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Effect of Drought Stress on Canopy Temperature, Growth and Yield Performance of Cowpea Varieties

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To evaluate the influence of drought stress on canopy temperature, growth and yield performance of cowpea.
Study Design: The experiments were laid out in a split plot design, with main plots arranged into three replications as a randomized complete blocks design. Water stress level was assigned to the main plot while the cowpea variety was assigned to the subplot.
Place and Duration of Study: Study was carried out at Pwani University research farm in July – October 2011/2012 cropping season.
Methodology: The treatments comprised three water stress levels (no water stress, water stress at vegetative stage and water stress at flowering stage) and 11 cowpea varieties: KVU 419, Khaki, K80, Macho, Kaima koko, Nyeupe, KVU 27-1, Nyekundu, M66, Kutambaa and Mwandato. The data collected included: Ground cover, canopy temperature, chlorophyll content, leaf number, days to anthesis, shoot dry matter at maturity, pods per plant, grains per pod, 100-grain weight and grain yield.
Results: Water stress imposed at vegetative growth stage and flowering reduced cowpea growth attributes, ground cover and chlorophyll content, but increased canopy temperature, time to

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anthesis, harvest index, grain yield and yield components for most varieties. Water stress at vegetative and flowering stages increased time to anthesis by 4 and 7 days, respectively.

Conclusion: The impact of water stress on growth is dependent on the cowpea variety. Moderate stress may be beneficial if cowpea is grown for grain production but not if grown for vegetable production. Cowpea varieties which were superior in yield and high harvest indices under water stress included Nyekundu, KVU 27-1, M66, and KVU 419.

Keywords: Cowpea; varieties; growth; yield; water stress.

1. INTRODUCTION

Cowpea (*Vigna unguiculata* (L) Walp) is an important food legume and multipurpose crop [1]. With its high protein content of 25% [2], cowpea may be regarded as a very nutritious food legume for many ethnic communities who use it in their diets [3]. All the plant parts that are used for food are nutritious, providing proteins, vitamins and minerals [4]. The crop is grown throughout the tropical and subtropical areas of the world, where rainfall resources are characteristically low (300 – 600 mm) and variable [5]. Generally, cowpea is better adapted to drought, high temperatures and other biotic stresses than most other crops [6]. It grows well in a wide range of soil textures, from well drained heavy clays to sandy soils, and grows best in slightly alkaline soils (pH 5.5 – 6.5). Cowpea naturally grows under wide and extreme moisture conditions and, once established, it is fairly drought tolerant [7]. It is often grown under rain-fed agriculture in areas receiving at least 600 mm annual rainfall.

Many cultivars of cowpea are, however, damaged by drought and high temperatures, especially during reproductive development [8]. According to [9], the combination of high temperature, drought and long hours of day can slow down or inhibit floral bud development, resulting in few flowers being produced and substantially reduced cowpea productivity. [10] Reported that cowpea yield reduction ranged from 63% to 98.4% under severe water stress, 42.6% to 65.8% under moderate water stress and 9.5% to 47.2% under mild water stress. Under water deficit conditions, as is often the case in the semi-arid zones, the flowering period is cut short and the seed matures earlier. Moreover, the formation of new floral nodes and flowers are delayed and/or aborted, thus leading to low productivity [11]. In addition, cowpea is also sensitive to drought at different stages of growth [8].

Cowpea response to drought stress varies with variety, economic portion of the crop, stage of growth when stress is imposed and the duration of the stress. Earlier studies indicated that cowpea could maintain seed yield when subjected to drought at vegetative stage, provided subsequent conditions were conducive for flowering and pod set [12]. [13] showed that the crop is highly sensitive to water deficits during flowering and pod filling stages. It has been reported by [14], that water stress has a significant adverse effect on the growth and biological nitrogen fixation of cowpea. [15] reported that a decrease in soil water potential can markedly affect root hair and retard nodule growth and nitrogen fixation.

Stability in yields of agronomically acceptable cultivars is generally regarded as the ultimate goal in cowpea improvement [16]. One way to obtain this is to identify genotypes with adequate levels of resistance to drought, heat and other stresses. There is need for cowpea cultivars, which are more tolerant to water deficit or more efficient in water use [17]. However, progress in breeding cultivars for dry environments has been slow [18]. Cowpea possesses high yield plasticity under diverse environments, and could alleviate the economic hardships of farmers in case of severe drought and heat [3]. The objective of the study was to determine the influence of drought stress on canopy temperature, growth and yield of cowpea varieties in coastal lowland Kenya.

2. MATERIALS AND METHODS

2.1 Study Site

The study was carried out on-station at Pwani University (PU) in coastal lowland (CL) Kenya; located at 60 km north of Mombasa, between latitudes 3º S and 4º S and longitudes 39º E and 40º E. The region receives an average annual rainfall of 600–1100 mm that comes in two seasons [19]. The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season and 75% of the annual rainfall is usually received during this time

[20]. Mean monthly minimum and maximum temperatures are about 22ºC and 30ºC, respectively, and the mean relative humidity is 80% [21]. According to [19], the soils in coastal lowland Kenya are mostly ferralsols. These soils have low organic matter content, are deficient in essential plant nutrients (especially nitrogen) and prone to leaching, and have a pH ranging between 5 and 7 [22]. The study was conducted during dry seasons of 2011 and 2012.

2.2 Experimental Design, Treatments and Crop Husbandry

The experiments were laid out in a split-plot design, with main plots arranged into three replications as a randomized complete blocks design. The main plots consisted of the water stress level while the subplots consisted of the cowpea varieties. The water stress levels were: Well watered (maintained at field capacity), water stress at vegetative stage and water stress at flowering stage. The sub-plots consisted of seven local and four improved varieties: (i). KVU 419 (improved variety from KALRO Katumani); (ii). Khaki (local variety); (iii). K80 (improved variety for the region); (iv). Macho (local variety); (v). Kaima-koko (local variety); (vi). Nyeupe (local variety); (vii). KVU 27-1 (improved variety from KALRO Katumani); (viii). Nyekundu (local variety); (ix). M 66 (improved variety from Katumani); (x). Kuhambala (local variety); and (xi). Mwandato (local variety). The plant spacing was 60 cm x 30 cm with two seeds per hill, no fertilizer was applied. Weeding was done twice; the first and second weedings were done on the second and fifth week after planting respectively.

Water stress was imposed at vegetative and flowering stages. For the vegetative stage, irrigation was stopped six weeks after planting the late maturing cowpea varieties (Nyeupe, Kutambaa and Mwandato) and three weeks after planting the early maturing varieties (KVU 419, Khaki, K80, Macho, Kaima koko, KVU 27-1, Nyekundu and M66). Water stress was imposed for two weeks. For water stress at flowering stage, the irrigation was stopped eight weeks after planting the late maturing varieties and five weeks after planting the early maturing varieties. The water stress was imposed for two weeks when flowering was 50%. The early maturing varieties were planted three weeks after planting the late maturing varieties to synchronize flowering for the drought to be imposed at the same time [23]. Drip irrigation was applied after every 12 hours for three hours to ensure that soil moisture was maintained at close to field capacity.

2.3 Data Collected

The data collected included chlorophyll content, days to anthesis, grains per pod, number of leaves, percent ground cover, canopy temperature, number of pods per plant, 100-grain weight, pod weight, dry matter and grain yield. Chlorophyll content was measured using a chlorophyll meter before flowering stage. A leaf was selected, put in the leaf chamber of a chlorophyll meter and readings recorded on the screen. Number of days to anthesis was calculated by counting the number of days from planting to 50% flowering. The number of grains per pod was determined by counting the number of grains in each pod at harvest. Ten pods were sampled from each of the ten plants sampled in each plot. Leaf number was determined by counting the number of leaves fortnightly after emergence to flowering stage. Percent ground cover was measured in the net plot (5.76 m^2) at vegetative stage using the string and dot method as described by [24]. A string measuring 10 m length was marked with ink every 15 cm and stretched across both diagonals of the plot. The number of marks lying over or under a living plant part were counted and recorded. Percent ground cover was calculated as:

% Ground cover = [(Number of marks over or under plant part/Total number of marks across plot diagonals) x 100]

Canopy temperature was taken in the middle part of the crop canopy using a canopy temperature meter prior to flowering stage. The number of pods per plant was determined from 10 plants in each plot at harvesting time. Weight of 100 grains was determined by weighing 100 grains of the harvested grains in each plot. Pod weight was determined by weighing 10 pods selected from the 10 plants sampled in each plot at harvest time. Total dry matter was determined by uprooting whole plants (together with the pods) at maturity, oven drying and weighing. Grain yield was taken after harvest from the middle part of the drip lines leaving five hills from each end. The area from which the plants were harvested for grain yield determination was 6.4 m^2.

2.4 Data Analysis

Collected data were analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical software [25]. Where the F values were significant, means were compared using the least significant difference (LSD) test with 5% of significance level. Linear regression analyses between grain yield and chlorophyll content, canopy temperature, days to anthesis, number of leaves, % ground cover, pods per plant, 100-grain weight, pod weight, and total dry matter were conducted.

3. RESULTS

3.1 Effect of Water Stress at Vegetative and Flowering Growth Stages on Cowpea Percent Ground Cover and Number of Leaves per Plant

Water stress level, cowpea variety and their interaction significantly affected percent ground cover and leaf number (Table 1). Water stress at both vegetative and flowering stages significantly reduced the percent ground cover and leaf number in most cowpea varieties except Macho, Nyeupe and Mwandato. Plants subjected to water stress during flowering had higher percent ground cover and leaf number than plants subjected to water stress during the vegetative stage for all varieties except Kaima koko, M66 and KVU 27-1. Under no water stress, Kutambaa had significantly the highest percent ground cover (99.4%) followed by Mwandoto (85.8%) and Nyeupe (83.6%), while M66 had significantly the lowest percent ground cover (49.2%). Percent ground cover varied from 49.2% (M66) to 99.4% (Kutambaa), 29.6% (Khaki) to 95.2% (Nyeupe) and 40.3% (M66) to 99.4% (Nyeupe) under no water stress, stress at vegetative and flowering stages respectively. Percent ground cover reduction due to water stress ranged from 2.3% to 46.4% at vegetative stage and 6.29% and 37.0% at flowering. Under no stress, Kutambaa had significantly the highest leaf number while Mwandato and Nyeupe had significantly the highest leaf number under water stress imposed during vegetative and flowering stages. Number of leaves per plant ranged from 62 (M66) to 134 (Kutambaa) under no stress, 34 (Khaki) to 128 (Nyeupe) under stress at vegetative stage and 49.3 (M66) to 134 (Nyeupe) under stress at flowering.

Table 1. Effect of water stress at vegetative and flowering stages on percent ground cover and number of leaves per plant of cowpea

Cowpea variety (V)	Ground cover (%)				Number of leaves per plant			
	Water Stress (WS)			V- mean	Water Stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	65.4	39.4	43.6	49.5	85.3	48.0	54.0	62.4
Khaki	55.2	29.6	49.2	44.7	70.7	34.0	62.0	55.6
K 80	58.4	39.4	46.4	48.1	75.3	48.0	58.0	60.4
Macho	57.4	56.1	63.8	59.1	74.0	72.0	83.0	73.3
Kaima-koko	73.6	52.6	46.4	57.5	97.0	67.0	58.0	74.0
Nyeupe	83.6	95.2	99.4	92.7	111.3	128.0	134.0	124.4
KVU 27 – 1	51.9	47.8	48.7	49.5	66.0	60.0	61.3	62.4
Nyekundu	65.9	47.8	55.2	56.3	86.0	60.0	70.7	72.2
M 66	49.2	46.4	40.3	45.3	62.0	58.0	49.3	56.4
Kutambaa	99.4	58.9	66.6	75.0	134.0	76.0	87.0	99.0
Mwandato	85.8	94.5	98.0	92.8	114.7	127.0	132.0	124.6
WS-mean	67.8	55.3	59.8		88.8	70.7	77.2	
p-value (V)	0.0001				0.0001			
p-value (WS)	0.0001				0.0001			
p-value VxWS)	0.0001				0.0001			
$LSD_{0.05}$ V	1.5				2.16			
$LSD_{0.05}$ WS	1.0				1.13			
$LSD_{0.05}$ V x WS	2.6				3.7			
CV *main plot* (%)	1.47				1.23			
CV *subplot* (%)	2.68				2.03			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

3.2 Effect of Water Stress at Vegetative and Flowering Stages on Cowpea Chlorophyll Content and Canopy Temperature

Water stress significantly reduced chlorophyll content of cowpea while the main effects of variety and the interaction between cowpea variety and water stress had no effect on this parameter (Table 2). Cowpea plants subjected to water stress during the vegetative stage had lower chlorophyll content than non-water stressed plants and plants subjected to water stress during flowering. Water stress during flowering had no effect on chlorophyll content. There were significant differences in canopy temperature due to water stress and the interaction between water stress and cowpea variety (Table 2). Cowpea variety main effect on canopy temperature was not significant. Water stress at vegetative stage significantly increased canopy temperature in Khaki, Kaima koko, and Mwandato but significantly reduced canopy temperature in Macho and Nyekundu. Water stress at flowering increased canopy temperature in K80, M66, Kutambaa and Mwandato. Canopy temperature varied from 20.70ºC (Mwandato) to 25.23ºC (Macho) under no stress, 20.20ºC (Kutambaa) to 24.83ºC (Kaima-koko) under water stress imposed at vegetative stage and 22.77ºC (KVU 27-1) to 25.60ºC (K80) under stress imposed at flowering stage.

3.3 Effect of Water Stress at Vegetative Stage and Flowering on Cowpea Number of Days to Anthesis

Cowpea variety and water stress had significant effects on the number of days to anthesis (Table 3), but their interaction had no significant effect on this attribute. Water stress at vegetative and flowering stages significantly increased the number of days to anthesis. There was no significant difference between water stress at vegetative and at flowering stage in the number of days to anthesis.

Mwandato had significantly the highest number of days to anthesis while KVU 419, Nyekundu and M66 had significantly lower number of days to anthesis than most of the varieties. Kutambaa had a lower number of days to anthesis than all varieties except Mwandato. The number of days to anthesis varied from 44.3 (Nyekundu) to 70.3 (Mwandato). Water stress at vegetative and flowering stages increased time to anthesis by 4 and 7 days respectively.

Table 2. Effect of water stress at vegetative and flowering growth stages on cowpea chlorophyll content and canopy temperature

Cowpea variety (V)	Chlorophyll content index				Canopy temperature (ºC)			
	Water Stress (WS)			V- mean	Water Stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	54.70	46.43	50.00	50.38	22.67	23.10	23.17	22.98
Khaki	53.37	51.47	56.23	53.69	21.97	24.43	22.93	23.11
K 80	54.43	50.67	50.13	51.74	22.53	23.50	25.60	23.87
Macho	56.13	46.23	55.67	52.68	25.23	21.50	23.27	23.33
Kaima-koko	51.20	47.00	50.77	49.66	22.47	24.83	23.23	23.51
Nyeupe	53.77	51.17	52.23	52.39	22.30	23.10	23.77	23.06
KVU 27 – 1	53.87	48.67	53.63	52.06	22.53	24.37	22.77	23.22
Nyekundu	52.13	45.27	49.53	48.98	24.96	20.47	23.03	22.82
M 66	53.23	46.20	50.20	49.88	21.63	22.33	24.67	22.87
Kutambaa	54.47	48.73	52.47	51.89	20.97	20.20	25.37	22.17
Mwandato	50.77	47.47	54.07	50.77	20.70	23.20	23.83	22.58
WS-mean	53.46	48.12	52.27		22.54	22.82	23.79	
p-value (V)	0.264				0.561			
p-value (WS)	0.0001				0.007			
p-value VxWS)	0.856				0.0003			
$LSD_{0.05}$ V	Ns				Ns			
$LSD_{0.05}$ WS	1.91				0.72			
$LSD_{0.05}$ V x WS	Ns				2.39			
CV *main plot* (%)	2.79				13.65			
CV *subplot* (%)	7.95				7.72			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

Table 3. Effect of water stress at vegetative and flowering growth stages on cowpea number of days to anthesis

Cowpea variety (V)	Number of days to anthesis			
	Water Stress (WS)			V- mean
	Nws	Vws	Fws	
KVU 419	42.67	43.00	48.0	44.56
Khaki	44.67	47.33	46.00	46.00
K 80	44.67	45.67	48.00	46.11
Macho	46.67	49.67	48.67	48.33
Kaima-koko	47.67	48.33	49.00	48.33
Nyeupe	58.33	59.67	58.33	58.78
KVU 27 – 1	44.67	46.00	47.00	45.89
Nyekundu	40.00	44.33	44.67	43.00
M 66	42.67	45.67	42.67	43.67
Kutambaa	61.00	62.33	70.00	64.44
Mwandato	63.00	70.33	67.33	66.89
WS-mean	48.70	51.10	51.80	
p-value (V)	0.0001			
p-value (WS)	0.0001			
p-value VxWS)	0.086			
$LSD_{0.05}$ V	2.51			
$LSD_{0.05}$ WS	1.31			
$LSD_{0.05}$ V x WS	Ns			
CV *main plot* (%)	9.81			
CV *subplot* (%)	5.31			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

3.4 Effect of Water Stress at Vegetative and Flowering Growth Stages on Cowpea Number of Pods per Plant and Grains per Pod

Cowpea variety, water stress and the interaction between cowpea variety and water stress significantly affected the number of pods per plant (Table 4). Water stress at vegetative and flowering stages significantly increased the number of pods per plant in cowpea varieties. The number of pods per plant varied from 4.3 (Kutambaa) to 10.3 (M66) under no water stress, 6.3 (Mwandato) to 11 (K80) under water stress at vegetative stage and 7.3 (Mwandato) to 12.3 (Macho) under water stress at flowering. Water stress increased the number of pods per plant by 5 and 5.7 at vegetative and flowering stages respectively. Plants subjected to water stress during flowering stages had higher number of pods per plant than water stress at vegetative stage. The varieties which had significantly higher number of pods per plant under water stress at flowering stage were Macho, Nyeupe and M66. Cowpea varieties, water stress and their interactions had no significant effect on the number of cowpea grains per pod (Table 4). The average number of grains per pod for plants under no water stress, water stress at vegetative stage and water stress at flowering was 13.8, 14.2 and 13.8, respectively. Number of grains per pod varied from 11.7 (Nyeupe) to 15.7 (Kaima Koko), 13.0 (Macho) to 15.3 (KVU 419), and 12.7 (Nyeupe and M66) to 16.0 (Khaki) under no stress, stress at vegetative stage and stress at flowering, respectively.

3.5 Effect of Water Stress at Vegetative and Flowering Growth Stages on Cowpea 100-Grain Weight and Pod Weight

Cowpea variety, water stress and interaction between cowpea variety and water stress significantly affected cowpea 100-grain weight (Table 5). Water stress at vegetative and flowering stages significantly reduced 100-grain weight of cowpea varieties. Plants subjected to water stress during flowering stages had a lower 100-grain weight than water stress at vegetative stage. Weight of 100-grains varied from 12.9 g (Nyekundu) to 19.3 g (Nyeupe), 12.0 g (Nyekundu) to 18.9 g (Nyeupe) and 11.7 g (Nyekundu) to 18.6 g (Nyeupe) under no water stress, stress at vegetative and flowering stages, respectively. Variety Nyeupe had significantly higher 100-grain weight than other varieties under all water stress levels. Variety and interaction between variety and water stress significantly reduced cowpea pod weight (Table 5). Main effects of water stress levels had no significant effect on cowpea pod weight.

Table 4. Effect of water stress at vegetative and flowering growth stages on number of pods per plant and grains per pod of cowpea

Cowpea variety (V)	Number of pods per plant				Number of grains per pod			
	Water Stress (WS)			V- mean	Water Stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	10.0	9.0	10.0	9.7	13.7	15.3	14.3	14.4
Khaki	7.3	10.7	9.0	9.0	15.3	15.0	16.0	15.4
K 80	9.0	11.0	7.7	9.2	14.7	15.0	14.0	14.6
Macho	10.0	10.0	12.3	10.8	12.3	13.0	13.7	13.0
Kaima-koko	9.0	10.0	9.3	9.4	15.7	14.3	13.0	14.3
Nyeupe	6.0	8.0	11.7	8.6	11.7	13.3	12.7	12.6
KVU 27 – 1	8.0	9.0	8.7	8.6	12.0	14.7	14.7	13.8
Nyekundu	10.0	10.0	9.3	9.8	15.0	13.0	14.3	14.1
M 66	10.3	10.7	11.7	10.8	15.3	14.0	12.7	14.0
Kutambaa	4.3	9.3	8.7	7.4	14.0	14.0	13.0	13.7
Mwandato	5.3	6.3	7.3	6.3	12.3	15.0	13.3	13.6
WS-mean	8.1	9.5	9.6		14.0	14.2	13.8	
p-value (V)	0.0001				0.141			
p-value (WS)	0.0003				0.549			
p-value VxWS)	0.006				0.625			
$LSD_{0.05}$ V	1.46				Ns			
$LSD_{0.05}$ WS	0.76				Ns			
$LSD_{0.05}$ V x WS	2.39				Ns			
CV *main plot* (%)	37.25				12.15			
CV *subplot* (%)	17.52				13.73			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

Table 5. Effect of water stress at vegetative and flowering growth stages on cowpea 100-grain weight and pod weight (t/ha)

Cowpea variety (V)	100-grain weight (g)				Pod weight (t/ha)			
	Water Stress (WS)			V- mean	Water Stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	13.6	13.1	12.7	13.1	11. 67	6.07	6.97	8.23
Khaki	13.6	13.1	12.8	13.2	9.50	3.97	8.17	7.21
K 80	13.5	13.4	13.3	13.4	10.17	6.07	7.57	7.93
Macho	16.4	15.8	15.6	15.9	10.00	9.70	11.33	10.34
Kaima-koko	13.5	13.5	12.9	13.3	13.43	8.90	7.57	9.97
Nyeupe	19.3	18.9	18.6	18.9	15.60	18.07	19.00	17.56
KVU 27 – 1	18.0	17.3	16.4	17.2	8.80	7.90	8.10	8.27
Nyekundu	12.9	12.0	11.7	12.2	11.77	7.90	9.47	9.71
M 66	14.6	14.4	13.5	14.2	8.17	7.57	6.27	7.33
Kutambaa	14.9	14.1	12.3	13.8	19.00	10.27	11.93	13.73
Mwandato	13.7	13.3	13.1	13.4	16.10	17.93	18.70	17.58
WS-mean	14.9	14.5	13.9		12.20	9.49	10.46	
p-value (V)	0.0001				0.0001			
p-value (WS)	0.0001				0.0001			
p-value VxWS)	0.0001				0.0001			
$LSD_{0.05}$ V	0.09				0.32			
$LSD_{0.05}$ WS	0.05				0.17			
$LSD_{0.05}$ V x WS	0.16				0.56			
CV *main plot* (%)	1.2				15.47			
CV *subplot* (%)	2.20				42.16			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

Water stress at vegetative stage significantly increased pod weight of KVU 27-1 but had no effect on the pod weight of the rest of the varieties. In contrast, water stress at flowering significantly increased pod weight of Nyeupe, Kutambaa and Mwandato and significantly reduced pod weight of KVU 419; but had no effect on the rest of the varieties. Under no water stress, KVU 419 and Mwandato had significantly higher and lower pod weight, respectively, than most varieties. Under water stress at vegetative stage, Mwandato and KVU 27-1 had significantly lower and higher pod weight, respectively, than most varieties. Nyeupe and Mwandato had significantly higher and lower pod weight, respectively, than most varieties under stress at flowering stage.

3.6 Effect of Water Stress at Vegetative and Flowering Growth Stages on Cowpea above Ground Dry Matter at Maturity and Grain Yield

Variety, water stress and interaction between variety and water stress significantly affected cowpea shoot dry matter and grain yield (Table 6). Water stress at vegetative and flowering stages significantly lowered the shoot dry matter in cowpea varieties by 56.2% and 36.2% respectively. At vegetative stage the reduction in shoot dry matter ranged from 26.4% in Macho to 86.8% in Mwandato, while, at flowering stage it ranged from 15.3% in KUV 27-1 to 78.3% in Mwandato. At vegetative stage Nyeupe and Mwandato had higher dry matter reduction of 76.3% and 86.8%, respectively while at flowering stage Mwandato had the highest reduction of 78.3% in shoot dry matter. Water stress at vegetative stage significantly increased grain yield in KVU 27, Nyekundu, Kaima Koko, K80 and M66 by 121.1, 102.2, 55.8, 52.8 and 52.4% respectively; but it significantly reduced grain yield in Nyeupe by 44.0%. Water stress at flowering significantly increased grain yield in Nyekundu and Kutambaa by 53.3 and 119.6%, respectively, but had no significant effect on grain yield in the rest of the varieties. KVU 419 had significantly higher grain yield than Kutambaa, Mwandato and Khaki under no stress but its yield was not significantly different from the rest of the varieties. Under water stress at vegetative stage, KVU 27-1, Nyekundu and Kaima koko had significantly higher grain yield than most of the other varieties. Under water stress at flowering, no major differences were noted among the varieties except that Mwandato

Table 6. Effect of water stress at vegetative and flowering growth stages on cowpea above ground dry matter yield at maturity and grain yield

Cowpea variety (V)	Dry matter yield (t/ha)				Grain yield (t/ha)			
	Water Stress (WS)			V- mean	Water Stress (WS)			V- mean
	Nws	**Vws**	**Fws**		**Nws**	**Vws**	**Fws**	
KVU 419	20.49	11.67	14.92	15.69	1.34	1.25	1.04	1.21
Khaki	22.67	9.50	12.56	14.91	0.68	0.90	1.03	0.87
K 80	22.41	10.20	16.25	16.29	0.89	1.36	1.23	1.16
Macho	9.18	10.00	12.48	10.55	1.09	0.89	1.41	1.13
Kaima-koko	19.78	13.40	16.27	16.48	1.13	1.76	1.23	1.37
Nyeupe	15.60	3.60	8.11	9.10	1.16	0.65	1.54	1.12
KVU 27 – 1	25.19	8.80	14.44	16.14	0.90	1.99	1.17	1.35
Nyekundu	23.54	11.70	14.89	16.71	0.92	1.86	1.41	1.40
M 66	21.33	8.20	18.06	15.86	1.05	1.60	1.12	1.26
Kutambaa	19.00	7.21	10.34	12.18	0.56	0.74	1.23	0.84
Mwandato	16.00	2.12	3.48	7.20	0.48	0.38	0.65	0.50
WS-mean	19.86	8.69	12.67		0.93	1.22	1.19	
p-value (V)	0.0001				0.0001			
p-value (WS)	0.136				0.0002			
p-value VxWS)	0.0003				0.0001			
$LSD_{0.05}$ V	0.41				0.27			
$LSD_{0.05}$ WS	Ns				0.14			
$LSD_{0.05}$ V x WS	0.70				0.47			
CV *main plot* (%)	1.62				4.92			
CV *subplot* (%)	4.48				28.4			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

had significantly lower grain yield than most varieties while Nyeupe had higher grain yield than Mwandato, KVU 419 and Khaki. Average grain yield across all water stress levels varied from 0.5 t/ha (Mwandato) to 1.40 t/ha (Nyekundu).

3.7 Effects of Water Stress at Vegetative and Flowering Growth Stages on Cowpea Harvest Index

Cowpea variety, water stress and the interaction between cowpea variety and water stress significantly affected the harvest index (Table 7). Water stress at vegetative stage significantly increased harvest indices of all cowpea varieties except Macho, Nyeupe and Kutambaa. Water stress at flowering enhanced cowpea harvest indices for only K80, Kaima-koko, Nyekundu, and Kutambaa varieties. Mwandato had significantly the highest harvest indices under all the stress levels. Under water stress at vegetative stage, Kutambaa and Nyeupe had significantly the highest indices than all other varieties. Harvest indices varied from 2.93% (Mwandato) to 12.8% (M66) under no stress, 2.13% (Mwandato) to 25.3% under stress at vegetative stage and 3.47% (Mwandato) to 18% (M66) at flowering.

4. DISCUSSION

4.1 Effects of Variety and Water Stress on Cowpea Chlorophyll Content, Canopy Temperature and Time to Anthesis

Water stress at vegetative stage significantly reduced cowpea chlorophyll content. This observation has been reported in previous studies. [26] Reported 100% reduction in the chlorophyll content of cowpea genotypes under both moderate and severe water stress. Chlorophyll content is among the morphological, biochemical and physiological traits for drought screening in cowpea [27]. In the current study, the response to drought in terms of chlorophyll content was, however, not dependent on the cowpea variety. Chlorophyll content could not therefore be used to identify drought tolerant cowpea varieties. Water stress during flowering had no effect on chlorophyll content.

Water stress significantly increased canopy temperature for varieties such as Khaki and Kaima-koko but reduced the canopy temperature of Macho and Nyekundu. [28] reported that water stress significantly increased canopy temperature of cowpea plants. They attributed this to the fact that cowpea plants Stomata

Table 7. Effects of water stress at vegetative and flowering growth stages on cowpea harvest index

Cowpea variety (V)	Harvest index (%)			
	Control (no stress)	Vegetative stage	Flowering stage	V-mean
KVU 419	11.53	20.53	14.87	15.64
Khaki	7.13	22.77	12.70	14.20
K 80	8.70	22.53	16.27	15.83
Macho	10.93	9.23	12.40	10.85
Kaima-koko	8.37	19.70	16.27	14.78
Nyeupe	7.43	3.57	8.13	6.38
KVU 27 – 1	10.20	25.30	14.90	16.80
Nyekundu	7.80	23.70	14.93	15.48
M 66	12.87	21.17	18.00	17.35
Kutambaa	2.97	7.20	10.33	6.83
Mwandato	2.93	2.13	3.47	2.84
WS-Means	8.26	16.17	12.93	
p-value (V)	0.0001			
p-value (WS)	0.0001			
p-value VxWS)	0.0001			
$LSD_{0.05}$ V	3.52			
$LSD_{0.05}$ WS	1.84			
$LSD_{0.05}$ V x WS	6.10			
CV main plot (%)	7.37			
CV subplot (%)	30.00			

closure is the first responsive event of plants to water deficiency [29]. There was a positive linear relationship between canopy temperature and grain yield, suggesting that stomatal closure resulted in increased water use efficiency. [18] reported that stomata closure under water stress resulted in increased water use efficiency (WUE). Canopy temperatures of Nyekundu and Macho decreased when water stress was imposed suggesting that they did not depend on stomata adjustment as a strategy to deal with water stress. Water stress at vegetative and flowering stages increased time to anthesis by 4 and 7 days, respectively. [10] reported that the onset of and dates to full flowering of cowpea were significantly delayed under high moisture stress. The interaction between variety and water stress did not affect the time to anthesis.

4.2 Effects of Water Stress on Cowpea Leaf Number, Percent Ground Cover and Shoot Dry Matter Yield at Maturity

Water stress caused reduction in cowpea leaf number, percent ground cover and dry matter yield at maturity. Reduction in leaf production and/or increase in leaf senescence and abscission due to water stress have been reported in previous studies [30]. [31] and [32] reported that post-flowering water stress reduced the cowpea total dry matter. Reduction in leaf and plant growth has been attributed to decrease in cellular expansion resulting from a decrease in plant water content [10], reduction in leaf formation and increased abscission of lower leaves [33]. The reduction in growth parameters under water stress conditions could also be attributed to decline in photosynthesis [34]. The effects of water stress on leaf number, percent ground cover and dry matter yield were dependent on cowpea genotypes [26].

4.3 Effects of Water Stress on Harvest Index, Grain Yield and Yield Components

Water stress at both vegetative and flowering stages significantly increased the number of pods per plant, pod weight, grain yield and harvest index for some varieties. Earlier studies indicated that cowpea could maintain seed yield when water stress was subjected at vegetative stage provided subsequent conditions were conducive for flowering and pod set [12]. However, [10] showed that cowpea is highly sensitive to water deficits during flowering and pod filling stages which lead to reduced grain yields. In the current study, there was a positive linear regression relationship between grain yield and number of pods per plant, 100-grain weight and pod weight. Grain yield in cowpea is determined by the product of the number of pods per plant that reach maturity, the average number of grains per pod and 100-grain weight [10]. Under water stress conditions, cowpea closes their stomata to avoid dehydration [28]. This reduces water loss [27] and increases water use efficiency (WUE) [18]. Cowpea varieties with high pod weight under water stress conditions could be making use of the additional photosynthetic capacity of their pods [35]. [3] reported that water stress increased cowpea harvest index. Most of the varieties in the current study apparently responded to water stress by partitioning more photosynthates to the grain relative to the shoot, thus leading to grain yield increases. This suggests that short-term moderate drought stress during vegetative growth and flowering enhances grain yield of some cowpea varieties but reduces shoot growth. Cowpea varieties which were superior in yield and high harvest indices under water stress included Nyekundu, KVU 27-1, M66, and KVU 419. Under no water stress, the cowpea varieties which had high harvest indices were M66, KVU 419, Macho and KVU 27-1.

5. CONCLUSION

Water stress imposed at vegetative and flowering reduced growth parameters and chlorophyll content, but enhanced grain yield and yield components of some varieties. The impact of water stress on growth is dependent on the cowpea variety. Moderate stress may be beneficial if cowpea is grown for grain production but not if grown for vegetable production. Cowpea varieties which were superior in yield and high harvest indices under water stress included Nyekundu, KVU 27-1, M66, and KVU 419.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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