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Research article

The effects of extreme climate on the invasive plant *Gutenbergia cordifolia*: implications for its future management in savannah ecosystems

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ABSTRACT

The aim of this study was to assess the effects of varying water stress levels on morphological and physiological parameters of an invasive plant *Gutenbergia cordifolia*. The assessment was conducted in the screenhouse at the Nelson Mandela African Institution of Science and Technology following a completely randomized design (CRD). Both morphological and physiological parameters were variable under water stress levels. While the maximum (159 cm) and minimum (9 cm) plant heights *for G. cordifolia* were observed under flood and drought water stress respectively, its maximum root collar diameter of 5 mm and the minimum of 1.3 mm were observed under moderate flood and drought water stress respectively. Generally, the number of leaves was highest under moderate flood stress (194 leaves/plant), and lowest under drought stress (13 leaves/plant). Similarly, the largest and smallest leaf surface area of 9×10^3 and $1 \times 10^3 mm^2$ were observed under flood and drought water stress respectively due to *G. cordifolia*'s tendency to retain water when exposed to water stress through a reduction in number of leaves and leaf surface area when under drought stress condition. While a decrease in leaf chlorophyll was observed across water stress levels with the lowest chlorophyll levels of 0.02 under drought water stress, an increase in leaf anthocyanin levels (0.29 Abs $g.DM^{-1}$) was observed particularly under flood stress due to increased chlorophyll breakdown and plants' water stress, respectively. This study informs that extreme climatic events such as excessive floods will likely facilitate invasions by *G. cordifolia* leading to decreased biotic resistance of native communities in savanna rangelands. Efforts to manage *G. cordifolia*'s effects in a changing climate must therefore include the development of strategies and action plans that account for catastrophic events like floods and drought.

1. Introduction

Species shift in range and their expansion have been linked to climate change (Lenoir et al., 2008; Rosenzweig et al., 2008). Ecosystems are facing gradual changes in average climate conditions, dramatic changes in climate variability, and prevalence of extreme climate events. Extreme climate events such as drought, flood and, heat waves are expected to increase in the coming decades (Diez et al., 2012; Platts et al., 2015). Climate change can induce stress in an ecosystem that might facilitate ecological invasion (Masters and Norgrove, 2010). Recently, invasive species have been reported as a serious threat to biodiversity (Genovesi et al., 2017) and therefore have a potential to negatively affect rangeland productivity. The rate of increase of invasive plants as an outcome of climate change is expected to rise more in the next decades if proper actions are not taken (Hellmann et al., 2008). Extreme weather occurrences are likely to be more frequent and intense, and their impacts are likely to further facilitate invasions as a result of increased non-native species migration and reduced native ecosystem biotic resistance to invader establishment (Diez et al., 2012). This will result in further changes in native biota, loss of ecological value and associated services and increasing cost of managing biological invasions (Mainka and Howard, 2010).

Environmental factors can potentially affect an invasive plant's ability to exploit available environmental resources for which plants compete (Patterson, 1995). Water stress is a common environmental factor experienced by plants that strongly reduce production and facilitates invasive plants like *Gutenbergia cordifolia* Benth. ex Oliv. var. *cordifolia* (Barnabás et al., 2008). Plant water stress is considered to be one of the main environmental constraints shaping natural variation and development of plant growth and physiology (Ruckelshaus et al., 2020). As

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populations of invasive plants increase in coverage and density in an area, they tend to threaten both economic and ecological stability (Wolde and Lal, 2018). These species affect native biota through hybridization, resources competition and disease transmission (Piero Genovesi et al., 2015). They are the greatest challenge to conservation because most of them have high fecundity, quickly evolve responses to control efforts, alter and respond to community interactions in complex ways. Unfortunately global climate change, increased globalization, international trade, insufficient baseline information for risk assessment, and inadequate public awareness of the problem favor the existence of most invasive plants (Vilà et al., 2010). If left without proper management, invasion is likely to result in loss of fodder and habitat for wildlife and livestock in most global rangelands (Ngondya et al., 2016).

In the Ngorongoro Conservation Area (NCA), a multiple land-use area and one of the biodiversity hotspots UNESCO Man and Biosphere (MaB) designated area in northern Tanzania, an invasive plant *G. cordifolia* is among the plants species that poses the biggest challenge to conservation of the area (Ngondya and Munishi 2021). *Gutenbergia cordifolia* is an annual plant in the family Asteraceae native to Kenya, Sudan, Democratic Republic of Congo, Rwanda, Burundi, Zambia, Malawi, and Zimbabwe (Ngondya et al., 2016). It is considered a serious problem in most parts of the Serengeti-Ngorongoro ecosystem and surrounding agricultural areas in the Northern part of Tanzania (Ngondya et al., 2016). Besides being unpalatable and toxic to ruminants, this plant suppresses and outcompetes palatable native species thus jeopardizing the ecologically diverse NCA and the entire Serengeti ecosystem (Ngondya et al., 2019; Ngondya and Munishi 2021).

Here, we used climate projections for the middle and the late 21st century for East Africa following Platts et al. (2015) to determine the extent to which extreme climate may affect the establishment and spread of *G. cordifolia* in East African rangelands. As plants respond to stress by altering both their morphological and physiological processes which manifest in their pigments often chlorophyll and anthocyanins (Garriga et al., 2014), we assessed the morphological and physiological parameters as evidence for extreme climate impacts on the invasion success of *G. cordifolia* and its future management implications. We believe that understanding *G. cordifolia* morphological and physiological responses to varying water stress under projected rainfall (2050–2100 years) as suggested by (Platts et al., 2015), will inform future *G. cordifolia* management options as influenced by spatio-temporal changes in rainfall patterns.

2. Materials and methods

2.1. Site description

2.1.1. Soils and climate

The soils of NCA are derived from underlying parent rocks and therefore almost all soils found in the area are basaltic in origin. Three main soil groupings are described as highlands soil type, short grass plains soil, and southwest soil types. Ngorongoro's climate is influenced by the season and topography of the area. There are two distinct seasons, wet and dry. The wettest area is the eastern and southern part of the highlands that face the prevailing and moisture-laden winds from the Indian Ocean (Hanby and Bygott, 1998). The driest parts are the plains and Olduvai Gorge, lying at the feet of the mountains on the rain-shadow (Hanby and Bygott, 1998). The mean temperatures are about 10 °C–38 °C, with higher temperatures occurring in the lower areas, around Masek and Ndutu. Overall, the average annual precipitation during the study period in sampling locations (Ndutu, Central, Lerai) within the NCA was 497mm with their minimum and maximum of 94 mm and 878 mm (Munishi et al., 2020).

2.1.2. Vegetation

The vegetation type identified in NCA includes scrub heath, montane long grasslands, high open moorland and the remains of dense evergreen montane forests covering the steep slopes. The crater floor is mainly open short grass plains with two patches of Acacia woodland: Lerai forest, with co-dominants yellow fever tree (*Vachellia xanthophloea*) and *Rauvolfia caffra*. The undulating plains to the west are grass-covered with occasional umbrella acacia *Vachellia tortilis* and *Commiphora africana* trees (Berry, 2009).Within undulating Savannah plain are occasional Umbrella Acacia trees thus, giving way to the more open areas and dry shrubs regenerating following disturbance. The dominant shrubs recorded on the site include *Grewia bicolour, Grewia smiles, Combretum sp., Vachellia brevispica, Maerua angorensis,* and *Vachellia senegal*. The ground cover is mainly grassy with some forbs and herbs. The characteristic grass species are *Andropogon greenwayi, Themeda triandra, Digitaria scalarum,* and *Aristida* species. Herb layer is characterized by *Helichrysum schimperi, Lippia javanica, Lupinus princei, Hypericum revolutum, Crotalaria* ssp, and *Hermanis verucosa.*

2.2. Seedling and soil sample collection

Gutenbergia cordifolia seedlings of one-month age and soil that were used for screen house-controlled study were collected from the beginning of (November 2019) during short rain season from areas that were highly invaded by *G. cordifolia* (Ndutu area (03º01′ S, 03º01′ E), Crater Center (03º13′ S, 035º31′ E) and Lerai forest (03º01′S 035º31′ E) within NCA located in northern Tanzania (Figure 1). Overall, areas in NCA where *G. cordifolia* grow have more or less the same physical-chemical properties of the soils with most of the NCA areas occupied by volcanic soils. Given this, the plant sampling was taken from the three different *G. cordifolia* growing locations. Seedlings collected from the three sites were mixed to form one composite sample that was later exposed under different water stress levels in the screen house experiment. Likewise, the collected soil samples were mixed to form one composite sample that was used as a growth media.

2.3. Screen house study design and experiment layout

The screen house experiment in this study was conducted under a completely randomized design with three replications (three pots per treatment) and five levels of water stress treatments making a total of 15 pots. Two seedlings of *G. cordifolia* were planted in 3 kg pots each filled with composite soil that were collected from NCA and were left to acclimatize for seven days in the screen house. Thereafter the pots were then exposed under different water stress levels using rainwater at the same growth phase and vigor. While control was calculated as the mean annual rainfall in the NCA for the period of 2010–2020 the other treatments (water stress levels) were calculated as projected by plats et al. (2015). Therefore, the following treatments were applied: V_0 (control) = 350 ml/1.5 kg soil sample, V_1 (moderate flood) = 500 mls/1.5 kg soil sample, V_2 (flood) = 800 ml/1.5 kg sample, V_3 (drought) = 150 ml x 1/1.5 kg soil sample and V_4 (moderate drought) = 150 ml x 3/1.5 kg soil sample. Treatments V_1 and V_2 were reflecting flood extremes and were irrigated 48 times for three consecutive months (twice per day) while the rest (V_3 and V_4) reflected the drought extreme and were irrigated once and thrice per month (once per day) for three months respectively. All plants in the screen house were re-randomized weekly to avoid any positional effects. At the end of the experiment (60 days), plants were destructively harvested for further laboratory analysis and biomass estimations.

2.4. Measurement of morphological traits

The effects of water stress on *G. cordifolia* morphological traits (height, leaf length and basal radius, root collar diameter, number of leaves, root and shoot biomass) were measured after twelve weeks. Height of seedlings and root collar diameter at 5cm height from the ground were determined using a 1-meter ruler and digital caliper respectively. The total number of leaves per plant was counted in each of

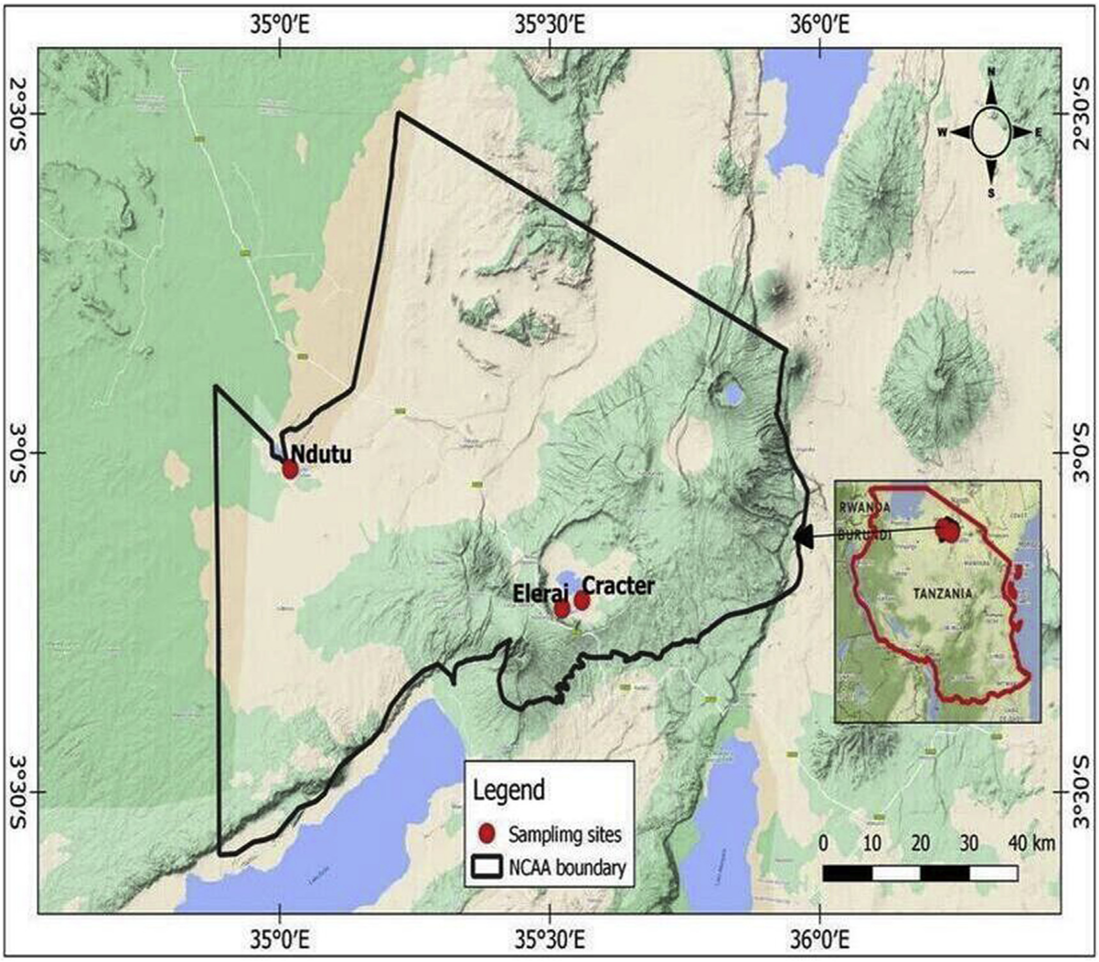

Figure 1. A map of Ngorongoro Conservation Area showing areas where *G. cordifolia* seedlings and soil samples were collected.

the three randomly selected plants in each pot. To determine leaf area, 30% of leaves in each pot were randomly collected. The area of the leaf surface was determined by measuring leaf basal radius and leaf length using a meter ruler (Tabot and Adams 2013). Leaf surface area was calculated geometrically (Eq. (1)) from the leaf basal radius and length applying area computations based on the leaf's conical shape (Tabot and Adams 2013):

$$\text{Leaf surface area}(S) = \pi r^2 + \pi rhQ \tag{1}$$

where S = leaf surface area, $\pi = 3.142$, r = leaf basal radius and h = leaf length.

After 60 days of screenhouse experiment, biomass was determined, root and shoot material were separated and weighed using a digital weigh balance to obtain total above/below ground fresh and dry weight (SERAS, 1994). The whole *G. cordifolia* plant was harvested (uprooted) washed and dried. Root to shoot ratios were calculated by separating above and below-ground biomass, roots were washed and samples were dried to a constant mass at 60 °C for two days (Makoi et al., 2010) prior to measurement.

2.5. Measurement of physiological traits

Leaf chlorophyll and leaf anthocyanin were measured after twelve weeks. For chlorophyll determination, young leaves from the top-most region of the seedlings were randomly picked per pot per treatment, whereas mature leaves were randomly sampled for anthocyanin level assessment (Ngondya et al., 2016). Leaf total chlorophyll of *G. cordifolia* was extracted according to Ngondya et al. (2016) as follows: 50 mg of fresh leaves of 2.25 cm^2 were immersed in 4 ml of Dimethyl Sulfoxide (DMSO) and incubated at 65 °C for 12 hours for auto extraction. To determine absorbance, the extract was put in glass cuvettes. The absorbance of blank liquid (DMSO) and samples were measured at 663 nm and 645 nm using a 2000 UV/VIS spectrophotometer (UNICO®) (Hiscox and Israelstam 1978), and the total leaf chlorophyll (total Chl) was computed as per Arnon's (1949), Eq. (2):

$$\text{Total Chl} = 0.0202A_{663} + 0.00802A_{645} \text{ and expressed as Abs g. DM}^{-1} \tag{2}$$

where A_{663} and A_{645} are absorbance readings at 663nm and 645nm respectively.

Leaf anthocyanins of *G. cordifolia* was extracted as described by Makoi et al. (2010) and calculated as per Eq. (3). *Gutenergia cordifolia* leaves were oven-dried for 48 h at 60 °C, weighed, and crushed into a fine powder. After that, 0.10 g of well-ground leaf material was weighed and combined with 10 ml of acidified methanol made from a 79:20:1 MeOH: H2: HCl mixture. For auto-extraction, the mixture was incubated for seventy-two hours in the dark and filtered through Whitman paper number 2. The extract was placed in a glass cuvette and the absorbance was measured. The absorbance of acidified methanol as a reference and samples was measured at 530nm and 657nm using a 2000UV/VIS Spectrophotometer (UNICO®) and expressed as Abs g. DM^{-1}.

$$\text{Anthocyanin concentration } A_{530} - \frac{1}{3}A_{657} \quad (3)$$

where $\mathbf{A_{530}}$ and $\mathbf{A_{657}}$ are absorbance readings at 530nm and 657nm, respectively.

2.6. Data analysis

Shapiro-Wilk test was used to test for normality of *G. cordifolia* physiological and morphological traits data under different water stress levels. For normally and non-normally distributed data, One-way analysis of variance (*ANOVA*) and the *Kruskal–Wallis* test were used. The Fisher's Least Significant Difference (LSD) was used to separate the resulting means for normally-distributed and *Wilcoxon* test with *Bonferroni* correction was used to test for significant differences in mean values for non-normally distributed data. All statistical analyses were performed using JAMOVI Software (version 1.2.2) with a significance level of <0.05.

3. Results

3.1. Effects of water stress on G. cordifolia height and stem diameter

Gutenbergia cordifolia height differed significantly across treatments ($F_{(2,4)} = 15.2$, $p < 0.001$). The maximum *G. cordifolia* mean height of 103.63cm was observed under flood irrigation while the minimum mean height of 39.5cm was observed under drought irrigation (Figure 2). A significant change in root collar diameter of *G. cordifolia* was observed across treatments ($\chi^2_{(4)} = 29.1$, $p = 0.001$) with the largest and smallest *G. cordifolia* mean root collar diameter of 4.2mm and 2.21mm observed under moderate flood and drought irrigation regimes respectively (Table 1).

3.2. Effects of water stress on G. cordifolia leaf characteristics

A significant changes in the number of leaves per plant was observed ($\chi^2_{(4)} = 26.6$, $p < 0.001$, Table 2, Figure 2) across treatments. Generally, the mean number of leaves was highest under moderate flood and flood treatments (98 and 99 leaves/plant respectively), while the lowest mean number of leaves of 41 leaves/plant were observed under drought treatment (Table 2). Different water stress levels caused a significant decrease in leaf surface area per plant ($\chi^2_{(4)} = 17.3$, $p = 0.002$). The largest and smallest mean leaf surface areas of 3458.4mm^2 and 1108.9mm^2 were observed under flood and drought irrigations respectively (Table 2).

3.3. Effects of water stress on G. cordifolia root to shoot ratio

Root to shoot ratio decreased significantly ($F_{(2,4)} = 57.9$, $p < 0.001$) across treatments. The highest and lowest mean root to shoot ratios of 0.14 and 0.05 were observed under drought and moderate flood treatments respectively (Figure 3).

3.4. Effects of water stress on G. cordifolia leaf pigmentation

Water stress significantly decreased leaf anthocyanin level ($F_{(2,4)} = 16.61$, $p = 0.001$). The maximum mean anthocyanin pigment level was 0.238 Abs g.DM^{-1} under flood treatment while the lowest was 0.101Abs g.DM^{-1} under drought treatment. A further significant decrease in leaf chlorophyll was observed ($\chi^2_{(4)} = 35.4$, $p = 0.001$). The maximum and minimum mean leaf chlorophyll levelS of 0.046 and 0.017 Abs g.DM^{-1} were observed under moderate flood and drought treatments respectively (Figure 4).

4. Discussion

4.1. Effects of water stress on G. cordifolia morphological traits

Gutenbergia cordifolia height and root collar diameter were significantly reduced by drought. The observed decrease in both height and root collar diameter under drought treatment might have been due to increasing drought stress, as previously reported by Nezami et al. (2008). The water potential of stem cells may have been reduced to lower concentrations required for cell elongation due to water stress. The taller and larger root collar diameter of *G. cordifolia* under flood and moderate flood are likely to allow for more branching for flower formation and therefore higher number of seeds to be produced. Shortage of water to ensure elongation and girth growth of *G. cordifolia* under drought treatment ultimately resulted in reduced height and root collar diameter and increased investment on root biomass (higher root to shoot ratio). On the other hand, the observed increase in *G. cordifolia's* height and root collar diameter under both flood and moderate flood treatments was likely due to the ability of a plant to adapt to different environmental conditions. The implications of these findings are that, although invading species may be more able to colonize areas where biotic resistance has been decreased by drought, native species in drought-prone ecosystems are better suited to tolerate chronic drought than non-native species (Diez et al., 2012). This means that to effectively manage drought intolerant invasive species such as *G. cordifolia,* management strategies and actions should target main actions for controlling them in infested areas during the drought season. With persistent and consistent effort in the management of this species under such climatic conditions, *G. cordifolia* is likely to be brought under control (Cavaleri and Sack, 2010).

Our results indicated that projected climate-mediated changes in the precipitation patterns are likely to favor the future establishment and spread of the *G. cordifolia* in East African rangelands (Figure 2) as *G. cordifolia* was observed to tolerate fluctuating flooding by producing many leaves and potentially producing more seeds (Ehlers and Olesen, 2004) that are likely to increase its soil seed bank. This will enable it to further spread and establish itself in new areas. A significant decrease in *G. cordifolia's* number of leaves was observed in drought and moderate

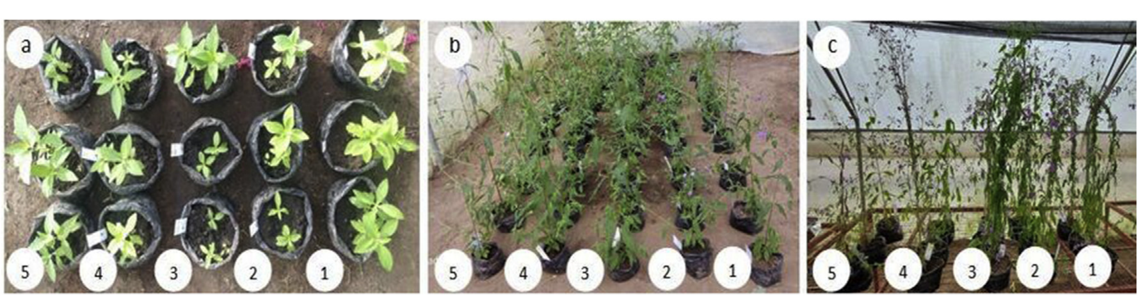

Figure 2. *Gutenbergia cordifolia* vigor at the age of (a) two weeks (b) six weeks and (c) twelve weeks under varying water stress levels (1 = normal, 2 = moderate flood, 3 = flood, 4 = moderate drought, and 5 = drought).

Table 1. One-way ANOVA and *Kruskal Wallis* test of *Gutenbergia cordifolia's* height and root collar diameter per treatment.

Treatments	Height (cm)		RCD (mm)	
	Range	Mean	Range	Mean
Control (350ml)	60.00–110.60	90.01 ± 5.80^a	2.83–5.00	3.65 ± 0.25^a
Moderate flood (500ml)	76.25–126.46	95.20 ± 7.24^a	3.17–5.00	4.09 ± 0.26^{ab}
Flood (800ml)	70.00–159.00	103.63 ± 9.73^a	4.10–4.80	4.20 ± 0.13^b
Moderate drought (150mlx3)	39.40–82.00	53.49 ± 3.98^b	2.25–2.60	2.64 ± 0.11^c
Drought (150mlx1)	9.00–65.50	39.54 ± 8.19^{cb}	1.24–3.57	2.21 ± 0.35^c
	F-statistics *p*-value	$F_{(2,4)} = 15.2$ $p < 0.001$	**H-statistics *p*-value**	$\chi^2_{(4)} = 29.1$ $p < 0.001$

S. E = Standard Error, RCD = root collar diameter, means with the same letter are not significant at $p < 0.05$.

Table 2. *Kruskal Wallis* test results of *Gutenbergia cordifolia's* number of leaves and leaf surface area per treatment.

Treatments	No_of leaves (leaves/plant)		LSA (mm^2)	
	Range	Mean	Range	Mean
Normal (350ml)	38.00–106.00	83.00 ± 7.30^a	2377.51–4683.94	3384.3 ± 313^a
Moderate flood (500ml)	69.00–143.00	98.00 ± 8.80^{ab}	1649.55–4565.62	3247.9 ± 268^a
Flood (800ml)	60.00–194.00	99.00 ± 18.10^{ab}	1239.83–9234.04	3458.4 ± 869^a
Moderate drought (150mlx3)	43.00–95.00	60.00 ± 5.20^{bc}	1079.57–4450.84	2465.7 ± 384^a
Drought (150mlx1)	13.00–52.00	41.00 ± 6.84^d	362.59–3120.98	1108.9 ± 323^b
	H-statistics *p*-value	$\chi^2_{(4)} = 26.6$ $p < 0.001$,	**H-statistics *p*-value**	$\chi^2_{(4)} = 17.3$ $p < 0.001$

S.E = Standard Error, L.S.A = Leaf surface area. Means with the same letter are not significant at $p < 0.05$.

drought, while an increased number of leaves was observed in flood and moderately flood conditions. This may be due to the tendency of the species to retain water when exposed to water stress by ensuring there is a reduced leaf surface area through which water from the plant can be lost (Chen et al., 2020). Water scarcity has a significant impact on plant's leaves formation, an increased drought therefore can severely affect *G. cordifolia* fitness which might in turn affect its seed production. The observed increase in the number of leaves under normal, moderate flood to flood, and the decrease under moderate drought to drought can similarly be explained by the tendency of plants to regulate the required amount of water through evapotranspiration (Passioura, 1996). While *Gutenbergia cordifolia* that was exposed under moderate flood and flood had excessive water with many and larger leaves that allowed for an increased evapotranspiration, those that were exposed under drought and severe drought conditions had water scarcity with fewer and smaller leaves so that to reduce evapotranspiration rate. Leaf surface area reduction under moderate flood and flood treatments was due to water stress increments where leaf became spindle and stunted (Riaz et al., 2013). Although *G. cordifolia* seems to adapt to changing water stress levels, it is interesting that in the event of future drought we are likely to have stunted *G. cordifolia* which is not likely to add many seeds to the soil, and therefore the overall outcome will be reduced abundance of this plant. Similar observation has been reported by Drenovsky et al. (2012) in which lower water availability was observed to favor native plants compared to invasives. The reduced abundance of *G. cordifolia* in rangelands will ensure the availability of pasture and hence healthier rangelands.

The observed higher root to shoot ratio under drought treatment compared to control and flood treatments could be due to its struggling efforts in search for limited below ground resources such as nutrients for survival (Nejad, 2011; Rahdari et al., 2012; Zhang et al., 2017). On the otherhand, the lower root to shoot ratio under control and flood treatments could be due to *G. cordifolia* investing more in shoot growth to compete for above ground resources such as light. Our findings suggest

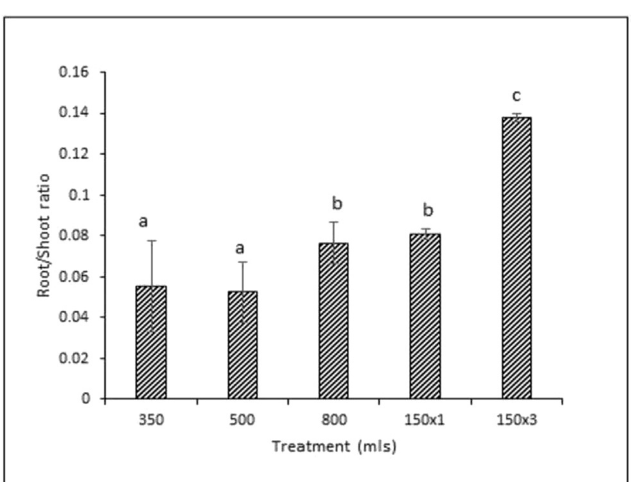

Figure 3. Effect of water stress on *G. cordifolia* root to shoot ratio.

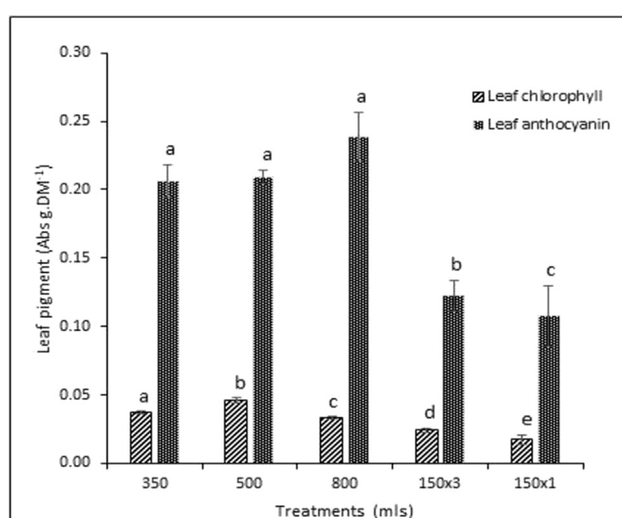

Figure 4. Effects of water stress on *Gutenbergia cordifolia* leaf pigments (chlorophyll and anthocyanins).

that in the event of increased future rainfall we should expect colonization of *G. cordifolia* in most rangelands as this will favor its growth. The overall impact therefore will be a reduced amount of palatable species and pasture shortage to herbivores.

4.2. Effects of water stress on G. cordifolia physiological traits

One of the most important chloroplast components for photosynthesis is chlorophyll (Rahdari et al., 2012) which is responsible for capturing energy from sunlight, converting it, and store it in energy storage molecules. On the otherhand, anthocyanins are a type of flavonoid produced by plants to tolerate a variety of stressors such as excess sunlight, salinity, and drought stress (Gould, 2004). In this study, while the maximum chlorophyll and anthocyanin levels were observed under moderate flood the minimum levels of both were observed under drought irrigation. While under drought stress, low chlorophyll concentration has long been thought to be an indication of pigment photo-oxidation and chlorophyll breakdown, a decrease in anthocyanin indicates that drought has less severe impacts on the leaf anthocyanin levels compared to chlorophyll level (Anjum et al., 2011). Similar studies have reported that drought stress reduces plant growth by influencing various physiological as well as biochemical functions such as chlorophyll synthesis (Hussain et al., 2018). On the otherhand, an increase in leaf chlorophyll under moderate flood shows that flood has no severe impacts on leaf chlorophyll (Rahdari et al., 2012) as compared to leaf anthocyanin. It has also been established that if a plant is exposed to stress (flood) both development and productivity are significantly harmed if this period is extended. Generally, an increase in anthocyanin level in leaves implies that a plant is stressed (Osakabe et al., 2014). The observed maximum chlorophyll and anthocyanin levels under moderate flood further indicate that *G. cordifolia* can survive under flood condition compared to drought as the localization of anthocyanin in leaf tissues have been reported to allow plants to develop resistance to several environmental stresses (Chalker-Scott, 1999). Based on the importance of chlorophyll in photosynthesis and therefore overall plant health, the reduction in leaf chlorophyll in drought-stressed *G. cordifolia,* presents an opportunity for a future reduced abundance of *G. cordifolia* in East African rangelands due to impaired photosynthesis in an event where there will be decreased rainfall. The opposite is then true in an event where the future will be characterized by increased rainfall. This information is important to understand *G. cordifolia's* physiological mechanisms involved in water stress tolerance or susceptibility, which will help to predict their future productive potential under predicted rainfall regimes (Platts et al., 2015) and ultimately, provide the needed information to manage the plant so that to ensure pastures availability in East African Rangelands (Dias-Filho and Carvalho, 2000).

5. Conclusion

The purpose of this study was to assess both morphological and physiological changes of an invasive plant *G. cordifolia* in response to water stress levels based on East African annual rainfall projections for 2050–2100 years. The study indicated that *G. cordifolia* can respond differently in varying water stress environments (varying future East African rainfall). Generally, both drought and flood stress had considerable effects on the morphology and physiology of the plant. The expected East African severe rainfall (for both the mid-century (2041–2070) and late-century (2071–2100) will favor the growth and development of *G. cordifolia* in most East African rangelands, preventing palatable plants from germinating and hence jeopardizing pasture supplies (Ngondya and Munishi, 2021). Therefore for management preparedness and prediction of invasion intensity of *G. cordifolia,* rainfall variability information (data) in East African rangeland needs to be well established and should be considered in planning for management and control of this plant. Extreme climatic events, such as floods will facilitate *G. cordifolia* invasions leading to decreased biotic resistance of native communities. Efforts to reduce *G. cordifolia*'s effects in a changing climate must therefore include the development of strategies and action plans that account for catastrophic events like floods and drought.

Declarations

Author contribution statement

Herieth A.Nyarobi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Issakwisa B. Ngondya & Linus K. Munishi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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