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RESEARCH PAPER

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Analysis of the morpho-physiological responses of four varieties of cowpea subjected to water deficit constraints under greenhouse conditions

Lassana Tioté[*1], Béket Séverin Bonny[1], Bouma James Neya[2], Kouamé Kevin Koffi[1], Irié Arsène Zoro Bi[1]

[1] *Nangui Abrogoua University, Faculty of Natural Sciences, Laboratory of Functional Genomics and Genetic Improvement, Abidjan, Côte d'Ivoire*

[2] *Institute of Environment and Agricultural Research, Ouagadougou, Burkina Faso*

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Abstract

Cowpea, a vital legume in the tropics, plays a crucial role in the diet of millions of people. However, its yield remains significantly low due to water deficit stress. The objective of this study was to evaluate the morphological and physiological responses of four cowpea varieties subjected to water deficit stress to establish their actual resistance capacities. Trials were conducted in a greenhouse at Nangui Abrogoua University, using three Fisher blocks in the experimental design. Water deficit conditions, at 25% field capacity (FC) and 12.5% FC (severe), were applied from seeding until the wilting of plants, in addition to a control condition (100% FC). Physiological (leaf moisture, leaf temperature) and morphological (number of branches, stem diameter, plant length) data were analyzed. The results showed that the highest leaf moisture rates were recorded at 12.5% FC for all varieties. Variety KVX745-11P recorded the highest leaf moisture rate (65.45%) and exhibited the lowest leaf temperatures, at 30.4°C. Leaf moisture rates increase as the degree of water deficit decreases, while leaf temperature increases as the degree of water deficit increases. The lowest numbers of branches, smallest stem diameters, and plant lengths were recorded at 12.5% FC for all varieties. It was concluded from this study that water deficit negatively impacted the physiology and morphological traits of the studied cowpea varieties.

[*] **Corresponding Author:** Lassana Tioté ✉ tiotelass@gmail.com

Introduction

Global agricultural production is facing significant challenges, notably ensuring sustainable food production in the context of climate change (Misra, 2014). Cultivated plants are often exposed to a multitude of environmental constraints that severely limit their productivity. Water deficit is one of the abiotic factors that most significantly affects agricultural production, particularly in semi-arid and arid regions (Medyouni *et al.,* 2017; Petkova *et al.,* 2019). Indeed, it can lead to much higher yield losses, ranging from 66 to 93% (Çakir, 2004). This situation could exacerbate food insecurity in developing countries where agriculture heavily relies on nature's bounty (Kassaye *et al.,* 2021).

The cowpea plays a crucial role in sustainable agriculture, food security, and human health (Omomowo and Babalola, 2021). One of the main reasons for its importance lies in its nutritional value, as it is a legume consumed as a source of high-quality plant proteins in many regions of the world (Jayathilake *et al.,* 2018). Additionally, cowpea is rich in protein, fiber, vitamins, and minerals, making it an excellent source of essential nutrients, particularly in regions where access to diverse food is limited (Abebe and Alemayehu, 2022).

Known for its resilience to drought, cowpea has been the subject of research leading to the selection of drought-tolerant varieties, which are also being disseminated (Souleymane, 2018). However, drought leads to a significant loss of cowpea production in arid areas (Tankari *et al.,* 2021). Indeed, cowpea production can drastically decrease from over 1000 kg/ha to approximately 360 kg/ha due to drought (Boukar *et al.,* 2019; Horn and Shimelis, 2020). The results of evaluating the adaptive capacity of cowpea varieties to water deficit under controlled conditions are useful not only to confirm their performance regarding water deficit but also to accurately determine their dissemination areas (Ilunga, 2014; Ritte *et al.,* 2022). A thorough understanding of cowpea's morpho-physiological responses to water deficit constraints is fundamental for developing resilient and adapted varieties (Singh *et al.,* 2021). Additionally, this can contribute to enhancing food security and promoting the resilience of agricultural systems in regions most vulnerable to climate change (Gil *et al.,* 2017; Kantamaneni *et al.,* 2020). In the context of this research, the main objective was to evaluate the morpho-physiological responses of four cowpea varieties selected by INERA under water deficit constraints. More specifically, it aimed to collect and analyze physiological and morphological data of these varieties subjected to water deficit constraints in greenhouses to establish their actual resistance capacities. Furthermore, this study can guide crop selection and management strategies to ensure sustainable agricultural production in drought-prone regions.

Materials and methods

Greenhouse condition and soil field capacity

The study was conducted at Nangui Abrogoua University (5°23'19''N and 4°0'54''W) from january to march and from may to july 2022, within a polyvinyl greenhouse measuring 10 x 10 x 4 m (L x W x H). The daily temperature inside the greenhouse ranged from 21°C to 47°C, with an average of 32.41±4.83°C. The daily average humidity was 51.52±20.25%, ranging from 20% to 87%. The greenhouse floor consisted of an approximately 8 cm thick layer of sand. The study employed the gravimetric method to determine the soil field capacity (Kramer and Boyer, 1995). Soil samples were collected at a depth of 0 to 25 cm, representing the A horizon of the university forest relic soil. An experimental pot, 25 cm in diameter and 50 cm in height, was filled with 6 kg of dry soil. The pot was saturated with water and covered with aluminum foil, then placed on a support to collect excess water after 24 hours of drainage. The volume of water retained in the soil, corresponding to the field capacity, was obtained by subtracting the poured water volume from the collected water volume after 24 hours of drainage. The soil field capacity was determined to be 2.08 L (100% FC) and subsequently reduced to 0.5 L (25% FC), and to 0.25 L (12.5% FC). The physicochemical characteristics of the university forest relic soil used in the experiment were described by (Vennetier, 1973).

Plant material

The plant material consisted of four varieties of cowpea provided by the Institute of the Environment and Agricultural Research (INERA) of Burkina Faso. These were KVX745-11P, Tiligre, Gourgou, and KVX780-6. The characteristics of these varieties are listed in Table 1.

Table 1. Characteristics of cowpea varieties studied

Cowpea varieties	Cycle (day)	Stem	Seeds color	Seeds size
KVX745-11P	70	Upright	Yellow khaki	Small
Tiligre	70	Creeping	White	Large
Gourgou	75	Creeping	White	Large
KVX780-6	70	Creeping	White	Large

Experimental design and crop management

The plants were exposed to three levels of water content : 100% field capacity (FC), 25% FC, and 12.5% FC. The water content levels of 25% FC, and 12.5% FC represented the various degrees of water deficit imposed on the plants. A three-block FISHER device was installed in the greenhouse. In each block, each treatment was replicated three times. Each block comprised 36 treatments arranged randomly. A treatment represented the combination of a variety and a water level. In total, 108 treatments were arranged in the greenhouse. Each block contained two rows of 18 treatments each. The rows were spaced 0.5 m apart, and the treatments within the rows were spaced 0.20 m apart. A distance of one meter was maintained between the blocks. Plant watering in pots was performed weekly to induce water deficit conditions (25% FC, and 12.5% FC), while regular watering was applied to plants in pots at 100% FC (control condition) from seeding to plant senescence. Thus, plants subjected to stress at 25% FC, and 12.5% FC received 4.5 L, and 2.25 L, respectively, throughout the nine-week experiment. Pots containing sown seeds were placed on supports to prevent root penetration into the ground.

Data collection

The physiological data included leaf temperature expressed in degrees Celsius (°C) and leaf moisture expressed as a percentage (%), both measured using a CCM200 Plus chlorophyllometer placed on the central leaflet of the leaves. The morphological data included manual counting of the number of branches, plant diameter expressed in millimeters (mm), measured at the base of the main stems using a caliper, and plant length in centimeters (cm), measured using a tape measure.

Statistical analysis of data

The data obtained in this study were analyzed using the ANOVA method with the R software (R Core Development Team, 2022). The LSD test was employed to compare mean results, and the level of statistical significance was determined at a probability of 0.5%. The homogeneity test results showed that there was no significant difference between the two sets of experiments ($p < 0.05$). Consequently, ANOVA was performed by combining the data from both sets of experiments (Levene, 1960). Graphs were constructed using Excel software (Microsoft Office Excel, 2016) based on the means recorded from nine repetitions per treatment.

Results

Leaf moisture and temperature

Fig. 1 illustrates the effects of water deficit on leaf moisture content in four cowpea varieties. The observed moisture levels indicate a significant difference ($P < 0.05$) in plant responses to the various levels of water deficit imposed on the four studied cowpea varieties. Indeed, the lowest leaf moisture content values are recorded at 12.5% FC (severe water deficit condition), while the highest leaf moisture content values are recorded at 100% FC (control condition) across all varieties. However, variety KVX780-6 recorded the lowest leaf moisture content value (57.68%) at 12.5% FC, whereas variety KVX745-11P recorded the highest leaf moisture content value (65.45%) at 12.5% FC. Leaf moisture content values gradually increase as the degree of water deficit decreases.

The results of the analysis conducted on the effect of different water levels on leaf temperature indicate a significant difference ($P<0.05$) among varieties subjected to water deficit constraints (Fig. 2).

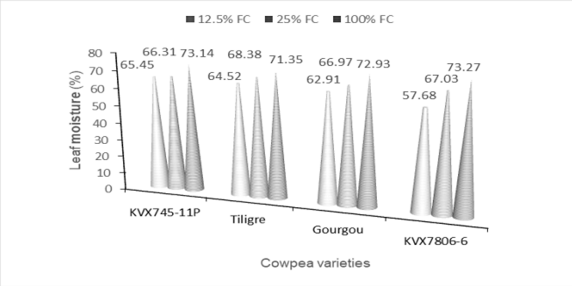

Fig.1. Leaf moisture content in cowpea varieties under water-deficit conditions

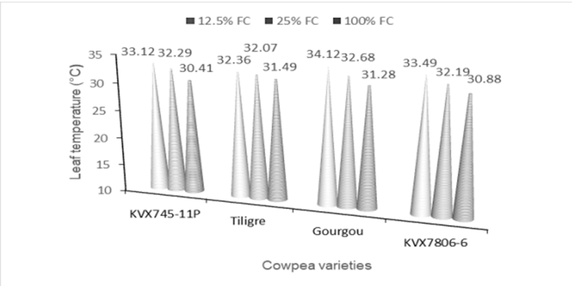

Fig. 2. Leaf temperature values for cowpea varieties in water-deficit conditions

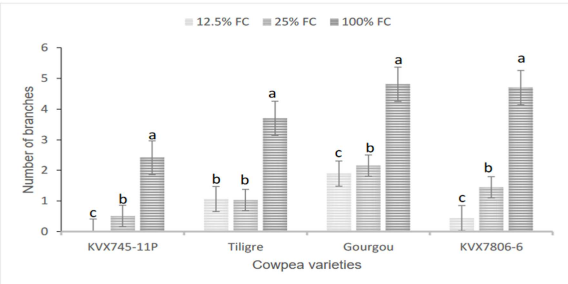

Fig. 3. Number of branches in cowpea varieties under water-deficit conditions

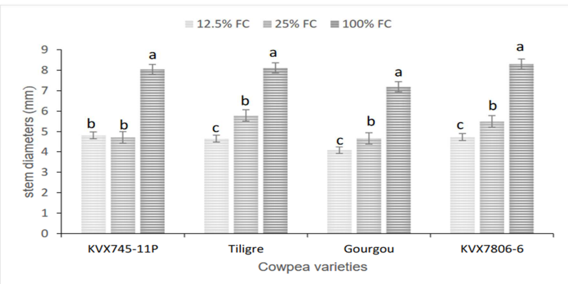

Fig. 4. Plant diameter of cowpea varieties under water-deficit conditions

Varieties KVX745-11P and KVX780-6 exhibit the lowest temperatures, at 30.4°C and 30.88°C, respectively. Conversely, under the same water deficit conditions, varieties Tiligre and Gourgou recorded the highest temperatures, at 31.49°C and 31.48°C, respectively. Dehydration has a significant effect on leaf temperature; indeed, in all varieties, the maximum leaf temperature is measured at a water deficit level of 12.5% FC, then gradually decreases until reaching the minimum leaf temperature at 100% FC, the control condition.

Number of branches

The results of the analysis conducted to assess the effect of different levels of water deficit on the number of branches in cowpea varieties are presented in Fig. 3. The results indicate that the various levels of water deficit had a significant effect ($P<0.05$) on the number of branches of the tested cowpea varieties. Indeed, all varieties showed the lowest numbers of branches at water deficit levels of 12.5% FC and 25% FC. Variety KVX745-11P did not produce any branches at 12.5% FC. The numbers of branches gradually increased to reach the highest values with the control treatment (100% FC) in all varieties.

Plant diameter

Fig. 4 presents the results of the effect of different levels of water deficit on plant diameter in cowpea varieties. The results indicate that the various levels of water deficit had a significant effect ($P<0.05$) on the plant diameter of the four cowpea varieties studied. The smallest stem diameters were recorded at the water deficit level of 12.5% FC in the Tiligre, Gourgou, and KVX780-6 varieties, and at 12.5% FC and 25% FC in the KVX745-11P varieties. However, plant diameter gradually increases as the applied water deficit level becomes less severe. The largest diameters were observed at 100% FC, the control condition of the experiment.

Plant length

The results of the analysis on the effect of different levels of water deficit on plant length in four cowpea varieties are presented in Fig. 5. The results show that the various levels of water deficit have a significant effect ($P<0.05$) on the plant length of the tested cowpea varieties. Indeed, the smallest plant lengths were observed at 12.5% FC in all varieties.

Plant lengths gradually increased until reaching their maximum at 100% FC (control condition). Plants are shorter when the applied water deficit is severe.

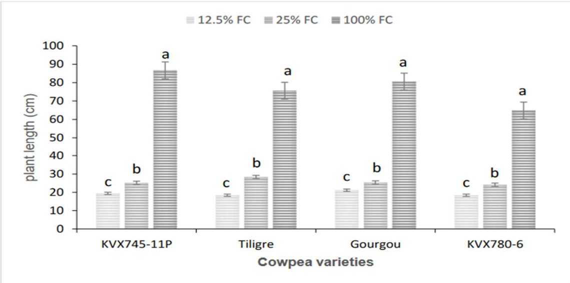

Fig. 5. Plant length of cowpea varieties under water-deficit conditions

Discussion

This study focused on evaluating the morpho-physiological responses of four cowpea varieties under greenhouse conditions of water deficit stress.

The foliar moisture rates obtained revealed a significant difference in the responses of the four varieties studied, demonstrating genetic diversity in plants' ability to maintain foliar water content during periods of water stress. Indeed, plants have the capacity to adjust their physiological response based on the level of stress to which they are subjected. The lowest foliar moisture values recorded under severe water deficit conditions and the highest values observed under non-stressful conditions confirm the direct impact of soil moisture level on plant foliar moisture. This observation aligns with findings by Sewore *et al.* (2023) on soft wheat genotypes. Additionally, Jungklang *et al.* (2017) also indicated that soil water availability influences leaf water content.

The KVX745-11P and KVX780-6 varieties exhibited the lowest leaf temperatures under water deficit stress, whereas the Tiligre and Gourgou varieties recorded the highest temperatures under the same conditions. This variation in response to water stress among different varieties could be attributed to genetic or physiological differences. Furthermore, our results demonstrated that as the degree of water deficit increases, leaf temperature gradually decreases until reaching the minimum temperature at 100% FC, the control condition. Similar findings were reported by Galat Giorgi *et al.* (2019) in grapevines and by Deveci and Celik (2016) in *Physalis peruviana* L.

The results highlight the significant impact of water stress on the number of branches in cowpea varieties. The decrease in the number of branches observed at higher levels of water deficit can be attributed to reduced meristematic activity and restricted root growth, indirectly affecting branch growth. Our findings are consistent with those of Wijewardana *et al.* (2018) and Ghanbarzadeh *et al.* (2019), who reported that water deficit negatively affects plant growth traits.

The results highlight the impact of water deficit on the diameter of plants from different cowpea varieties. The reduced diameters observed at the most severe levels of water deficit are likely due to decreased cell division and cell expansion under water stress. On the other hand, observations of larger diameters at less severe water deficit levels may be associated with water regulation mechanisms in plant tissues. These results are consistent with those obtained by Bhattacharya (2021). Moreover, water deficit affects morphological and physiological aspects, potentially enabling adaptation to unfavorable conditions, as indicated by Sánchez-Blanco *et al.* (2019).

The results clearly demonstrate that the cowpea varieties studied are negatively affected by water stress in terms of their length. Plants exposed to higher levels of water deficit show reduced growth, likely due to decreased cell turgor, reduced water uptake, and inhibition of cell expansion. These findings are consistent with those obtained by Medyouni *et al.* (2021) in tomato plants.

Conclusion

Cowpea plays a significant role in the nutritional balance and economy of rural populations. However, its cultivation is susceptible to water deficits, leading to substantial losses in production. The objective of this study was to evaluate the morphological and physiological responses of four cowpea varieties under water deficit stress conditions to establish their actual resistance capacities. The findings indicate that water deficit negatively impacted the physiology and morphological traits of the studied cowpea varieties. The lowest foliar moisture values were recorded at 12.5% FC (severe water deficit condition), while the highest foliar moisture values were recorded at 100% FC for all varieties. The variety KVX745-11P exhibited the highest foliar moisture content (65.45%) at 12.5% FC. Conversely, under the same water deficit conditions, the Tiligre and Gourgou varieties recorded the highest foliar temperatures, at 31.49 and 31.48 °C, respectively. Foliar moisture levels increase as the degree of water deficit decreases, while foliar temperature increases as the degree of water deficit rises. The lowest numbers of branches, smallest diameters, and plant lengths were observed at the 12.5% FC water deficit level for all varieties. These results are valuable for selecting tolerant varieties in arid regions. Observations of the effects of water deficit stress on plants underscore the importance of conducting in-depth research on the molecular mechanisms regulating cowpea responses to water stress, to develop more resistant varieties.

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