Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 58 (2025) 150-162 EISSN 2543-5426

Relationship Between Spectral Traits and Crop Vigour Scores to Grain Yield of Diverse Cowpea (*Vigna unguiculata* (L.) Walp.) Genotypes

A. A. Adnan and **E. A. Shittu***

Department of Agronomy, Bayero University Kano, PMB 3011, Kano State, Nigeria

*E-mail address: seabraham.agr@buk.edu.ng

ABSTRACT

A field experiment was conducted at the Teaching and Research Farm of the Faculty of Agriculture, Bayero University Kano, during the 2023 dry season to determine the relationship between the leaf chlorophyll content and Normalized Difference Vegetation Index (NDVI) to grain yield among different cowpea genotypes. The treatments consisted of four diverse cowpea genotypes (IT90K-277-2, IT99K-573-1-1, UAM09-1046-6-2, and UAM09-1051-1) arranged in a randomized complete block design (RCBD) with three replications. Normalized Difference Vegetation Index (NDVI) and Soil-Plant Analysis Development (SPAD) were measured at different developmental stages to derive their relationships with grain yield. Data collected was subjected to a general analysis of variance (ANOVA). The results revealed a significant difference among the four cowpea genotypes for the measured traits. A positive and significant correlation was also observed among crop vigor score and grain yield at the different growth stages. The NDVI values measured during the different growth stages correlated significantly with the yield of all the genotypes, while SPAD had an inverse correlation with grain yield. It was concluded that the results could be used for the selection of genotypes based on SPAD and NDVI. Importantly, this study was limited to dry season evaluation where spectral parameters are at the minimum in the area under study.

***Keywords*:** Crop vigor, Leaf chlorophyll content, NDVI, Cowpea genotypes, Yield

(Received 25 October 2024; Accepted 28 November 2024; Date of Publication 30 November 2024)

1. INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the most important edible grain legumes in Africa whose wide variety of uses and economic crop makes it a key crop contributing to food security and maintenance of environment for millions of smallholder farmers in sub-Saharan Africa (SSA) (Abebe and Alemayehu, 2022; Sarr *et al.,* 2022). Nigeria is the world's largest producer of cowpea that supplies up to 40% of the daily protein intake of its constantly increasing population (Kamara *et al.,* 2018; Nwagboso *et al*., 2024). According to FAOSTAT, in 2021, Nigeria had the highest cowpea production of 3.63 million metric tons (MT) across an extensive area harvested of 4.7 million hectares. Niger followed closely with 2.66 million MT produced, with a larger area harvested of 5.97 million hectares (Nwagboso *et al*., 2024). Cowpea income helps smallholder farmers in Sub-Saharan Africa by providing ground cover, fixing nitrogen, and suppressing weeds, all of which increase soil fertility and crop sustainability (Kyei-Boahen *et al.,* 2017; Mohammed *et al*., 2020). Notwithstanding the significance of cowpea, its grain production has remained stagnant at 200–275 kg ha^{-1} (Kyei-Boahen *et al*., 2017; FAOSTAT, 2020) as a result of cultivar selection, inadequate soil fertility, and other biotic stressors. Cowpea productivity and SSA's overall agricultural productivity are both under risk from climate change (Ajetomobi and Abiodun, 2010; Omomowo and Babalola, 2021). This makes it necessary to carry out more innovative research in order to improve and sustainably produce cowpeas in Nigeria (Bello *et al*., 2018).

The leaf photosynthetic capacity of different crop varieties is one of the important factors that affect grain yield. This can be monitored by the measurement of several physiological and agronomic traits to diagnose nutritional limitations and other related stresses (Nemeskéri *et al*., 2018; Faralli and Lawson, 2020). The leaf chlorophyll content, net photosynthetic rates (Pn), and stomatal conductance are some of the physiological traits that are often investigated (Song *et al*. 2012; Abid *et al*., 2017). One of the reasons for using leaf nitrogen is that changes in nitrogen and chlorophyll content of the leaf are major stress indicators, and they influence light absorption and reflectance (Bauerle *et al*., 2004), which in turn affect leaf photosynthetic ability and consequently reduce yield (Carvalho *et al*. 2011). The leaf chlorophyll content is directly diagnosed using the SPAD (Soil-Plant Analysis Development) meter. The SPAD chlorophyll meter measures the absorbance of solar energy of the leaf in the red and near-infrared region and determines the relative chlorophyll content of the leaf by SPAD value. Chlorophyll content of plant leaves is closely related to the nutritional content and the crop vigor of the plant (Kyei-Boahen *et al*. 2017).

The correlation between the photosynthetically active radiation and spectral reflectance on crop canopy can predict the yield of some crops (Yang *et al*. 2007). The Normalized Difference Vegetation Index (NDVI) is a non-destructive index of "plant greenness" or photosynthetic activity that is correlated to crop productivity under stress (Ibitoye, 2015). According to relationships, high grain yielding potential for green biomass formation at the seedling stage may be a predictor of high grain yielding potential, and NDVI may be a useful selection tool for improving cowpea grain yield under drought stress (Verhulst and Govaerts, 2010).

Nevertheless, vegetation characteristics and, more recently, biomass and yield forecasting are the most common uses of the normalized difference vegetation index (NDVI). The NDVI and the amount of chlorophyll in turf grass were shown to be positively associated (Bell *et al*. 2004), as was the NDVI and the leaf area index (LAI) in common beans (Monteiro *et al.,* 2012) and castor beans (Li *et al*., 2011). Indirect monitoring of the impact of water stress on plant growth and the selection of drought-adapted genotypes are also possible with NDVI measurement (Romano *et al*. 2011). The use of SPAD and NDVI are good ways of removing production uncertainties, thereby increasing precision. The two parameters can be used in cowpea production to investigate the crop's health condition, as they have been used by some researchers to monitor the effect of abiotic factors such as humidity, light, water stress, mineral nutrients, especially nitrogen in the early stages of cowpea, phosphorus, iron, and magnesium, as well as good indicators of early stages of disease infection caused by either viruses, bacteria, fungus, or insects.

The two parameters have successfully been used to monitor crop cover, crop health, soil moisture, nitrogen stress, and crop yield. It has been used on different agronomic crops, and considerable correlation coefficients have been recorded, but there are no records in relation to cowpea crops. The results obtained from the two meters will be used to compare and check which is more accurate.

Precision can be increased by eliminating production uncertainty through the use of SPAD and NDVI. Since some researchers have used the two parameters to track the effects of abiotic factors like humidity, light, water stress, mineral nutrients — particularly nitrogen in the early stages of cowpea — phosphorus, iron, and magnesium, as well as good indicators of early stages of disease infection caused by either viruses, bacteria, fungi, or insects, they can be used in cowpea production to examine the health condition of the crop. Crop cover, crop health, soil moisture, nitrogen stress, and crop production have all been effectively tracked using the two parameters. Significant correlation coefficients have been found when it has been applied to several agronomic crops, but when it comes to cowpea crops, there are no records. The results obtained from the two meters will be used to compare and check which is more accurate. The study aims to:

(i) assess how the chlorophyll content and crop vigor of various cowpea genotypes change over time; and
(ii) determine how the chlorophyll content and crop vigor relate to yield and yield attributes of diverse cowpea genotypes.

2. MATERIAL AND METHODS

2. 1. Description of the Study Site

The experiment was carried out at the Teaching and Research farm (orchard) of the Faculty of Agriculture, Bayero University, Kano (11°59' N, 8°25' E, 466 m above sea level) situated in the Sudan savannah ecological zone of Nigeria, with annual rainfall of 834.5 mm as well as 19.40 °C and 35 °C mean minimum and maximum temperature, respectively (B.U.K. Meteorological Unit, 2023).

2. 2. Experimental design and field procedures

The experiment was conducted during the dry season of 2023. The treatments consisted of four different varieties of cowpea: IT90K-277-2, IT99K-573-1-1, UAM09-1046-6-2, and UAM09-1051-1, with different maturity levels. The varieties were arranged in a Randomized Complete Block Design (RCBD) with three replications. The plot consisted of 6 ridges spaced at 0.75 m interrow, while the cowpea was planted at intra row spacing of 10 cm and 3 seeds per hole. The gross plot size was 18 m^2, while the net plot size was 3 m^2. All necessary agronomic practices were carried out appropriately. The experiment was conducted during the dry season, and the crops subsisted on irrigation. There are six rows in each plot from which five plants are sampled for observation from the two innermost rows.

2. 3. Data collection and Data analyses

Data related to crop vigor and chlorophyll content were collected continuously at a weekly interval using SPAD and NDVI. Biomass data was also collected at a two-week' interval up to the time of flowering and physiological maturity of the seed. Other parameters measured are: days to flowering, days to pod setting, pod and seed yield, harvest index, biomass measured at different crop developmental stages, days to 50% flowering, days to 50% pod setting, and pod yield per hectare (tons/ha). The data was subjected to analysis of variance (ANOVA). Mean separation was done using Fisher unprotected LSD. Correlation analysis (Kendall's tau-b) was used to check the relationship between chlorophyll content in leaves and yield, as well as crop vigor and yield. All the data analyses were performed using JMP PRO version 13 (SAS, Inc., 2018).

3. RESULTS AND DISCUSSION

Figure 1 shows the result of NDVI scores for the cowpea varieties tested within the periods between 3 and 9 weeks after planting. At week 3, UAM-09-1046-6-2 produced the highest NDVI readings; IT90K-277-2 and IT99K-573-1-1 produced similar NDVI values, while the lowest values were recorded for UAM-09-1051-1. A similar trend was observed at 4WAS, although at this period, IT99K-573-1-1 and UAM-09-1046-6-2 produced the highest scores, while the rest were significantly different. There was no significant variation among varieties at weeks 5, 6, and 7. Maximum values of NDVI were observed in week 7 associated with IT99K-573-1-1 and minimum values in week 5 associated with IT90K-277-2.

At week 8, the varieties IT90K-277-2, IT99K-573-1-1, and UAM-09-1046-6-2 produced statistically similar NDVI values, which were significantly higher than those of UAM-09-1051-1. A significant difference was recorded for treatments at week 9. Crop vigor increased with time, which results from more vegetative growth, height, and spread of the plant. This leads to increased soil cover as the crop grows. The lowest values recorded at the earliest stage were due to the narrow spread of crop aerial parts. According to Boyer (1996), some drought-tolerant varieties stopped growth after the onset of drought stress and maintained uniformity but displayed a declining turgidity in all tissues of the plants, which can be linked to the varieties IT90K-573-1-1 and UAM-09-1046-6-2.

Mai-Kodomi (1999) and Muchero *et al.* (2008) found that some drought-tolerant lines remained green for a longer time and continued slow growth under drought stress, as shown by IT90K-277-2 and UAM-09-1051-1 at 5 weeks after sowing. For all determinate varieties, the highest NDVI score was recorded at 7 weeks after sowing. This could be attributed to cowpea crops reaching their vegetative bloom. IT90K-277-2 gave the highest score at 9 weeks after sowing.

This could be attributed to early pod setting, which promoted bending and horizontal growth. There was an increase in NDVI scores of IT99K-573-1-1 and UAM-09-1051-1 due to the same reason, in contrast to UAM-09-1046-6-2, which flowered and set pod lately.

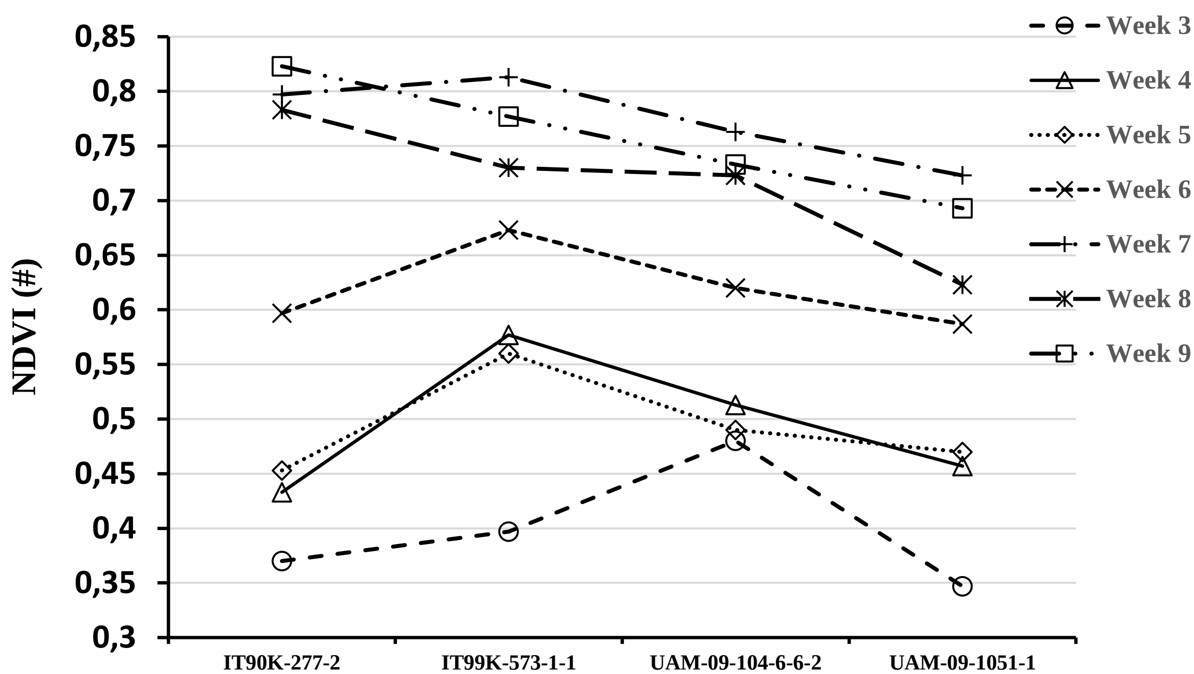

Figure 1. Relationship between Crop vigour scores and NDVI values of different Cowpea genotypes during dry season of 2023.

The chlorophyll content measured within the periods between 3 and 9 weeks after sowing is presented in Figure 2. At week 3, IT90K-277-2 and IT99K-573-1-1 statistically produced similar but highest values, followed by UAM-09-1046-6-2, while the lowest values were recorded for UAM-09-1051-1. At week 5, UAM-09-1046-6-2 produced the lowest SPAD readings while the remaining varieties remained statistically at par. All the varieties produced statistically similar SPAD values at weeks 4, 6, 7, and 9. At week 8, however, IT99K-573-1-1 produced the lowest SPAD readings while the remaining varieties remained at par with higher SPAD. There was a decrease in SPAD value of all varieties at week 5, which could be attributed to water stress, which induces stomatal closure since atmospheric CO_2 diffuses through stomata to the intercellular spaces, then across the mesophyll to the carboxylation sites.

The limitations to CO_2 assimilation imposed by stomatal closure (i.e., stomatal limitation of photosynthesis) in leaves during water stress may lead to an imbalance between electron generation at photosystem II (PSII) and electron requirements for photosynthesis. In turn, this could lead to over-excitation and subsequent photo-inhibitory damage of PSII reaction centers from mesophyll and biochemical limitations of photosynthesis. This can be related to the findings of Pinheiro and Chaves (2011) and Sánchez-Martín *et al.* (2015). It might possibly be because cowpeas have a mechanism for avoiding drought that allows them to shift the position of their leaflets and lower their chlorophyll content (Agbicodo *et al.*, 2009). They become para-heliotropic and oriented parallel to the sun's rays when subjected to soil drought, causing them to be cooler and thus transpire less (Shackel and Hall, 1979).

The decrease of SPAD value after the vegetative bloom phase (week 7) is as a result of a decrease in chlorophyll synthesis since leaf photosynthetic rate and leaf N concentration are closely related and N is an essential constituent of chlorophyll. A minimum concentration of N in the leaves is needed to attain a higher yield level. This is because as the crop moves to its reproductive stage, stored structural assimilates are being reallocated to the grains.

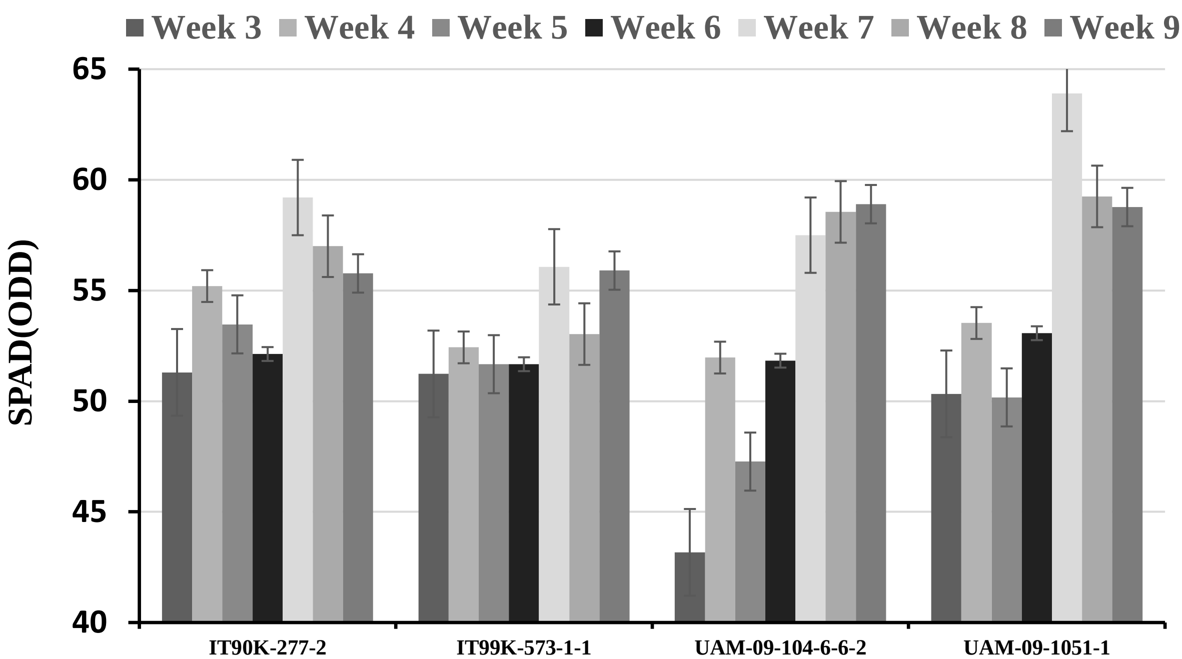

Figure 2. Chlorophyll Content of Different Cowpea genotypes during dry season of 2023.

Comparison between crop vigor and yield using correlation analysis is shown in Table 1. A significantly strong positive correlation between crop vigor scores and pod yield was observed at all sampling periods except at 5 and 9 WAS. The strongest positive correlation was observed between pod yield and NDVI reading at week 8, while the weakest was observed between pod yield and NDVI reading at week 4. Positive correlations were also observed between NDVI measurements; measurement of NDVI at week correlated with weeks 4 and 5. NDVI measurements at week 7 also correlated with measurements at weeks 8 and 9.

There was a significant difference in the results of the correlation between NDVI score and yield across all measurement periods except at 5 and 9 weeks after sowing. All correlations were positive, indicating that high values of NDVI result in high yield. The term crop vigor is the increase in plant growth or foliage volume through time after planting. It covers the measurements of all areal plant parts, such as the leaves, stems, and branches. While NDVI is the measure of leaf greenness (chlorophyll content) and is considered to be correlated with crop productivity under abiotic stress. Number of leaves is related to stem diameter and number of seeds per pod. This implies that the more the number of leaves, the wider the stem girth, and the more the number of seeds produced per pod on each plant. This is in line with the findings of Falconer (1989). Vegetative growth at the reproductive stage, especially during pod filling, is at the expense of yield, which is why there was no significant difference at 9 weeks after sowing. At that time, pod filling has commenced for all the varieties.

There was no significant effect at week 5 due to water stress, as yield decreases resulting from water stress are generally associated with decreases in the activity of these physiological factors and dry matter production. Water stress caused a reduction of seed yield in cowpeas by decreasing total biomass and photosynthesis (Neto *et al*., 2017). Water stress can also cause a direct reduction of about 50–67% in cowpea grain yield (Fatokun *et al*., 2012; Sanda and Maina, 2013). In addition to the direct effect on yield, many aspects of plant growth are affected by drought stress (Hsaio, 1973), including leaf expansion, which is reduced due to the sensitivity of cell growth to water stress. Reduction in leaf area reduces crop growth and thus biomass production. Seed production, which is positively correlated with leaf area (Rawson and Turner, 1982), may also be reduced by reduction in leaf area caused by water stress. Similar findings were also reported by Anda *et al*. (2021) in soybean.

Table 1. Correlation matrix for association between crop vigour scores (NDVI) at different sampling periods and pod yield at harvest

1								
2	0.612*							
3	0.585*	0.494ns						
4	0.340ns	0.366ns	0.556ns					
5	0.617*	0.399ns	0.794**	0.655*				
6	0.605*	0.342ns	0.502ns	0.275ns	0.626*			
7	0.631*	0.416ns	0.224ns	0.201ns	0.279ns	0.751**		
8	0.492ns	0.116ns	0.101ns	0.178ns	0.398ns	0.701*	0.822**	
	1	2	3	4	5	6	7	8

1 = Pod Yield Per Hectare
2 = NDVI Score Week 3
3 = NDVI Score Week 4
4 = NDVI Score Week 5
5 = NDVI Score Week 6
6 = NDVI Score Week 7
7 = NDVI Score Week 8
8 = NDVI Score Week 9

Table 2 presents the result of the correlation between grain yield and SPAD measurements at different time intervals. Significant negative correlations existed between chlorophyll content and pod yield at 7 WAS, while all other correlations were not significant. Negative correlations also existed between individual chlorophyll measurements. Measurement of chlorophyll at week 5 correlated negatively with measurements at weeks 3 and 4, while measurement at week 9 correlated negatively with measurements at weeks 5 and 8.

All other correlations remained insignificant. The negative correlations were obtained from all SPAD scores in relation to yield from 3 weeks to 9 weeks after sowing. The only positive correlation was from 4 weeks after sowing but is very low. All correlations were very low except results from 7 weeks and 9 weeks after sowing. This implies that an increase in the chlorophyll content of leaves results in a decrease in yield. A significant difference was obtained only 7 weeks after sowing (with the highest negative correlation). This is the bloom of vegetative growth and the period when flowering started, while week 8 was a transition between flowering and pod filling.

The relationship between SPAD value and yield is actually not direct. High SPAD values indicate high vegetative growth, whereas high vegetative growth, especially during the reproductive stage, results in low yield. Hence, it can be said that a high SPAD value has an inverse effect on yield. Although this is different for crops with a higher harvest index, as they have a higher ability to partition current assimilates to the grain and the allocation of stored structural assimilates to the seed.

However, during the reproductive stage, additional vegetative growth is at the expense of assimilates, which are to be reallocated to the seeds. According to Rebecca *et al*. (2017), reducing chlorophyll content may improve the conversion efficiency of absorbed photosynthetically active radiation into biomass. Reducing chlorophyll content in leaves has been proposed to improve crop canopies, and this is also in agreement with the study of Long *et al*., (2016).

Table 2. Correlation matrix for association between chlorophyll contents (SPAD) at different sampling periods and pod yield at harvest

1								
2	-0.123^{ns}							
3	0.199^{ns}	0.138^{ns}						
4	-0.08^{ns}	0.590*	0.695*					
5	-0.325^{ns}	0.183^{ns}	0.377^{ns}	0.211^{ns}				
6	-0.664*	0.234^{ns}	-0.125^{ns}	0.174^{ns}	-0.029^{ns}			
7	-0.573^{ns}	-0.443^{ns}	-0.383^{ns}	-0.303^{ns}	-0.092^{ns}	0.427^{ns}		
8	-0.292^{ns}	-0.613*	-0.246^{ns}	-0.603*	-0.150^{ns}	0.252^{ns}	0.630*	
	1	2	3	4	5	6	7	8

1 = Pod Yield Per Hectare
2 = SPAD Score Week 3
3 = SPAD Score Week 4
4 = SPAD Score Week 5
5 = SPAD Score Week 6
6 = SPAD Score Week 7

7 = SPAD Score Week 8
8 = SPAD Score Week 9

Table 3 presents the correlation matrix for relationships between biomass, pod yield, and yield attributes. The only significant correlations observed were between number of days to first pod setting and first flowering, total dry matter at maturity, and number of pods per plant. All other correlations were insignificant. The results for yield attributes versus yield in this study show no significant difference, most of which have very low correlations. Negative significance was expected for days to flowering and days to pod setting, as the shortest days are required for plant maturity, the shortest time for pollination and pod setting, and a longer time is required for higher accumulation of assimilates (Fig. 3).

The period between flowering and maturity implies that these varieties must fill their seeds very fast. Reports have shown that almost all cowpea varieties are photosensitive, which is in agreement with the results of Nuhu and Mukhtar (2013), who revealed that day length has a significant effect on the phenology of all tested genotypes.

Table 3. Correlation matrix for association between pod yield at harvest, biomass at different developmental stages and yield attributes

1									
2	0.110^{ns}								
3	0.097^{ns}	0.984^{**}							
4	0.314^{ns}	-0.290^{ns}	-0.272^{ns}						
5	0.109^{ns}	-0.131^{ns}	-0.073^{ns}	0.523^{ns}					
6	-0.012^{ns}	-0.334^{ns}	-0.361^{ns}	-0.105^{ns}	-0.395^{ns}				
7	-0.079^{ns}	0.065^{ns}	0.126^{ns}	-0.270^{ns}	-0.326^{ns}	0.481^{ns}			
8	-0.079^{ns}	0.065^{ns}	0.126^{ns}	-0.270^{ns}	-0.326^{ns}	0.481^{ns}	0.991^{**}		
9	0.287^{ns}	0.093^{ns}	0.154^{ns}	-0.041^{ns}	0.591^{*}	-0.186^{ns}	0.124^{ns}	0.124^{ns}	
	1	2	3	4	5	6	7	8	9

1 = Pod Yield Per Hectare
2 = Days to First Flowering
3 = Days to First Pod setting
4 = Number of Branches Per Plant
5 = Number of Pods Per Plant
6 = Total Dry Matter at Juvenile Stage
7 = Total Dry Matter at Pre-Flowering Stage
8 = Total Dry Matter at Post-Flowering Stage
9 = Total Dry Matter at Physiological Maturity Stage

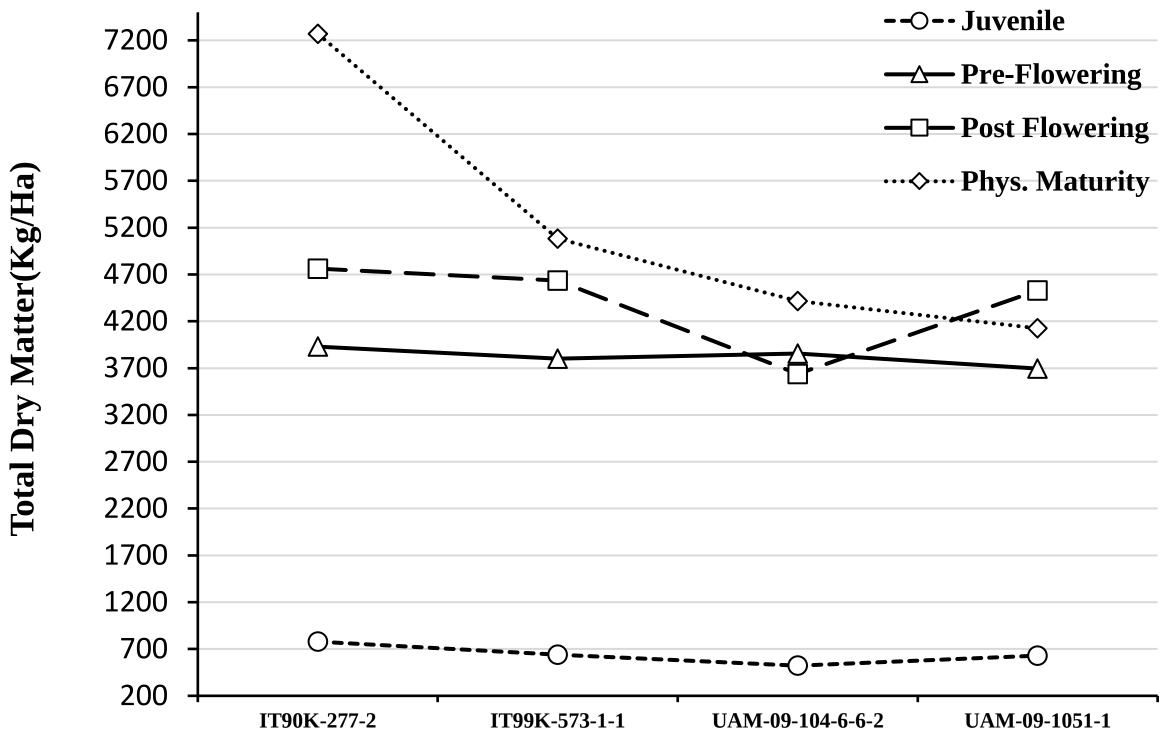

Figure 3. Total Dry Matter of Different Cowpea genotypes Tested in Each Stage of Growth Development

4. CONCLUSION

The findings of this study have shown that crop vigor increased with cowpea developmental stage, which results from more vegetative growth, height, and spread of the plant. There were variations in crop vigour scores, chlorophyll content of the leaf, normalized difference vegetation index (NDVI), seed yield, and biomass among the four cowpea genotypes. Correlations have shown a positive relationship between crop vigor scores and yield at the different growth stages. SPAD has an inverse correlation with grain yield. The NDVI values measured during the different growth stages correlated significantly with the yield of all the genotypes. These results could be used for the selection of genotypes based on vigor scores, SPAD, and NDVI. Importantly, this study was limited to dry season evaluation and will require validation under rainfed conditions at large scale before general recommendations could be made.

References

[1] Abebe, B.K and Alemayehu, M.T. (2022). A review of the nutritional use of cowpea (Vigna unguiculata [L.] Walp) for human and animal diets. *Journal of Agriculture and Food Research,* 10, 100383. https://doi.org/10.1016/j.jafr.2022.100383

[2] Abid G, M'hamdi M, Mingeot D, Aouida M, Aroua I, Muhovski Y, Sassi K, Souissi F, Mannai K, and Jebara M. (2017). Effect of drought stress on chlorophyll fluorescence, antioxidant enzyme activities and gene expression patterns in faba bean (Vicia faba L.). *Arch Agron Soil Sci*. 63(4), 536-552

[3] Agbicodo, E.M., Fatokun, C.A., Muranaka, S., Visser, R.G.F. and van der Linden, C.G. (2009). Breeding drought tolerant cowpea: Constraints, accomplishments, and future prospects. *Euphytica*, 167, 353-370

[4] Ajetomobi, J. and Abiodun, A. (2010). Climate change impacts on cowpea productivity in Nigeria. *African Journal of Food Agriculture Nutrition and Development,* 10(3), 2258-2271

[5] Anda, A., Simon, B., Soós, G., Teieira da Silva and Menyhart, L. (2021). Water stress modifies canopy light environment and qualitative and quantitative yield components in two soybean varieties. *Irrigation Science,* 39, 549-566. https://doi.org/10.1007/s00271-021-00728-0

[6] Bauerle, W.L., Weston, D.J., Bowden, J.D., Dudley, J.B., and Toler, J.E. (2004). Leaf absorbance of photosynthetic active radiation in relation to chlorophyll meter estimates among woody plant species. *Sci Hortic*. 101, 169-178

[7] Bell, G.E., Howell, B.M., Johnson, G.V., Raun, W.R., Solie, J.B., and Stone, M.L. (2004). Optical sensing of turfgrass chlorophyll content and tissue nitrogen. *HortScience*. 39(5), 1130-1132

[8] Bello, S.K., Yusuf, A.A. and Cargele. M. (2018). Performance of cowpea as influenced by native strain of rhizobia, lime and phosphorus in Samaru, Nigeria. *Symbiosis*. 75, 167-176. DOI 10.1007/s13199-017-0507-2

[9] Boyer J.S. (1996). Advances in drought tolerance in plants. *Advances in Agronomy* 56: 189-218

[10] Carvalho, R.F., Takaki, M., and Azevedo, R.A. (2011). Plant pigments: the many faces of light perception. *Acta Physiology of Plant,* 33(2), 241-248

[11] Falconer, D.S. (1989). Introduction to Quantitative Genetic. 3rd Edition. Longman Science and Technical. England.

[12] FAOSTAT (2020). World Food and Agriculture - Statistical Yearbook 2020. Rome. Faostat, F. (2020). Food and agriculture data. 2019. Available at: http://www. fao.org/faostat/en/#data/EP/visualize (Accessed October, 2022).

[13] Faralli, M., and Lawson, T. (2020). Natural genetic variation in photosynthesis: an untapped resource to increase crop yield potential? *The Plant Journal: for Cell and Molecular Biology,* 101(3), 518–528. https://doi.org/10.1111/tpj.14568

[14] Fatokun, C.A., Boukar, O., and Muranaka, S. (2012). Evaluation of cowpea (Vigna unguiculata (L.) Walp.) germplasm lines for tolerance to drought. *Plant Genetic Resources,* 10(3), 171-176. https://doi.org/10.1017/S1479262112000214

[15] Ibitoye D.O. (2015). Performance of Cowpea (Vigna unguiculata (L.) Walp) hybrids under drought induced and well-watered conditions. West Africa Centre for Crop

Improvement, University of Ghana. TEEAL Research Paper Competition, 2015, Pg 1-20.

[16] Kamara, A. Y., Omoigui, L. O., Kamai, N., Ewansiha, S. U., and Ajeigbe, H. A. (2018). Improving cultivation of cowpea in West Africa. In R. J. Summerfield (Ed.), Achieving sustainable cultivation of grain legumes: Volume 2. Improving cultivation of particular grain legumes (pp. 1-18). Burleigh Dodds Series in Agricultural Science. Burleigh Dodds Science Publishing. http://oar.icrisat.org/id/eprint/10804

[17] Kyei-Boahen, S, Savala, E.N.A, Chikoye, D. and Abaidoo, R. (2017). Growth and Yield Responses of Cowpea to Inoculation and Phosphorus Fertilization in Different Environments. *Frontiers in Plant Science,* 8(646), 1-13. https://doi.org/10.3389/fpls.2017.00646

[18] Li, G., Zhang, H., Wu, X., Shi, C., Huang, X., and Qin, P. (2011). Canopy reflectance in two castor bean varieties (Ricinus communis L.) for growth assessment and yield prediction on coastal saline land of Yancheng District, China. *Industrial Crops and Products*, 33, 395–402

[19] Mai Kodomi, Y, Singh B.B., Myers, O., Yopp, J.H., Gibson, P.J. and Terao, T. (1999). Two mechanisms of drought tolerance in cowpea. *Indian Journal of Genetics*, 50(3), 309-316

[20] Mohammed, S. B., Mohammad, I. F., Pangirayi, T. B., Vernon, G., Dzidzienyo, D. K., Umar, M. L., and Umar, S. (2020). Farmers' knowledge, perception, and use of phosphorus fertilization for cowpea production in Northern Guinea Savannah of Nigeria. *Heliyon*, 6(10), e05207. https://doi.org/10.1016/j.heliyon.2020.e05207

[21] Monteiro PFC, Filho RA, Xavier AC, Monteiro ROC. (2012). Assessing biophysical variable parameters of bean crop with hyperspectral measurements. *Sci Agric.* 69: 87-94

[22] Muchero W., Ehlers J.D. and Roberts P.A. (2008). Seedling stage drought-induced phenotypes and drought-responsive genes in diverse cowpea genotypes. *Crop Science*, 48, 541–552

[23] Nemeskéri, E., Molnár, K., and Helyes, L. (2018). Relationships of spectral traits with yield and nutritional quality of snap beans (Phaseolus vulgaris L.) in dry seasons. *Archives of Agronomy and Soil Science,* 64 (9), 1222-1239

[24] Neto, M.C., Bartels, P.G. (2017). Dry matter partitioning of cowpea (Vigna unguiculata (L.) Walp.) Under water deficit conditions. *Vegetable Report,* 167-170. http://hdl.handle.net/10150/214526

[25] Nuhu Y., and Mukhtar F.B. (2013). Screening of some cowpea genotypes for photosensitivity. *Bayero University Journal of Pure and Applied Sciences,* 6(2), 12-19

[26] Omomowo OI and Babalola OO (2021) Constraints and Prospects of Improving Cowpea Productivity to Ensure Food, Nutritional Security and Environmental Sustainability. *Front. Plant Sci*. 12: 751731. doi: 10.3389/fpls.2021.751731

[27] Nwagboso, C., Andam, K.S., Amare, M., Bamiwuye, T., and Fasoranti, A. (2024). The Economic Importance of Cowpea in Nigeria: Trends and Implications for Achieving Agri-Food System Transformation. IFPRI Discussion Paper 02241. February 2024.

Development Strategies and Governance Unit in Collaboration with International Food Policy Research Institute, Pp 30.

[28] Pinhero C., Cheves M.M. (2011). Photosynthesis and drought: can we make metabolic connection from available data*? J. Exp. Ext.* 62: 869-882. 10.1093/jxb/erq340

[29] Rawson, H.M. and Turner, N.C. (1982). Recovery from water stress in five sunflower (Helianthus annus L.) cultivars. I. Effect of timing of water application on leaf area and seed production. *Australia Journal of Plant Physiology*, 9, 437-448

[30] Rebecca A.S., Andy V., Carl J.B., Xin Guang Zhu and Donald R.O. (2017). Rachie, K.O. and Singh S.R. (1985). Cowpea Research, Production and Utilization. John Wiley and Sons, New York, USA, ISBN-13:9780835760799 pages:460

[31] Romano G, Zia S, Spreer W, Sanchez C, Cairns J, Araus JL, Müller J. (2011). Use of thermography for high throughtput phenotyping of tropical maize adaptation in water stress. *Computers and Electronics in Agriculture*, 79, 67-74

[32] Sánchez-Martín, J., Heald, J., Kingston-Smith, A., Winters, A., Rubiales, D., Sanz, M., Mur, L. A., and Prats, E. (2015). A metabolomic study in oats (Avena sativa) highlights a drought tolerance mechanism based upon salicylate signalling pathways and the modulation of carbon, antioxidant and photo-oxidative metabolism. *Plant, Cell and Environment*, 38(7), 1434-1452. https://doi.org/10.1111/pce.12501

[33] Sanda, A.R., and Maina, I.M. (2013). Effect of drought on the yields of different cowpea cultivars and their response to time of planting in Kano State, Nigeria. *International Journal of Environment and Bioenergy*, 6(3): 171-176

[34] Sarr, A., Bodian, A., Gueye, M.C., Gueye, B., Kanfany, G., Diatta, C., Bougma, L.A., Diop, E.A.M.C., Cissé, N., Diouf, D., and Leclerc, C. (2022). Ethnobotanical study of cowpea (*Vigna unguiculata* (L.) Walp.) in Senegal. *Journal of Ethnobiology and Ethnomedicine*, 18, 6. https://doi.org/10.1186/s13002-022-00506-y

[35] Shackel, K.A. and Hall, A.E. (1979). Reversible leaflet movement in relation to drought adaptation of cowpeas, [Vigna unguiculata (L.) Walp.]. *Australian Journal of Plant Physiology*, 6: 265-276

[36] Song H, Gao JF, Gao XL, Dai HPP, Zhang P, Feng BL, Wang PK, Chai Y. (2012). Relations between photosynthetic parameters and seed yields of Adzuki bean cultivars (Vigna angularis). *J Integr Agric.* 11(9), 1453-1461

[37] Srinivasan, V., Kumar, P. and Long, S.P. (2016). Decreasing, not increasing, leaf area will raise crop yields under global atmospheric change. *Glob. Chang. Biol.* 23, 1626-1635. doi/10.1111/gcb.135226

[38] Verhulst, N. and Govaerts, B. (2010). The nominalized difference vegetation index (NDVI) Greenseeker^{TM} handheld sensor: Toward the integrated evaluation of crop management Part A: Concepts and Case Study Mexico, D.F.; CIMMTT.

[39] Yang, F., Zhang, B., Song, K., Wang, Z., You, J., Liu, D., and Xu, J. (2007). Hyperspectral estimation of corn fraction of photosynthetically active radiation. *Agricultural Science in China*, 6(10), 1173-1181