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ENHANCING CROP BREEDING PROGRAMMES: THE CASE OF SORGHUM AND PEARL MILLET IN SOUTHERN AFRICA

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ABSTRACT

Crop breeding and variety release systems remain largely focused on national markets while seed markets are becoming increasingly globalised. Breeding programs are also poorly staffed and under-funded in relation to the number of each country's crop breeding challenges. Studies and analyses were conducted and a synthesis is presented to provide a scientific and economic justification for improving the efficiency of crop breeding and variety registration for sorghum (*Sorghum bicolor*) and millet (*Eulisia indica*) in southern Africa. Geographic Information system (GIS) analyses was used to delineate the region into 4 recommendation domains based on lengths of growing periods. Multiple variety releases exemplify potential adaptability of the varieties across country borders. Sequential retrospective pattern analyses (SEQRET), using grain yield data from Multi Environment Trials (METs) conducted over a span of 12 years, stratified the 39 Southern Africa Development Community (SADC) test sites into 6 groups according to their similarity of line- yield differentiation. This provided an objective basis for selection of a few representative benchmark test sites for future efficient regionalized variety testing through the "Lead NARS" approach of regionalised breeding for increased efficiency and cost effectiveness. Mechanism for regional release to facilitate farmers' fast access to new improved varieties will address constraints of small seed markets.

Key Words: Crop improvement, improved varieties, seed systems, variety release

RESUME

La reproduction de plante et les systèmes de libération de variété restent largement focalisés sur les marchés nationaux pendant que les marchés des graines sont devenus de plus en plus globalisés. Les programmes de reproduction sont aussi pauvrement garnis en terme du personnel et sont sous financés en relation avec les défis du nombre de reproduction de plante de chaque pays. Les études et analyses étaient conduites et une synthèse est présentée en vue de pourvoir une justification scientifique et économique pour améliorer le rendement de reproduction de plante et l'enregistrement des variétés de sorgho (*Sorghum bicolor*) et millet (*Eulisia indica*) dans le sud de l'Afrique. Les analyses du système d'information géographique (GIS) étaient utilisées pour démarquer la région en quatre domaines de recommandation basés sur les longueurs des périodes de croissance. Les libérations de variété multiple illustrent l'adaptabilité potentielle des variétés à travers les frontières du pays. Les analyses du modèle respectif séquentiel (SEQRET), utilisant les données de rendement en graines provenant des essais de l'environnement (METs) conduits au delà d'une période de 12 années, les 39 sites teste de la Communauté de Développement des Etats du Sud de l'Afrique (SADEC) stratifiés en 6 groupes selon leur similarité de différenciation de lignée de rendement. Ceci pourvoit une base objective pour la sélection d'un petit nombre représentatif du point de référence des sites teste pour le future teste de rendement de variété régionalisée

à travers l'approche "Lead NARS" de reproduction régionalisée pour augmenter le rendement et la rentabilité. Le mécanisme pour la libération régionale à l'accès rapide des fermiers aux nouvelles variétés améliorées adressera les contraintes des petits marchés des graines.

Mots Clés: Amélioration de plante, variétés améliorées, systèmes de graines, libération de variété

INTRODUCTION

The Southern Africa Development Community (SADC); Sorghum and Millet Improvement Program (SMIP) was initiated in 1983 with International Centre for Research in Semi Arid Tropics (ICRISAT) taking responsibility for strengthening the sorghum and millet improvement programmes in each of the then eight-targeted SADC countries (House *et al.* 1997). This initiative resulted into some 92 sorghum (*Sorghum bicolor*) and millet (*Eulisia indica*) scientists being trained at the postgraduate degree level. Virtually all of them returned to take up positions in their own home countries. ICRISAT availed germplasm and the National Agricultural Research System (NARS) scientists over time were able to establish multi location testing of varieties developed and selected by ICRISAT scientists alongside their own materials. By year 1997, national programs had released more than 32 new improved sorghum and pearl millets varieties (Obilana, 1998). However at this same period, we estimate that less than 50% of the trained scientists remain in place. In addition, National Agricultural Research Systems (NARES) are also faced with declining aggregate funding for agricultural research and sorghum and millet programs have in the whole weakened. National research programs cannot be expected to support research for all crop and livestock enterprises in all agro-ecologies. This leaves us facing a conundrum. One option is to search ways to improve the efficiency with which limited research resources are deployed. In this context, a key strategy for improving the efficiency and impacts of agricultural research investments is to target regional technology development rather than individual NARS focus and exploit potential technology spillovers (Mgonja *et al.*, 2002).

One of the justifications for regionalised breeding and variety registration is based on the fact that environments cut across political

boundaries with implications that outputs of a breeding program in one country can potentially be adapted and adopted in similar environments in other countries. Evidence of such gains to regionalised variety development and variety sharing is available in the record of germplasm spillovers in southern Africa. However, a fundamental challenge in plant breeding is choosing selection and test environments (Simmonds, 1979; Stoskopf *et al.*, 1993). In a large region, such as the SADC, knowledge of production zones within the region could help not only in choosing appropriate testing sites, but also in objective targeting of varieties for maximizing production (Peterson, 1992). A conceptual framework for justifying regionalised breeding and variety registration is examined in this paper and we report on results obtained from (i) environmental characterization and delineation of recommendation domains, to elucidate that environments cut across country borders; (ii) analyses of historical multi environmental trials (MET) data to improve biophysical characterisation and stratification of test sites; and (iii) multiple variety releases to demonstrate variety spillover across countries.

MATERIALS AND METHODS

Agro-ecological zonation using Geographical Information System (GIS). Sorghum and millet researchers in the region based on their experiences hand-delineated areas where the two crops are predominantly being grown. In addition, geo-referenced climate data derived from the Africa dataset compiled by Corbett and O'Brien (1997), consisting of interpolated monthly values of precipitation, potential evapotranspiration, ratio of precipitation over potential evapotranspiration, minimum temperature and maximum temperature for the whole SADC region. Given this database, zonations of areas based on climate were carried out. A total of 39 geo-referenced SADC test sites

were also overlaid on the zonations in order to determine sites that are in the same agro-ecology. Table 1 presents names and the major biophysical characteristics of the SADC region testing sites.

Maximisation of crop productivity requires accurate selection and targeting of varieties for appropriate production areas. The number and location of testing sites are critical factors that affect the efficiency and effectiveness of breeding programmes. The sites must be representative of the conditions in the target production areas. Sequential retrospective (SeqRet) pattern analysis (Mirzawan *et al.*, 1994; DeLacy *et al.*, 1996) was used for stratification of the testing sites according to their similarity of genotype-yield-differentiation patterns. An outline of this methodology is described in Mgonja *et al.* (2002). The methodology was implemented using the sequential retrospective pattern analyses (SEQRET) package Version 1.1 (DeLacy *et al.*, 1998). The stratification was done using data

from 90 pearl millet METs and 147 sorghum METs conducted in the region. The pearl millet METs were conducted across 25 sites over nine years (1989/90 to 98/99). The sorghum METs were from 34 sites over seven years (87/88 to 92/93, and 99/2000).

Multiple variety releases and economic analyses to justify regionalized variety registration. By 1999, NARES in southern Africa in collaboration with ICRISAT released a total of 47 sorghum and pearl millet varieties. Most of these releases were done independently through national release systems. However, it was also realised that there were multiple variety releases whereby one genotype was released in more than one country though at different times.

A survey was conducted across eight SADC countries to determine multiple variety releases and the period of release. An analysis on the cumulative production gain derived from national

TABLE 1. Multi-country releases of sorghum and pearl millet varieties in the SADC region during 1989 - 2000

Variety	Country of release	Year of release	Local name	Number of years that lapsed from first to last release
SDS 3220 (Macia)	Mozambique	1989	Macia	11
	Botswana	1994	Phofu	
	Zimbabwe	1998	Macia	
	Namibia	1998	Macia	
	Tanzania	1999	Macia	
ICSV 112 (SV 1)	Zimbabwe	1987	SV1	6
	Swaziland	1992	MRS12	
	Malawi	1993	Pirira 1	
	Mozambique	1993	Chokwe	
ICMV 88908 (Okashana 1)	Namibia	1990	Okashana1	9
	Malawi	1996	Nyankombo	
	Botswana	1999	Bontle	
SDMV93032 (Okashana 2)	Namibia	1998	Okashana 2	2
	Zimbabwe	1996	Okashana 2	
SDMV89004	Zimbabwe	1992	PMV 2	7
	Botswana	1999	Legakwe	
SDMV92040	Zimbabwe	1998	PMV 3	0
	Namibia	1998	Kangara	
SDMV89005	Malawi	1996	Tupatupa	4
	Mozambique	2000	Kuphanjalal	

versus regional release was done on a sorghum variety Macia (first released in Mozambique in 1989 and latest in Tanzania in 1999), to provide an economic justification for the on-going southern Africa discussions on harmonisation of seed laws and regulations especially with respect to regional variety registration. A GIS mapping was also done (Mgonja *et al.*, 2001) to determine other areas in the SADC region where such released varieties could be adapted in countries other than those of release.

To assess the practicality of the regionalised breeding approach for increased efficiency, results from agro-ecological zonations, stratification of sorghum and pearl millet test sites and multiple variety releases were shared broadly with both public and private partners in southern Africa.

RESULTS

The southern Africa region was grouped according to lengths of growing period (LGP), that is the period when water and temperature regimes permit crop growth (Fig. 1). It is also a continuous period with rainfall more than half of the potential evapotranspiration, excluding periods when temperatures are below crop growth levels. The results further indicated that the bulk of pearl millet growing areas have LGP of 3, 4 or 5 months, with the majority in LGP of 3 and 4 months. For sorghum, the LGP of 3, 4 and 5 months, and to a lesser extent 6 months. More than three quarters of the sites were in LGPs of 3, 4, 5 and 6 months and the rest were lying outside these LGPs.

Basing on the SEQRET, to stratify sorghum and pearl millet variety testing sites according to their similarity for yield discrimination among genotypes using grain yield data from historical multi-environment trials (METs), the 25 pearl millet sites were clustered into six groups with $R^2=76\%$ (Fig. 2) and were reported by Mgonja *et al.* (2002). The 34 sorghum sites were similarly clustered into six major groups (Fig. 3) with a model fit of $R^2=75\%$ (Mgonja *et al.*, in press).

Results of the analyses of released varieties indicated presence of multiple sorghum and pearl millet variety releases across the SADC region. The varying national variety testing, registration and release schemes for each country resulted

into a lapse of as many as 11 years between the first and last release for Macia (Table 1). An economic analysis (Fig. 4) on the individual national releases for Macia across the five countries *versus* a hypothetical regional registration demonstrates a cumulative loss of approximately US\$43m as a result of fragmented national release schemes (Rohrbach pers. comm.). In order for other countries to benefit from these releases, major test sites and areas of adoption for each of these multiple released varieties have been characterised. Other areas in the SADC region with similar climatic characteristics have been mapped using GIS to identify potential areas where these varieties might be adapted (Mgonja *et al.*, 2001), even in countries where intensive testing has not been done.

The results further established scientific and economic justifications for laying a policy foundation for shifting the focus of crop breeding from independent national investments toward a coordinated regionalized investment linked with the global research community.

Regionalised crop breeding will allow national breeding programs to share data, responsibilities, expenses, and breeding materials much more efficiently across the region. The various NARS have already begun using the "Lead NARS" concept whereby one national program with a comparative advantage is assigned to lead research in a particular research theme on behalf of other NARS with similar problems and/or similar agro-ecological zones. The "Lead NARS" then shares results/breeding materials with the others. With this approach, resources are saved because most of the R&D work is done by one program on behalf of the region, instead of each country running a separate program. Two pilot "Lead NARS" programs are already operating. Tanzania leads the research to incorporate *Striga* resistance into sorghum landraces; Zambia is the lead NARS for improving photoperiod-sensitive sorghum landraces. National programs are enthusiastic about the approach, and there is considerable opportunity for expansion.

DISCUSSIONS

Results from biophysical analyses, firstly deploying GIS and climatic data, delineated and

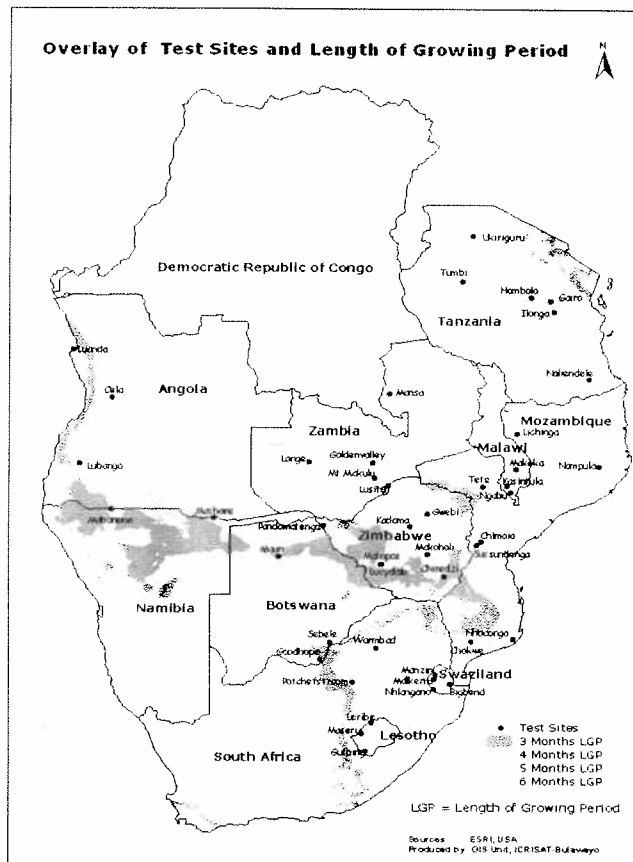


Figure 1. Overlay of test sites and lengths of growing period in the SADC region.

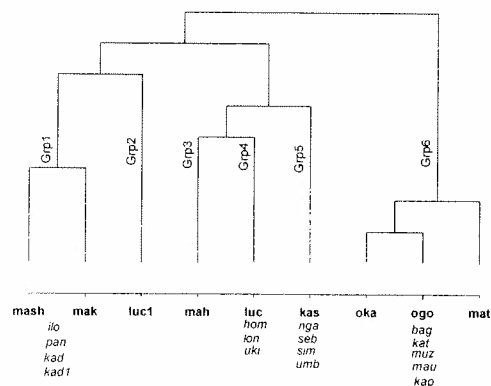


Figure 2. Dendrogram of cumulative classification of pearl millet test sites (1989/90 - 1998/99) in the SADC region based on grain yield using weighted environment-standardised squared Euclidean distance as dissimilarity measure and incremental sum of squares as clustering strategy. Italics indicate the sites added to site-groups based on nearest centroid criterion.

mapped agro ecological zones by LGP indicating that multiple environments exist in a given country and that environments cut across countries. The implications are that outputs of a breeding program in one country can potentially be adapted and adopted in similar environments in other countries. These results increase potential interest of commercial seed companies/ entrepreneurs in

variety multiplication and distribution. A methodical regionalised breeding can be pursued targeting specific environments at regional level, while gaining from increased acreage summed across countries and therefore realizing greater potential economic benefits from higher yields on a wide geographic crop area. Maps of the region showing zones of adaptation of specific (widely

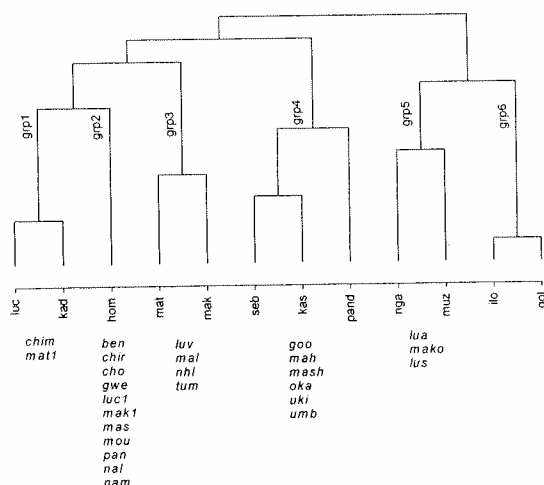


Figure 3. Dendrogram for cumulative classification of 38 sites in the SADC region based on grain yield per hectare of sorghum varieties planted during 1987/88 - 1992/93 and 1999/2000 using weighted environment-standardised squared Euclidean distance as dissimilarity measure and incremental sum of squares as clustering strategy.

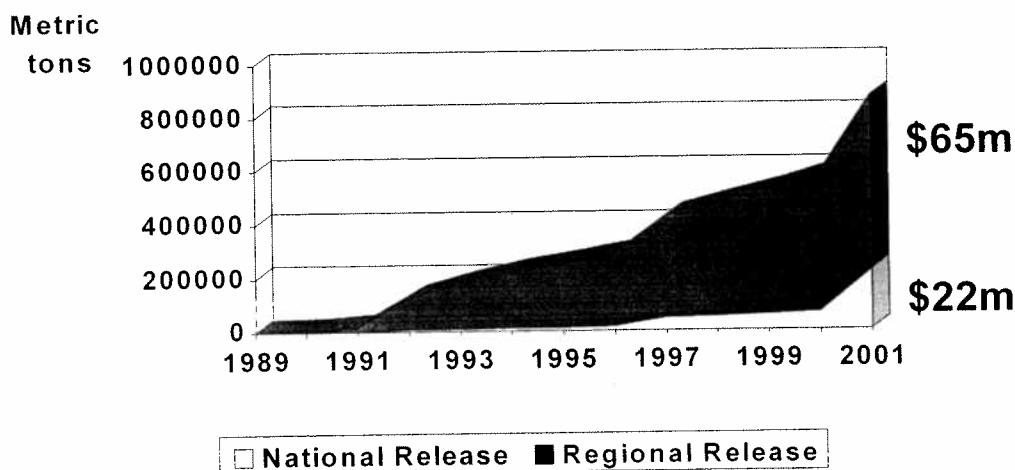


Figure 4. Economic analyses of mica at national level.

adapted) sorghum and pearl millet varieties can strengthen regional seed security and accelerate the spread of improved varieties, reducing the cost of research programs, and speeding the delivery of benefits to farmers. Another important implication is the targeting of relief seed. These maps make it easy to identify varieties adapted to the afflicted areas, identify where else in the region those varieties are grown, and where seed might be sourced. In future, it may also be possible to set up a regional seed security system wherein seed stocks of regionally important varieties could be held as a regional reserve.

Regional test sites have been characterized and stratified for pearl millet varieties (Mgonja *et al.*, 2002) and for sorghum varieties (Mgonja *et al.* in press) using GIS as well as historical data METs. The results have implications both for the efficiency of breeding procedures and for the logical grouping of environments for breeding. The results suggest that future sorghum and pearl millet variety and hybrid could be restricted to a few representative sites selected from within each of the six identified site-groups. Aggarwal (1993) has deployed similar procedures.

The methodical testing on benchmark sites can support regional variety registration for an efficient seed system. We are currently pursuing testing in environments grouped based on climatic agro-ecological zonations, known production systems, and biological site stratification grouping. The entails utilisation of SEQRET exploiting available historical MET data, provided an objective selection of a few representative test sites for future testing of varieties and hybrids. The results suggest that future variety /hybrid testing could be restricted to a few sites picked from within each of the identified site-groups.

ICRISAT in collaboration with NARES breeders for private and public institutions have successfully established an agreed model of regionalised breeding to be led by either international or national institutions. The latter has been a new innovation of breeding through "Lead NARS" or breeding networks. The salient feature is the focus and research targeting by environments rather than political boundaries. All these efforts will contribute to objective criteria and procedures for regionalised breeding and variety registration and expand the regional seed

market. Future work will focus on testing and reinforcing the proposed model and placing it on a firmer, regionally led footing. The initial strategic analyses pursued for sorghum and pearl millet need to be extended to crops such as groundnuts (*Arachis hypogea*), pigeon peas (*Cajanus cajan*) and chickpeas (*Vigna* sp.) which are also widely grown in the SADC region.

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REFERENCES

- Aggarwal, P.K. 1993. Agro-ecological zoning using crop growth simulation models: characterization of wheat environments in India. In: Penning de Vries, F.W.T., Teng, P. and Metselaar, K. (Eds.), pp.97-109. Systems Approaches for Sustainable Agricultural Development. Vol 2. Kluwer Academic Publishers. Dordrecht, the Netherlands.
- Corbett, J.D. and O'Brien, R.F. 1997. The Spatial Characterization Tool – Africa v 1.0. Texas Agricultural Experiment Station, Texas A&M University System, Blackland Research Center Report No. 97-03, CD-ROM Publication.
- DeLacy, I.H., Basford, K., Cooper, M. and Fox, P. 1998. The SEQRET Package: Computer Programs for Retrospective Pattern Analysis, Version 1.1. The University of Queensland, Brisbane 4072, Australia.
- DeLacy, I.H., Basford, K.E., Cooper, M., Bull, J. K and McLaren, C.G. 1996. Analysis of Multi – environment trials. – A Historical perspective. In: *Plant Adaptation and Crop Improvement*. Copper, M. and G L Hammer (Eds.), pp. 39-124. CAB International.
- House, L.R., Verma, B.N., Ejeta, G., Rana B.S, Kapran, I., Obilana, A.B. and Reddy, B.V.S. 1997. Developing countries breeding and

- potential of hybrid sorghum. In: *Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl millet*. Lubbock Texas. ICRISAT publication 97-5. pp. 84-97.
- Mirzawan, P.D.N., Cooper M., DeLacy, I. H. and Hogarth, D.M. 1994. Retrospective analysis of the relationships among the test environments of Southern Queensland sugarcane breeding program. *Theoretical and Applied Genetics* 88:707-716
- Mgonja, M.A., Monyo, E.S., Obilana, A.O., Rohrbach, D.D., Murambadoro, D. and Mpande, C. 2001. Regional collaboration for research impact: the case for SADC regional development and adaptability of improved sorghum and pearl millet varieties. *SMINET News* 3:16-20.
- Mgonja, M.A., Monyo, E.S., Chandra, S., Murambadoro, D. and Chinhema, E. 2002. Stratification of SADC regional pearl millet testing sites based on variety grain yield. *Field Crops Research* 72:143-151.
- Obilana, A.B. 1998. Sorghum improvement. *International Sorghum and Millets Newsletter* 39: 4-17.
- Peterson, C.J. 1992. Similarities among test sites based on line performance in the hard red winter wheat region. *Crop Science* 32:907-912
- Simmonds, N.W. 1979. Principles of Crop Improvement. London, UK: Longman Group Ltd
- Stoskof, N.C., Tomes D.T. and Christie B.R. 1993. Plant breeding theory and practice. Boulder, Colorado: Westview Press.