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Review

A review of plant characterization: First step towards sustainable forage production in challenging environments

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This review paper attempts to give account of how plant characterization assists the availability of information on desirable plant traits, to enhance selective breeding for environmental stresses and thus attain sustainable forage production. Plant characterization is referred to as an account for heritable characters varying from agronomical, morphological to molecular markers. It simplifies grouping of accessions, development of core collections, identification of gaps and retrieval of valuable germplasm for breeding programmes resulting in better insight about the composition of the collection and its genetic diversity. Plant characterization by morphological, physiological and agronomic traits has long been used in selective breeding. Advancement of characterization to the use of molecular markers speed up the process and permits optimal utilization of the adaptive traits harboured in all breeds for stressful environments. In countries like Tanzania, where agro-climatic conditions are challenging, technological progress is slow and market institutions are poorly developed, selecting highly adaptive local varieties is important. Knowledge from characterization of local varieties could be used to breed adaptive and resilient varieties. This will help the farmers to produce enough forage in the fast changing and stressful environmental conditions.

Key words: Characterization, *Cenchrus ciliaris*, drought, salinity, traits.

INTRODUCTION

Livestock producers in developing countries depend on rangelands' forage to feed their stocks (Msalya et al., 2017). The forages from these rangelands are, however, seasonally low in quality and quantity, and therefore negatively influence livestock productivity (Waterman et al., 2007). Butchart et al. (2010) observed that valuable local species are becoming rare, some disappearing or on the brink of extinction. Loss of diversity has consequences beyond just the extinction of species. Once local populations are wiped out, the genetic diversity contained in each species to adjust to environmental stresses is weakened; in turn the livestock production systems are also affected.

Livestock production systems in Tanzania like most

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other developing countries are facing losses in response to a number of drivers (Thornton et al., 2009). Environmental stresses are among the drivers that affect plant and animal productivity (Singh et al., 2011). The effects of these stresses to plants have been documented (Naqvi et al., 2015; Forni et al., 2017; Dzavo et al., 2019). The prevalent ones are those affecting plant water statuses (Claeys et al., 2014). According to Verslues et al. (2006), not having enough water potential for a plant to perform its biological roles can be caused by drought, extreme temperatures and salinity. Plants usually stimulate a complex cellular and molecular mechanism as adaptive response to stresses (Fahad et al., 2015). The United Nation Food and Agricultural Organisation (FAO, 2007) corroborates that wild plants distribution, species' range shifts and gradual biological changes are associated with responses to environmental stresses. Responses of plants to stress differ within and among species depending on stress intensity, stage of plant growth and duration of exposure to stress (Claeys et al., 2014). Availability of varieties and ecotypes of species with different levels of tolerance to environmental stresses is an opportunity for selection and breeding for stress tolerance. Selection and breeding of grasses with stress tolerance traits is inevitable across the globe amid escalating environmental stresses. This paper examines available literatures on plant characterization focusing on sustainable forage production in drought and salinity environments. Several forage species have been characterized but this paper will focus on agro-morphological, physiological and molecular characterization of *C. ciliaris*. The species is selected because it grows well in a wide range of soil types and climatic conditions and it has been adopted by farmers in different regions of Tanzania for pasture establishment. *C. ciliaris* is a perennial deep rooted, tufted and rhizomatous grass, traits which make it fairly adapted to heavy grazing and tolerant to drought (Jackson, 2005; Burson et al., 2012). The grass is wealth of natural ecotypes with morphological diversity which can be visually distinguished and rapidly screened (Burson et al., 2012). Morphological diversity of ecotypes signifies variability of response to environmental stresses hence the need to be characterised.

METHODOLOGY

The information search process was done using Google scholar, an internet- search engines which makes it easy to access online databases. Some of the databases accessed include African Journals Online, Directory of Open Access Journals, Emerald, JSTOR, Research4Life, Science Direct and Web of Science. Furthermore, publications from FAO and International Livestock Research Institute were searched and reviewed. Peer reviewed journal articles, conference papers, government reports, book chapters and thesis published from year 2002 to 2020 were considered for this review. Key words or search terms used were 'characterization', 'plant characterization', *'Cenchrus ciliaris'* 'forage'/ 'pasture'/ 'fodder'/, 'environmental stress', 'drought stress'/'water stress' and 'salt stress'/ 'salinity stress', 'molecular characterization', 'physiological characterization', 'agronomical characterization' and 'morphological characterization'. Screening of the papers was done by reading the titles followed by the abstracts and where relevant, a full document was read to extract facts, evidences and key messages. A total of 97 publications were recovered of which 19 were reports and book chapters, 78 were journal articles and conference papers. A total of 46 articles were removed of which 10 were abstracts and their full paper could not be accessed, 6 were duplicates and 28 were not relevant, remaining with 51 articles used in this paper.

FINDINGS AND DISCUSSION

The review findings show the description of plant characterization by scholars, approaches of plant characterization, characterization for drought tolerance, characterization for salinity tolerance, plant characterization endeavours in Tanzania, and the novelty of plant characterization.

Plant characterization as concept

There are several definitions or description of plant characterizations given by scholars. However, many scholars refer to it as an account for heritable characters varying from morphological, to molecular markers (Hassen et al., 2006; El-Esawi, 2019). A process which involves recording and compilation of data on important characteristics which distinguish one species from the other and accessions or varieties within species, to enable an easy and quick discrimination among phenotypes (Bioversity International, 2007). Plant characterization reveals desirable traits for both farmers and breeders (Mwenda, 2019; Bucheyeki et al., 2010; Laurentin, 2009). Ability to adapt to environmental stresses, varieties with better quality and high yield are among the desirable plant traits (Laurentin, 2009; Mwenda, 2019).

Approaches of plant characterization

The review reveals that there are several approaches to plant characterization. Substantial works could be sorted in the main approaches, which are agronomic, morphological, biochemical and physiological and molecular characterization.

Agronomic, morphological, biochemical and physiological characterization

Past reviewed works pointed out that visual assessment of growth forms and structure of plants in different types of soils and using variable amount of required nutrients is agronomical and morphological characterization (Jorge et al., 2008; Lima et al., 2018; Wassie et al., 2018). Ago-

Table 1. Phytochemical screening of extracts from different parts of the three ecotypes of *Cenchrus ciliaris* (▲indicates the presence and ◊ indicates the absence of the substances).

Bioactive groups	White			Green			Black		
	Stem	Leaf	Florets	Stem	Leaf	Florets	Stem	Leaf	Florets
Phenol	▲	▲	▲	▲	▲	▲	▲	▲	▲
Flavanoins	▲	▲	▲	▲	▲	▲	▲	▲	▲
Saponins	▲	◊	▲	▲	▲	▲	▲	▲	▲
Glycosides	◊	◊	◊	▲	▲	▲	◊	◊	◊
Steroids	▲	▲	▲	▲	▲	◊	◊	▲	◊
Alkaloids	▲	▲	▲	▲	▲	▲	▲	▲	▲

Source: Kannan and Priya (2020).

morphological traits include plant height, tiller number, tiller type, leaf size and number, internode distance; flower type, size and colour; root type and length. Agro-morphological traits are non-destructive parameters (Fuzy et al., 2019) and they describe plant morphologies efficiently (Blazakis et al., 2017). There are limitations on the use of agro-morphological traits for plant characterization such as limited number of traits to characterize, heritable traits showing insignificant variations and trait expression being influenced by environmental conditions, age and cultivation systems (Blazakis et al., 2017; Laurentin, 2009). Despite the limitations, morphological or visible descriptors remain important for identifying landraces to enhance selection and utilization. These descriptors will continue to be used especially in developing countries until sophisticated methods like molecular markers are easily accessible and affordable. Biochemical characterization refers to characterization based on the types of phytochemicals present in a plant in a given environmental condition, root electrical capacitance, membrane stability index in roots and leave, the amount of methane (CH_4) produced, dry matter and nutrient composition (Kannan and Priya, 2020; Fuzy et al., 2019). On the other hand, characterization of plants based on their functions such as their photosynthesis process, respiration gases produced and nutrient circulation is referred to as physiological characterization (Saini et al., 2007). Furthermore, transpiration rate, CO_2 assimilation rates, is some of physiological descriptors (Fuzy et al., 2019; Mansoor et al., 2015). The limitation of biochemical and physiological descriptors is that they use destructive measurement techniques (Fuzy et al., 2019). Saini et al. (2007) conducted morpho-physiological characterization study with four genotypes of *Cenchrus ciliaris*, two genotypes of *Cenchrus setigerus* and one genotype of *Panicum maximum* grass in an arid ecosystem. In their experiment, seven morphological characteristics and nutritive values were used for characterization. *C. ciliaris* cv. CAZRI 75 had higher total green fodder yield, DM and nutritive value. Based on their results *C. ciliaris* cv. CAZRI 75 was found to be of high potential among the studied grasses to be used in the arid regions of south-west Haryana India. On the other hand, Kannan and Priya (2020) characterised ecotypes of *C. ciliaris* on biochemical compounds found in different components. The ecotypes were grouped based on inflorescence colour variation (white, green and black). According to Kannan and Priya (2020) all ecotypes had the phytochemicals screened regardless of the part containing the compound, with exception of glycosides which were absent in white and black variants (Table 1). Phytochemicals composition is very much affected by environmental stresses, absence or presence of these compounds can be used as a measure the effects of stresses (Daniels et al., 2015).

Molecular characterization

Reviewed studies referred to characterization of organisms using DNA based markers as molecular characterization (Laurentin, 2009, Kumar and Saxena, 2016). The process of molecular characterization used by Ouédraogo et al. (2019) involved DNA extraction and quantification, purifying of the PCR products, sequencing followed by editing of the raw sequences and finally assembly of the readings to check their identity. Molecular markers are prominently used for evolutionary studies, evaluating interrelationship among accessions and among geographical groups. They are also potential for estimation of genetic diversity and identification of duplicates (Laurentin, 2009). It allows simple grouping of accessions, development of core collections, identification of gaps and retrieval of valuable germplasm for breeding programmes, resulting in better insight about the composition of the collection and its genetic diversity (Bioversity International, 2007).

Diversity is important if forage species are to adapt to different environmental conditions and provides a room for selection and breeding. Kumar and Saxena (2016) characterised eight species of genus *Cenchrus* (Table 2) based on their mode of reproduction. There was further characterization using Sequence Characterized Amplified

Table 2. Characterization of Cenchrus species based on mode of reproduction and ploidy status.

***Cenchrus* species**	**Accession number**	**Habit**	**Ploidy status**	**Mode of reproduction**
C. biflorus	IG-03308	Annual	Diploid (2n = 2x = 34)	Sexual
C. ciliaris	G-693108	Perennial	Tetraploid (2n = 4x = 36)	Apomictic
C. echinatus	IG-96377	Annual	Tetraploid (2n = 4x = 68)	Sexual
C. glaucus	IG-96649	Perennial	Tetraploid (2n = 4x = 36)	Apomictic
C. myosuroides	IG-96380	Perennial	Heptaploid (2n = 7x = 70)	Sexual
C. pennisetiformis	IG-96707	Perennial	Hexaploid (2n = 6x = 54)	Apomictic
C. prieurii	IG-97473	Annual	Diploid (2n = 2x = 34)	Sexual
C. setigerus	IG-01346	Perennial	Diploid (2n = 2x = 36)	Apomictic

Source: Kumar and Saxena (2016).

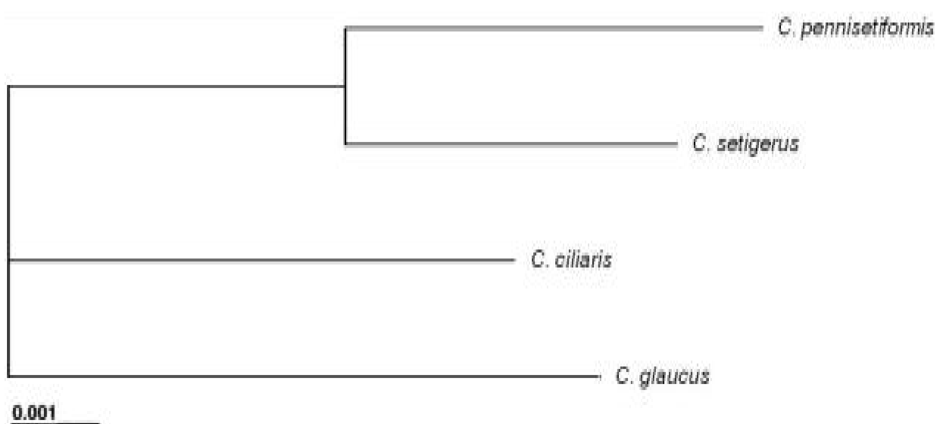

Figure 1. A dendrogram showing sequence diversity among the four apomictic *Cenchrus species* (Kumar and Saxena, 2016).

Regions (SCAR) markers within the apomictic group to establish their diversity. It was observed that *Cenchrus glaucus* had more genetic diversity than the other three species as shown in Figure 1. They concluded based on their research findings that identified markers would be useful for comparative studies and marker assisted breeding of *Cenchrus* (Kumar and Saxena, 2016).

Characterization for drought tolerance

Drought or soil moisture stress is characterised by periods of below average precipitation which are poorly distributed and has become more frequent and enormous problem worldwide (Dzavo et al., 2019; Forni et al., 2017). Drought has negative impact on species diversity, quantity, quality and reliability of forage as well as rangeland vegetation patterns (Giridhar and Samireddypalle, 2015; Nardone et al., 2010). For plants to colonize and continue surviving in drought affected areas need to adapt. Morphological adaptations like development of thick leaves and epidermal layer, waxy cuticle, complex root system and diverse set of molecular mechanisms allow plants to live in extreme conditions (Clauw et al., 2015; Nawazish et al., 2006). According to Acuna et al. (2012) a systematic study of morphological, physiological and biochemical characteristics that provide the ability to tolerate stress can lead to understanding the response of plants to water dearth. Furthermore, Acuna et al. (2012) pointed out traits which can be used in selection for drought tolerance including plant water status, stomata conductance and canopy temperature, spectral vegetation indices, chlorophyll fluorescence and water use efficiency. Understanding desirable traits for high output and drought tolerance is a step towards plant improvement through selective breeding. A study by Mansoor et al. (2002) on 16 biotypes of *C. ciliaris* from the germplasm in Pakistan was conducted to examine the effect of drought on agro-botanical and morpho-genetical characters. Although certain biotypes expressed good individual scores with regard to various characters, one excelled all in plant height, number of leaves, root length and fresh and dry weight. Based on their research findings, Mansoor et al. (2002) concluded that high volume root system is a good index to judge the level of drought tolerance. In another study on root morpho-anatomical adaptation for drought tolerance in *C. ciliaris,* Mansoor et al. (2015) reported the increase in root number, development of epidermis, endodermis and cortical parenchyma for drought tolerant ecotypes. Drought sensitive ecotypes expressed a decrease in all morphological and anatomical root characteristics (Mansoor et al., 2015). On the other hand, Nawazish et al. (2006) characterised two ecotypes of *C. ciliaris* based on their response to drought by treating them with 100, 75 and 50% field capacity of soil moisture levels. Ecotypes were collected from salt range of Punjab and irrigated soils of Faisalabad in Pakistan. From their results it was shown that the ecotype from salt range adapted better to moderate and high drought levels. The drought adaptive ecotype had increased leaf thickness, cuticle deposition and epidermal layer thickness but had reduced metaxylem area for efficient water transportation in adverse condition. Nawazish et al. (2006) concluded that highly developed bulliform tissue (responsible for leaf culling) and reduced stomata size on the upper surface of the leaf to prevent water loss are important leaf anatomical traits for adaptation to drought. Koech et al. (2014) characterized six range grasses (*Chloris roxburghiana, Eragrostis superba, Enteropogon macrostachyus, Chloris gayana, Soghum sudanense* and *Cenchrus ciliaris*) from the rangelands of Kenya. The aim was to evaluate the effect of different levels of moisture content (80%, 50%, 30% and rain fed) to seed yield of the six species. Among all species characterized, *C. ciliaris* expressed a potential for seed production even under moisture deficit by having no significant difference with the watered treatments (Koech et al., 2014). A good number of ruminants are lost in Sub-Saharan Africa in the periods of drought causing financial loss and food insecurity (Dzavo et al., 2019). Nardone et al. (2010) pointed out that drought affect production in terms of growth, yield and quality of forage produced. The negative effect of drought on forage pose a significant financial burden to livestock producers through decrease in milk component and milk production, meat production, reproductive efficiency and animal health (Naqvi et al., 2015).

Characterization for salinity tolerance

Studies revealed that accumulated salt in soils is a major constraint in agricultural production as it decreases the osmotic potential of the soil with resultant effects on plant water uptake (Roy et al., 2014; Verslues et al., 2006). More than 20% of cultivated land and about 62 million hectare of the world's irrigated soils have been affected by salt (Gupta and Huang, 2014; Fahad et al., 2015). In arid and semi-arid lands, soil salinity is caused by evapotranspiration, lack of leaching water and poor-quality irrigation water (Jouyban, 2012). Resultant effect of soil salinity is visible on seed germination, survival percentage, growth, yield and quality of plants. Report by Verslues et al. (2006) showed that salinity affect metabolism of carbon and nitrogen, assist the accumulation of toxic ions and alter uptake of ions especially K^+ and Ca^{2+} which are important nutrients for plant growth and development. Thus, the effects of salinity on plants can be summarized to include, water deficit due to high pressure on the root zone, ion toxicity and nutrient imbalance (Ronen, 2016). Plants develop physiological and biochemical mechanisms in order to survive in salt affected areas (Gupta and Huang, 2014). Some plant species have moderate salt tolerance and are capable of providing 5 to 10 tonnes of edible dry matter (DM) year^{-1}, at the lower levels of salinity (<15 dS m^{-1}) particularly when the availability of water is high (Masters et al., 2007). Production levels drop and the plant options decrease significantly at high salt concentrations (>25 dS m^{-1}). Al-Dakheel and Hussain (2016) conducted a study in Dubai on genotypic variation for salinity tolerance on 160 accessions of *C. ciliaris.* The levels of salinity used were 10, 15 and 20 dS m^{-1} and 0 for a control and the trait tested for salinity tolerance was biomass yield. Their results revealed that a number of accessions could be grouped in one cluster due to their similar response to salinity levels. Out of 160 accessions characterized, only 12 were stable, salt tolerant and produced a good dry biomass yield, suggesting their potential to contribute to the improvement of grass crops through genetic mechanisms in saline areas (Al-Dakheel and Hussain, 2016). There have been developments in this area with purposes to produce stress tolerant species. A study by Lopez et al. (2011) targeting to obtain a new *C. ciliaris* germplasm that would tolerate salinity and drought was conducted through induced physical and chemical mutation and invitro selection. 500 mature seeds of *C. ciliaris* were subjected to treatment with x-ray (400 Gy) or ethyl methanesulfonate water solution (EMS), 5.5 mM for 24 h. After 7 days germinated seeds were subjected to NaCl and mannitol to simulate salinity and drought respectively. 20 seedlings grown from seeds treated with x-ray tolerated up to 200 mM NaCl, 8 tolerated up to 100 mM mannitol. 21 seedlings grown from seeds treated with EMS tolerated up to 200 mM NaCl and 5 tolerated up to 100 mM mannitol. Hence, a total of 54 tolerant plants were obtained from induced mutation. According to Lopez et al. (2011), 10 plants out of 54 tolerant plants obtained indicated polymorphism with respect to the control cv Biloela using RAPD technique. Only 5 among the polymorphic plants exhibited morphological modification under *ex vitro* conditions.

Studies on forage species characterization in Tanzania

Several studies on plant characterization have been conducted in Tanzania but these studies have been biased on food crops. Gramineae family (a family were forage grasses belong) selected as examples of characterized food crops in the country are Mangosongo et al. (2019), Dolo (2018), Fisher et al. (2015) and Bucheyeki et al. (2010). Mangosongo et al. (2019) characterized four wild rice populations based on their agro-morphological traits. Their result indicated a wide range of variation for all traits studied among and within populations. The variation in agro-morphological traits presents an opportunity for selection and breeding. A study by Dolo (2018) evaluated the response of 8 rice genotypes to salinity at levels of 0, 50 and 100 mM NaCl. Reduction in physiological traits, ion accumulation and dry matter content of rice were used to distinguish salinity tolerant and susceptible genotypes. The study used marker assisted selection technique to identify salinity associated traits in order to increase selection efficiency and accelerate breeding process. One of the 8 studied genotypes was found tolerant to salinity and was used as a donor parent to improve salinity susceptible genotypes. According Dolo (2018), improved genotypes were more tolerant to salinity than the parent genotypes. Bucheyeki et al. (2010) characterized 40 sorghum landraces from Tanzania and 2 from Zambia. The aim was to determine genetic relationship among landraces and to assess important agronomic traits. Their study observes 78.6% total variability among the races. Bucheyeki et al. (2010) concluded based on their research findings that molecular markers undoubtedly separated landraces within and between groups than morphological markers. On the other hand, a report by Fisher et al. (2015) showed that 25% of maize crop cultivating areas in Africa suffers frequent drought with losses of up to half the harvest. Drought tolerant maize developed after a process of screening, selection and breeding enhanced by information on desirable traits were disseminated to 13 African countries including Tanzania. There was limited adoption of drought tolerant maize seed by famers which varied considerably between countries. Among the factors that hindered fast adoption of drought tolerant maize seed by farmers was limited knowledge on beneficial traits harboured in those new maize seed (Fisher et al., 2015). Farmers and breeders need reliable information to make informed decisions for selection and breeding of forage plants. As it was pointed out earlier, when desirable traits of species, varieties or ecotypes are properly understood, makes a good step towards selection and breeding for environmental stresses. Conversely, there is limited work on range grass characterization for environmental stresses in Tanzania thus deliberate efforts from researchers is required if we are to attain sustainable forage production amid environmental challenges

The novel of plant characterization

With advancement of agricultural and allied science and technology, still the ability to feed the increasing number of both human and livestock in the next twenty years is uncertain, particularly because of the challenging environmental conditions. The demand for good quality soils to produce food crops and fruits has escalated, pushing production of forage crop to marginal lands with a multitude of environmental challenges (Acuna et al., 2012). In this perspective, the ability of forage plants to tolerate environmental stresses is an indispensable character. Various strategies to optimize the reliability and resource use for increased forage demand have been proposed (Busby et al., 2017). Plant characterization is one of priority areas expected to contribute in ensuring adaptive and productive characters are identified and appropriately utilized to enhance plant productivity. Plant breeders will easily access and utilize this information to develop new productive plants of improved tolerance to environmental stresses (El-Esawi, 2019). Govindaraj et al. (2015) suggested that application of plant characterization will lead to long-lasting increased productivity and benefit the environment. It is explicitly that plant characterization can lead to capturing of plant genetic diversity; store it in the form of plant genetic resources like the gene bank and DNA library for long period. The conserved plant genetic resource is readily available materials to be utilized for crop improvement in order to meet future global challenges in relation to food and nutritional security. The use of genetic resources is limited by inadequate essential information on phenotypic and genotypic characters (Shantharaja et al., 2015).

Since plant breeding research and cultivar development are integral components of improving food production, therefore, availability of and access to information on diverse genetic and phenotypic sources will ensure that the global food production network becomes more sustainable (Govindaraj et al., 2015). It was denoted by Hoffman (2010) that, most tropical adapted varieties are essentially uncharacterized and the characterized plants ended at species level documenting a specie’s response to different levels and types of stress. On the other hand, there are variations of characters within species important for development of stress resistant cultivars and varieties (Jorge et al., 2008; Acuna et al., 2012). Understanding of adaptation in stressful environments and optimal utilization of the adaptation traits harboured in all breeds needs to be strengthened for the sustainable livestock forages production.

Conclusion

Evidence on substantial decline in livestock feeds quality and quantity due to environmental stresses calls for appropriate strategies to optimize reliability of forage production with scarce resources. Drought and salinity threaten the sustainability of forage production by negatively impacting plant growth and productivity. A good knowledge of response variation among and within forage species to stress is required to facilitate identification of effective tolerance mechanism. It is worthy taking advantages of available tools and technologies like plant characterization to improve plant selection and breeding targeting adaptable traits to environmental stresses. Agro-morphological, physiological, biochemical and molecular characterization are among the approaches used to generate information on desirable plant traits. *C. ciliaris,* a forage species focused on in this review, revealed its ability to adapt to drought and salinity, stresses which affect water potential for a plant to perform its biological roles. Its adaptation was enhanced by a complex root system, reduced stomata size on the upper side of the leaf, increased leaf thickness, cuticle deposition, epidermal layer thickness and reduced metaxylem area for efficient water transportation. It is through this process that plant characterization fast track systematic information generation to assist plant breeders to efficiently select adapted plants to specific environmental stresses. Limited literature on forage species characterization in Tanzania call for deliberate efforts from researchers in this area.

CONFLICT OF INTERESTS

This review paper is a part of a PhD research work in Animal Science at Sokoine University of Agriculture.

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