

Full Length Research Paper

Ecological effects on the flowering phenology of *Cenchrus ciliaris* L. collections from the arid and semiarid lands of Kenya

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Flowering is critical in plant ecology. Through flowering, plants evolve into new plant species that are better adapted to environmental variations. *Cenchrus ciliaris* is an important forage grass in Kenya, which is drought tolerant but is increasingly becoming depleted in grazing areas requiring reseeding. To identify suitable germplasm for such initiatives, collections from varied ecologies were evaluated at Kiboko to assess any adaptive morphological traits, particularly flowering related, that they may have been acquired in their evolution. Significant variation in days to start flowering (DSF) and days to full flowering (DFF) were observed between sites of ecotype origin and among the ecotypes. Ecotypes collected from Kilifi flowered significantly earlier than those from Kiboko while one Magadi ecotype, MGD3, was late flowering despite being collected from an arid zone. DSF was negatively correlated ($p \leq 0.001$) to percent fertile tillers and the number of inflorescence per plant. Inflorescence length was positively correlated ($p \leq 0.05$) to the number of spikelets per inflorescence but negatively correlated ($p \leq 0.001$) to the percent fertile tillers. There was a trade-off between plant size and period to flowering where early flowering ecotypes were smaller in size and vice versa. However, a unique ecotype that defied the trade-off, MGD1 from arid agro-ecological zone VI, with both early flowering and robust traits was identified. Findings from Magadi collections indicate that collections from special niches may not be applied as wide area adaptations, especially with regard to drought tolerance. The early flowering trait of some of the ecotypes matched results from various studies involving a wide range of crops other than grasses. The findings of the study provide opportunities for further selection and breeding work.

Key words: Grasses, *Cenchrus ciliaris*, ecotype, flowering, grass reseeding.

INTRODUCTION

Grass reseeding in arid and semi-arid areas has been promoted for adoption as an option for rehabilitating

denuded lands. Among the commonly promoted grasses is *Cenchrus ciliaris*, (*African foxtail grass*) which is well

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adapted, grazing resistant, persistent and extremely drought tolerant with good response to both small and large rainfall amounts. It is mostly preferred by livestock due to its high nutritive value and herbage yield (FAO, 2012). The species is apomictic resulting in insignificant intra-variety variation. This has led to the selection of true breeding genotypes from ecotypes that are highly variable in traits of both ecological and agronomic importance due to adaptation to multiple environments (Boonman, 1993; Arshad, 2007). The species has been evaluated in various studies for reseeding potential (Mnene, 2006; Kirwa et al., 2010), allelopathic effects (Kirwa et al., 2012), performance in mixtures (Mganga et al., 2010a) and seed and herbage yields (M'seddi, 2005; Visser et al., 2008). Studies on morphological characterization of accessions of *C. ciliaris* resulted in various groupings particularly using variation in plant size and flowering time (Pengelly et al., 1992; Jorge et al., 2008). Examples of commonly known cultivars from selections include the American and Gayndah for medium height and early flowering and Biloela and Molopo as tall and late flowering varieties. Despite the progress made in selection and release of varieties of *C. ciliaris*, this benefit is yet to be felt in Kenyan arid and semiarid lands (ASALs). Although the species is widely cultivated in the agro-pastoral parts of the Southern rangelands of the country for both seed and herbage production, this is being done using the wild collections resulting in an informal seed marketing system. This study aimed at evaluating collections of *C. ciliaris* on various traits, particularly variation in flowering phenology.

Flowering time has been used as a trait of importance in the development of cultivars for various plant species. It is critical in plant ecology and may determine the presence or absence of a species in a community (Craine et al., 2011). Variation of flowering time between plant populations is an effective way for their isolation in the speciation process. Flowering phenology is affected by a wide range of genetic and environmental factors (Rathcke and Lacey, 1985). It is variety specific (Hauser and Weidema, 2000), but can also evolve as an adaptation to environmental conditions, such as edaphic properties (Antonovics and Bradshaw, 1970; Rajakaruna, 2004), grazing (Reisch and Poschlod, 2011), pollinator presence or other climate related factors such as temperature and drought. Correlation between flowering time and latitude of plant population origin has also been established (Stinchcombe et al., 2004; Novy et al., 2013). While studying the effect of management on grasslands, Reisch and Poschlod (2011) found that mowing resulted in earlier flowering populations than grazing. In another study by Macnair and Gardiner (1998), edaphic factors resulted in early flowering serpentine endemic species *Mimulus pardalis* and *Mimulus nudatus*, and copper-mine endemic *Mimulus cupriphilus* from *Mimulus guttatus*. On the other hand, the observed global climate change with

increasing temperature is resulting in reduced time to start flowering in plants (Cleland et al., 2006; Bloor et al., 2010). The increasing temperatures have been linked to reduction in flowering time by 4.5 days in 385 plants species, studied for 4 years in South Central England (Fitter and Fitter, 2002). Similar findings were recorded by Bloor et al. (2010).

This study evaluated 11 ecotypes of *C. ciliaris* collected from different agro-ecological zones in Kenya for identification of unique important genotypes that could be registered and used in a formal seed system. The main assessment was with regards to flowering time and related traits.

MATERIALS AND METHODS

Ecotypes collection

The study involved collection of grass seeds and tuft splits of *C. ciliaris* from the wild in four agro-ecological zones (AEZ), represented by Kilifi, Taita Taveta, Makueni and Kajiado counties for AEZ III, IV, V and VI, respectively (Mganga et al., 2010b). The targeted collection sites per county were Kilifi, Taveta, Makindu and Magadi districts, respectively. Three sites were purposively selected in each of the target sites of ecotype origin and actual collections done. Samples of 20 plants per species were harvested in each site using randomly stratified technique (Guarino et al., 1995), where seeds were not available or available in small quantities, tuft splits were uprooted as collections. The collections were made in July to September 2012 (Table 1).

Study site

The study was carried out at KALRO's Arid and Rangelands Research Institute (ARLRI) - Kiboko Centre pasture plots located in Makindu Sub-County in the semi-arid County of Makueni, Kenya. Kiboko Research Centre is located 160 km South East of Nairobi on Longitudes 37° 83'E, latitudes 02° 28'S and an altitude of 975 m above sea level. The area receives a bi-modal rainfall pattern with the long rains occurring in March to May and short rains in October to December. The dry seasons come in the months of January to February (short dry season) and June to October (long dry season). The annual mean rainfall and temperature are 534 mm and 23.4°C, respectively (Ndathi et al., 2011).

Planting and field management

Seeds were planted in plastic germination trays in September 2012 and seedlings transplanted after one month to 4 by 4 m un-replicated plots. Individual plants were spaced at 1 and 0.5 m between and within rows, respectively. In cases where tuft splits had been collected, they were directly transplanted to the experimental plots. The target was to have 45 plants per plot per ecotype. The plots were irrigated once a week during the dry seasons. Standardization through cutting of the herbage to 5 cm was done in May 14th 2013 and repeated in September 2013. From then on, data were collected on the regrowth following successive harvest of entire plot herbage. Nitrogen fertilizer at 100 kg N per ha was applied 7 to 10 days after every cutting. The September harvest has been used as the first cut (C1) data in this paper. Cut 2 and 3 (C2 and C3) was a result of 2 other consecutive cuttings (Table 2). C1 data was collected during the dry season while C2

Table 1. Ecotypes of *Cenchrus ciliaris* and description of site of origin.

No.	Collection No/ Ecotype	Site of ecotype origin	GPS point	Altitude (m)	Rainfall (mm)	Temperature (°C)	Management/use
K1	CeciKBK 1	Kiboko	37M 0356997 UTM 9754961	900	575	14 - 35	Controlled grazing land
K 2.	CeciKBK 2	Kiboko	37M 0364664 UTM 9742932	1059	"	"	Riverine, grazing land
K 3.	CeciKBK 3	Kiboko	37M 0358340 UTM 9751011	900	"	"	Controlled grazing land
K 4.	CeciKLF 1	Kilifi	37M 0592230 UTM 9602470	49	1200	20 - 31	Continuously grazed individual land
K 5.	CeciKLF 2	Kilifi	37M 0588462 UTM 9609848	97	"	"	Edge of cultivated land
K 6.	CeciKLF3	Kilifi	37M 0591436 UTM 9583080	32	"	"	Frequently mowed Sisal farm
K 7.	CeciMGD 1	Magadi	37M 0206621 UTM 9799034	822	600	28.6 – 32.9	Open communal grazing land
K 8.	CeciMGD 2*	Magadi	37M 0209795 UTM 9805824	856	"	"	Open communal grazing land
K 9.	CeciMGD 3	Magadi	37M 0206631 UTM 9781498	810	"	"	Controlled communal grazing land
K 10.	CeciTVT 1	Taveta	37M 0360211 UTM 9623156	770	440	20 -30	Edge of cultivated land with controlled grazing
K 11.	CeciTVT 2	Taveta	37M 0361675 UTM 9632568	908	"	"	Open grazing land
K 12.	CeciTVT 3	Taveta	37M 0362386 UTM 9637556	922	"	"	Edge of irrigation canal with minimal grazing

*not included in the study.

and C3 were on a rainy season. C3 received high intensity rainfall, although it was expected to be a short dry season. The time to cut was dependent on the conditions of the subsequent season, following Visser et al. (2008) who also worked with *C. ciliaris* ecotypes. For instance, C2 was done at the beginning of the short rains.

Data collection

Flowering, defined as emergence of an inflorescence per plant was recorded daily from the date of each cut. The total number of plants that had flowered per plot was recorded daily until all the plants in the plot had flowered. The days to the first plant flowering was recorded as the days to start flowering (DSF), days to all plants in the plot flowering as days to full flowering (DFF) and the days from DSF to DFF as the flowering period (FP). Collection of all the other plant growth attributes was done in one season (C2) to reduce variations due to environmental effects in characterization data (Van de Wouw et al., 1999). Measurements were done in ten randomly selected plants per ecotype as also recommended by Van de Wouw et al. (1999) (Table 3). Where measurements targeted parts of a tiller such as leaf or stem thickness then ten observations were done on ten randomly selected plants. Leaf attributes

were recorded on the second leaf below the flag leaf.

Data analysis

Data analysis was performed using Genstat 15th edition analysis tools (Payne et al., 2012). Data for the flowering traits (DSF, DFF and FP) for the 3 cuts were subjected to analysis of variance (ANOVA) and their means separated using least significant difference (LSD). These means were then used to generate a principal components analysis and to develop a similarity matrix whose output was used to produce hierarchical cluster analysis. Finally, the means of all the plant measurements for the different ecotypes were subjected to correlation analysis.

RESULTS AND DISCUSSION

Variation in flowering between cuts

There was significant variation ($p \leq 0.05$) in DSF among the 3 cuts. The number of DSF reduced with increase in the growth cycle of the ecotypes

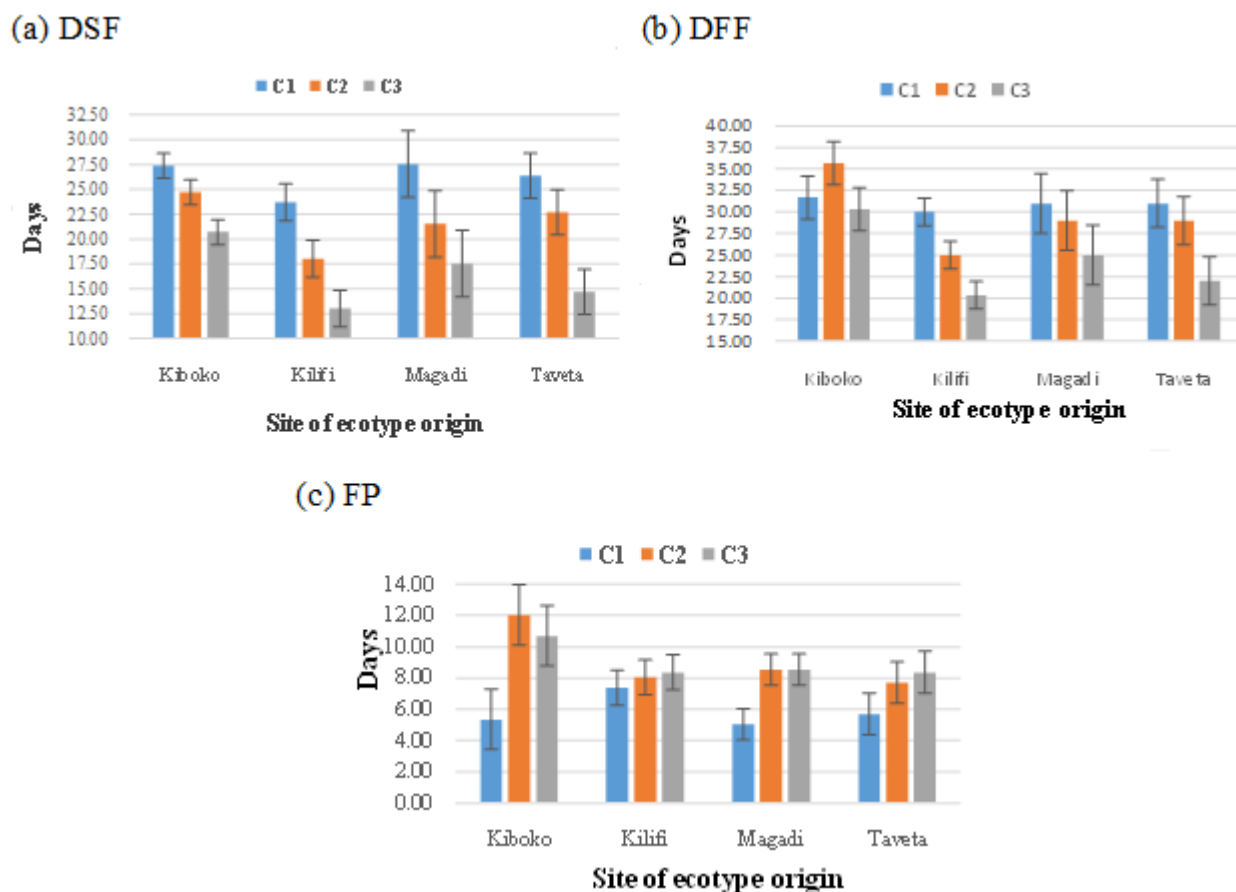
or change from one cut to the successive one (C1 26.1^a, C2 21.7^b and C3 16.4^c; $P \leq 0.001$; coefficient of variation (CV)=11.2%). Similar trends are indicated within sites of ecotype origin analysis (Figure 1a) where C3 remained significantly lower than C1 in all the sites. The trends in variation on DFF were similar to DSF. It took significantly fewer days to reach DFF in C3 than in both C1 and C2 (C1 30.9.1^a, C2 29.7^a and C3 24.4^b $P \leq 0.001$; CV=9.9%). Kiboko collections had significantly ($p \leq 0.05$) longer DFF and FP than the rest of the ecotypes in C2 (Figure 1b and c).

Flowering period in C1 was significantly ($P \leq 0.001$) shorter (5.9 days) than C2 and C3 with 9.1 and 9.0 days, respectively. This probably indicated uniformity to flowering pattern among the ecotypes than in the other two cuts. Kiboko and Magadi collections had similar trends in FP. Their flowering period in C1 was significantly shorter than C2 and C3 (Figure 1c).

The variation in DSF between cuts could be attributed to differences in temperatures during

Table 2. Cutting dates, rainfall amounts and length of preceding growing periods.

	Cut 1	Cut 2	Cut 3
Cutting date	11-09-2013	6-11-2013	14-02-2014
Number of days between cuts	55	99	67
Rainfall amounts (mm)	Irrigated	172.9	203.6

**Figure 1.** Mean of DSF, DFF and FP and LSD^{0.05} for sites of ecotype origin at different cuts (a) DSF, (b) DFF, (c) FP; C1=cut 1, C2=cut 2 and C3 = cut 3.

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The variation in DSF between cuts could be attributed to differences in temperatures during the three periods (C1, C2 and C3) of data collection. These results could be explained by findings of several other workers who worked on different plants species and populations. Mean monthly temperatures in Kiboko are above the annual mean from October to June except December and February to March temperatures are normally the highest (Ndathi et al., 2011). Cong and Brady (2012) noted that temperatures significantly affect the length of the growing

Table 3. List of morphological characteristics used in data collection and their descriptions.

Growth stage	Morphological characteristic	Description	Units	No. of observations
Full bloom	1. Flag leaf length	From the ground to the tip of the flag leaf	cm	10 Plants
	2. Plant height	From the ground to the tip of inflorescence	cm	10 Plants
	3. Stem thickness	Average culm diameter above the lowest node	mm	10 Observations
	4. Number of nodes	Count of all nodes in 1 randomly selected tiller per plant	No.	10 Observations
	5. Leaf length	Ligule to the tip of the leaf	cm	10 Observations
	6. Leaf breadth	Width of leaf at widest point	mm	10 Observations
	7. Days to start and days to full flowering	Daily record of no. of flowering plants per plot from the time of cutting	No.	Whole plot
Seed maturity	8. Total tiller number	Count of all tillers on a plant	No.	10 Plants
	9. Inflorescence count	Count of all panicles on a plant	No.	10 Observations
	10. % Fertile tillers	Tillers with panicles as a percentage of all tillers on the particular plant	%	
	11. Inflorescence length	From the lowest cluster to the top of bristle	cm	10 Observations
	12. Spikelet number	Count of all spikelets on an inflorescence	No.	10 Observations

Table 4. Mean of DSF, DFF and FP in relation to the site of origin of *Cenchrus ciliaris* ecotypes.

SITE	DSF	DFF	FP
Kiboko	24.2 ^{a*}	32.6 ^a	9.3
Magadi	22.2 ^{ab}	28.3 ^{ab}	7.3
Taveta	21.2 ^{ab}	27.3 ^{ab}	7.2
Kilifi	18.2 ^b	25.1 ^b	7.9
P value	<.001	<.001	n.s
LSD	2.46	3.27	1.93
CV (%)	11.2	11.3	23.5

*Column means with different letter superscript significantly different at P values≤0.001.

seasons. The previous month's temperature has the greatest effect on flowering (Fitter and Fitter, 2002). Cleland et al. (2006), in studies on possible effects of global warming, found out that increase in temperature reduces the time to start flowering. Also, while assessing effect of manipulated climatic conditions, Bloor et al. (2010) recorded acceleration in flowering by 3.2 days per degree

rise in warming.

Variation in flowering between sites of ecotype origin

Comparison between sites of ecotype origin on DSF indicate that Kilifi (KLF) collections started to

flower significantly ($P \leq 0.001$) earlier than Kiboko's (KBK) (Table 4). Magadi (MGD) and Taveta (TVT) collections on the other hand were not significantly different in DSF to either KLF or KBK collections. Similar results were recorded with DFF while there were no significant differences in FP between the sites of origin.

However, results within the cuts indicated that

Table 5. Mean and ranges of DSF, DFF and FP for two major clusters developed using Hierarchical cluster analysis.

Group	Ecotypes	DSF	DFF	FP
Early flowering	KLF1, KLF2, KLF3, TVT1, TVT2 and MGD1	17.2 (17 - 20.7)*	25.6 (24 - 26.7)	7.4 (6.3 - 8.7)
Late flowering	KBK1, KBK2, KBK3, MGD3, TVT3	24 (22. - 25.7)	31.6 (29.7 - 34.7)	8.7 (7 - 11.3)
	P value	<.001	<.001	0.106
	Grand mean	21.4	28.3	8.0
	LSD	1.98	2.28	1.69
	CV (%)	6.8	5.9	15.4

*Range of the mean.

Kiboko collections significantly ($p \leq 0.05$) took longer (FP=12 days) to reach full plot flowering in C2 than the rest which were at 7.7, 8 and 8.5 for TVT, KLF and MGD collections, respectively. Also, Kiboko (35.7) collections had significantly the highest DFF than KLF (25) in C2. Similar results were recorded with DSF in C2 and C3 (KBK 20.7; KLF 13 days; $p \leq 0.05$). The TVT (14.7 days) collections also flowered earlier than Kiboko in C2. From these results, KLF collections are seen to be early flowering ecotypes hence implying that DSF and DFF are related to the site of ecotype origin. This was confirmed by cluster analysis using the three flowering attributes (DSF, DFF and FP) (Table 5). All KLF and KBK collections clustered in Groups 1 and 2, the early flowering and late flowering group, respectively.

Days to start flowering (DSF) is related to the prevailing environmental conditions of the site of ecotype origin (Boonman, 1993) and has a strong relationship with the length of growing season. Late heading implies long growing seasons and vice versa. Plants in long growing seasons would spend more time in exponential growth phase and thus accumulate disproportionately more resources which is also reflected in the reproductive phase (Franks et al., 2006). However, under short seasons, late flowering plants are disadvantaged with seed setting occurring during unfavourable conditions. Such conditions have led to an escape mechanism of flowering early (Franks et al., 2006; Wissman, 2006; Boonman, 1993). This is described as a conservative strategy in “bet-hedging evolutionary theory” (Childs et al., 2010) and plant species do optimize fitness with regards to prevailing environmental conditions. Although the site for origin for KLF1, KLF2 and KLF3 receives the highest rainfall as compared to all the other sites and with potentially longer growing periods, grazing for KLF1 and 2 and mowing for KLF3 could have led to early flowering. KLF1 and KLF2 were collected from unprotected grazing areas adjacent to cultivated areas and KLF3 from a sisal plantation that is periodically mowed.

Early flowering is adaptive in environments with highly variable resource availability (Houle, 2002) and allows successful allocation of resources to reproduction before the onset of the harsh environmental conditions (Latta

and McCain, 2009). It is an escape mechanism to a predictable disturbance, such as drought (Franks et al., 2006), grazing (Wissman, 2006) or light in case of other plant’s canopy cover. Levin (2009) notes that selective divergence in flowering time is associated with tolerance to marginal habitats.

Early flowering has been observed to occur in certain ecotypes as an adjustment to terminal drought occurrences. For instance, Franks et al. (2006) observed that in an extreme drought event in 2000 to 2004 that resulted in a shortened growing season, descendant ecotypes of *Brassica rapa* significantly shifted to early flowering when compared to their ancestors. Similarly, Craufurd and Wheeler (2009) reported late flowering genotypes of sorghum that reduced their optimum flowering time by about 20 days due to reduced rainfall amounts and consequently the growing seasons. However, caution is made against treating escape from drought as drought tolerance (Boonman, 1993).

It was clear from this study that KLF collections (3.6° S) are from the more southern latitudes and, therefore, more distant from the equator compared to KBK (2.2° S) collections, an observation similar to several other previous findings (Rathcke and Lacey, 1985; Stinchcombe et al., 2004; Novy et al., 2013). These authors reported close relationship between the sites of ecotype origin, especially latitude, with flowering attributes. Our results also agree with those of Stinchcombe et al. (2004) who found ecotypes of *Arabidopsis thaliana* from the more Northern latitudes flowering later than those from less Northern latitudes. On the contrary, Novy et al. (2013) reported that the more northern latitude collections of *Microstegium vimineum*, an annual grass were earlier flowering and small-sized with lower biomass.

Variation in flowering between ecotypes

a) DSF between ecotypes

The ranges for DSF were 17 (for KLF 3) to 25.7 days (for KBK2), with a significant ($p \leq 0.001$) variation among the

Table 6. Mean of days to start flowering for each *Cenchrus ciliaris* ecotype in different cuts.

ECOTYPE/ CUT	KLF1	KLF2	KLF3	TVT1	TVT2	TVT3	MGD1	MGD3	KBK1	KBK2	KBK3
Sep-Oct	22	27	22	29	24	26	26	29	27	29	26
Nov-Dec	18	18	18	19	23	26	18	25	25	26	23
Feb-Mar	12	16	11	14	13	17	16	19	21	22	19
Mean*	17.3 ^{bc}	20.3 ^{abc}	17 ^c	20.7 ^{abc}	20 ^{abc}	23 ^{ab}	20 ^{abc}	24.3 ^a	24.3 ^a	25.7 ^a	22.7 ^{abc}

CV=9.3%; LSD=3.37 days; *Row means with different letter superscript are significantly different at P value≤0.001.

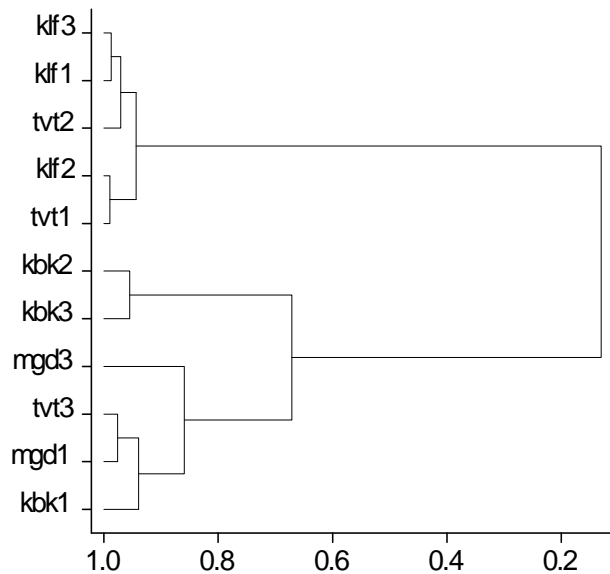


Figure 2. Dendrogram of 11 ecotypes of *C. ciliaris* based on robust related characteristics developed.

ecotypes (Table 6). Also, KLF1 and KLF3 flowered significantly ($p \leq 0.001$) earlier than MGD3, KBK1 and KBK2. Ecotypes from the same site of origin did not differ in DSF.

Genetic differentiation in flowering time has been established between populations of different plant species (Boonman, 1993; Craine et al., 2011). As expected, long DSF produced most robust plants, that is, tall plants, long and broad leaves, thick stems with many nodes. The results were confirmed by cluster analysis using robust related traits where two cluster groups were formed (Figure 2). All Kiboko and Magadi ecotypes were grouped in the robust cluster together with TVT3 while all Kilifi ecotypes and TVT1 and TVT2 were clustered as small size. All the late flowering ecotypes were in the robust group, except MGD1, which is an early flowering ecotype. Generally, early flowering plants even in other crops such as soybean are associated with inferior yields under long no-stress seasons because they are unable to fully utilize the seasonal potential (Kuol, 2004). The small size and early flowering are described as features for dehydration-avoidant phenotype by Blum (2005) resulting

from a trade-off between allocation of resources to vegetative production and reproduction (Gardner and Latta, 2008). Plants growing under drought conditions have their leaves mature at smaller size than well watered plants (Chaves et al., 2003). Generally, late flowering grasses are associated with superior herbage yields (Boonman, 1993) and also with higher leaf tissue density Craine et al. (2011).

The expected trade-off between plant size and period to flowering (Zopfi, 1995; Colautti et al., 2010) did not occur in MGD1. The ecotype which was collected from the edges of a dry sandy stream in association with short *Acacia spp* and *Aristida spp* about 10 km from Lake Magadi exhibited early flowering but robust related traits. Although, the ecotype seemed to have moisture stress avoidant trait, which is early flowering as well as having been collected from an arid agro-ecological Zone VI, it should not be assumed to be drought tolerant especially because of its special habitat. The early flowering nature could be due to the arid conditions of the site of ecotype origin. High evaporation rates probably results in soil moisture being available only during the short periods of rains and thus an escape through early flowering. On the contrary, MGD3 ecotype collected at the end of a flooding valley in Magadi was late flowering probably because it was grazed late since the area was strictly used as dry season grazing land for the pastoral Maasai community. While selecting ecotypes for *Chloris gayana* at Kitale Research Station in Kenya, Boonman (1993) found a strong relationship between flowering time and rainfall patterns in sites of population origin and not to drought tolerance. Ecotypes from semi-arid zones (*Kapedo*, *Mpwapwa* and *Rongai*) flowered earlier than humid zone collections (*Pokot* and *Masaba*) due to the short rainy seasons in their sites of origin. The former were from Zone III/IV while the latter were from Zone II/III corresponding to semi-arid and humid conditions, respectively. But, he noted that the *Pokot Rhodes*, a robust and very late heading variety was initially thought to be drought tolerant due to arid conditions of collection region. But, it was later discovered to have been collected from the moist cool parts of the region. The MGD1 results indicated that it is possible to select for early and robust ecotypes of *C. ciliaris*. Also, further studies on its extent of tolerance to drought conditions needs to be done. The positive correlation with the

Table 7. Mean of days to full flowering for each *Cenchrus ciliaris* ecotype in different cuts.

ECOTYPE/ CUT	KLF1	KLF2	KLF3	TVT1	TVT2	TVT3	MGD1	MGD3	KBK1	KBK2	KBK3
Sep-Oct	29	31	30	32	29	32	30	32	33	32	30
Nov-Dec	25	25	25	25	29	33	25	33	38	35	34
Feb-Mar	18	24	19	22	18	26	24	26	33	33	25
Mean	24 ^c	26.7 ^{abc}	24.7 ^c	26.3 ^{bc}	25.3 ^{bc}	30.3 ^{abc}	26.3 ^{bc}	30.3 ^{abc}	34.7 ^a	33.3 ^a	29.7 ^{abc}

CV=9.9%; LSD=4.771; Column means with different superscript are significantly different at $P \leq 0.001$.

number of nodes is similar to results by Zopfi (1995) and Pleines et al. (2013) who worked with *Rhinanthus* spp. Zopfi (1998) noted that the number of internodes was a very stable trait that is not affected by management regimes.

There was a positive correlation between inflorescence length ($p \leq 0.01$) and the number of spikelets per inflorescence ($p \leq 0.05$) but negative to the percent fertile tillers ($p \leq 0.001$) (Appendix 1). This implies that the late flowering ecotypes produce more spikelets per inflorescence than early flowering ecotypes. This is further an indication of a mechanism by the early flowering to compromise in resource allocation to growth. Faba beans are known to escape droughts through early flowering and short grain filling periods to optimize production under unfavourable conditions (Kuol, 2004). In other studies on flowering time genes in rice, Heading-date 1 (Hd1) and Early heading date 1 (Ehd1) were found to reduce the number of primary branches in a panicle, resulting in reduced spikelet numbers per panicle (Naokuni and Izawa, 2011). These findings could probably explain the low spikelet number results in early flowering given that the two species are in the same Gramineae family.

Number of fertile tillers and spikelet number per fertile tiller are the 2 main components contributing to potential seed yield (Boelt and studer, 2010). Days to start flowering (DSF) was strongly negatively correlated ($p \leq 0.001$) with percent fertile tillers and the number of inflorescence per plant. This means ecotypes that flowered early had higher percent fertile tillers. Although, this could imply that the seed yield potential for the early flowering ecotypes is high, there was no significant correlation between DSF and seed yield in the study. The high number of fertile tillers and thus high inflorescence number in early flowering ecotypes is not in agreement with findings by Zopfi (1995) where there was a trade off on the number of flowers with early flowering in *Rhinanthus glacialis* herb.

Days to full flowering (DFF) between ecotypes

There was a significant difference ($p \leq 0.001$) between ecotypes in DFF (Table 7). KLF1 and KLF3 had full plot flowering significantly earlier than KBK1 and KBK2. There

was no variation between ecotypes from the same site of origin. These results are further depicted by the flowering patterns of the ecotypes in C3 (Figure 3). A clear isolation of KBK1 and KBK2 as late flowering in the cuts is shown.

Days to full flowering (DFF) was significantly positively correlated with DSF ($p \leq 0.001$) and FP ($p \leq 0.05$). This indicates that ecotypes with delayed DSF, took longer to reach DFF and the FP was also longer. This is shown by the curves in Figure 2. As an escape mechanism, early flowering within the shortest time is necessary to avoid an impending disturbance as opposed to flowering with abundant resources to allocate. Variation in individual plant flowering time within a population is positively related to plant vigor (Boonman, 1993). Plants with higher vigor flower early and vice versa. Based on the preceding results, it could be deduced that there was a big variation in plant vigour within the late flowering ecotypes and thus the delay in their DFF. Days to full flowering (DFF) were significantly correlated to robust related traits (stem thickness, plant height, leaf length and breadth), number of nodes and flowering period (Appendix 1). This was similar to the findings on DSF.

Flowering period between ecotypes

There was no significant difference between the ecotypes in FP (Table 8). The mean flowering period ranged from 6.3 days for TVT2 to 11.3 days for KBK1. However, there was a positive correlation between FP and DFF (Appendix 1) and there was a trend of increasing FP with increase in DFF. FP was not correlated with any of the plant attributes measured except DFF.

CONCLUSIONS AND RECOMMENDATIONS

Ecotypic differentiation among the 11 ecotypes of *C. ciliaris* in regard to flowering patterns was observed which could infer genetic differentiation due to environmental variation. Significant variations were observed between sites of ecotype origin in regard to days to start flowering and days to full flowering. Kilifi collection significantly flowered earlier than Kiboko collections.

There was also a strong relationship between plant robustness and flowering time. These findings are

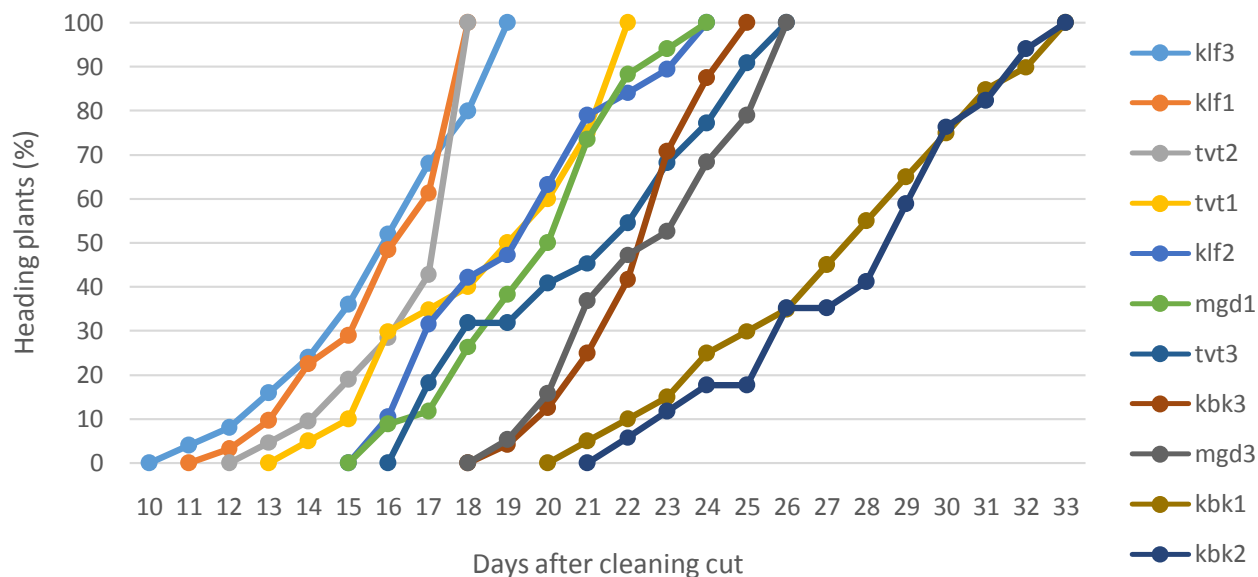


Figure 3. Heading patterns in spaced plants' plots of *Cenchrus ciliaris* ecotypes from the time of cleaning cut in mid Feb. 2014 to DFF.

Table 8. Mean of flowering period for each *Cenchrus ciliaris* ecotype in different cuts.

Ecotype/Cut	KLF1	KLF3	TVT2	KLF2	TVT1	TVT3	MGD1	MGD3	KBK3	KBK1	KBK2
Sep-Oct	8	9	6	5	4	7	6	4	5	7	4
Nov-Dec	8	8	7	8	7	9	8	9	12	14	10
Feb-Mar	7	9	6	9	9	10	9	8	7	13	12
Mean	7.7	8.7	6.3	7.3	6.7	8.7	7.7	7	8	11.3	8.7

P>0.05; CV=22.3%; I.s.d.=3.04.

important in breeding work since selection can be done based on the flowering patterns, which strongly correlate with robustness. Kilifi collections could be selected for the early flowering while Kiboko ones could be selected for late flowering traits. However, further analysis using molecular tools is necessary to ascertain the genetic variability within and among the ecotypes.

Magadi 1 ecotype was unique due to its early flowering and robustness traits. However, caution should be exercised in interpreting special niches as wide area adaptations.

Conflict of interests

The authors have not declared any conflict of interests.

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Appendix

Appendix 1. Correlation matrix between morphological attributes among *Cenchrus ciliaris* ecotypes

1	%FT	-																					
2	SWT	0.3	-																				
3	AD	0.3	-0.4	-																			
4	BT	-0.1	-0.2	0.0	-																		
5	CNO	-0.1	0.6	-0.6*	0.3	-																	
6	CWT	0.1	0.6	-0.5	0.0	0.9***	-																
7	DFF	-0.6*	-0.4	-0.3	-0.1	0.0	-0.1	-															
8	DSF	-0.8***	-0.3	-0.5	-0.1	0.1	0.0	0.9***	-														
9	EDS	-0.1	-0.1	-0.3	0.4	0.4	0.3	0.2	0.2	-													
10	FP	0.0	-0.4	0.2	-0.1	-0.4	-0.3	0.7*	0.4	0.1	-												
11	FLH	-0.6	-0.4	-0.3	0.0	0.1	0.1	0.7**	0.8**	0.6	0.4	-											
12	ITH	-0.5	-0.2	-0.3	-0.1	0.1	0.2	0.8**	0.7**	0.5	0.5	0.9	-										
13	ID	-0.4	-0.9***	0.3	0.5	-0.4	-0.6*	0.2	0.1	0.2	0.2	0.2	-0.1	-									
14	IL	-0.7*	-0.2	-0.7*	0.1	0.3	0.2	0.7**	0.8**	0.6*	0.2	0.8	0.8	0.1	-								
15	IR	-0.1	-0.3	-0.2	0.6*	0.4	0.4	0.0	0.0	0.6*	-0.1	0.4	0.3	0.2	0.4	-							
16	LR	-0.6*	-0.2	-0.5	0.4	0.5	0.2	0.4	0.6	0.5	-0.2	0.7	0.5	0.3	0.7	0.5	-						
17	LB	-0.5	-0.3	-0.3	-0.4	-0.1	0.1	0.8**	0.8**	0.3	0.6	0.8	0.8	0.0	0.7	0.0	0.1	-					
18	LL	-0.7*	-0.3	-0.5	0.0	0.3	0.2	0.8**	0.8**	0.5	0.2	1.0	0.9	0.1	0.9	0.4	0.8	0.7	-				
19	NOD	-0.3	0.4	-0.5	-0.3	0.4	0.4	0.6*	0.6*	0.2	0.4	0.3	0.5	-0.4	0.5	-0.3	0.1	0.6	0.5	-			
20	SNO	-0.6*	-0.6*	-0.1	0.0	-0.2	-0.2	0.7*	0.7*	0.3	0.4	0.9	0.7	0.4	0.7	0.3	0.6	0.7	0.8	0.1	-		
21	ST	-0.7*	-0.4	-0.3	-0.2	0.0	0.0	0.9***	0.9***	0.3	0.4	0.9	0.9	0.1	0.8	0.2	0.5	0.9	0.9	0.5	0.8***	-	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	

***= p≤0.001; **=p≤0.01 and *= p≤0.05.

No.	Abbrev.	Meaning	No.	Abbrev.	Meaning	No.	Abbrev.	Meaning	No.	Abbrev.	Meaning
1	%FT	Percent fertile tillers	7	DFF	Days to full flowering	13	ID	Inflorescence density	19	NOD	Number of nodes
2	SWT	Spikelet weight	8	DSF	Days to start flowering	14	IL	Inflorescence length	20	SNO	Spikelet number
3	AD	Awn density	9	EDS	Ease to drop seed	15	IR	Inflorescence ratio	21	ST	Stem thickness
4	BT	Basal tillers	10	FP	Flowering period	16	LR	Leaf ratio			
5	CNO	Caryopsis number	11	FLH	Flag leaf height	17	LB	Leaf breadth			
6	CWT	Caryopsis weight	12	ITH	Inflorescence height	18	LL	Leaf length			