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Effect of intensity and frequency of leaf harvesting on growth, nodulation, and yield of selected cowpea varieties

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Abstract

Cowpea (Vigna unguiculata (L.) Walp) is a leguminous crop widely cultivated across the world and is considered more useful than other vegetables particularly in Sub-Saharan Africa. The objective of this study was to determine the effect of intensity and interval of leaf harvesting on growth, nodulation, and yield of cowpea varieties M66, *Lubia* and *Areng* in South Sudan. The experiment was set up at Awerial and Bor sites in South Sudan in a randomized complete block design (RCBD) in a 4×3×3 factorial arrangement. The factors evaluated were cowpea variety at three levels (M66, *Lubia* and *Areng*), intensity at four levels (0%, 20%, 40% and 60%) and interval of leaf harvesting at three levels (2, 3 and 4 weeks). Cowpea variety *Areng* had the best performance among the three varieties evaluated. *Areng* took 52 days to flower and 108.7 days to attain maturity followed by *Lubia* and M66 which took the shortest time to flower and reach maturity. In contrast, the highest number of nodules of 124 at vegetative and 136 at flowering stage was observed on variety M66 followed by *Areng* while the lowest number of nodules was observed on variety *Lubia*. Effects due to environment, variety, interval, and intensity were significant ($p \leq 0.001$) for days to flowering, maturity, number of nodules at flowering, weight of pod, grain weight, shoot fresh weight and shoot dry weight at flowering stages. Harvesting intensity and interval has significant effect on yield and yield components of cowpea varieties and therefore, cowpea variety *Areng* is suitable for seed weight and foliage harvesting because irrespective of intensity of leaf harvesting, the dry matter was not reduced to a level that can affect production. Moreover, the variety M66 was the best in grain weight across and within sites.

Keywords: *Cowpea; Defoliation; Frequency; Intensity; Variety*

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Introduction

Cowpea (*Vigna unguiculata* L. Walp) is a leguminous crop widely cultivated in Africa and other parts of the world. It is mostly considered a very useful protein vegetable in many parts of the world and particularly in sub-Saharan Africa (Adeoye *et al.*, 2011). Being a legume, cowpea fixes nitrogen into the soil hence it contributes to nitrogen enrichment into the soil for cereal crops such as sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum americanum* L.) and maize (*Zea mays* L.). It is particularly so when it is intercropped or grown in rotation especially in the areas where farmers do not use fertilizer or the cost is prohibitive. In South Sudan, women are mainly responsible for growing cowpeas thus improving their livelihoods and empowering them from income realized from the sale of the produce. In South Sudan cowpea production is rainfed and yields are very low. The low yields are realized due to lack of improved cultivars, poor agronomic practices, lack of certified seeds, poor extension services and poor techniques in leaf harvesting (Ahmed *et al*., 2012). Genetic constitution of cowpea plays a significant role in production potential of different varieties of cowpeas despite being a subject of environmental influence (Badawy, 2018). Method of analysis of nutrient contents in cowpea might also influence detectable nutrient (Afiukwa *et al*., 2013). As much as cowpea is tolerant to water stress and heat and grows well in different types of soils, hot temperature has a significant effect on maturity period of cowpea. For instance, photosensitive varieties mature earlier than photo-insensitive ones which are affected by short-days and long-days duration (Ishiyaku *et al*., 2005). Increases in number of flowers per plant depend on the increase of peduncles per plant which results in the positive effects of grain yield (Manggoel *et al*., 2012). Despite cowpea vegetative growth being affected by photoperiod under hot environment, the vegetative stage has been improved on various varieties to allow canopy growth which is important for yield increase (Ishiyaku and Singh, 2003). Cowpea is also affected by plant density whereby high plant density reduces the number of leaves, branches peduncles, flowers per plant and total dry matter yield (Malami and Sama'ila, 2012). Harvest index (HI) is also reduced due to high total dry matter of the shoot and low grain yield per plant under high population density (Ahmed *et al*., 2012).

Photosynthesis activities are affected by the increase in leaf harvesting interval, consequently the grain yield is also reduced with increased leaves harvesting frequency (Mwanarusi *et al*., 2007). Leaves harvesting at 5 weeks' intervals can also affect the total seed yield however, it has no effect on concentration of protein in seeds (Nielsen *et a*l., 1994). Reduction in leaf harvesting frequencies results in a high rate of photosynthetic processes on leaf surface area which result in low rate of leaf development, grain, and nodule formation (Mwanarusi *et al*., 2007). High leaf harvesting frequency delays the time to flowering which allows appropriate development of shoot leading to high production of growth components. Leaf harvesting on a weekly basis at low intensity levels result in increased leaf yield (Matikiti *et al*., 2012). Harvesting cowpea leaves at one-week interval result in high leaf and grain yields (Mwanarusi *et al*., 2007). Leaf harvesting techniques play a major role in achieving high vegetable production in cowpea production (Matikiti *et al*., 2012). Therefore, the objective of this study was to determine the effect of intensity and interval of leaf harvesting on growth, nodulation and yield of cowpea varieties M66, *Lubia* and *Areng* in South Sudan.

Material and methods

Experimental site

This study was conducted in Awerial and Bor sites in South Sudan. Bor is located 6˚ 21′ 45′′ N; 31˚ 55′ 39′′ E at an altitude of 407 m above sea level (m.a.s.l). Bor experiences an average temperature range of 27 to 38 °C and a unimodal rainfall pattern with 1105 mm rainfall per annum. The rainy season occurs from March to December and the dry season is experienced from December to April of every year. Awerial is located 6˚, 5′ 0′′ N; 31˚, 30′ 22′′ E at an altitude of 450 m.a.s.l. Awerial experiences an average rainfall of 805 mm per annum, in a single season from April to December. This site experiences temperature range of 40 °C- 26 °C with the maximum and minimum range experienced in March and July, respectively (South Sudan Livelihood Zones and descriptions, 2013).

Experimental procedure

The field was ploughed and harrowed twice to a moderately fine tilth using a handheld hoe. Seeds were inoculated with *Bradyrhizobium* spp before sowing in a 4-row plot measuring 2 m × 1.5 m. Three seeds were planted per hill at a spacing of 30 cm × 20 cm and later thinned to one plant per hill a week after emergence. The experiment was conducted in a randomized complete block design (RCBD) in 4×3×3 factorial arrangement with 3 replications. The factors evaluated were cowpea varieties, intensity and frequency. Cowpea varieties Kunde M66, *Lubia* and *Areng*, were used in this study. Leaf harvesting intensities and intervals were imposed on plots according to treatments. The treatments were intensity at four levels, control, 20%, 40% and

60% while leaf harvesting intensities were at 2-, 3- and 4-weeks intervals of harvesting. The growth of broad leaf and grass weeds were controlled by carrying out hand weeding three times during the growth period of the cowpea. Chewing and sucking insect pests were controlled by applying single doses of BESTOX® 100EC broad-spectrum insecticide at the rate of 50 g L^{-1} active ingredient (*alpha- cypermethrin* 50).

Data collection

A random sample of five plants was obtained from the central two rows of each plot and tagged. The first sampling commenced 4 weeks after sowing (WAS) and this coincided with the start of leaf harvesting. From these samples, the following data were obtained and processed for analysis. Plant height was determined by measuring from the base to the tip of the longest leaf of each plant at 4, 6, 8 and 10 weeks after sowing. To show the progression of development of number of branches, the number of branches per plant was determined by counting branches from each plant as the crop was growing. Number of leaves per plant was determined from the sample plants from each plot from each category of the 4-harvesting frequencies. The number of days to anthesis was determined from each plot by calculating the difference between anthesis and sowing dates. Plants were considered to have reached anthesis stage when 50% of plants per plot had flowers (Shimelis *et al*., 2010).

The number of nodules per plant was determined as an average of number of nodules from 5 plants randomly selected from the middle rows of each plot. This was achieved by carefully uprooting, gently shaking, and washing in running water to remove the soil before the number of nodules per plant was counted at vegetative and 50% flowering stages (Matikiti *et al*., 2012). Biomass was obtained by cutting the plants at the ground level and measuring the weight at vegetative, 50% flowering and maturity stage. The number of pods per plant was determined as the mean number of pods from 5 randomly selected plants in each plot at harvesting time. The number of seeds per pod was determined as the mean of seeds from 5 pods per plant from 5 randomly selected plants and calculating the mean numbers seeds of the five plants in each plot at physiological maturity. The 100-seed weight was determined by randomly selecting 100 seeds per plot and weighed using a sensitive weighing balance in grams (g). Pod weight was determined by counting and weighing total number of pods selected from the five plants sampled and tagged in each plot at harvest time.

Data analyses

The data collected were analyzed following a two-step procedure where data were first analyzed for individual sites (Bor and Awerial) to get the mean performance of the varieties for traits determined followed by combined analysis of variance over the sites using Statistical Analysis Software (SAS) software (SAS NC., 2001; Gomez and Gomez, 1984). Means were separated using Least Significant Difference (LSD) whenever main effects were significant at 95% critical level. Standard error of the mean was calculated using the following formulae, $SE = \frac{\sigma}{\sqrt{n}}$ where SE=standard error, σ=standard deviation and n=sample size and used to separate individual means. Regression analysis was carried out to determine the response of varieties to intensity and frequency of plucking.

Results

Combined analysis of variance

Effects due to environment were significant for all the traits except number of seeds and 100 seed weight. Variety had a significant effect on all the traits except shoot dry weight at vegetative stage (Table 1). Effects due to the environment × variety interaction were significant for shoot fresh weight at vegetative stage (p≤0.01), shoot at fresh weight at vegetative stage and shoot dry weight at flowering (p≤0.01) (Table 1). Harvesting interval had a significant effect on all the traits except shoot dry weight at vegetative weight. Significant differences were observed on number of nodules at flowering (p≤0.01) and number of seeds (p≤0.05) environment × interval interaction effects. Intensity had significant effects on all the traits except shoot dry weight at vegetative stage whereas environment × intensity interaction had significant effects on days to flowering, number of nodules at flowering, number of seeds (p≤0.05), number of pods (p≤0.01), days to maturity, shoot fresh weight at vegetative stage and shoot fresh weight at flowering stage (p≤0.001) (Table 1).

Effects due to variety × intensity interaction was significant for number of nodules at flowering, number of seeds, shoot fresh weight at flowering ($p \le 0.05$), days to flowering, and 100 seed weight ($p \le 0.01$).

Environment × variety × intensity interaction had a significant effect on days to maturity and grain weight, shoot dry weight at flowering ($p \le 0.05$) and shoot fresh weight at vegetative stage ($p \le 0.01$) (Table 1). Effects due to interval × intensity interaction was significant for shoot fresh weight at vegetative stage, shoot dry weight at flowering stage, number of pods, pod weight, grain weight ($p \le 0.05$) and shoot fresh weight at flowering ($p \le 0.001$). Significant ($p \le 0.05$) differences for pod weight, shoot fresh weight at flowering and shoot dry weight at flowering were observed for environment × interval × intensity interaction effects whereas environment × variety × interval × intensity had significant effect on grain weight (Table 1).

Table 1. Combined analysis of variance for leaf harvesting interval and intensity for Yield and yield components of 3 cowpea varieties evaluated in Awerial and Bor, South Sudan

Source of variation	df	Days to flowering	Days to maturity	No. of nodules at vegetative stage	No. of nodules at flowering	No. of pods	No. of seeds	100 seed weight	Pod weight
Environment (E)	1	4908.89[c]	56689.69[c]	1211.61[c]	1264.05[c]	12583.47[c]	18.69	0.00	2372456.81[c]
Replicate (E)	4	2.86	76.83	76.31	600.62	797.91	157.39	0.81	1982.49
Variety (V)	2	605.09[c]	3454.62[c]	16662.16[c]	11124.20[c]	7282.11[c]	1158.76[b]	434.02[c]	150149.11[c]
E × V	2	46.29[c]	294.51[c]	25.09	3125.07[c]	273.50	5.49	0.00	344691.37[c]
Interval (IT)	2	121.52[c]	181.41[c]	497.64[c]	2435.80[c]	2372.22[c]	1024.02[c]	25.41[c]	26405.86[c]
E × IT	2	2.04	5.01	17.41	302.67[b]	325.00	76.47[a]	0.00	173.41
V × IT	4	1.65	1.91	7.35	49.03	17.70	12.71	1.62[b]	233.79
E × V × IT	4	0.38	3.04	20.73	27.86	9.78	4.06	0.00	339.96
Intensity (IN)	2	280.04[c]	726.01[c]	274.27[c]	1083.69[c]	6558.19[c]	864.15[c]	20.67[c]	38049.56[c]
E × IN	2	8.56[a]	143.71[c]	54.49	179.08[a]	1345.85[b]	86.56[a]	0.00	1608.00
V × IN	4	9.51[b]	15.70	22.38	126.04[a]	89.53	80.06[a]	2.22[b]	411.22
E × V × IN	4	3.45	33.27[a]	29.30	59.21	13.49	36.54	0.00	591.79
IT × IN	4	2.62	2.73	45.40	65.59	468.32[a]	31.52	0.74	2342.68[a]
E × IT × IN	4	0.95	1.28	22.68	55.51	127.52	17.51	0.00	2904.07[a]
V × IT × IN	8	1.16	2.52	15.43	23.11	58.88	11.53	0.52	296.28
E × V × IT × IN	8	2.31	1.50	28.89	4.19	3.49	16.20	0.00	501.81
Error	116	1.80	9.70	23.67	41.44	155.73	18.02	0.45	735.92
CV%		2.76	3.11	4.29	5.07	8.13	6.83	5.60	5.14
R^2		0.97	0.94	0.93	0.91	0.77	0.82	0.95	0.98

[a], [b],[c]=Significant at $p \le 0.05$, $p \le 0.01$ and $p \le 0.001$, respectively, CV=coefficient of variation

Table 1. Continue.

Source of variation	df	Grain weight	Shoot fresh weight at vegetative stage	Shoot dry weight at vegetative weight	Shoot fresh weight at flowering	Shoot dry weight at flowering
Environment (E)	1	13397753.69***	2706.68***	262739.60*	52804.93***	63882.67***
Replicate (E)	4	163683.46	125.92***	48829.83	42.62***	323.27*
Variety (V)	2	20908635.05***	349.35***	56604.20	6755.48***	5370.70***
E × V	2	299664.74***	44.35**	41978.33	4174.68***	7741.90***
Interval (IT)	2	602325.93***	71.72***	52862.48	175.22***	3606.68***
E × IT	2	46313.69	10.63	46416.24	6.79	18.70
V × IT	4	28507.70	0.61	42491.87	6.06	46.87
E × V × IT	4	3952.05	5.19	40326.14	2.53	257.83
Intensity (IN)	2	1431573.78***	301.16***	48324.52	1018.83***	5622.35***
E × IN	2	35209.24	61.37***	50468.68	193.55***	108.00
V × IN	4	17584.91	2.16	41771.33	24.67*	82.95
E × V × IN	4	75240.96*	1.54	39237.28	31.12**	277.05*
IT × IN	4	91935.20*	14.86*	46023.70	83.13***	355.62*
E × IT × IN	4	60973.62	5.66	43578.31	20.01*	292.05*
V × IT × IN	8	40864.16	3.83	42896.12	9.76	46.08
E × V × IT × IN	8	69600.95*	1.30	43142.69	4.35	109.85
Error	116	25711.04	5.82	37847.09	5.59	110.69
CV%		5.88	8.74	74.25	4.24	5.40
R^2		0.95	0.88	0.39	0.99	0.90

*, **,***=Significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively, CV=coefficient of variation

Cowpea variety *Areng* took long (52 days) to flower while variety M66 took the least number of days (47 days) to flower (Table 2). This was also observed on days to maturity where variety M66 reached physiological maturity earlier (94 days) than *Lubia* and *Areng* which took 98 and 122 days to mature, respectively. Further, variety M66 had the highest number of nodules at both flowering and vegetative stages followed by *Areng* and *Lubia*. *Areng* and M66 were not significantly ($p \leq 0.05$) different in fresh shoot vegetative stage (Table 2). On the other hand, all the 3 varieties did not differ in dry shoot at vegetative stage. Significant differences were observed among the varieties for both fresh shoot at flowering and shoot dry weight at flowering. Variety *Areng* had the highest fresh shoot weight at flowering while variety M66 had the highest shoot dry weight at flowering (Table 2).

Table 2. Means for three cowpea varieties on defoliation intensities and frequencies at Awerial and Bor South Sudan.

Variety	Days to flowering	Days to maturity	Number of nodules at vegetative stage	Number of nodules at flowering	Fresh Shoot at vegetative stage	Dry Shoot at vegetative Stage	Fresh Shoot at flowering	Shoot dry weight at flowering
Areng	52.30a	108.75a	121.85b	133.45b	29.40a	270.75a	66.68a	184.80c
Lubia	47.07b	97.58b	93.98c	111.45c	24.87b	287.40a	45.48c	196.57b
M66	46.57c	94.27c	123.75a	136.35a	28.57a	227.87a	55.25b	203.52a
LSD (0.05)	0.49	1.13	1.76	2.33	0.87	70.35	0.85	3.80
Mean	48.56	100.30	113.19	127.08	27.61	262.01	55.80	194.96

Means followed by the same latter in the same column are not significantly different at *p*<0.05

Table 2. Continue…,

Variety	Number of pods	Number of seeds	100 seed weight	Pod weight	Grain weight
			…………………..…..g……………………………...		
Areng	160.53a	62.97b	14.83a	562.23a	2934.43b
Lubia	140.85c	57.37c	9.47c	470.02c	2059.98c
M66	159.27b	66.03a	11.83b	549.73b	3184.18a
LSD (0.05)	4.51	1.53	0.24	9.81	57.98
Mean	153.55	62.12	12.04	527.33	2726.20

Means followed by the same latter in the same column are not significantly different at *p*<0.05

Table 2. Continues…,

Variety	Plant height	Number of leaves	Number of branches	Fresh dry weight	Dry weight	Dry matter plant^{-}	Total dry matter plot^{-1}
	Cm			…………………………..g …………………………			
Areng	368.50a	239.60a	44.30a	169.82a	71.53a	209.87a	1468.38a
Lubia	343.59b	231.36b	40.72b	144.38b	51.46b	190.62c	1335.20c
M66	299.72c	200.07c	36.64c	134.53c	51.28b	201.03b	1406.53b
LSD (0.05)	3.85	3.59	0.63	5.50	2.23	3.24	22.77
Mean	337.26	223.68	40.55	149.57	58.09	200.51	1403.37

Means followed by the same latter in the same column are not significantly different at *p*<0.05

Table 3 Means for Areng, Lubia and M66 cowpea varieties evaluated at Awerial and Bor sites for days to flowering, days to maturity, number of nodules at vegetative stage and number of nodules at flowering stage

Variety	Days to flowering		Days to maturity		Number of nodules at vegetative stage		Number of nodules at flowering	
	Awerial	Bor	Awerial	Bor	Awerial	Bor	Awerial	Bor
Areng	47.333	57.27	100.63	116.87	120.00	123.70	135.00	131.90
Lubia	42.566	51.57	93.70	101.47	91.07	96.90	112.93	109.97
M66	40.366	52.77	89.400	99.13	120.73	126.77	125.37	147.33

The means on defoliation intensity and frequencies showed that, *Areng* had the highest number of pods (161) compared to *Lubia* (141) and M66 (159) (Table 2). Variety M66 performed better compared to *Lubia* and *Areng* in terms of number of seeds and grain weight whereas variety *Areng* performed better than *Lubia* and M66 in terms of 100 seed weight and pod weight (Table 2). Interestingly, variety *Areng* was taller, had the highest number of leaves, branches, fresh dry weight, dry weight, dry matter and total dry matter per plot compared to variety *Lubia* and M66. Although, *Areng* performed best in the named traits, a significant difference was observed between *Lubia* and M66. *Lubia* was taller, had high number of leaves, number of branches and fresh dry weight compared to M66 (Table 2). On the other hand, M66 had higher dry matter and total dry matter per plot compared to *Lubia*. However, M66 and *Lubia* did not differ in dry weight. In this study, the mean highest yield was observed on variety M66 (3184.18 g) across the two test experimental sites followed by variety *Areng* (2934.43 g) (Table 2).

Effect of environment on performance of cowpea

All the three varieties had almost similar performance in dry weight at flowering in Awerial (Figure 1). However, there was variation in performance in Bor where *Areng* had the highest mean followed by M66 and *Lubia*. *Areng* took long to flower and mature in both Awerial and Bor (Table 3). *Areng* had the highest seed weight in both Awerial and Bor sites (Figure 2). However, *Areng* and M66 both had highest mean number of nodules at vegetative stage in Awerial whereas in Bor M66 performed better than *Areng* and *Lubia* (Table 3). Interestingly, Awerial seemed to be conducive for *Areng* in production of nodules at flowering while Bor favored variety M66 (Table 3). In both Awerial and Bor, M66 had the highest mean for grain weight which suggests there was minimal influence of the environment in expressing its production potential (Figure 3). In general, growth and physiology of *Lubia* seemed to be influenced by the environmental variability.

Regrowth of Cowpea varieties at different intensities of defoliation

Among the three varieties evaluated increase in harvesting intensity led to increased number of days to flowering of the three cowpea varieties. Flowering period for *Lubia* ($Y=38.915 +2.745x$, $\beta=2.745$ and $R^2=0.997$) and M66 ($Y=38.915 +2.745x$, $\beta=2.745$ and $R^2=0.997$) was significantly delayed compared to *Areng* ($Y=47.58 +1.689x$, $\beta=1.689$ and $R^2=0.920$) (Figure 4).

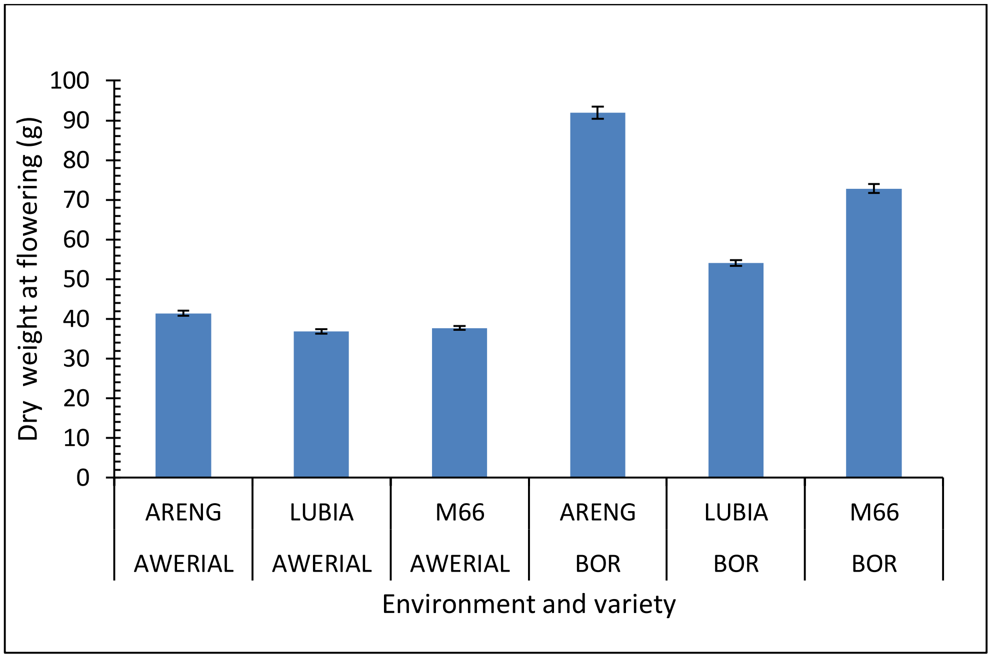

Figure 1. Accumulation of dry matter of 3 cowpea varieties at flowering stage Grown across Awerial and Bor experimental sites

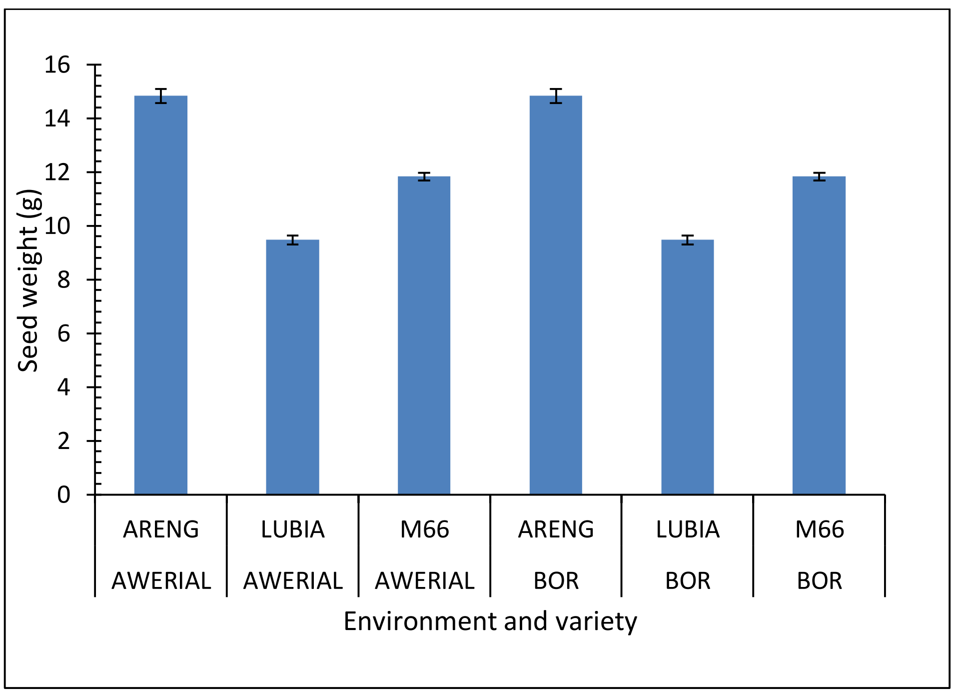

Figure 2. Mean Seed weight in grams from 3 cowpeas varieties evaluated across Awerial and Bor experimental sites in South Sudan

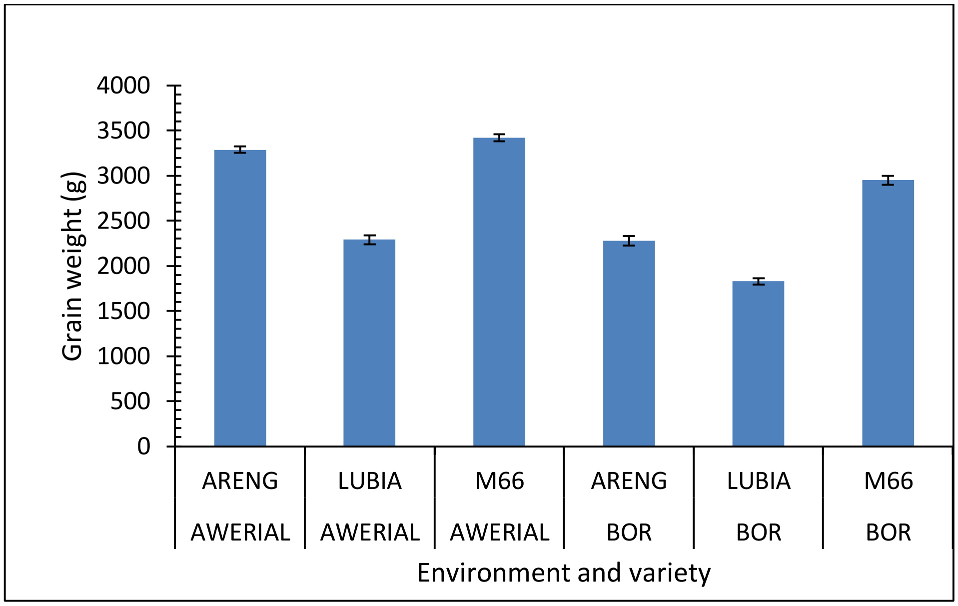

Figure 3. Grain weight of 3 cowpea varieties evaluated across Awerial and Bor experimental sites in South Sudan

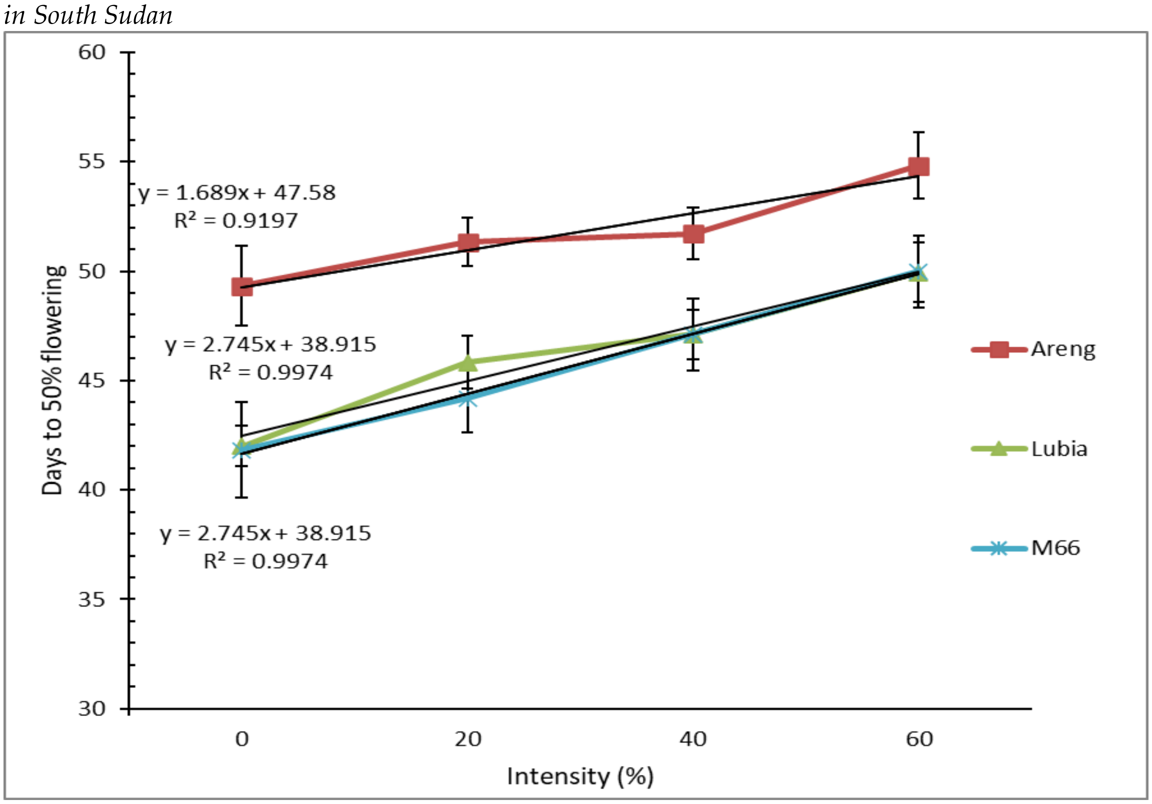

Figure 4. Showing the response of 3 cowpea varieties to 4 levels of defoliation intensities at flowering. Means are from 3 replicates (n=3)

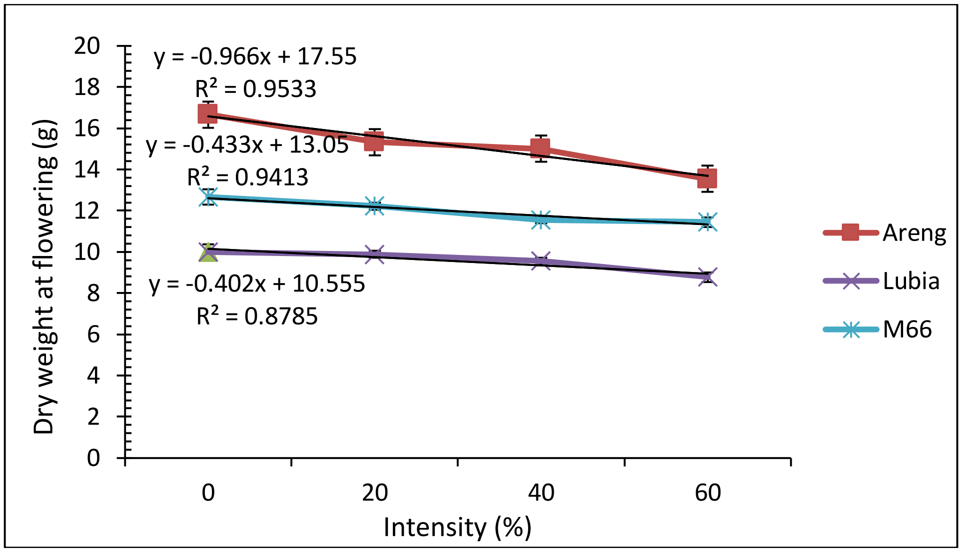

Figure 5. Response of cowpea varieties to accumulation of dry matter at different levels of intensities of defoliation

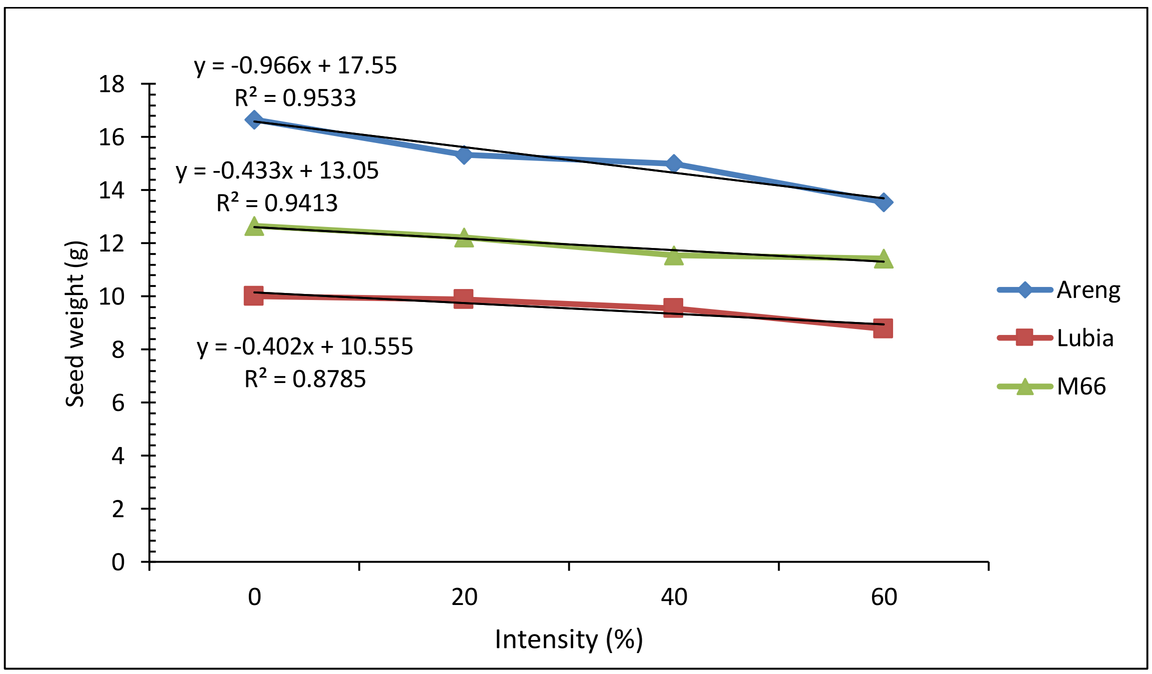

*Figure 6. Showing the seed weight of 3 cowpea varieties to intensity of defoliation. Early leaf harvested had no significant effect on leaf and stem weight per plant at maturity. However, there was a significant decrease in seed weight when leaves were harvested early (*Nielsen *et al.*, 1994*)*

Dry matter in cowpea is an important trait for the farmers who produce cowpea for herbage consumption. An increase in intensity of defoliation decreased dry matter weight of all the cowpea varieties at flowering. However, the decrease in dry matter at flowering stage was less pronounced on variety *Areng* ($Y = 17.55 - 0.966x$, with β=-0.966 and R^2 =0.953) than the other 2 varieties with the increase in defoliation intensities (Figure 5). Variety M66 accumulated the least dry matter at different intensities ($Y=13.05 - 0.4335x$, β=-0.433 and $R^2=0.941$) and rate consequently suggesting it is less suitable for foliage harvesting before flowering. Although harvesting intensity had a negative impact on seed weight, variety *Areng* had the highest decreasing rate in seed weight (*Y=17.55 - 0.966x*, β=-0.966 and $R^2=0.953$) the compared to *Lubia* (*Y=13.05 – 0.4335x*, β=-0.433 and R^2=0.941) and M66 (*Y=10.56 – 0.402x*, β=0.402 and $R^2=0.879$) (Figure 6). Similarly, harvesting intensity increased with decrease in grain weight in both varieties. Variety *Lubia* had the highest grain weight decreasing rate (*Y=2380.2 – 117.49x*, β=-117.49 and $R^2=0.914$) compared to *Areng* (*Y=3210.7 – 104.42x*, β=-104.42 and $R^2=0.914$) and *Lubia* (*Y=3377.8 - 0.73.985x*, β=-0.73.985 and $R^2=0.6278$) (Figure 7).

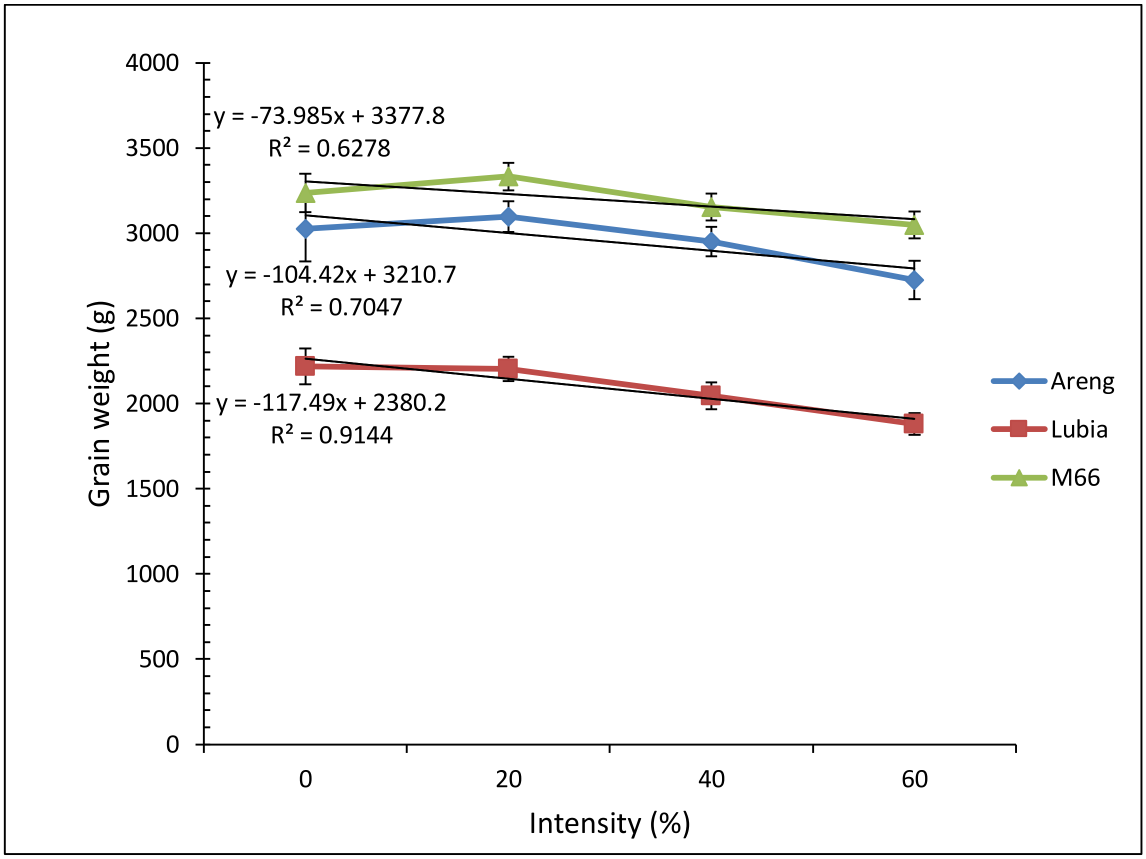

Figure 7. Showing the total grain weight in grams of 3 cowpea varieties to intensity of defoliation

Discussion

The two environments influenced the growth and physiology of the varieties. This suggests that varieties evaluated have agronomical stability for the test traits. However, the number of seeds and 100 seed weight were not influenced by the environmental variation. This shows that they are less sensitive to genotype × environment (Adewale *et al*., 2010). Despite being influenced by the changing environment, the varieties differed for all the traits tested.

Differential maturity growth in cowpea suggests that variety *Lubia*, M66 and *Areng* filled grains and translocated photosynthates to the grains at varied rates. The high number of nodules observed on variety M66 suggests that it may contribute to high levels of nitrogen fixation in the soil and may be beneficial for soil nutrient improvement. High yield in M66 indicated that this variety could be adopted for grain production by the farmers in South Sudan with annual precipitation of 804.9 mm in Awerial and 1104.5 mm in Bor with average temperature of 25 to 33.7°C during the growing season. Even though M66 exhibited the highest mean grain weight, there was no significant ($p \geq 0.05$) difference between variety *Areng* and M66 for shoot fresh weight at vegetative stage. According to Thornley (2002), several factors and varietal effects influence leaf nutrient position and leaf anatomy and the rate of photosynthesis. Further, Vu *et al*., (2006) and Kataria *et al*., (2019) reported that high ultra violet radiation decreases soluble nutrients in the leaf extracts of legumes and reducing leaf area, decreasing crop foliage, which limits photosynthetic performance which influences yield by reducing the number and weight of grains. Often, algometric relationship between traits of plants have been observed in wheat (Barkshandeh *et al*., 2012). Photosynthetic area is increased by the high number of leaves in a plant. In this study, variety *Areng* had 240 leaves compared to 231 and 200 observed on variety *Lubia* and M66, respectively. The results of this study showed that all the 3 varieties accumulated more dry matter at Bor than at Awerial. The difference in growth and physiology of the test varieties in Awerial and Bor with precipitation of 804.9 mm and 1104.5 mm, respectively, during growing season was attributed to the weather factors that favor growth of cowpea at the former environment. Therefore, at Awerial cowpea variety *Areng* significantly accumulated dry matter at flowering compared to the *Lubia* and M66 varieties suggesting favorable weather condition for variety adaptation and growth.

There were no marked environmental differences in seed weight suggesting that seed weight of the cowpea varieties evaluated were not influenced by the different environments (Awerial and Bor). The results showed that the varieties did not perform differently across the environments with respect to seed weight. Mean grain weight from the three varieties was a replica of the seed weight observed across the environments Awerial and Bor sites. The results suggest that there was no significant differential response of varieties in grain yield across the environments. It is therefore clear that variety *Areng* is the best performer across the 2 environments.

Defoliation of cowpea is an important event in most sub-Saharan countries, because cowpeas are grown for leaf consumption. In this circumstance, the rate of regrowth and recovery is important phenomena on cowpea physiology. In all the varieties evaluated, as the intensity of defoliation increased positive effects of delaying anthesis were observed. The results from defoliation intensity on the 3 varieties suggest that anthesis occurs much early in variety *Lubia* and M66 however, this was not reflected in the yield performance in which variety *Areng* produced the highest mean grain quantity. The yield of cowpeas could be increased by judicious defoliation of the older leaves or by topping the growing apices at the onset of flowering. High leaf harvesting frequency delayed the flowering time which allows appropriate development of shoot leading to high production of growth components (Igbal *et al*., 2006). Cowpea defoliated at the early stages just prior to podding significantly reduces growth, developmental characters' yield, and yield components (Ibrahim *et al*., 2010). In this study, it was evident that intensity of leaf harvesting delays flowering as depicted in the results, but delay was more pronounced in variety *Areng* which showed the highest mean yield contrary to the study conducted by Ibrahim *et al*. (2010). Defoliation results suggest that cowpea variety *Areng* is suitable for foliage harvesting because irrespective of intensity of leaf harvesting, the dry matter was not reduced to a level that could affect production (Badawy, 2018).

Conclusion

This study showed that interval and intensity of defoliation affect the weight of pod and shoot dry weight at flowering stage suggesting that the weight of the pod which is a determinant factor for seed weight varied with intensity and interval of defoliation across Awerial and Bor. Therefore, grain yield of cowpea varieties was influenced by interval and intensity of defoliation. Cowpea varieties in different environments may require different defoliation intensities. This could be due to influence of weather-related factors that prevail in specific environments and this also indicated that cowpea varieties established nodules on the roots differently across the environments in South Sudan.

Recommendations

There is need to select varieties that are suitable for specific environment for different purposes hence Awerial environment is suitable for cowpea varieties that are grown for grain production. However, Bor environment is good for cowpea grown for leaf production. Development parameters in cowpea showed that variety *Lubia* and M66 are suitable for the areas that experience less soil moisture in the soil. Cowpea variety *Areng* is suitable for foliage harvesting because irrespective of intensity, the dry matter was not reduced to a level that can affect production.

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