	-0.08	-0.436					
Grain Moisture	0.031	-0.159	0.122*				
Grain Texture	0.056	0.067	-0.213	-0.1300			
Grain Yield	-0.39	-0.853	0.187*	0.2380*	-0.167		
Plant Height	0.058	0.0210	0.067	-0.2510	-0.159	0.0198	

Appendix 3.9 Correlations coefficients among measured parameters of Pop62SR1Q population in C 1

	ASI	Downy Mildew	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Downy Mildew	-0.0285						
Ear per Plant	-0.060	-0.234					
Grain Moisture	0.0186	0.0154	-0.0100				
Grain Texture	0.026	-0.340	-0.0230	0.1320*			
Grain Yield	0.0102	0.091	0.1540	0.02810	0.3240*		
Plant Height	0.003	-0.136	0.0650	0.0520	0.1000	-0.0230	

Chapter 4: Response to selection for maize streak resistance, grain yield, and secondary traits in three quality protein maize populations in Zimbabwe

Abstract

Maize Streak Virus disease (MSVD) is a major problem in quality protein maize (QPM) in Mozambique. Recurrent selection was applied to improve MSVD resistance in three QPM populations, Sussuma, ZM521Q and Pop62SRQ at CIMMYT-Harare Research Station in Zimbabwe, during 2003-2006. Maize streak virus disease incidence and severity were rated at four weeks after emergence and at flowering stage based on visual assessment of the whole plot. Two selection cycles were formed and evaluated. Selection intensity was 50%, and 25% in cycle 1 (C1) and cycle 2 (C2), respectively. The C1 and C2 were evaluated in a randomized complete block design with three replications in 2005/6 season. Results showed significant improvement in MSVD resistance from C1 to C2, with scores of 3.4-2.9 in Sussuma, 2.7-2.3 in ZM521Q and 3.47-3.0 in Pop62SRQ, respectively. Results also indicated increase in genetic variances (σ^2_G) for MSVD from C1 to C2, from 0.314 in C1 to 0.559 in C2 in Sussuma; from 0.519 in C1 to 0.640 in C2 in ZM521Q, and from 0.135 in C1 to 0.781 in C2 in Pop62SRQ. Broad sense heritability estimates (H^2) ranged from moderate to high and increased from C1 to C2 in all populations. The H^2 estimates were 0.83-0.94 in Sussuma; 0.70-0.88 in ZM521Q and 0.65-0.87 in Pop62SRQ. This was associated with an increase in yield of about 4.57% in Sussuma, 4.62% in ZM521Q and 4.37%) in Pop62SRQ. There was also an improvement in flintiness of the grain with texture scores of 2.7-1.5 in Sussuma, 2.9-1.9 in ZM521Q and 2.5-1.7 in Pop62SRQ. There were no significant changes in anthesis-silking interval, plant height and number of ears plant^{-1}. This study showed that S1 recurrent selection was effective in improving QPM populations for MSVD resistance, increasing genetic variances and broad sense heritability estimates without compromising grain yield, texture, and other important characteristics.

4.1 Introduction

Maize streak virus disease (MSVD) is one of the most important diseases affecting quality protein maize (QPM) in Mozambique. It is the second most important disease in cereal crops in Africa (Engelbrecht, 1975) and causes severe damage to maize in the mid-altitude and highland areas in Mozambique (DINA, 1995). Breeding for resistance to MSVD in maize is therefore important in northern and central Mozambique (DINA, 1995), where it is most prevalent. The disease is also important in other countries in sub-Saharan Africa and causes yield losses reaching 100% (Mzira, 1984; Bjarnason, 1986; Bosque-Perez, 2000). van Rensburg (1991) reported that yield reduction due to MSVD was higher when young plants are infected.

Different methods can be used to control the disease. Insecticides can be used to control leafhoppers which transmit the disease, but the chemicals are not always available in Africa due to limited resources. Outbreaks of MSVD is associated with the behaviour of the Cicadulina vector species in Southern African (Pham 1992), while it has been associated with drought, irregular and early rains in West Africa (Bosque-Pérez, 2000). High MSVD epidemics have also been associated with increasing intensity of maize production (Bosque-Pérez, 2000). Due to limitation of resources it sounds most economical to control MSVD by breeding for resistance in QPM varieties, since the crop is grown by subsistence farmers in Mozambique (Barrow, 1992; Bosque-Pérez, 1998; DeVries and Toenniessen, 2001).

There are few reports of recurrent selection for MSVD in QPM germplasm. However, resistance to MSVD can be improved by recurrent selection (RS) methods which have resulted in significant gains for yield and other traits in maize populations (Efron *et al.,* 1989), without compromising the genetic variation required for future improvement (Moll and Smith, 1981). Quality protein maize (QPM) varieties have been introduced in Mozambique but are very susceptible to MSVD. There is need to breed for durable resistance to MSVD in these populations.

4.2 Objective and research hypothesis of the study

The specific objectives of the study were:

a) To study the response to recurrent selection for MSVD resistance using full-sib and selfed progenies (S1) of three QPM populations.
b) To determine correlated responses of the three populations for yield, ASI, grain texture, grain moisture and other important characteristics after two cycles of recurrent selection.

The hypothesis tested was:

> Resistance to MSVD in QPM populations can be improved by using recurrent selection, and genetic variability of important traits remains high after cycles of recurrent selection.

4.3 Material and Methods

4.3.1 Location of the experiment

The experiments were conducted at International Maize and Wheat Improvement Centre (CIMMYT) in Harare, Zimbabwe, test plots located on the University of Zimbabwe Farm, about 13 km North of Harare.

4.3.2 Germplasm

The three quality protein maize populations Sussuma (S_2 generation), ZM521Q and Pop62SRQ (Table 3.1) were used in this study. They are high grain yielding and highly susceptible to maize streak virus (MSV). These populations were designated Sussuma, ZM521Q and Pop62SRQ, respectively, in this study. All three populations were originally developed at the International Maize and Wheat Improvement Centre (CIMMYT) in Harare. All the populations were adapted to tropical environments in East and Southern Africa. They were improved for QPM at Instituto de Investigação Agrária de Moçambique (IIAM), in Mozambique.

4.3.3. Establishment of screening nurseries, artificial inoculation for Maize Streak Virus Disease and formation of the cycles

At CIMMYT-Harare Research Station, in November 2003, November 2004, and November 2005 MSVD nurseries were established every season to screen the progenies. Selected ears from selfed seeds of each population were planted for screening for MSVD resistance. The population size of plants was established and was equal number of that used for screening to DM, around 5000 plants for each population.The progenies of the selected plants were planted in an ear-to-row method in which progenies of each plant were planted in one row only. Screening nurseries were laid out in three blocks for each population on one row plots of 5 m long. The blocks were made up of 275 rows. Virus-free leafhoppers were allowed to acquire the virus on stocks of infected MSVD susceptible maize plants for 2 d. Maize streak virus inoculum source was a composite of isolates obtained from infected maize sampled throughout Zimbabwe. Three to five leafhoppers were dropped into the plant whorl at the V3 stage (Efron *et al.,* 1989), about 3 weeks after planting. When streak symptoms appeared, plants were thinned to one plant per hill. All plants per row were individually rated two times at biweekly intervals beginning 2 weeks after infestation. The numbers of diseased and healthy plants were recorded and percentage of plants with systemic MSVD was calculated. Agronomic practices included fertilizer application at planting with NPK (120:60:60), herbicide application with glyphosate before planting followed by weeding and top dressing with urea (46% of N) at 150 kg ha-1 during the vegetative stage. Stalk borer control was done by spraying with insecticide Decis (pyrethroid) at regular intervals to reduce crop loss.

During flowering time, all selected plants had their ear shoots covered. The ears of the selected progenies were self-pollinated to provide S1 seed, and other ears of other randomly selected plants were also cross-pollinated using pollen from the selfed plants to form FS seed. Selfed S1 progenies from the best FS were used to advance to the next generation as described in section 3.3.3 of this thesis. To keep the protein quality, the best S1 progenies were also again selected in laboratory, using ELISA test. Although FS and S1 progenies from an equal number of plants in each of the three populations were sought, the proportion of plants obtained was 50% (around 2658 plants), 25% (around 665 plants) and 25% (around 166 plants) for the populations

Sussuma, ZM521Q and Pop62SRQ, respectively. These were plants with adequate FS seed with resistance to MSVD used to form the base population referred to herein as a cycle 1.

In November 2005, a trial was planted for evaluation of the two cycles of each population in the season 05/06. A lattice design with nine blocks and three replications was used. Selected high yielding progenies of full-sib families were randomly assigned to each block planting density was 53,333 plants ha^{-1}. Plot size was one row of 5m length with hills spaced 80cm between rows and 25cm within rows. The hills were over planted and thinned to one plant per hill. Additional variables, such as days to 50% pollen shedding, plant height and ear height were recorded for each plot. Plots were hand harvested and shelled grain weight recorded. Grain moisture at harvest was determined and plot yields adjusted to 13.5% moisture level converted to yield. Data were analyzed on a per block basis and individual analyses of variance pooled over blocks for a trial. Selection was based on FS performance within blocks. Only those FS that yielded above their respective block means and were equal to or below the average grain moisture at harvest and with quality protein content were selected. Selfed (S1) progenies of superior FS families were advanced to the next generation.

4.3.4 Selection method

The selection method used was the same for DM selection process. It was based on single plant selection. This was done just before flowering stage (because of cross and self pollination). Best rows were selected and in each row the best five plants were selected. The best plants were those that showed resistance to maize streak virus. The selected progenies were self-pollinated to generate selfed progenies, and crossed to form full-sib progenies formation using the same selected plants crossed to randomly selected plants from the population. Although the resistance to maize streak virus disease was the principal criterion of the progenies selection, grain yield, ASI, grain moisture and grain texture were also considered during selection. The full-sib families were also selected at harvest for yield and other environmental responses. Selection of plants for advancement to the next generation was conducted in stages: First, plants with zero (0) severities were not selected and only those that showed symptoms with severity scores of 2 and 3 were selected. About 10% (510/5,316) of the plants with scores of 2 to 3 (rating scale 0-5) were selected, equivalent to a selection intensity of

1.74 (Falconer, 1981). Second, the self-pollinated progenies of each population were again selected during harvest time and taken to the laboratory for the tryptophan analysis. Selected progenies with resistance to MSVD were also selected on the basis of grain texture. Selection for grain texture was based on levels of flintiness of the grain using a scale of 1 (flint) to 5 (completely dent). Only plants showing grain texture scores between 1.9 and 2.8 were selected and advanced to the next generation of selection.

4.3.5 Experimental layout of yield trial

For yield evaluation and other agronomic characteristics full-sib families formed through cross pollination of the selected progenies were used. Cycles C1 and C2 were evaluated at CIMMYT-Harare Research Station (planted in November 2005 -season 05/06). Trials were laid out as a randomized complete block design with three replications. Each entry was planted in two rows: 5m long with 80cm between rows and 25cm between hills within rows. All entries were over planted and later thinned to one plant per station to give 53 333 plants ha^{-1}.

4.3.7 Data collection

Disease development was monitored throughout the growth cycle, and the data recorded. Maize streak virus disease incidence and severity were scored twice; at four weeks after emergence and at flowering (critical stages for MSVD effect on yield) based on visual assessment of the whole plot. Disease incidence was scored by recording the number of plants in each population showing MSVD symptoms and expressing that as a percentage of the total plant population. Disease severity was scored on the whole plant as a proportion of total leaf area diseased using a scale of 0 to 5. Details of the rating scale were as follow: 0= no visible disease symptoms, 1 = very few streaks on some leaves, 2 = light streak symptoms on most leaves, 3 = moderate streak symptoms on most leaves, 4 = abundant symptoms on all leaves (≥60%) leaf area affected, 5 = severe symptoms on all leaves (≥80%) of leaves affected with no yield (Bosque-Perez, 1998). The rating scale was used to evaluate the disease at CIMMYT-Harare Research Station during 2004/05 to 2005/06 seasons. The number of days to mid-silking (DMS) and anthesis (DMP) were estimated as number of days from planting to 50% plants with silks emerged and tassels shedding pollen, respectively. Plant and ear height were measured as the distance from the base of the plant to the height of the first tassel branch and the height of the node bearing the uppermost ear, respectively. Grain weight and moisture content per plot were obtained at harvest and values obtained were used to estimate grain yield (t ha^{-1}) adjusted to 13.5% moisture content.

4.4. Data analysis

Quantitative data generated from 2006 infected trials were each subjected to a separate ANOVA using REML tool in Field book. Data were analyzed using the following model: $Y_{ijk} = \mu + \beta_i + g_j + e_{ijk}$, where μ is the general mean, β_i the effect of $_i$th block, g_j the effect of $_j$th genotype and e_{ij} the error associated with particular measurement.

Table 4.1 Skeleton analysis of variance when g genotypes are raised in RCBD with r replications

Source	Df	S.S	MS	Expected Mean square
Replications	(r-1)			
Among genotypes	(g-1)	$r\Sigma (yi-y.)^2$	M1	$\sigma^2e + \sigma^2g$
Within genotypes	(r-1)(g-1)	$\Sigma(yij-yi.)^2$	M2	σ^2e
Total	(rg-1)			

Response to selection was determined using the following formula: $R = iH^2\sigma^2_P$ (Falconer, 1961), where i = selection intensity of 50 and 25%; H^2 = broad sense heritability; and σ^2_P = phenotypic variance. Broad-sense heritability estimates were calculated using the following formula: $H^2 = \sigma^2g/\sigma^2P \times 100$ (Falconer, 1961). Genetic covariance between FS was estimated as: $Covg\ (FS) = t\ (1/2VA + 1/4VD + VEc)$ (Lonnquist *et al., 1967)*; Genetic coefficient of variation for DM and yield were obtained using the following formula: $GCV = \sqrt{\sigma}/X \times 100$ (Eberhart *et al.,1973)*; and the correlations for the FS were obtained using the following formula $t = (1/2VA + 1/4VD + VEc)/VP$ (Falconer, 1961).

4.5 Results

Variances associated with differences among FS families in three QPM populations were highly significant (Tables 4.3, 4.4, and 4.5). Responses to selection per cycle^{-1} in C1 and C2 for all three QPM populations are presented in Table 4.2.

4.5.1 Maize Streak Virus

Maize streak virus disease rating decreased by 0.35 in Sussuma, 0.15 in ZM521Q, and 0.25 in Pop62SRQ per cycle (Table 4.2). The gain cycle^{-1} was reduced by 4.26% for Sussuma, 3.88% for ZM521Q, and 4.32% for Pop62SRQ (Table 4.2). Mean square for maize streak virus disease scores were highly significant ($P \leq 0.01$) among full-sib families in all QPM populations (Appendices 4.1, 4.2, and 4.3). Genetic variances for MSVD increased from 0.314 in C1 to 0.559 in C2 in Sussuma, from 0.519 in C1 to 0.640 in C2 in ZM521Q, and from 0.135 in C1 to 0.781 in C2 in Pop62SRQ (Tables 4.3, 4.4, and 4.5).

Table 4.2 Means and response to selection for MSVD rating, yield and other agronomic traits of different cycles of selection in three QPM population

	SUSSUMA					ZM 521Q					Pop 62 SR Q				
Trait	C0	C1	C2	+Resp. cycle^{-1}	LSD	C0	C1	C2	+Resp. cycle^{-1}	LSD	C0	C1	C2	+Resp Cycle^{-1}	LSD
MSV rating (1-5)	3.4	3.25	2.9	-0.35	0.8	2.70	2.45	2.3	-0.15	1.3	3.47	3.25	3.0	-0.25	1.0
Yield (t ha^{-1})	3.18	3.38	3.58	0.20	0.9	4.30	4.40	4.70	0..30	1.65	2.75	2.95	3.15	0.20	1.52
Plant height (cm)	187.6	185.7	183.8	-1.9	13.8	185.8	184.9	183.8	-1.1	12.3	189.2	187.6	186.3	-1.3	22.0
Ear height (cm)	83.3	82.7	81.1	-1.6	0.34	87.6	85.8	84.8	-1.0	0.27	93.6	92.8	92.4	-0.4	0.36
Days to 50% silking	88.7	87.7	85.6	-2.1	0.17	87.5	86.3	84.7	-1.6	0.14	89.2	88.0	86.3	-1.7	0.19
Days to 50% pollenshed	85.3	84.5	82.5	-2.0	0.13	83.9	82.9	81.4	-1.5	0.11	86.6	85.6	84.1	-1.5	0.12
Anth-Silk Interval (ASI)	4.10	3.30	2.50	-0.8	3.1	4.6	4.10	3.20	-0.9	2.0	2.60	2.40	2.20	-0.20	2.0
Ear per plant	0.9	1.07	1.20	0.13	2.3	0.94	1.07	1.16	0.12	2.1	0.89	1.06	1.20	0.14	0.22
Grain moisture (%)	12.90	12.60	12.22	-0.38	1.6	14.90	14.40	13.80	-0.60	1.0	17.90	17.50	17.00	-0.5	4.3
Grain Texture (1-5)	2.7	2.1	1.5	-0.6	0.8	2.9	2.4	1.9	-0.5	0.9	2.5	2.0	1.6	-0.4	0.6

+ Response to selection cycle^{-1} = C2-C1

Comparatively, higher heritability estimates for MSVD were observed in C2 in Sussuma (0.94) than in ZM521Q (0.88) and Pop62SRQ (0.87) (Tables 4.3, 4.4 and 4.5). Genetic coefficients of variation (GCV) for MSVD in Sussuma changed very little from C1 to C2, compared with that in Pop62SRQ (Tables 4.6).

Table 4.3 Estimated variance components of the Sussuma related to the different agronomic traits in cycles C1 and C2

		C1			C2	
Traits	σ^2_g	Se	H^2	σ^2_g	Se	H^2
Maize Streak Virus	0.314	0.139	0.83	0.559	0.164	0.94
Yield	0.209	0.132	0.64	0.347	0.132	0.81
Plant height	14.22	10.80	0.36	10.85	6.920	0.86
Ant-silking Interv	0.047	0.037	0.63	0.135	0.053	0.79
Grain moisture	0.038	0.056	0.71	1.043	0.378	0.82

Using a selection intensity of 50% in C1 and 25% in C2 selection intensities (from the Table of Falconer, 1981) respectively, the response to selection was 0.41 in C1 and 0.92 in C2 for Sussuma, 0.53 in C1 and 0.86 in C2 for ZM521Q, and 0.24 in C1 and 1.0 in C2 for Pop62SRQ (Table 4.8).

Table 4.4 Estimated variance components of the ZM521Q related to the different agronomic traits in cycles C1 and C2

			ZM 521 Q			
		C1			C2	
Traits	σ^2_g	Se	H^2	σ^2_g	Se	H^2
Maize Streak Virus	0.640	0.150	0.70	0.519	0.171	0.88
Yield	0.116	0.066	0.64	0.172	0.104	0.70
Plant height	4.660	4.460	0.26	16.67	9.190	0.77
Ant-silking Interv	0.149	0.096	0.58	0.199	0.060	0.86
Grain moisture	1.426	0.696	0.68	7.201	2.347	0.75

4.5.2 Grain yield

The gain cycle-1 of grain yield of each selection cycle contributed in 150 kg in Sussuma, 180 kg in ZM521Q and 200 kg in Pop62SRQ (Table 4.2). Mean squares for grain yield were highly significant ($P \leq 0.01$) among full-sib families in all populations (Appendices 4.1, 4.2, and 4.3). Similarly the heritability estimates were higher in Sussuma population (0.64 in C1, and 0.81 in C2), followed by ZM521Q (0.64 in C1 and 0.70 in C2), and, and Pop62SRQ (0.51 in C1 and 0.59 in C2) (Table 4.3, 4.4 and 4.5). Genetic variances for grain yield increased from 0.209 in C1 to 0.347 in C2 in Sussuma, from 0.116 in C1 to 0.172 in C2 in ZM521Q; and 0.197 in C1 to 0.728 in C2 in Pop62SRQ (Tables 4.3, 4.4, and 4.5). Genetic coefficients of variation (GCV) for yield in Sussuma and ZM521Q changed very little from C1 to C2, than in Pop 62 SRQ where GCV values on C2 were approximately two times higher compared to the C1 (Tables 4.6). Little increase was observed in genetic covariance (Covg (FS-S1) for yield from C1 to C2 in ZM521Q but higher increase of these variances were achieved from C1 to C2 in Pop 62SRQ (Table 4.6).

Table 4.5 Estimated variance components of the Pop62SRQ related to the different agronomic traits in cycles C1 and C2

		C1			C2	
Traits	$\sigma^2_{g g}$	Se	H^2	σ^2_g	Se	H^2
Maize Streak Virus	0.135	0.042	0.65	0.781	0.840	0.87
Yield	0.197	0.146	0.51	0.728	0.211	0.59
Plant height	19.13	15.73	0.54	28.86	12.53	0.70
Ant-silking Interv	0.239	0.556	0.71	1.894	0.507	0.72
Grain moisture	0.032	0.047	0.52	0.298	0.018	0.87

Table 4.6 Genetic parameter estimates for FS families of the three QPM populations

GCV = Genetic coeficient of variation; Covg = genetic covariance; σ^2G = genetic variance; H^2 = broad-sense heritability

Using a selection intensity of 50% in C1 and 25% in C2 the response to selection was 0.29 in C1 and 0.67 in C2 for Sussuma, 0.22 in C1 and 0.44 in ZM521Q, and 0.24 in C1 and 0.89 in C2 for Pop62SRQ population (Table 4.9).

Table 4.7 Genetic parameter estimates for FS families of the three QPM populations on cycles C1 and C2

				Maize Streak Virus			
	SUSSUMA			ZM 521 Q		Pop 62 SRQ	
	C1	C2		C1	C2	C1	C2
Parameter	FS	FS		FS	FS	FS	FS
GCV	15.66	21.81		15.84	17.03	12.23	28.06
$\sigma 2_{G}$	0.314	0.559		0.519	0.640	0.135	0.781
Covg(FS-S1)	13.12	16.81		18.65	38.52	9.28	29.06
H^2	0.83	0.94		0.70	0.88	0.65	0.87

GCV = Genetic coefient of variation; Covg = genetic covariance; σ^2G = genetic variance; H^2 = broad-sense heritability

			YIELD			
	SUSSUMA		ZM 521 Q		Pop 62 SRQ	
	C1	C2	C1	C2	C1	C2
Parameter	FS	FS	FS	FS	FS	FS
GCV	12.76	17.17	7.49	8.82	14.10	28.43
σ^2_G	0.208	0.347	0.116	0.172	0.197	0.728
Covg(FS-S1)	14.89	15.07	8.37	10.37	16.87	78.14
H^2	0.64	0.81	0.64	0.70	0.51	0.59

4.5.3 Plant height

The gain per cycle^{-1} for plant height was negligible in all the three populations (Table 4.2). Mean squares among full-sib families (Appendices 4.1, 4.2, and 4.3) were significant ($P \leq 0.01$) for plant height in all three QPM populations. Similarly estimates of heritability for plant height were higher and are presented in Table 4.3, 4.4, and 4.5. Heritability estimates were 0.36 in C1 and 0.86 in C2 for Sussuma, 0.54 in C1 and 0.70 in C2 and C2 for Pop62SRQ, and 0.26 in C1 and 0.77 in C2 for ZM521Q. Genetic variances increased from 10.85 in C1 to 14.22 in C2 in Sussuma, from 4.660 in C1 to 16.67 in C2 in ZM521Q, and from 19.13 in C1 to 28.86 in C2 in Pop62SRQ (Tables 4.3, 4.4, and 4.5).

Table 4.8 Response to selection for MSV on three QPM populations in C1 and C2

RS = response to selection; i= selection intensity
H^2 = broad-sense heritability; σ_P = standard error of phenotypic variance

	Sussuma		ZM 521Q		Pop 62 SR	
	C1	C2	C1	C2	C1	C2
i	0.798	1.271	0.798	1.271	0.798	1.271
H^2	0.83	0.94	0.70	0.88	0.65	0.87
σ_P	0.617	0.772	0.956	0.769	0.453	0.950
RS	0.41	0.92	0.53	0.86	0.24	1.0
RS = $ih^2\sigma_P$						

4.5.4 Anthesis-Silking Interval

The ASI was reduced by 0.8 d in Sussuma; 0.9 d in ZM521Q and 0.2 d in Pop62SRQ populations (Table 4.2). Mean squares for ASI (Appendices 4.1, 4.2, and 4.3) were significant ($P \leq 0.01$) among full-sib families in all three QPM populations. Similarly estimates of heritability for ASI were higher and are presented in Table 4.3, 4.4, and 4.5. Heritability estimates were 0.63 in C1 and 0.79 in C2 for Sussuma, 0.58 in C1 and 0.86 in C2 for ZM521Q, and 0.71 in C1 and 0.72 in C2 for Pop62SRQ. Genetic variances showed an increase from C1 to C2 for ASI from 0.047 to 0.135 in Sussuma higher increase from 0.239 to 1.894 in Pop62SRQ and from 0.1490 to 0.1990 in ZM521Q (Tables 4.3, 4.4, and 4.5).

Table 4.9 Response to selection for yield on three QPM populations in C1 and C2

RS = response to selection; i= selection intensity

			Yield			
	Sussuma		ZM 521Q		Pop 62 SR	
	C1	C2	C1	C2	C1	C2
i	0.798	1.271	0.798	1.271	0.798	1.271
H^2	0.64	0.81	0.64	0.70	0.51	0.59
σ_P	0.569	0.654	0.426	0.495	0.581	1.189
RS	0.29	0.67	0.22	0.44	0.24	0.89
RS = $iH^2\sigma_P$						

H2 = broad-sense heritability; σP = standard error of phenotypic variance

4.5.5 Correlations

In Sussuma population high correlations coefficients were observed between grain moisture and MSV. Grain yield also exhibited correlations with grain texture. ASI and MSV were less correlated (Table 4.10).

Table 4.10 Correlations coefficients among measured parameters (below) and probabilities (above) of Sussuma population in C 2

	ASI	Maize Streak Virus	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Maize Streak Virus	-0.2800						
Ear per Plant	-0.0880	0.1210					
Grain Moisture	0.0180	0.3320*	-0.0244				
Grain Texture	0.0550	0.0060	-0.0350	-0.0180			
Grain Yield	0.0690	-0.1590	-0.1200	-0.0420	0.0740		
Plant Height	0.1000	0.0640	0.0460	0.0090	0.0090	0.0350	

In ZM521Q population significant correlation coefficients were observed between grain moisture and ASI and grain texture with ear per plant. Grain yield was also correlated with grain texture (Table 4.11).

Table 4.11 Correlations coefficients among measured parameters (below) and probabilities (above) of ZM521Q population in C 2

	ASI	Maize Streak Virus	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Maize Streak Virus	-0.1231						
Ear per Plant	-0.1640	-0.0420					
Grain Moisture	0.2610*	-0.0180	0.0740				
Grain Texture	-0.1451	0.0350	0.3440*	0.0090			
Grain Yield	-0.1123	0.0180	0.0690	0.0550	0.1000		
Plant Height	0.2020	-0.2440	-0.1211	-0.0350	0.0460	-0.0812	

In Pop62SRQ population Grain yield was highly correlated with ear per plant and grain moisture. Plant height exhibited high correlation with grain yield and grain texture (Table 4.12).

Table 4.12 Correlations coefficients among measured parameters of Pop62SRQ population in C 2

	ASI	Maize Streak Virus	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Maize Streak Virus	0.0155						
Ear per Plant	-0.0880	-0.0521					
Grain Moisture	0.0180	0.0320	-0.2440				
Grain Texture	0.0550	-0.1423	-0.0350	-0.0180			
Grain Yield	0.0690	0.1350	0.3200**	0.4200**	0.0740		
Plant Height	0.1000	-0.3020	0.0460	0.0350	0.3440*	0.3652**	

4.7 Discussion

4.7.1 Sussuma, ZM521Q and Pop62SRQ populations

Conventional breeding methods are among some of the practical tools used by breeders to develop cultivars resistant to MSV disease. In this study recurrent selection method was utilised to select for resistance to MSVD in three QPM populations.

All selected progenies that had low incidence also experienced low disease severity. This observation appeared to suggest preferences by leafhoppers to feed on some plants. Higher MSVD decrease severity was recorded in C1 than in C2 indicating that recurrent selection method was effective in improving resistance to MSVD. These observations conform to findings reported in earlier studies (Dudley, 1984; Lamkey *et al.,* 1993). High heritability estimates for MSVD were shown in all the three populations. This indicates that once MSVD disease occurs it would be easy to score, the symptoms are highly evident and easy to score. These results support earlier reports by Welz et al. (1998); Kyetere et al. (1999), and Pernet et al. (1999). All QPM populations under study had highly significant variations among progenies. In the current study, two cycles of recurrent selection for MSVD resistance significantly reduced the infection in Sussuma, ZM521Q and in Pop62SRQ. It was concluded that all QPM populations were responsive to selection for MSVD resistance. Analysis of variance of full-sib progenies indicated the presence of highly significant ($P \leq 0.01$) genetic variation in all populations for days to 50% tasseling, silking and pollen shedding.

In Sussuma population analyses of variance of FS indicated highly significant variations among progenies which could be useful for effective selection against MSVD resistance. After two cycles of recurrent selection for MSVD resistance higher decrease in disease severity was recorded indicating that recurrent selection method was effective in improving resistance to MSVD, which support earlier fingings (Welz et al., 1998; Kyetere et al., 1999; Pernet et al., 1999). The decrease of MSVD severity from cycle 1 to cycle 2 in Sussuma population was presented by reduction the infection scores from 3.4 to 2.9 (1.0 to 5.0 scales).

Genetic variance and heritability estimates for MSVD presented an increase from C1 to C2. This was probably due to the large number of S1 progenies advanced to the next cycle. Denic et al. (1997) observed that MSVD was highly heritable and not very complex to score and concluded that screening of advanced lines should be sufficient to identify MSVD. High heritability estimates for MSVD indicates that once MSVD disease occurs it would be easy to score, the symptoms are highly evident and easy to score. These results support earlier reports by Welz et al. (1998); Kyetere et al. (1999), and Pernet et al. (1999). Mean square values for grain yield in MSVD were highly significant ($P \leq 0.01$) for cycles and high correlation was observed between MSVD and grain moisture. It could be argued that improvement in grain yield was related with increased resistance to MSVD. Heritability estimates for grain yield were high indicating that an improvement would be achieved from field selection for grain yield. These results were comparable to those of Denic et al. (2001), who reported very close correspondence of expected and observed responses (365 vs. 350 kg ha-1) after two cycles of S1 recurrent selection in a high yielding maize variety.

Recurrent selection significantly ($P \leq 0.01$) increased grain yield in Sussuma from 3.38 to 3.58 tha^{-1}. This response of Sussuma population could be a possible manifestation of its increased resistance to MSVD as observed in the present study. Grain yield increased by 200 kg ha^{-1} per cycle in Sussuma. Analysis of variance of full-sib progenies indicated the presence of highly significant ($P \leq 0.01$) genetic variation in Sussuma for days to tasseling, silking and pollen shedding. These results suggested that despite high genetic variability among S1 lines, they were indeed highly consistent in performance over the two cycles of S1 line recurrent selection. These results are in agreement with those of Kyetere et al. (199), who reported significant differences for maturity in four tropical maize populations implementing S1-S2 line recurrent selection for MSVD resistance. Pernet et al. (1999) also observed significant variations for mid-silking and mid-pollen shedding using recurrent selection for MSVD resistance in maize populations. The reduction in days to silking and pollen shed per cycles in Sussuma was 3.3 to 2.5. Johnson et al. (1986) reported early flowering with a 4.4% increase in grain yield $cycle^{-1}$ after 15 cycles of full-sib recurrent selection in one lowland tropical maize population, Tuxpeno Crema1.

Populations ZM521Q and Pop62SRQ showed similar responses as Sussuma population. These two populations showed highly significant variations among progenies. Maize streak virus (MSVD) resistance rating was significantly reduced from

2.45 to 2.3 after two cycles of recurrent selection in ZM521Q, while in Pop62SRQ the MSVD severity was reduced from 3.25 to 3.0. In both populations increases in genetic variances and heritability estimates were observed for MSVD from C1 to C2. Highly significant correlation coefficients between grain moisture and MSVD; MSVD and ASI and grain yield with grain moisture in Sussuma were observed. In ZM521Q correlation coefficients were grain texture and ear per plant; grain yield and grin texture, while in Pop62SRQ correlation coefficients were grain yield and grain moisture; grain yield and ear per plant and grain yield and plant height.

The grain yield increase after two cycles of recurrent selection was from 3.38 to 3.58 t ha-1 for Sussuma; from 4.40 to 4.70 t ha-1 for ZM521Q and from 2.95 to 3.15 t ha-1. The increase in yield cycle-1 was 200 kg ha-1 in Sussuma, 300 kg ha-1 ZM521Q and 200 Pop62SRQ kg ha-1. All selected progenies that had low incidence also experienced low disease severity. This observation appeared to suggest preferences by leafhoppers to feed on some plants. Higher MSVD decrease severity was recorded in C1 than in C2 indicating that recurrent selection method was effective in improving resistance to MSVD. These observations conform with finding reported in earlier studies (Dudley, 1984; Lamkey *et al.,* 1993).. In the current study, two cycles of recurrent selection for MSVD resistance significantly reduced the infection in Sussuma, ZM521Q and in Pop62SRQ. It was concluded that all QPM populations were responsive to selection for MSVD resistance. Analysis of variance of full-sib progenies indicated the presence of highly significant ($P \leq 0.01$) genetic variation in all populations for tasseling, silking and pollen shedding. Genetic co-variances were high in all three populations indicating recurrent selection significantly improved MSVD resistance. Variability in all the populations indicates the possibility of more selections in future breeding activities.

4.8 Conclusions

Breeding for resistance to MSVD using recurrent selection method was highly effective.

Two cycles of S1 recurrent selection significantly improved MSVD resistance in the three QPM populations although the basic levels differed.

There was concurrent improvement in grain yield performance, ASI, grain texture, grain moisture, ears per plant and other desirable characteristics.

Genetic variances and heritability estimates for MSVD resistance and other important characteristics generally increased or remained unchanged which was important for future continued selection within these populations.

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Appendix 4.1 Means of MSVD, grain yield and secondary traits of Full-Sib families of Sussuma population in cycle two

Entry Sussuma	Maize Streak Virus	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
	(1-5)	t ha^{-1}	Rank	d	Cm	#	%
		Bottom Ten					
5	3.0	2.5	30	2.5	204.9	1.05	13.0
41	3.8	2.6	29	4.3	178.0	1.09	10.4
40	3.4	2.7	28	3.0	149.0	1.01	12.3
43	2.0	2.8	27	4.3	174.0	1.14	12.4
29	2.8	2.8	26	0.8	166.8	1.13	12.1
25	3.1	2.9	25	3.4	174.1	1.21	12.6
22	2.9	3.1	24	3.3	188.5	1.04	12.6
38	1.4	3.3	23	2.7	189.7	0.86	12.4
8	3.3	3.3	22	1.4	181.4	1.31	10.8
30	1.4	3.4	21	6.1	175.1	1.14	12.0
		2.5					
		Top Ten					
4	3.0	5.6	1	2.3	169.1	1.45	11.8
3	2.9	4.8	2	3.7	175.8	1.28	11.3
11	3.0	4.6	3	4.1	173.5	1.24	12.6
18	4.1	4.5	4	3.1	176.4	1.06	12.6
1	2.4	4.5	5	5.3	173.6	1.02	12.3
42	2.9	4.5	6	3.3	165.4	1.14	13.2
32	3.8	4.3	7	2.2	176.3	1.32	12.1
34	3.1	4.2	8	3.6	172.5	0.76	11.6
7	3.3	4.2	9	4.0	198.1	1.04	13.0
12	1.7	4.0	10	2.4	186.9	1.24	12.8
Mean	2.9	3.58		2.5	183.8	1.20	12.2
LSD (0.05)	0.8	0.9		3.1	13.8	0.34	1.6
MSe	0.2	0.80		3.0	285.0	0.04	1.0
CV	17.1	25.05		52.0	9.5	18.18	8.3
P	0.000			0.361	0.000	0.024	0.002
P	***	Ns		Ns	***	*	**
Min	1.4	1.89		0.8	149.0	0.76	9.9
Max	4.4	5.64		6.1	204.9	1.45	13.2
Standard Error	0.3971	0.7597		1.5	6.765	0.1676	

Appendix 4.2 Means of MSVD, grain yield and secondary traits of Full-Sib families of ZM521Q population in cycle two

Entry	Maize Streak Virus	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
ZM 521 Q							
	(1-5)	t ha^{-1}	Rank	D	cm	#	%
		Bottom Ten					
9	3.5	4.0	30	3.2	163.8	1.10	14.2
32	2.7	4.0	29	3.3	152.8	1.18	12.9
13	2.5	4.1	28	3.3	157.4	1.18	13.5
18	3.2	4.1	27	3.7	218.7	1.44	14.8
7	3.3	4.2	26	3.1	165.4	1.13	13.9
2	2.8	4.3	25	3.2	177.6	1.42	13.6
15	3.4	4.5	24	3.8	169.8	1.04	14.0
6	3.1	4.5	23	3.7	184.4	1.37	13.6
23	3.0	4.5	22	3.9	163.7	1.28	14.3
22	2.4	4.6	21	4.0	162.1	1.13	14.0
		Top Ten					
14	1.1	7.6	1	3.4	164.4	1.16	14.6
3	1.4	6.2	2	2.8	179.1	1.20	13.9
21	1.6	6.0	3	4.5	174.5	1.18	13.3
33	1.7	5.6	4	4.0	179.9	1.08	14.1
16	1.8	5.5	5	5.3	190.5	1.06	12.7
10	1.9	5.3	6	3.3	176.0	1.15	13.3
24	2.1	5.2	7	3.7	144.1	1.03	15.0
8	2.2	5.2	8	3.9	190.8	1.37	14.3
11	1.5	5.1	9	4.4	173.2	1.10	14.2
4	1.2	5.1	10	3.5	162.1	1.09	13.2
Mean	2.3	4.70		3.2	173.0	1.16	13.8
LSD (0.05)	1.3	1.65		2.0	12.3	0.27	1.0
Mse	0.6	1.06		1.5	216.4	0.03	0.4
CV	33.5	21.93		33.1	8.5	14.79	4.3
P	0.118	0.001		0.435		0.158	0.000
P	Ns	**		Ns	ns	ns	***
Min	1.1	4.0		2.6	144.1	1.00	12.7
Max	3.5	7.6		5.6	218.7	1.44	15.0
Standard Error		0.8093					

Appendix 4.3 Means of MSVD, grain yield and secondary traits of Full-Sib families of Pop62SRQ population in cycle two

Entry	Maize Streak Virus	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
Pop 62 SR							
	(1-5)	t ha^{-1}	Rank	D	Cm	#	%
		Bottom Ten					
5	4.3	2.98	30	2.5	154.0	0.92	17.0
41	3.0	3.04	29	2.4	142.9	0.88	16.1
40	3.3	3.11	28	1.0	141.9	0.88	15.9
43	3.1	3.14	27	2.1	142.5	0.72	16.6
29	3.0	3.19	26	1.9	145.9	0.83	14.9
25	3.2	3.28	25	2.0	146.5	0.97	17.0
22	2.9	3.29	24	2.5	143.6	0.93	17.1
38	3.1	3.33	23	4.0	159.4	0.99	16.6
8	2.5	3.34	22	2.4	156.5	0.86	17.3
30	2.2	3.34	21	3.0	160.7	1.02	17.0
		Top Ten					
4	2.0	4.85	1	2.4	164.1	1.00	15.7
3	3.1	4.60	2	2.5	161.7	0.88	16.0
11	2.5	4.57	3	2.4	151.3	0.90	24.6
18	2.1	3.98	4	2.0	162.6	0.85	16.5
1	3.5	3.84	5	2.5	148.6	0.99	25.5
42	3.1	3.80	6	1.5	146.4	0.97	17.4
32	3.2	3.79	7	2.5	145.2	0.75	16.0
34	2.5	3.75	8	2.0	153.9	0.89	16.3
7	3.2	3.70	9	2.5	143.1	0.98	16.3
12	3.2	3.69	10	3.4	156.9	1.05	16.3
Mean	3.0	3.15		2.2	144.1	1.20	17.0
LSD (0.05)	1.0	1.52		2.0	22.0	0.22	4.3
MSe	0.3	0.54		1.1	273.6	0.03	5.3
CV	18.0	23.45		42.9	11.0	17.64	13.7
P	0.001	0.025		0.883	0.067		0.013
P	**	*		ns	+	Ns	*
Min	2.0	2.98	1	-2.0	141.9	0.61	14.5
Max	4.3	4.85	49	4.0	164.1	1.21	25.5
Standard Error	0.5	0.76		0	10.7	0.16	2.1

Appendix 4.4 Means of MSVD, grain yield and secondary traits of Full-Sib families of Sussuma population in cycle one

Entry Sussuma C 1	Maize Streak Virus	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
	(1-5)	t ha^{-1}	Rank	d	Cm	#	%
		Bottom Ten					
5	3.0	2.5	30	2.5	204.9	1.05	13.0
41	3.8	2.6	29	4.3	178.0	1.09	10.4
40	3.4	2.7	28	3.0	149.0	1.01	12.3
43	3.0	2.8	27	4.3	174.0	1.14	12.4
29	2.8	2.8	26	0.8	166.8	1.13	12.1
25	3.1	2.9	25	3.4	174.1	1.21	12.6
22	2.9	3.1	24	3.3	188.5	1.04	12.6
38	3.4	3.3	23	2.7	189.7	0.86	12.4
8	3.3	3.3	22	1.4	181.4	1.31	10.8
30	2.4	3.4	21	6.1	175.1	1.14	12.0
		2.5					
		Top Ten					
4	3.0	5.6	1	2.3	169.1	1.45	11.8
3	3.0	4.8	2	3.7	175.8	1.28	11.3
11	3.0	4.6	3	4.1	173.5	1.24	12.6
18	3.9	4.5	4	3.1	176.4	1.06	12.6
1	3.4	4.5	5	5.3	173.6	1.02	12.3
42	2.9	4.5	6	3.3	165.4	1.14	13.2
32	3.8	4.3	7	2.2	176.3	1.32	12.1
34	3.1	4.2	8	3.6	172.5	0.76	11.6
7	3.3	4.2	9	4.0	198.1	1.04	13.0
12	2.7	4.0	10	2.4	186.9	1.24	12.8
Mean	3.25	3.38		3.3	185.7	1.07	12.6
LSD (0.05)	0.8			3.1	13.8	0.34	1.6
MSe	0.2	0.80		3.0	285.0	0.04	1.0
CV	17.1	25.05		52.0	9.5	18.18	8.3
P	0.000			0.361	0.000	0.024	0.002
P	***	Ns		ns	***	*	**
Min	1.4	1.89		0.8	149.0	0.76	9.9
Max	4.4	5.64		6.1	204.9	1.45	13.2
Standard Error	0.3971	0.7597		1.5	6.765	0.1676	

Appendix 4.5 Means of MSVD, grain yield and secondary traits of Full-Sib families of ZM521Q population in cycle one

Entry	Maize Streak Virus	Grain Yield	Rank	ASI	Plant Height	Ears/ Plant	Grain Moist
ZM 521 Q C1							
	(1-5)	t ha^{-1}	Rank	D	cm	#	%
		Bottom Ten					
8	3.5	2.8	30	3.2	163.8	1.10	14.2
29	3.7	3.0	29	3.3	152.8	1.18	12.9
17	3.5	3.2	28	3.3	157.4	1.18	13.5
21	3.2	3.8	27	3.7	218.7	1.44	14.8
12	3.3	3.9	26	3.1	165.4	1.13	13.9
15	2.8	4.1	25	3.2	177.6	1.42	13.6
19	3.4	4.2	24	3.8	169.8	1.04	14.0
7	3.1	4.4	23	3.7	184.4	1.37	13.6
32	3.0	4.4	22	3.9	163.7	1.28	14.3
21	2.4	4.5	21	4.0	162.1	1.13	14.0
		Top Ten					
9	2.1	5.6	1	3.4	164.4	1.16	14.6
45	1.4	5.2	2	2.8	179.1	1.20	13.9
53	1.6	5.0	3	4.5	174.5	1.18	13.3
6	1.7	4.6	4	4.0	179.9	1.08	14.1
23	1.8	4.5	5	5.3	190.5	1.06	12.7
43	1.9	4.3	6	3.3	176.0	1.15	13.3
26	2.1	4.2	7	3.7	144.1	1.03	15.0
14	2.2	4.2	8	3.9	190.8	1.37	14.3
11	1.5	4.1	9	4.4	173.2	1.10	14.2
4	1.2	4.1	10	3.5	162.1	1.09	13.2
Mean	2.45	4.40		4.1	184.9	1.07	14.4
LSD (0.05)	1.3	1.65		2.0		0.27	1.0
Mse	0.6	1.06		1.5	216.4	0.03	0.4
CV	33.5	21.93		33.1	8.5	14.79	4.3
P	0.118	0.001		0.435		0.158	0.000
P	Ns	**		Ns	ns	ns	***
Min	1.1	2.95	1	2.6	144.1	1.00	12.7
Max	3.5	7.62	35	5.6	218.7	1.44	15.0
Standard Error		0.8093					

Appendix 4.6 Means of MSVD, grain yield and secondary traits of Full-Sib families of Pop62SRQ population in cycle one

Entry				ASI	Plant	Ears/	Grain
	Maize Streak Virus	Grain Yield	Rank		Height	Plant	Moist
Pop 62 SR C1							
	(1-5)	t ha^{-1}	Rank	D	Cm	#	%
		Bottom Ten					
5	4.3	2.98	30	2.5	154.0	0.92	17.0
41	3.0	3.04	29	2.4	142.9	0.88	16.1
40	3.3	3.11	28	1.0	141.9	0.88	15.9
43	3.1	3.14	27	2.1	142.5	0.72	16.6
29	3.0	3.19	26	1.9	145.9	0.83	14.9
25	3.2	3.28	25	2.0	146.5	0.97	17.0
22	2.9	3.29	24	2.5	143.6	0.93	17.1
38	3.1	3.33	23	4.0	159.4	0.99	16.6
8	2.5	3.34	22	2.4	156.5	0.86	17.3
30	2.2	3.34	21	3.0	160.7	1.02	17.0
		Top Ten					
4	2.0	4.85	1	2.4	164.1	1.00	15.7
3	3.1	4.60	2	2.5	161.7	0.88	16.0
11	2.5	4.57	3	2.4	151.3	0.90	24.6
18	2.1	3.98	4	2.0	162.6	0.85	16.5
1	3.5	3.84	5	2.5	148.6	0.99	25.5
42	3.1	3.80	6	1.5	126.4	0.97	17.4
32	3.2	3.79	7	2.5	145.2	0.75	16.0
34	2.5	3.75	8	2.0	153.9	0.89	16.3
7	3.2	3.70	9	2.5	143.1	0.98	16.3
12	3.2	3.69	10	3.4	156.9	1.05	16.3
Mean	3.25	2.95		2.4	187.6	1.06	17.5
LSD (0.05)	1.0	1.52		2.0	22.0		4.3
MSe	0.3	0.54		1.1	273.6	0.03	5.3
CV	18.0	23.45		42.9	11.0	17.64	13.7
P	0.001	0.025		0.883	0.067		0.013
P	**	*		ns	+	Ns	*
Min	2.0	1.63		-2.0	126.4	0.61	14.5
Max	4.4	4.85		4.0	164.1	1.21	25.5
Standard Error	0.5	0.76		0	10.7	0.16	2.1

The correlation coefficients in Sussuma population showed grain yield highly correlated with ear per plant and grain texture.

Appendix 4.7 Correlations coefficients among measured parameters and probabilities of Sussuma population in C 1

	ASI	Maize Streak Virus	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Maize Streak Virus	-0.2612						
Ear per Plant	-0.3464	-0.0240					
Grain Moisture	-0.2310	-0.0380	0.0740				
Grain Texture	-0.2451	0.0350	0.0440	0.0790			
Grain Yield	-0.2330	0.0189	0.1900*	0.0450	0.1430*		
Plant Height	-0.2020	-0.2640	-0.2211	-0.3800	0.0460	0.0182	

The correlation coefficients in ZM521Q population showed grain yield highly correlated with ear per plant.

Appendix 4.8 Correlations coefficients among measured parameters and probabilities of ZM521Q population in C 1

	ASI	Maize Streak Virus	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Maize Streak Virus	-0.0680						
Ear per Plant	-0.0380	0.1240					
Grain Moisture	0.0197	-0.3120	-0.0468				
Grain Texture	0.0650	0.0760	-0.0345	-0.1180			
Grain Yield	0.0670	-0.1890	0.1320*	-0.0450	0.02400		
Plant Height	0.0187	0.0680	0.0460	0.0190	0.0860	0.0370	

The correlation coefficients in Pop62SRQ population showed grain yield highly correlated with grain moisture, and plant height with grain texture and grain yield

Table 4.13 Correlations coefficients among measured parameters and probabilities of Pop62SRQ population in C 2

	ASI	Maize Streak Virus	Ear per Plant	Grain Moisture	Grain Texture	Grain Yield	Plant Height
ASI							
Maize Streak Virus	0.0133						
Ear per Plant	-0.7540	-0.241					
Grain Moisture	0.0580	0.0430	-0.2654				
Grain Texture	0.0350	-0.234	-0.3860	-0.480			
Grain Yield	0.0480	-0.350	-0.3420	0.2400*	0.0740		
Plant Height	0.0127	-0.320	0.0654	0.0350	0.1880*	0.2565*	

Chapter 5: General Overview

5.1 Introduction

The purpose of this overview is to close the thesis by reviewing and concluding the completed research, and drawing out some of its implications for breeding. The study was conducted with the objective to enhance productivity of QPM cultivars in smallholder and commercial maize sectors in Mozambique by improving the resistance to DM and MSVD of three QPM populations. The following research hypotheses were tested:

b) Farmers' preferences correspond to the characteristics that breeders select for;
c) Resistance to DM and MSVD in QPM populations can be improved by using recurrent selection without compromising other important traits.

5.2 Research findings

Farmers' preferences

Manica district

Farmers in Manica district preferred maize varieties that are tolerant to DM, MSVD, drought and insect pests particularly stalk borers. Farmers also wanted sweet tasting varieties and flint grain types which they thought stored better and were easier to process (poundability) than dent types commonly used in improved varieties. As a result most farmers used recycled seed from previous generations because they said improved varieties did not always meet these criteria. Breeding programmes in Mozambique have mostly targeted improving yield and disease resistance particularly DM, MSVD and gray leaf spot (GLS). Therefore many of the traits preferred by farmers have not have not concentrated on farmer preferred traits included in breeding objectives. The findings of this study should be used to formulate new breeding objectives in Mozambique which incorporate farmer preferred traits particularly drought tolerance, weevil resistance, stalk borer resistance, flint grain type and sweet taste. This might partly address the low adoption rates of improved varieties in this district.

Angonia district

Farmers in Angonia district preferred high yielding varieties with good husk cover to avoid ear rots, flint grain type which was also thought to improve storage of the grain, resistance to diseases and pests and sweet taste. The sweet taste identified in both districts is probably because of the common practice of roasting or boiling the maize still at the soft dough stage for consumption. The differences in varietal preferences between the districts were due to environmental conditions where Angonia district is a better maize production environment than Manica district. However, like in Manica district, some of the farmer preferences in Angonia are not part of breeding objectives in Mozambique. In the case of Angonia district breeding objectives extra objectives cited include high yield potential and good husk cover in addition to flintiness, sweet taste, disease and pest resistance.

The implications of outcomes from this study are that farmer preferences will vary depending upon their environmental conditions. Results from this survey will help to formulate breeding objectives targeting specific environments where differences occur. In both districts most farmers were not aware of QPM varieties and the benefits they could bring to the consumers. The few farmers who had some information on QPM varieties thought that they were more susceptible to disease both in the field and in storage than ordinary maize. There is a need for promotion of QPM varieties because these are the communities likely to benefit most from the nutritional advantages offered by these varieties.

Adoption of the improved varieties

Farmers in Mozambique have special preferences such a taste, size of cobs, good husk cover,and grain flint type that breeders have not take seriously in the developing a new variety. These preferences are part of the reasons farmers do not readily adopt improved varieties even if they have important traits such as resistance to diseases. A way to achieve higher adoption rates of new cultivars is to involve farmers from the beginning of the breeding programme. By Involving farmers from early breeders can appreciate and comprehend farmer’s preferences and include them in their selection process. However this is expensive and there may be problems of ownership of the variety at the end of the breeding process. Another reason for the low adoption of improved varieties in Mozambique by farmers is unavailability of preferred improved seed, lack of cash to purchase improved seed among other reasons. The challenge is that before the release of the variety, evaluation process in different environments must be conducted by breeders and other stakeholders such as Non-Governmental Organisations (NGOs), Projects and farmers' associations so that at the end the breeders will be able to recommend the variety for the appropriate environment. A strong seed industry must be in place to provide improved seed to the market and to the farmers.

Implication for the response to selection

The good response to selection for both DM and MSVD in the three QPM populations implies that there is inherent quantitative resistance genes for both pathogens which can be exploited by selection. There is therefore scope for the generation of durable resistance in these populations through recurrent selection. Yield and other correlated traits improved due to selection showing that these traits were not compromised as a result of the improvement in disease resistance of the populations. In addition, genetic variances and heritability estimates generally increased for the primary traits under selection and the other related traits. Increased genetic variances between cycles was probably due to the large number of S1 progenies (>500) included in forming the next cycle. The implications are that continued selection will result in further improvements in these populations provided large numbers of progenies are advanced to the next cycle.

New developed QPM populations

Six new QPM populations were developed in this study. Sussuma DMR (Sussuma downy mildew resistant), Sussuma SVR (Sussuma streak virus resistant), ZM521Q DMR (ZM521Q downy mildew resistant), ZM521Q SVR (ZM521Q streak virus resistant), Pop62SRQ DMR (Pop62SRQ downy mildew resistant), and Pop62SRQ SVR (Pop62SR streak virus resistant). These new populations will be evaluated in different locations in Mozambique. At least two seasons of evaluation will be carried out before release and making available for marketing to the farmers. The short term challenge is to produce adequate seed of these populations and to make them available to the farmers, in conjunction with a strong promotion effort to bring awareness to the farmers about QPM varieties per se and improved DM and MSVD diseases in these populations. The improvement in flintiness observed in these populations during selection should make them attractive to farmers because this was identified as a farmer preferred trait. In the long term, breeders should incorporate the other traits identified by farmers into these populations to improve their adoption. Efforts should be made to improve these populations by incorporating drought tolerance,, ear rot resistance, and further improvement of flintiness, weevil resistance and sweet taste, among other traits. In order to fully capture farmer preferences needed for inclusion in the breeding objectives, PRA studies should be conducted in the different agro-ecological zones in the country.