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The quest for high yielding drought-tolerant cassava variety

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Abstract

This study was planned to assess the morpho-physiological response of cassava varieties under well-watered and water-deficit stress conditions along with the exploration of potential yield attributing traits that could facilitate in achieving higher productivity under water stress conditions. Scrutiny of the data revealed that all the traits under study viz; plant height, leaf area index, the number of leaves and leaf retention index reduced significantly ($P<0.05$) due to less water availability. Physiological parameters were also affected severely due to the central role of stomatal activity under water stress. Photosynthetic efficiency of plants subjected to water stress was about ½ fold of the plants grown under well-watered condition. Detailed investigation of various traits revealed that the variety which maintained higher photosynthetic activities along with the higher number of leaves, leaf area index, leaf retention index and harvest index produced a higher yield under water-deficient environment. Hence we are of the strong opinion that these traits are the drivers of higher productivity under water stress environments. Involvement of these traits in the breeding programme would lead to the breeding of a drought-tolerant cassava variety.

Keywords: Cassava, drought, drought tolerance, photosynthetic efficiency, tuber yield

Introduction

Human activities lead climate change is taking a serious toll on humans' life. Till date, climate change has caused an estimated increase of 1°C in the mean global surface temperature (MGST) and is likely to enhance by 1.5°C till 2050 and by 2°C till the end of 21st century, if current global warming rate sustains [1]. Such changes in the climatic factors will further intensify the situation with an increased frequency in the extreme climatic events like floods, drought, hail-storms, salinity and heat stress [2]. Global warming by 1.5-2°C coupled with drought/heat stress will have severe repercussions on the food and nutrition security, as most of the major/staple crops are vulnerable to the vagaries of climate change [3, 4]. Yield losses in major crops viz; wheat, maize, rice and soybeans are expected to be ranged between 9–12%, 5.6–6.3%, 18.1–19.4% and 15.1–16.1%, respectively, by the end of 21st century [5]. There is a big deficit between the amount of food we produce today and the amount needed to feed everyone in 2050. Feeding 10-11 billion people by 2050 with diminishing natural resources (water and land) is the biggest challenge that lies before human society [6]. Developing climate-smart genotypes is the need of the hour. To achieve this, physiological research should be linked with the breeding programme to develop climate-smart genotypes because water deficit stress is known to hamper physiological processes and tuber yield [7, 8]. Promotion of drought-tolerant crops or the use/development of drought-resistant varieties is hailed as one of the adaptation strategies to cope up climate change [9].

Cassava is popularly known as tapioca, yuca or mandioca. It is one of the most important starchy food crops of tropical and sub-tropical regions. Cassava is considered as food security crop, cash crop, feed crop and also as raw material for industrial uses and can be processed into a wide variety of products for food and industrial uses such as starches, flours, alcohol, glucose and other products. Cassava is the third most important food crop in the world after cereals and legumes and was initially adopted as popular famine reserve crop. It provides a more reliable source of food during drought and hunger. In recent times it has emerged as both staple food and a profitable cash crop of industrial significance. Cassava has enormous potential in India for poverty alleviation, food security and industrial uses due to its ability to grow and yield well in marginal and wastelands [10, 11, 12]. It is regarded as the drought-tolerant crop, moreover, it can sustain in harsh environments and marginal soils where other major cereal-pulse crops fail to deliver [13]. But several reports are available depicting significant yield reduction in cassava under water stress environments [14, 15, 16, 17]. The severity of yield reduction depends upon the variety, location and phase of cropping period to which cassava plants are subjected. Tuber yield is hampered rigorously during early water stress (i.e. 2-4 MAP) which is also a tuber bulking and starch accumulation phase [12]. But when compared to other major cereal-pulse crops, cassava produces considerable yield even though severe drought condition exists [18]. Such a remarkable ability to produce higher yield has made cassava a model plant subject to detailed physiological investigation under harsh and marginal environments. Several research reports are available revealing physiological mechanisms underlying drought tolerance in cassava [13, 18]. Based on these mechanisms, cassava breeding programmes are underway at CTCRI, India, CIAT, Colombia and IITA, Nigeria to develop drought-tolerant variety based on the selection of yield attributing traits under water stress environments.

This experiment was planned to identify the drought-tolerant variety and the high yield contributing morpho-physiological traits of cassava under water deficit stress. This paper also describes the effect of early water stress (3-5 MAP) on morpho-physiological and yield of cassava along with the drivers/mechanisms that help cassava plant to achieve higher tuber yield. We believe that research results reported in this paper will help cassava research fraternity to formulate breeding programmes to breed the drought-tolerant variety/genotype based on the potential traits identified.

Materials and methods

a. Experimental details and stress imposition

The experimental material consisting of 10 improved varieties released by ICAR-CTCRI (Table 1) were evaluated under well-watered (WW) and water deficit stress condition (WDS) at Block-I (8°32'43.4"N 76°54'53.5"E) of ICAR–Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India during 2017-18 and 2018-19. Experiments were conducted under rain-fed condition. 3 months early water deficit stress was imposed by withholding irrigation during 3–5 MAP [7]. Supplement irrigation was given to the plants grown under well-watered (WW) condition. The experiment was laid out in split-plot design with two replications. Water regime i.e. well-watered condition (WW) and water deficit stress (WDS) condition was treated as main plots while 10 varieties were treated as subplots. Details of varieties used for the experiment are illustrated in table 1.

Table 1: Details of varieties used for the experiment

Sr. No.	Variety	Peculiar trait	Purpose (E/I)
1	H 226	High yielding and tolerant to spider mite and scale insect.	I
2	H 165	High yielding and field tolerant to CMD, spider mite and scale insect.	I
3	Sree Jaya	High yielding and excellent cooking quality	E
4	Sree Vijaya	High yielding and excellent cooking quality	E
5	Sree Athulya	High yielding variety with a high starch content	I
6	Sree Swarna	High yielding, good culinary quality and tolerance to CMD.	E
7	Sree Pavithra	K efficient variety with excellent cooking quality and high yield.	E
8	Sree Visakham	High yielding and less susceptible to spider mite and scale insect.	I
9	Sree Raksha	High yield with resistant to CMD	E/I
10	PDP CMR 1	High yield with resistant to CMD	E/I
Note: E–Edible, I–Industrial, CMD–Cassava mosaic disease			

b. Growth parameters

Plant height (cm), leaf area index (LAI), leaf retention index (%) and the number of leaves (NOL) were measured during 3–5 MAP at monthly interval. LAI was measured as per the method described by Ramanujam and Indira [19]. LRI was measured by the following formula.

$$\text{LRI (\%)} = \frac{\text{height of stem with retained leaves (cm)}}{\text{total plant height (cm)}} \times 100$$

c. Physiological parameters

Photosynthesis rate (P_n), stomatal conductance (g_s) and transpiration (E) were simultaneously measured under short-term exposure (10 minutes) at 400 ppm CO_2 concentration, 30°C block temperature and 1500 μmol m^{-2} h^{-1} photosynthetic photon flux density (PPFD) using controlled climate cuvette of LI-6400 portable photosynthesis system (LI-COR Inc, Lincoln, USA). These parameters were recorded in the third to sixth fully expanded leaves at 3–5 MAP [7].

d. Yield parameters

Data on fresh root yield (t ha^{-1}) was recorded at 9 months after planting under both WW and WDS condition.

e. Soil moisture estimation (%)

Soil moisture content was estimated by the method described by Reeuwijk [20].

f. Data analysis

The data were statistically analysed using SAS/Software Version 9.3, SAS Institute Inc., Cary, NC, USA 2010.

Results and discussion

Effect of water stress on various morpho-physiological is reported in this section. Stress physiology altered the morpho-physiological behaviour of cassava plants significantly *($P<0.05$)*. All the traits under study were reduced or inhibited due to water deficiency.

1. Physiological parameters

Physiological parameters like photosynthesis (P_n), stomatal conductance (g_s) and transpiration (E) were reduced significantly ($P<0.05$) up to 30.03-47.54, 47.70-63.56 and 33.69-60.99%, respectively (Fig. 1). Results align with results reported by El-Sharkawy [7], El-Sharkawy and Tafur [14], Zhao *et al.* [15], Adjebeng-Danquah *et al.* [16] and Vongcharoen *et al.* [17]. P_n and E were affected due to the central role of stomatal activity under water stress. Several researchers have suggested sensitive stomatal activity as one of cassava's mechanisms for drought tolerance [21, 22, 23, 24, 13, 7]. P_n and E were reduced due to partial closure of stomata under water stress. Reduced g_s further reduced the intracellular carbon concentration by 10-20% (data not reported).

2. Canopy dynamics

Key drivers of canopy viz; LAI, number of leaves, plant height, leaf retention index was diminished drastically *($P<0.05$)* under water stress. The number of leaves as a consequence of water deficit stress was reduced by 23.40-53.53, 37.06-54.60 and 38.83-58.34% at 3, 4 and 5 MAP, respectively (Fig. 1). There was severe reduction up to 23.33-47.60, 34.87-53.61, 41.20-56.42 and 24% in plant height at 3,4,5 MAP and at final harvest, respectively (Fig. 2).

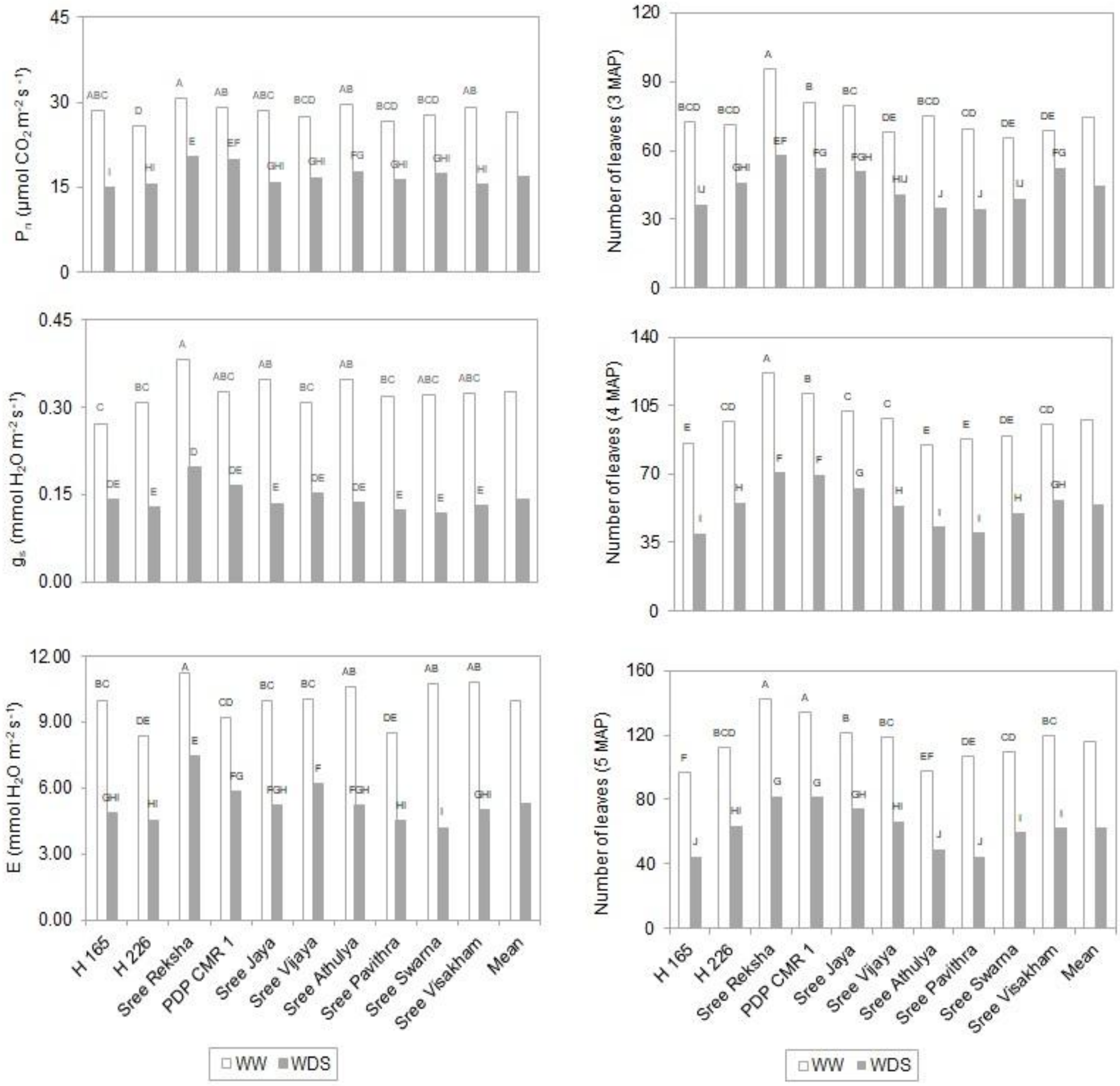

Fig 1: Effect of well-watered (WW) and water deficit stress (WDS) condition on photosynthesis, stomatal conductance, transpiration rate and the number of leaves (3, 4 and 5 MAP) of cassava. [a] Means followed by the same letter do not differ statistically by the Tukey test *($P<0.05$)*

LAI was reduced up to 57.48-75.40, 46.14-47.77 and 56.89-75.40% at 3, 4 and 5 MAP, respectively (Fig. 3). LRI is one of the important factors that affected canopy architecture. LRI was reduced up to 9.05-29.13, 12.10-33.88 and 15.23-40.36% at 3, 4 and 5 MAP, respectively (Fig. 3). Severe reduction in canopy dynamics and architecture is the consequence of reduced biomass accumulation pertaining to reduced photosynthetic activities. The cassava plant is characterized by the simultaneous growth of source (leaves) and sink (tubers). Cassava plant moderates the accumulation of photosynthates in a balanced way to regulate the simultaneous growth of canopy and tuber bulking. 3-6 MAP is a very critical phase for cassava as it is the canopy development as well as tuber bulking phase. Water stress at such a stage could have a detrimental effect on cassava starch yield and quality [7, 18].

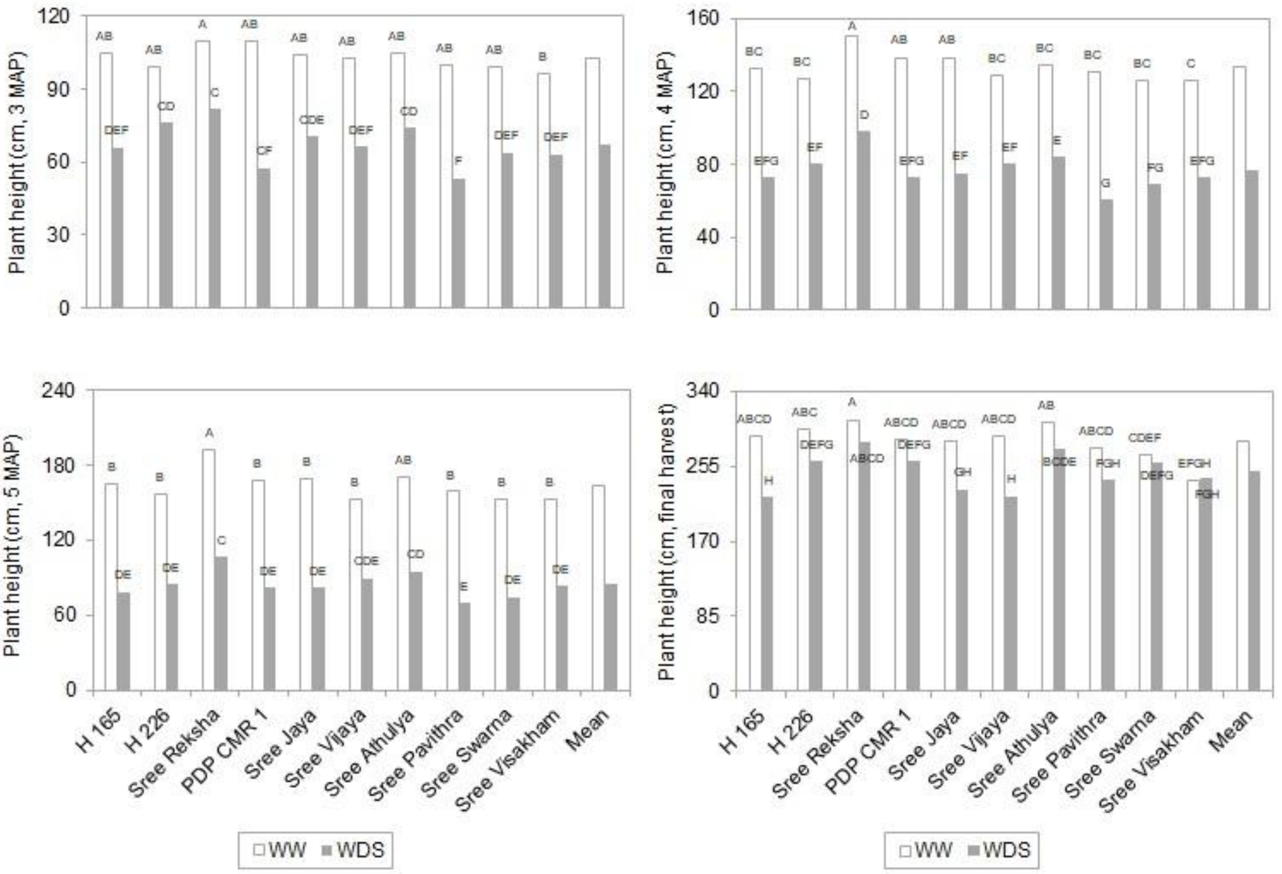

Fig 2: Effect of well-watered (WW) water deficit stress (WDS) condition on plant height (cm) of cassava at 3, 4, 5 MAP and final harvest. ^{a} Means followed by the same letter do not differ statistically by the Tukey test (*P<0.05*)

In this study, the water stress was imposed at 3-5 MAP. Due to less water availability, P_n is reduced causing the deficiency of photosynthates. Several contradictory research results reported that photosynthates are diverted more towards sink development rather than the source development [23, 7, 14, 25]. In other words, soon the cassava plant experiences stress it diverts a significant amount of photosynthates or carbohydrates to maintain bulking. As a consequence growth of canopy dynamics is compromised [13, 7, 18]. Blum [26] has associated these consequences to growth retardation through the inhibition of both cell expansion and cell division under drought stress. Reduction in canopy dynamics was higher with the advancement of growth period during stress imposement. Moreover, reduction in LAI, LRI, number of leaves and plant height is the defence mechanism adopted by the plant to reduce the transpirational water losses to maintain turgidity [7].

3. Yield parameters

In this study, the range for mean root yield under WW and WDS condition was 42.0–67.9 t ha^{-1} and 23.3-52.8 t ha^{-1}, respectively (pooled mean; Fig. 4). The yield was reduced up to 19.27-53.04% under WDS condition as compared to WW conditions. Water stress is responsible for significant yield reduction which may go down up to 50-83% [21, 27, 28, 29, 30]. This is because WDS conditions can critically affect the leaf area development, dry matter accumulation and root bulking but the extent of effect depends upon plant age and period of WDS. Effect of WDS is more pronounced if water scarcity occurs in the first 1–5 MAP as this is the critical period for canopy architecture development, biomass accumulation, tuberization initiation and starch accumulation [21, 31, 27, 32]. When early-season stress was imposed, cassava had less than 0.8 LAI with less than 2 t ha^{-1} of total dry biomass and with no visible storage roots [7]. Connor *et al.* [33] reported that, when rainfall was withheld from cassava for 10 weeks commencing 12 weeks after planting, tuber yield was reduced by 32% compared to the control. Oliveira *et al.* [34] revealed that Water stress in this period reduced storage root yield by 60%. Reduction in the number of tubers due to WDS was reported by Vandegeer *et al.* [29].

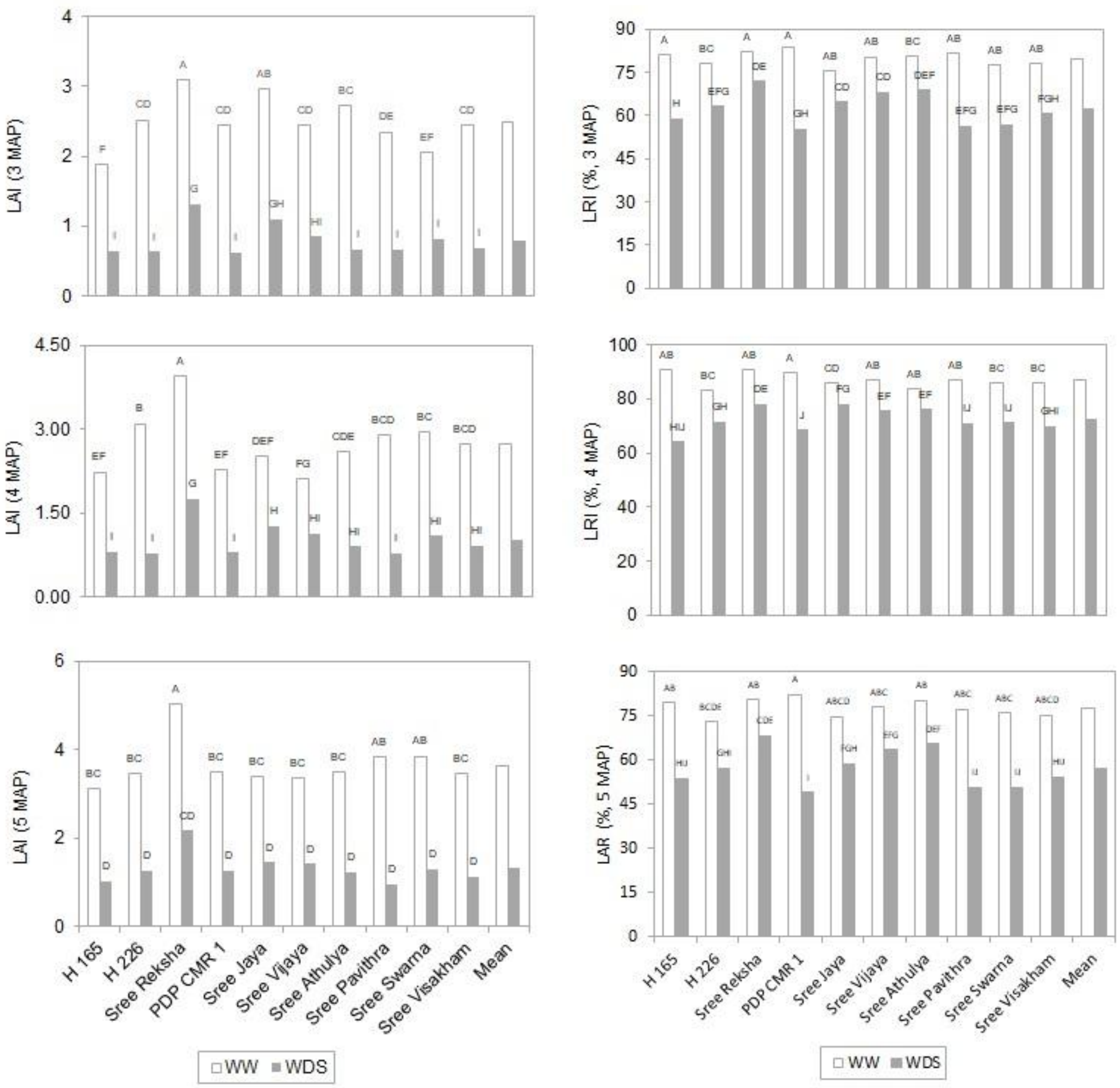

Fig 3: Effect of well-watered (WW) water deficit stress (WDS) condition on leaf area index and leaf retention index (%) of cassava at 3,4 and 5 MAP. ^{a} Means followed by the same letter do not differ statistically by the Tukey test (*P<0.05)*

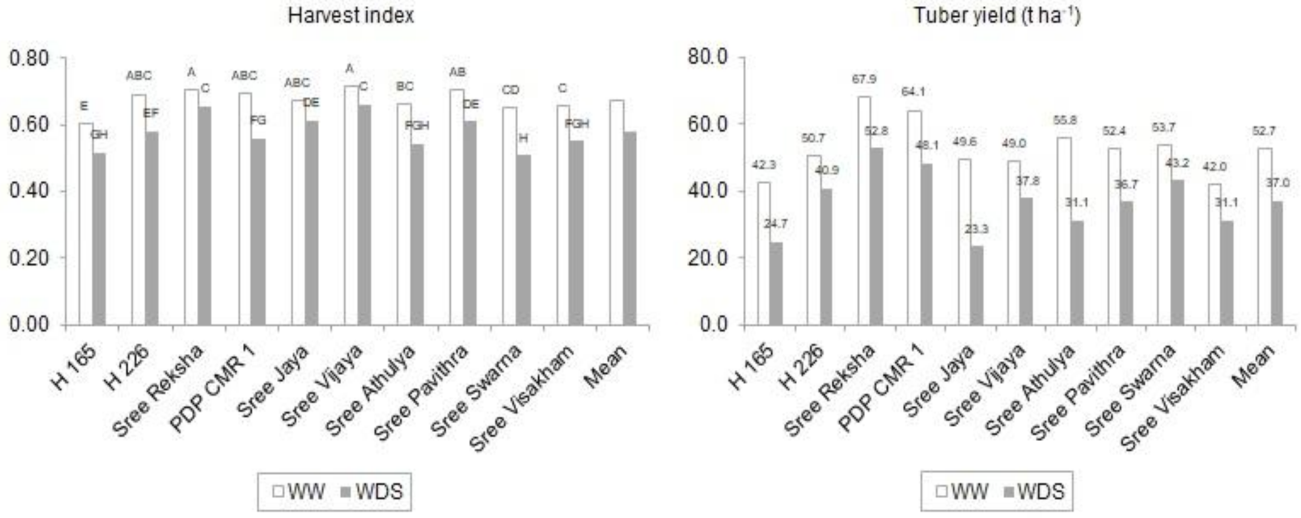

Fig 4: Effect of well-watered (WW) water deficit stress (WDS) condition on harvest index and tuber yield (t ha^{-1}) of cassava. ^{a} Means followed by the same letter do not differ statistically by the Tukey test (*P<0.05)*

The key drivers of high yield under WDS

Since long researchers are in a search of yield attributing traits that could moderate high yielding capacity under harsh and marginal environments. Formulating breeding programme based on the selection of such traits could help to achieve higher productivity under stress environments. This particular section of the articles deals with the exploration of potential traits that would lead to higher productivity under water-deficient environments. In this experiment, under WDS conditions, Sree Reksha variety recorded higher yield. It was revealed that Sree Reksha variety was able to maintain higher mean photosynthetic efficiency, stomatal conductance and transpiration under water deficit stress conditions depicting Sree Reksha variety's capacity of efficient use of water. The basis for this inference corresponds with other morphological parameters like maintenance of higher mean plant height, leaf area index, higher leaf retention index, number of leaves, harvest index and tuber yield under water deficit stress condition. Because increased root yield under stressed and unstressed conditions was associated with increased leaf retention and increased harvest index [35]. Significant ($P>0.05$) correlations were observed among the different traits and storage root yield. Canopy dynamics contributing traits viz; Plant height ($r=0.69^*$), LAI ($r=0.59^*$), LRI ($r=0.68^*$) and number of leaves ($r=0.80^*$). In addition to this, physiological parameters like P_n ($r=0.78^*$), g_s (0.76^*) and E ($r=0.64^*$) were positively and significantly correlated to yield. Hence from this study, it was established that P_n, g_s, E, LAI, LRI, NOL, PH and HI are the drivers of the high production potential of cassava under WDS (Fig. 5). The positive impact of photosynthetic parameters on the tuber yield of cassava is already well established [13, 7, 18]. We are of the strong opinion that the involvement of above said traits in a breeding programme would help to develop/breed a drought-tolerant variety of cassava.

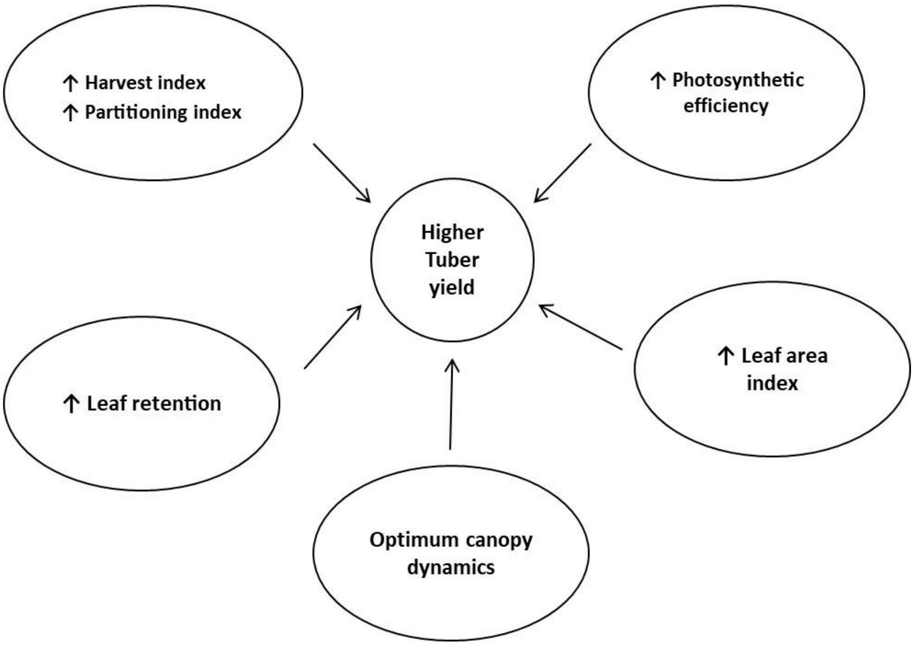

Fig 5: Key drivers of the higher productivity of cassava under water stress environments

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