Collection Priorities of Pasture Genetic Resources in the Paniceae Native to South Africa

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Abstract
There is an urgent need for the prioritization and *ex situ* conservation of pasture grass species. Many pasture grasses are still in the process of domestication and grasslands in the tropical, subtropical, semi-arid and arid regions of the world are therefore a major source of genetic material for future forage improvement. Within South Africa, it was found that the Paniceae contains several species with high pasture value and that many populations of these species are found in water-limited environments. Therefore, it was proposed that a strategy be developed for the South African National Forage Genebank to prioritize efforts to collect and conserve seed of grass species within the Paniceae, focussing especially on those species in genera *Anthephora*, *Brachiaria*, *Digitaria*, *Panicum* and *Setaria* located in areas receiving less than 600 mm of annual precipitation.

Introduction
Grasslands within the water-limited regions of the world are major sources of plant genetic resources (PGR) that can, and should be explored for forage improvement. This is especially true for tropical and sub-tropical grasses (TSTG) which are still in the process of domestication. However, although these TSTG are still being domesticated, during the past 50 years species such as *Cenchrus ciliaris*, *Chloris gayana* and various *Brachiaria* species have already made significant impacts on global livestock production systems (Pengelly and Maas 2019). *Brachiaria* species especially, are believed to have an even bigger role to play under future bioclimatic conditions (Njarui et al. 2020). Therefore, with global climate change, there is an urgent need for the prioritisation and *ex situ* conservation of grass genetic resources with pasture potential that can be developed as alternative forages or used in forage improvement programs for the development of varieties and cultivars that can be used under drier agro-ecological conditions (Trytsman et al. 2020). Although approximately 73 % of South Africa (SA) receives less than 600 mm of annual precipitation (Schulze and Lynch 2007), it houses a large diversity of grasses (Trytsman et al. 2020), making it the ideal country to collect PGR that can be used to especially improve drought tolerance of grass pastures. Trytsman et al. (2020) found that in SA, the Panicoideae are the most speciose sub-family of grasses, and within the tribe Paniceae, there are several species with high pasture potential or with existing and known pasture value. However, with the primary focus in SA being on the improvement of exotic forage resources (Truter et al. 2015), very little efforts towards collection and subsequent evaluation and domestication of these SA PGR for forage improvement has occurred (Truter et al. 2015, Trytsman et al. 2020). These PGR, however, could become important sources of breeding material under future bioclimatic conditions, and therefore efforts to prioritise collections of these PGR are currently underway at the Agricultural Research Councils (ARC) South African National Forage Genebank (SA-NFG) and Range and Forage Sciences (RFS) divisions. The aim of this study was therefore to characterise populations of key grass species focusing on the genera *Anthephora*, *Brachiaria*, *Cenchrus*, *Digitaria*, *Panicum* and *Setaria* to guide more targeted collections of prioritised PGR for further evaluation and cultivar improvement for use in water-limited agro-ecological areas.

Methods
Perennial grass species with high forage potential based on the work done by Trytsman et al. (2020), and those species with known commercial cultivars in the genera *Anthephora*, *Brachiaria*, *Cenchrus*, *Digitaria*, *Panicum* and *Setaria* were prioritized for further characterization. Distribution records of native populations of each of the selected species were obtained from the Botanical Database of Southern Africa (BODATSA) maintained by the South African National Biodiversity Institute (SANBI), and from botanical records maintained in the PHYTOBAS database, a national vegetation data archive (2003 – 2009) maintained by the ARC SA-NFG (Trytsman et al. 2020). The distribution data were superimposed on a map indicating mean annual precipitation (MAP) of South Africa (Schulze and Lynch 2007) which was the first criterion for prioritisation of populations. Thereafter rainfall seasonality (Schulze and Maharaj 2007a), rainfall concentration index (RCI) (Schulze and Maharaj 2007b), and coefficient of variation of annual precipitation (CVAP) (Schulze 2007) were considered for further division and prioritization of PGR from distinct populations.

Results and Discussion

MAP: Schulze and Lynch (2007) describes MAP (mm) as the long term quantity of water available to a region for hydrological and agricultural purposes. Under non-irrigated conditions, and if other factors such as light, temperature, soil and mineral nutrients are not limiting, MAP gives the upper limit to a regions sustainable agricultural potential in regard to biomass production (Schulze and Lynch 2007). Approximately 20 % of SA receives less than 200 mm MAP, 47 % receives less than 400 mm MAP, and 73 % receives less than 600 mm MAP. Only 9 % of the country receives rainfall in excess of 800 mm (Schulze and Lynch 2007). From the current study, it was found that *A. pubescens*, *C. ciliaris*, *D. eriantha* and *P. maximum* contained populations that were found in areas that receive less than 200 mm of annual precipitation, with approximately 15 % of *C. ciliaris* populations falling within this MAP zone (Table 1). *A. pubescens* and *C. ciliaris* were found to have more than 30 % of their populations occurring in areas that receive less than 400 mm of annual precipitation while approximately 83 %, 36 %, 73 %, 77 %, 65 %, 57 % and 38 % of *A. pubescens, B. brizantha, B. nigropedata*, *C. ciliaris*, *D. eriantha*, *P. maximum* and *S. sphacelata* populations occurred in areas that receive less than 600 mm annual precipitation (Table 1). This provides a large number of native populations for collection of PGR that can be compared to commercial varieties for their drought tolerance. If these PGR are found to perform better under water limited conditions, they should be considered for further evaluation and characterisation for inclusion in forage improvement programs. Populations of the prioritised PGR, occurring in areas receiving more than 600 mm of MAP could potentially also be important sources of genetic, morphological and physiological variability for selection of beneficial agronomic traits, other than drought tolerance. However, with this study only focussing on identifying species with potential drought tolerance, a significant number of populations of the prioritised species (Table 1) were excluded from further consideration in the current study, but should be considered when collecting and screening PGR for various beneficial traits, other than drought tolerance. This is especially true for *B. humidicola*, where 100 % of the known SA populations occur in areas that receive more than 600 mm MAP. This species however, is an important forage for utilisation under climate change conditions as it has been proved to reduce soil biological microbial nitrification and by doing so reduce N_2O emissions from grazed pastures (Karwat et al. 2017, Simon et al. 2020).

Table 1: Percentage of known prioritised grass species classed into different mean annual precipitation zones in South Africa.

	% of total population							
MAP (mm)	***A. pubescens***	***B. brizantha***	***B. nigropedata***	***B. humidicola***	***C. ciliaris***	***D. eriantha***	***P. maximum***	***S. sphacelata***
< 200	6.6	0.0	0.0	0.0	14.7	2.7	1.4	0.0
200 - 300	9.5	2.8	0.0	0.0	15.1	6.2	4.8	1.2
300 - 400	18.2	6.4	14.6	0.0	16.2	15.1	9.4	4.2
400 - 500	24.8	6.4	22.2	0.0	11.4	18.5	15.7	11.3
500 - 600	24.1	20.2	36.3	0.0	20.2	22.8	25.6	20.9
≤ 600 mm MAP	**83.2**	**35.8**	**73.1**	**0.0**	**77.6**	**65.2**	**57.0**	**37.6**
600 - 700	14.6	25.7	20.5	22.2	12.5	17.8	17.7	23.8
700 - 800	2.2	10.1	4.1	11.1	4.8	7.9	7.7	14.6
800 - 900	0.0	6.4	0.0	11.1	2.9	3.4	4.6	8.9
900 - 1000	0.0	7.3	1.2	16.7	0.7	2.1	4.6	5.6
> 1000	0.0	14.7	1.2	38.9	1.5	3.6	8.5	9.4
> 600 mm MAP	**16.8**	**64.2**	**26.9**	**100.0**	**22.4**	**34.8**	**43.0**	**62.4**

Rainfall Seasonality: South Africa can be divided into three main rainfall distribution zones, namely, the all year round rainfall zone (AYR), winter rainfall zone (WR) and summer rainfall zone (SR) (Roffe et al. 2020). In the current study, all of the prioritised grass species occurring in areas receiving 600 mm or less of MAP were primarily found within the SR regions of SA, with more than 80 % of populations of each of the targeted species having a SR distribution. However, approximately 4 %, 3 %, 3 % and 6 % populations of *C. ciliaris*, *D. eriantha*, *P. maximum* and *S. sphacelata* were found within the WR distribution zones, and 2 %, 7 %, 5 % and 14 % of populations of the same species were found within the AYR rainfall zone (Table 2). The SR zone in SA can be divided further into an early, mid, late and very late summer rainfall zone (Schulze and Maharaj 2007a). The early summer rainfall zones in SA are areas where the rainfall season peaks in December, mid-summer rainfall zones where the rainfall season peaks in January, late summer rainfall zones where the rainfall season peaks in February and very late summer rainfall zones where the rainfall season peaks in March to May (Schulze and Maharaj 2007a). Populations of *A. pubescens*, *B. brizantha* and *B. nigropedata* had a 100 % SR distribution, although variation in the amount of populations which occur in early, mid, late and very late summer rainfall regions were found (Table 2). Although some of the *C. ciliaris, D. eriantha, P. maximum* and *S. sphacelata* populations occurred within the WR and AYR rainfall zones, the majority of their distribution falls within the summer rainfall zone (Table 2).

The timing of the rainfall season has a significant impact on the potential agricultural production of an area as it directly influences the duration of the growing season, and therefore, the species that can be planted. In order to fully exploit the agronomic potential of forage species, it is important to select PGR from a range of bioclimatic conditions, including those that are found in different rainfall distribution zones. The larger the potential distribution of the species, the bigger the agronomic impact it may have. Also, species occurring in different rainfall distribution zones, will have different beneficial traits that can be targeted during forage improvement initiatives, and selection of traits for specific agro-ecological conditions and agronomic practices becomes possible. For instance, ecotypes of species that occur in the late and very late summer rainfall zones will have much shorter growth periods than those occurring in early and mid-summer rainfall zones due to the length differences in the wet season (Roffe et al. 2020).

Table 2: Percentage of prioritised grass populations, obtained from herbarium records occurring in areas receiving more than 600 mm MAP in different rainfall distribution zones in SA.

	% of prioritised populations					
Species	Winter	All Year	Early Summer	Mid-Summer	Late Summer	Very Late Summer
A. pubescens	0	0	7	32	45	16
B. brizantha	0	0	21	28	44	8
B. nigropedata	0	0	14	60	26	0
C. ciliaris	4	2	9	30	14	41
D. eriantha	3	7	9	37	28	17
P. maximum	3	5	15	53	13	12
S. sphacelata	6	14	11	30	28	10

RCI: The selection of crops as well as the production systems used on a farm depend not only on the annual amounts of rainfall or rainfall seasonality for that specific area, but also on the duration of the rainy season, i.e. whether the rainfall season is concentrated over a short period of the year only, or spread over a longer period, expressed by Schulze and Maharaj (2007b) as the RCI (%). A total of 72 %, 84 %, 55 % and 53 % of *A. pubescens*, *B. nigropedata*, *C. ciliaris* and *P. maximum* populations occurred in areas with a relatively concentrated rainfall season (RCI > 60 %) while the approximately 1 %, 17 %, 4 %, 22 %, 32 %, 29 % and 39 % of *A. pubescens*, *B. brizantha*, *B. nigropedata*, *C. ciliaris*, *D. eriantha, P. maximum* and *S. sphacelata* populations occurred in areas with a rainfall season that is relatively spread (RCI < 50 %) throughout the year (Table 3). Species that occur in areas with a short rainfall period are often adapted to complete their life cycle faster, and therefore are able to reach maturity earlier than those in areas with a longer rainfall period. In areas where the rainfall/growing season is short, the selection of species that are adapted to short growing periods are important as these will allow for the diversification of production systems and crops, and allow for improved production in areas where most agronomic crops are not able to produce appreciable amounts of biomass due to the short growing seasons.

Table 3: Percentage of populations of prioritised PGR occurring in areas with different rainfall season durations in SA.

Rainfall concentration index	*A. pubescens*	*B. brizantha*	*B. nigropedata*	*C. ciliaris*	*D. eriantha*	*P. maximum*	*S. sphacelata*
< 15 %	0.0	0.0	0.0	1.9	5.0	3.0	9.9
15 - 30 %	0.0	0.0	0.0	2.9	4.2	4.5	14.9
30 - 45 %	0.0	0.0	0.0	7.7	10.2	6.0	9.9
45 - 50 %	0.0	0.0	0.0	8.2	10.8	1.5	8.5
50 - 55 %	7.9	0.0	2.4	8.2	7.9	4.0	9.2
55 - 60 %	19.3	17.9	7.2	12.1	9.7	8.5	8.5
60 - 65 %	64.0	71.8	68.8	40.6	38.3	47.5	30.5
> 65 %	8.8	10.3	21.6	18.4	13.9	25.0	8.5

CVAP: MAP, rainfall seasonality and RCI maps do not show the natural year-to-year variability of rainfall that occurs, and for this reason the CVAP (%) is used (Schulze 2007). The higher the CVAP, the more variable the year-to-year (i.e. inter-annual) rainfall of a locality is. Therefore, the CVAP is an index of climatic risk, indicating a likelihood of rainfall and stored water fluctuations, or crop yield from year to year. Agriculturally it is, perhaps, a more crucial statistic to use in marginal areas than in either very dry areas, where farming practices have adapted to variability, or in wet areas, where relatively lower inter-annual variabilities are generally expected. Due to climate change, variability in rainfall distribution and fluctuations in the amount of rainfall across years is expected, which means that species able to cope with fluctuations in rainfall between years will be beneficial for future production practices. This is because these species will be able to better survive years of below average rainfall compared to those adapted to constant high rainfall or low rainfall areas. In the current study, 85 %, 69 %, 74 %, 97 %, 84 %, 77 % and 73 % of *A. pubescens*, *B. brizantha, B. nigropedata*, *C. ciliaris, D. eriantha, P. maximum and S. sphacelata* populations are well adapted to relatively large inter-annual variability in rainfall, occurring in areas with a CVAP of more than 30 % (Table 4). More than 20 % of *B. brizantha*, *B. nigropedata*, *P. maximum* and *S. sphacelata* populations, however, will primarily fall within areas with relatively low (< 30 %) inter-annual variability in annual precipitation (Table 4).

Table 4: Percentage of populations of prioritised PGR occurring in areas across SA with different levels of inter-annual variability in rainfall.

	% of prioritised populations						
CVAP (%)	*A. pubescens*	*B. brizantha*	*B. nigropedata*	*C. ciliaris*	*D. eriantha*	*P. maximum*	*S. sphacelata*
> 20 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 - 25 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25 - 30 %	14.9	30.8	25.6	13.0	16.0	22.5	27.0
30 - 35 %	64.0	59.0	72.0	42.0	64.8	61.5	67.4
35 - 40 %	21.1	10.3	2.4	43.0	19.2	16.0	5.7
> 40 %	0.0	0.0	0.0	1.9	0.0	0.0	0.0

Conclusions/Implications

In this study we prioritised seven important pasture grass species for collection, characterisation and evaluation initiatives and to maintain these PGR at the SA-NFG. Populations of these species found within the different prioritised ecological zones identified in this study are believed to contain traits that enable them to be better adapted to water-limited agro-ecological areas, as well as to cope with additional climate change related issues such as inter-annual rainfall variability. If these newly acquired PGR are found to contain higher drought tolerances, compared to current commercially available cultivars, as well as the different breeding lines and accessions from national and international forage genebanks, they will be included in forage improvement programs at the ARCs Cedara forage breeding campus, with the goal of selecting superior individuals and breeding new cultivars, adapted to water-limited agro-ecological conditions in the near future.

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