

Morpho-physiological traits and yield quality for cassava genotypes planted under drought during canopy establishment (#116450)

1

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Morpho-physiological traits and yield quality for cassava genotypes planted under drought during canopy establishment

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Growth analysis provides better insight into the adaptability of cassava genotypes grown under drought conditions during canopy establishment and full irrigation. This study is intended to determine the growth rate and starch yield of different cassava genotypes grown under irrigation and drought treatments during canopy establishment. The experiment was conducted in two growing seasons at Khon Kaen University, Thailand, from August 2021 to August 2022 (2021/2022), and from August 2022 to August 2023 (2022/2023) using six cassava genotypes. A 2 x 6 split-plot design with four replications was used. The main plots were full irrigation and drought conditions during canopy establishment (90 to 150 days after planting (DAP)). Six cassava genotypes were assigned as subplots. Measurements of soil moisture during the growing season, crop data, and weather data were conducted. The results showed that drought treatment from 90 to 150 DAP reduced soil moisture and relative water contents (RWC), stem growth rate (SGR), storage root growth rate (SRGR), and crop growth rate (CGR). Re-watering after a drought supported cassava's growth rate, resulting in desirable yield and biomass at final harvest. The Rayong 72 and CMR38-125-77 produced significantly higher storage root dry weight, harvest index (HI), and starch yield than the other tested genotypes. Growing under drought treatment, the best performance in storage root dry weight with statistical significance for both years was recorded for CMR38-125-77 (11.2 and 11.4 t ha⁻¹ for the 2021/2022 and 2022/2023 growing seasons, respectively), and this was associated with a high crop growth rate (CGR, 12.3 g m⁻² day⁻¹ for the 2021/2022 growing season) and relative growth rate (RGR, 1.11 x 10⁻² g day⁻¹ for the 2022/2023 growing season) during 180 to 360 DAP. These favorable cassava genotypes should be utilized for future plant breeding programs and cultivation to achieve the desired productivity in the growing areas

with drought during canopy establishment.

1 Running title: Performance of cassava under drought conditions during canopy establishment

2

3 **Morpho-physiological traits and yield quality for cassava genotypes planted under drought**
4 **during canopy establishment**

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14

15 **ABSTRACT**

16 Growth analysis provides better insight into the adaptability of cassava genotypes grown
17 under drought conditions during canopy establishment and full irrigation. This study is intended
18 to determine the growth rate and starch yield of different cassava genotypes grown under
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23 drought conditions during canopy establishment (90 to 150 days after planting (DAP)). Six

24 cassava genotypes were assigned as subplots. Measurements of soil moisture during the growing
25 season, crop data, and weather data were conducted. The results showed that drought treatment
26 from 90 to 150 DAP reduced soil moisture and relative water contents (RWC), stem growth rate
27 (SGR), storage root growth rate (SRGR), and crop growth rate (CGR). Re-watering after a
28 drought supported cassava's growth rate, resulting in desirable yield and biomass at final harvest.
29 The Rayong 72 and CMR38-125-77 produced significantly higher storage root dry weight,
30 harvest index (HI), and starch yield than the other tested genotypes. Growing under drought
31 treatment, the best performance in storage root dry weight with statistical significance for both
32 years was recorded for CMR38-125-77 (11.2 and 11.4 t ha⁻¹ for the 2021/2022 and 2022/2023
33 growing seasons, respectively), and this was associated with a high crop growth rate (CGR, 12.3
34 g m⁻² day⁻¹ for the 2021/2022 growing season) and relative growth rate (RGR, 1.11×10^{-2} g day⁻¹
35 for the 2022/2023 growing season) during 180 to 360 DAP. These favorable cassava genotypes
36 should be utilized for future plant breeding programs and cultivation to achieve the desired
37 productivity in the growing areas with drought during canopy establishment.

38

39 **Keywords:** drought, growth rate, irrigation, starch yield

40

41 1. Introduction

42 Cassava (*Manihot esculenta* Crantz) is extensively cultivated in Africa, Asia, and Latin
43 America, and it plays a vital role in food, animal feed, and bioethanol production (Bayata, 2019;
44 Ferguson et al., 2019). In 2022, Thailand was a major cassava producer, with an output of 35.10
45 million tons, the harvested area was 1.67 million hectares, and the average yield was 21.44 tons
46 per hectare (Office of Agricultural Economics, 2023). However, the average yield for Thailand is

47 lower than expected (Konsil et al., 2024). The major cassava growing area in Thailand is in the
48 Northeast, characterized by sandy soils with poor soil fertility, low soil water holding capacity,
49 and unpredictable rainfall. Cassava in this region is typically cultivated in two seasons: the main
50 rainy and the late rainy seasons (Polthanee, 2018). For growing cassava in the late rainy season,
51 storage root yield can be affected by drought during the early growth phase, specifically the
52 canopy establishment, and it causes a decrease in yield by approximately 32 to 60 percent
53 (Palanivel & Shah, 2021). There are several options for increasing cassava yields in drought-
54 prone areas. These include the application of supplemental irrigation and the selection of suitable
55 cassava genotypes. Recommending drought-adaptive cassava genotypes is a strategy to help
56 farmers achieve high productivity with low investment.

57 Determinations of the agronomic traits, physiological traits, and starch content of cassava
58 genotypes have been done for different water regimes. Photosynthesis, growth, productivity, and
59 nutrient use efficiency among cassava genotypes under rain-fed conditions were documented by
60 El-Sharkawy & De Tafur (2010). In arid and semi-arid lands, different cassava genotypes were
61 evaluated under drought and irrigated conditions in agro-climatic zone five (ACZ-V) (Orek et
62 al., 2020). Wongnoi et al. (2020) studied the performance of different cassava genotypes in
63 upland in a dry environment during the high storage root accumulation stage. Various cassava
64 genotypes grown under different irrigation levels (100%, 60%, and 20% crop water requirement
65 (ET crop)) during the early growth phase were reported (Ruangyos et al., 2024). Mahakosee et
66 al. (2019) reported a Rayong 9 cassava genotype grown under rain-fed and irrigated conditions.
67 Growth and yield of cassava genotypes grown under rain-fed upper paddy field conditions were
68 assessed (Sawatraksa et al., 2018 and 2019). These studies did not cover the performances of

69 some cassava genotypes for drought conditions during the canopy establishment and under full
70 irrigation.

71 Photosynthesis, carbohydrate partitioning, growth, and yield were studied in different
72 cassava genotypes under full irrigation and early drought conditions (Santanoo et al., 2024).

73 However, this report was only based on a single experiment, necessitating further research for
74 more robust conclusions. In addition, morpho-physiological traits and yield quality based on
75 growth analysis for cassava offer valuable insights into crop growth habits, aiding in the
76 selection of suitable cassava varieties for various environments (Phuntupan & Banterng, 2017;
77 Phoncharoen et al., 2019a; Sawatraksa et al., 2019; Ruangyos et al., 2024). The information on
78 growth analysis can help design suitable cassava genotypes for the dry period during the early
79 growth phase and provide appropriate water management practices. Growth analysis for cassava
80 on the basis of crop growth rate (CGR), stem growth rate (SGR), leaf growth rate (LGR), storage
81 root growth rate (SRGR) and relative growth rate (RGR) for different cassava genotypes can
82 support a better understanding of cassava adaptability in different growing environments.

83 Previous studies mentioned growth analysis for cassava growing under different nitrogen
84 fertilizer applications (Phuntupan & Banterng, 2017), various environments (Sawatraksa et al.,
85 2019), and different planting dates (Phoncharoen et al., 2019a). However, an investigation on the
86 performance of different cassava genotypes in terms of growth rate under non-irrigation (drought
87 conditions) during the canopy establishment and under full irrigation is still necessary for a
88 tropical savanna climate (Aw). This study is designed to determine the growth rate and starch
89 yield of different cassava genotypes grown under irrigation and drought during canopy
90 establishment.

91

92 **2. Materials and methods**93 **2.1. Experimental detail**

94 This experiment was conducted under field conditions from August 2021 to August 2022
95 (2021/2022) and from August 2022 to August 2023 (2022/2023) at the Field Crop Research Station
96 of Khon Kaen University, Khon Kaen, Thailand (16°28' N, 102°48' E, 200 m a.s.l.). The soil type
97 for the experimental field was Yasothon Series (Yt: Oxic Paleustults). The experiment was a 2 x
98 6 split plot design with four replications (main plot factor = water regime, subplot factor =
99 genotype). Two water regimes, including drought conditions in the dry season and full irrigation,
100 were assigned as main plots. Six cassava genotypes, Kasetsart 50, Rayong 9, Rayong 72, CMR38-
101 125-77, CMR 35-91-63, and CM523-7, were assigned as subplots. The cassava genotypes were
102 selected for high environmental adaptability (Kasetsart 50), high yield and high starch content
103 (Rayong 9 and CMR38-125-77), high yield and drought tolerance (Rayong 72), high yield
104 (CMR35-91-63), and low yield and drought tolerance (CM523-7).

105 Land preparation and tillage were conducted, and soil ridges were created with a **distance between**
106 **the ridges of 1 m.** The plot size was 7 x 10 m. Cassava stem cuttings of 20 cm from healthy 12-
107 month-old plants were planted at 1 x 1 m spacing after soaking for 15 minutes in thiamethoxam
108 [3-(2-chloro-thiazol-5-ylmethyl)-5-methyl-(1,3,5)-oxadia-zinan-4-ylidene-N-nitroamine, 25%
109 water-dispersible granules] to prevent pest infestation. The stakes were inserted vertically to a
110 depth of 14 cm into the soil ridges. Manual weed control was conducted between 30 to 90 days
111 after planting (DAP). At 30 DAP, chemical fertilizer was applied according to the nutrient
112 requirements for cassava as suggested by Howeler (2002) and the soil characteristics that were
113 identified before planting. Chemical fertilizer (N-P-K) formula of 15-7-18 was applied at a rate of
114 312.5 kg ha⁻¹ at 60 DAP (Department of Agriculture, 2008). Before planting, soil at 0-30 cm and

115 30-60 cm depths were sampled to assess physical and chemical properties (Table 1). The soil
116 texture at the Field Crop Research Station of Khon Kaen University was a sandy loam, the values
117 for soil pH ranged from 6.3 to 6.8, total nitrogen varied from 0.2 to 0.3 g kg⁻¹, available phosphorus
118 was between 8.0 to 36.8 mg kg⁻¹, and exchangeable potassium varied from 13.6 to 54.7 mg kg⁻¹.
119 The soil chemical analysis indicated low total nitrogen and exchangeable potassium. From 30 to
120 90 days after planting (DAP), full irrigation based on a mini-sprinkler system was applied to all
121 experimental plots under both irrigation and drought conditions. In the dry season (90 to 150 DAP),
122 drought treatment was imposed by withholding irrigation, and supplementary irrigation was
123 applied back for the recovery period during 151 to 360 DAP. For the plots that received full
124 irrigation, the plants were irrigated throughout the crop duration. Irrigation was conducted based
125 on the amount of crop water requirement (ET_{crop}) that was calculated as described by Doorenbos
126 & Pruitt (1992):

$$127 \quad ET_{crop} = ETo \times Kc \quad (1)$$

128 where ET_{crop} is the crop requirement (mm day⁻¹), E_{To} is the evapotranspiration of a reference
129 plant under specified conditions calculated by the pan evaporation method, and K_c is the crop
130 water requirement coefficient that varies as a function of the growth stage. The K_c value for
131 cassava was provided by the FAO, but it is inappropriate for the cassava growing conditions. The
132 K_c value for FAO was calculated using a crop duration of 210 days. However, the crop duration
133 of the cassava was 330 days. Therefore, we decided to use the K_c of sugarcane, which has a crop
134 duration that covers 330 days (Doorenbos et al., 1986). In addition, the period for yield formation
135 for cassava is also similar to sugarcane. The crop water requirement coefficient (K_C) for cassava
136 was not available in the literature. The amount of water for irrigation was then calculated.

137

138 2.2. Data collection

139 Measurements of soil moisture were taken at 90, 120, 150, 180, and 360 DAP at depths of
140 0-30 cm and 30-60 cm. The soil samples were oven-dried at 105°C for 72 h or until weights were
141 constant and the moisture percentage was calculated. Soil moisture was determined by the
142 gravimetric method described by Shukla et al. (2014) as shown below (2):

$$143 \text{Soil moisture content (\%)} = \frac{\text{Soil wet weight (g)} - \text{Soil dry weight (g)}}{\text{Soil dry weight (g)}} \times 100 \quad (2)$$

144 Crop data was collected from two plants of each plot at 90, 120, 150, 180, and 360 DAP.
145 The plants were separated into leaves, stems, storage roots, and fibrous roots. All plant parts
146 were subsampled) about 10% of the total fresh weight of each organ). A subsample of fresh
147 leaves was then used to measure leaf area by using a leaf area meter (LI-3100, LI-COR, Inc.,
148 Lincoln, NE, USA). Subsamples were oven-dried at 80 °C to achieve a constant dry weight. The
149 harvest index (HI) was calculated as the ratio of the dry weight of storage roots to the total dry
150 weight of the crop. Calculations for crop growth rate (CGR), leaf growth rate (LGR), and stem
151 growth rate (SGR) during 90 to 120 DAP, 120 to 150 DAP, 150 to 180 DAP, and 180 to 360
152 DAP were performed based on the function below (Sawatraksa et al., 2019) (3):

$$153 \text{CGR (g m}^{-2}\text{d}^{-1}\text{)} = \left(\frac{1}{G}\right) \times \left(\frac{\text{DW}_2 - \text{DW}_1}{\text{T}_2 - \text{T}_1}\right) \quad (3)$$

154 where G is sample area (m^2) and DW_1 and DW_2 are crop dry weight (g) at the times T_1 and T_2
155 (d). The equation for CGR was applied to calculate LGR and SGR.

156 Relative growth rate (RGR) was calculated using the following equation (Sawatraksa et al.,
157 2019) (4):

$$158 \text{RGR (g g}^{-1}\text{d}^{-1}\text{)} = \frac{\ln(\text{DW}_2) - \ln(\text{DW}_1)}{\text{T}_2 - \text{T}_1} \quad (4)$$

159 where DW_1 and DW_2 are crop dry weight (g) at the times T_1 and T_2 (d).

160

161 2.3. Statistical Analysis

162 Analysis of variance (ANOVA) was performed for all crop traits by following a model for
163 split-plot design (Gomez & Gomez, 1984) and by using the statistix10 program (Statistix10, 2013).
164 Mean comparisons were conducted for the least significant difference test (LSD) at $p \leq 0.05$.

165

166 **3. Results**

167 The weather data shows that the drought treatment that was applied from November to
168 January coincided with the low rainfall period for both the 2021/2022 and 2022/2023 growing
169 seasons (Figure 1), which is generally observed for most of the years in Thailand. This period
170 was recognized for its cooler and drier conditions, characterized by lower temperatures and
171 reduced rainfall compared to other times.

172 The information on soil moisture content during growing seasons was shown in Figure 2,
173 indicating that the values of soil moisture content for full irrigation treatment for the 2021/2022
174 growing season were close to field capacity (FC) values for both soil depths (Figure 2a). On the
175 other hand, the values of soil moisture content for drought treatment during 120 to 150 DAP
176 (during canopy establishment) for both soil depths were lower than FC values (Figure 2b), and
177 the value of soil moisture content at a depth of 30 cm for 150 DAP was close to the permanent
178 wilting point (PWP). Similar results were found for the 2022/2023 growing season (Figure 2c,
179 d).

180 The relative water content value (RWC) indicates the water content in a leaf at the time
181 of sampling relative to its maximum water-holding capacity. The results revealed the different
182 responses of six cassava genotypes in two water regimes. In comparison between water

183 treatments, the drought treatment exhibited lower RWC values than the irrigated treatment
184 during the 2021/2022 and 2022/2023 growing seasons (Figure 3).

185 Based on the effect of the drought treatment during 90 to 150 DAP, Kasetsart 50,
186 CMR38-125-77, and CM523-7 for 2021/2022 growing season and Rayong 9, Rayong 72,
187 CMR38-125-77, and CM523-7 for 2022/2023 growing season, showed the highest RWC values
188 at 120 DAP (Figure 4). For 150 DAP, it marks the peak of a dry period, as evidenced by the very
189 low soil moisture content (Figure 2). The highest RWC values were observed from CMR35-91-
190 63 for 2021/2022 growing season and Kasetsart 50 and CMR35-91-63 for 2022/2023 growing
191 season.

192 In terms of growth rate for the 2021/2022 growing season, the results indicated the
193 different responses of six cassava genotypes in two water regimes (Table 2). The drought
194 treatment during 90 to 150 DAP provided higher LGR and SGR than the irrigation treatment, but
195 not SRGR. Comparing growth rates from 90 to 150 DAP among different cassava genotypes,
196 Rayong 72 had the highest value of LGR, while CMR38-125-77 exhibited SGR and SRGR that
197 were higher than those of the other genotypes. After the drought during the early growth phase,
198 full irrigation was applied to all experimental plots, resulting in higher LGR and SRGR (from
199 180 to 360 DAP) for the drought treatment compared to the irrigation treatment. Among
200 different cassava genotypes, the highest growth rate values from 150 to 180 DAP were observed
201 for CMR35-91-63 in terms of LGR and SGR, and for Rayong 72 based on SRGR. Kasetsart 50
202 displayed higher LGR, SGR, and SRGR values from 180 to 360 DAP compared to the other
203 genotypes.

204 For CGR and RGR for the 2021/2022 growing season, different effects of two water
205 regimes on six cassava genotypes were found, as indicated by an interaction between water

206 treatment and genotype, except for RGR for 90 to 150 DAP (Table 3). CGR and RGR during the
207 periods of 90 to 150 were not different between the two water regimes, but it was not the same
208 for CGR during 150 to 180 and 180 to 360 DAP and RGR from 150 to 360. CMR38-125-77
209 exhibited the highest CGR values for all ranges: 90 to 150, 150 to 180, and 180 to 360 DAP,
210 compared to the other tested genotypes. Rayong 9 and CMR35-91-63 had a greater value of
211 RGR for 150 to 360 than the other genotypes.

212 According to the final harvest data for the 2021/2022 growing season (Table 4), the
213 interaction between water regime and genotype for storage root fresh weight, storage root dry
214 weight, total dry weight, HI, and starch yield indicated the various responses of six cassava
215 genotypes in two water regimes. The drought treatment produced more storage root fresh weight,
216 total dry weight, HI, and starch contents than the irrigation treatment. Comparing among
217 genotypes, Rayong 72 and CMR38-125-77 performed well for almost all traits, except for total
218 dry weight.

219 Based on the growth rate for the 2022/2023 growing season, the results showed an
220 interaction between water regimes and cassava genotype (Table 5). During 90 to 150 DAP, the
221 drought treatment gave higher LGR and SRGR values than the irrigation treatment. Among the
222 tested genotypes, the highest growth rate values were observed for CMR38-125-77 regarding
223 LGR, Rayong 72 and CM523-7 for SGR, and Rayong 72 for SRGR. During the late growth
224 phase, all experimental plots received full irrigation. This led to drought treatment having a
225 higher LGR during 180 to 360 DAP and SRGR from 150 to 360 DAP compared to the irrigation
226 treatment. Comparing among genotypes, the highest LGR values were recorded for CMR35-91-
227 63 during 150 to 180 DAP and Rayong 72 from 180 to 360 DAP. For SGR, Kasetsart 50,
228 CMR38-125-77, and CMR35-91-63 had the highest values for 150 to 180 DAP and CMR35-91-

229 63 for 180 to 360 DAP. The highest SRGR for the ranges of 150 to 180 and 180 to 360 DAP was
230 identified from CMR35-91-63.

231 Regarding CGR and RGR for the 2022/2023 growing season, the interaction between
232 water regime and genotype indicated the response variation of six cassava genotypes to different
233 water regimes (Table 6). Among water regimes, irrigation treatment gave higher CGR from 90 to
234 150 and 150 to 180 DAP, but not for 180 to 360 DAP. A greater value of RGR from 150 to 360
235 DAP was recorded for the drought treatment. In comparison between cassava genotypes,
236 CMR35-91-63 showed the highest CGR from 90 to 150 and from 150 to 180 DAP, and Rayong
237 9 recorded the highest CGR from 180 to 360 DAP. Rayong 72 and CM523-7 demonstrated the
238 highest RGR for 150 to 360.

239 In the final harvest data for the 2022/2023 growing season (Table 7), the responses of six
240 cassava genotypes under two water regimes were different for all crop traits. The drought
241 treatment produced higher storage root dry weight, total crop dry weight, HI, and starch yield
242 than the irrigation treatment. CMR38-125-77 is a desirable genotype for almost all crop traits,
243 except for storage root fresh weight.

244

245 **4. Discussion**

246 This study focused on the growth analysis of different cassava genotypes under drought
247 conditions during the canopy establishment and full irrigation. The findings can help select
248 suitable cassava genotypes for dry periods during early growth and develop effective water
249 management practices. The soil moisture content and RWC were used to explain water status in
250 soil and crops, respectively, during the growing season. The RWC is a measure of the water
251 status within the plant tissue (specifically the leaves), reflecting the water deficit experienced by

252 the plant. Low rainfall decreased soil moisture contents and led to a low value of RWC (Figures
253 1, 2, and 3). The relationship between RWC and soil moisture content was established, leading to
254 the use of RWC values to identify suitable cassava genotypes across various water regimes in
255 Thailand (Ruangyos et al., 2024; Sawatraksa et al., 2018; Wongnoi et al., 2020). The genotype
256 with high RWC value during the dry periods serves as a mechanism for drought resistance,
257 resulting from either enhanced osmotic regulation or reduced elasticity of tissue cell walls
258 (Ritchie et al., 1990). As indicated by high RWC values (Figure 4) during the peak of the dry
259 period (150 DAP) for both growing seasons (Figure 2), CMR35-91-63 would be classified as a
260 genotype with a good balance of the water content between leaves and water shortage conditions
261 during the early growth phase.

262 The result revealed that even though cassava faces drought conditions during its early
263 growth phase, some tested genotypes can still produce desirable results at final harvest if there is
264 supplementary irrigation or rainfall in the later growth phase. The dry period from 90 to 150
265 DAP in this study, therefore, did not decrease the final yield for some tested genotypes, and
266 ultimately produced slightly higher average values of biomass and yield compared to the
267 irrigation treatment (Tables 4 and 7). Cassava is a remarkably drought-resistant crop that can
268 thrive with minimal water during its growth period (El-Sharkawy, 1993; El-Sharkawy et al.,
269 2012; Howeler, 2002; Howeler et al., 2013; Sawatraksa et al., 2018). Santanoo et al. (2024)
270 conducted a single-year experiment on the photosynthetic performance and growth of different
271 cassava genotypes grown under the dry period during the early growth phase and irrigation
272 treatment. They found that net photosynthesis rate (Pn), petiole, root dry weight, leaf, stem, and
273 storage root dry weight were reduced after 60 days of the dry period. After 30 days of re-
274 watering, Pn fully recovered, leading to a significantly higher dry weight at 12 months after

275 planting for the drought treatment than the irrigation treatment. Mahakosee et al. (2019) planted
276 cassava genotype cv. Rayong 9 under drought and irrigated conditions in Thailand. They found
277 that the drought treatment with a planting date during the early growth phase, which had a dry
278 period, produced higher storage root fresh weight, storage root dry weight, and total crop dry
279 weight than the irrigation treatment.

280 The study on growth rate during different growing periods, along with crop dry weights
281 at the final harvest, offers valuable insights into growth habits and enhances the understanding of
282 adaptability. The drought treatment displayed slightly higher values of LGR from 90 to 150 DAP
283 when compared to the irrigation treatment (Tables 2 and 5). This is due to efficient leaf
284 production under water-limited conditions in certain cassava genotypes, such as Rayong 72,
285 CMR35-91-63, and CMR38-125-77, whose leaves continue to grow well despite water
286 shortages. However, a better growth rate of the stem and storage root for the irrigation treatment
287 led to a higher CGR from 90 to 150 DAP compared to the drought treatment (Tables 3 and 6).
288 The results of this study indicate that although cassava experiences low water availability during
289 the early growth phase, it is capable of recovering well when water is supplied again during the
290 storage root development phase. This is evidenced by the high RGR and CGR between 150 and
291 360 DAP (after re-watering) in the drought treatment, which led to greater storage root fresh
292 weight, total dry weight, HI, and starch yield compared to the full irrigation treatment throughout
293 the entire crop duration (Tables 4 and 7). CGR in the late growth period was identified as a
294 physiological determinant of storage root dry weight for cassava grown under different nitrogen
295 applications (Phuntupan & Banterng, 2017) and various environments (Phoncharoen et al.,
296 2019a).

297 Based on the average performance among cassava genotypes, this study highlighted that
298 Rayong 72 (Table 4) and CMR38-125-77 (Tables 4 and 7) excelled in storage root dry weight,
299 HI, and starch yield. The performance of these two cassava genotypes is associated with the
300 growth rates of plant organs. For example, in the 2021/2022 growing season, Rayong 72
301 exhibited high LGR from 90 to 150 DAP (Table 2). Enhanced leaf growth during canopy
302 establishment enables the plant to produce more photosynthates, resulting in greater storage root
303 accumulation (El-Sharkawy, 1993; El-Sharkawy et al., 2012; Santanoo et al., 2024). Meanwhile,
304 CMR38-125-77 demonstrated high SGR and SRGR during the 90 to 150 DAP range. To
305 determine the relationship between the final harvest data and CGR, however, high values of
306 CGR for CMR38-125-77 during the 2021/2022 growing season are associated with high storage
307 root dry weight, HI, and starch yield (Tables 3, 4, 6, and 7). A previous report has shown that not
308 only does a higher CGR during the formation of storage roots support greater growth and yield,
309 but also that a high LGR during storage root formation and a strong SRGR in the early growth
310 phase are essential factors for enhancing cassava production (Phuntupan & Banterng, 2017).
311 Phoncharoen et al. (2019a) reported that CGR and SRGR during 300-360 DAP and LGR during
312 60-120 and 300-360 DAP were the components for the physiological determinants of storage
313 root dry weights for cassava genotypes grown under different planting dates. A report by
314 Sawatraksa et al., 2019 on cassava grown in various environments also highlighted that specific
315 growth rates, such as SGR, SRGR, and CGR, significantly correlated with total biomass and
316 storage root dry weight.

317 A comparison among the combination of six genotypes and two different water regimes
318 showed that CMR38-125-77 under drought treatments performed well in terms of storage root
319 fresh weight, storage root dry weight, total dry weight, and starch yield for both the 2021/2022

320 and 2022/2023 growing seasons as compared to the other genotypes (Tables 4 and 7). This final
321 harvest data of CMR38-125-77 under drought treatment related to high CGR during 180 to 360
322 DAP in the 2021/2022 growing season (Table 3) and a large value of RGR from 150 to 360 DAP
323 in the 2022/2023 growing season (Table 6). This suggests that the high productivity of cassava
324 can be attributed to either the rapid accumulation of biomass over a specified period (CGR)
325 (Phuntupan & Banterng, 2017) or the plant's strong ability to recover after experiencing drought
326 stress (RGR) (Awal & Ikeda, 2002; Abid et al., 2016; Ruangyos et al., 2024; Vandegeer et al.,
327 2013).

328 A study about growth analysis of different cassava genotypes grown under different
329 planting dates by Phoncharoen et al. (2019a, 2019b) reported that CMR 38-125-77 is likely to be
330 an optimal genotype relative to total crop dry weight and storage root dry weight at final harvest
331 for almost all growing dates. The previous study has also recorded the desirable performance in
332 chlorophyll fluorescence of a CMR 38-125-77 genotype grown after rice harvesting and under
333 rain-fed upper paddy field conditions (Sawatraksa et al., 2018). Wongnoi et al. (2020) have
334 mentioned the desirable physiology, growth, and yield characteristics of a genotype CMR 38-
335 125-77 grown in upland fields under a dry environment during the maximum storage root
336 accumulation phase. A study by Ruangyos et al. (2023) regarding the evaluation of the
337 physiological performance of different cassava genotypes grown under different irrigation levels
338 also found that a CMR 38-125-77 had high net photosynthesis rate compared to other genotypes.

339 Selection of the superior cassava genotypes under different growing conditions based on
340 only final yield is inefficient and analysis of morpho-physiological traits can provide useful
341 information (Phoncharoen et al., 2019a; Phuntupan & Banterng, 2017; Sawatraksa et al., 2019).
342 This study offers a better understanding of how particular cassava genotypes perform under

343 drought during canopy establishment, and it could support prescient decision-making in
344 identifying suitable genotypes within a given environment.

345

346 **5. Conclusions**

347 The drought treatment during the canopy establishment decreased soil moisture contents,
348 RWC, SGR, SRGR, and CGR (from 90 to 150 DAP). Re-watering after the drought period could
349 enhance the growth rate of cassava and produce a higher final yield and biomass than irrigation
350 treatments. The preferred genotypes for storage root dry weight, HI, and starch yield were
351 Rayong 72 and CMR38-125-77 for the 2021/2022 growing season, and CMR38-125-77 for the
352 2022/2023 growing season. In addition, the best performance in the storage root yield was
353 CMR38-125-77 grown under drought treatment, and this was related to high CGR during 180 to
354 360 DAP in the 2021/2022 growing season and high RGR from 150 to 360 DAP in the
355 2022/2023 growing season. The identified cassava genotypes from this study are valuable
356 material for future plant breeding and cultivation, aiming to enhance productivity in areas
357 experiencing dry conditions during canopy establishment.

358

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361

362 **Conflict of interest statement**

363 The authors declare that they have no known competing financial interests or personal
364 relationships that could have appeared to influence the work reported in this paper.

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374

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470

Table 1(on next page)

Physical and chemical properties of the soil for depths of 0-30 and 30-60 cm.

Each data point indicates the average value for for depths of 0-30 and 30-60 cm.

1 **Table 1:**

2 **Physical and chemical properties of the soil for depths of 0-30 and 30-60 cm.**

Soil property	2021/2022		2022/2023	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Physical property				
Texture class	Sandy loam	Sandy loam	Sandy loam	Loamy sand
Sand (%)	75.0	71.0	82.9	67.9
Silt (%)	18.0	17.0	11.8	18.1
Clay (%)	7.0	12.1	5.4	14.1
Chemical property				
pH (1:1 H ₂ O)	6.4	6.3	6.4	6.8
Cation exchange capacity (cmol kg ⁻¹)	3.3	3.6	2.9	4.3
Electrical conductivity (dS m ⁻¹)	0.03	0.02	0.02	0.02
Organic matter (g kg ⁻¹)	4.3	2.9	2.9	1.9
Total nitrogen (g kg ⁻¹)	0.3	0.2	0.2	0.2
Available phosphorus (mg kg ⁻¹)	36.8	27.8	27.5	8.0
Exchangeable potassium (mg kg ⁻¹)	54.7	21.3	13.6	18.2

3

Table 2(on next page)

Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate (SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava genotypes under two water regimes in the 2021/2022 growing season.

Each data point indicates the average performance of six cassava genotypes under two water regimes in the 2021/2022 growing season.

1 **Table 2:**

2 **Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate**
 3 **(SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava**
 4 **genotypes under two water regimes in the 2021/2022 growing season.**

Treatment	LGR (g day ⁻¹)			SGR (g day ⁻¹)			SRGR (g day ⁻¹)		
	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP
Water treatment (W)									
Drought (W1)	0.18A	0.59B	2.90A	3.0A	6.0B	2.0	8.6B	11.7	11.1A
Irrigation (W2)	0.13B	0.91A	1.11B	2.2B	8.4A	2.0	11.6A	12.0	4.9B
F-test	*	*	**	**	**	NS	**	NS	**
C.V. (%)	29.53	16.74	28.14	15.29	2.94	20.85	7.92	8.97	21.45
Genotype (G)									
Kasetsart 50 (G1)	0.07E	0.72B	3.06A	2.5B	8.0B	3.2A	7.1E	12.5B	10.7A
Rayong 9 (G2)	0.08E	0.63B	2.30B	2.5B	6.0D	1.3C	8.8D	11.6B	10.0A
Rayong 72 (G3)	0.26A	0.54B	1.59C	2.0C	5.0E	1.3C	10.0C	15.5A	5.8C
CMR38-125-77 (G4)	0.17C	0.69B	2.10B	3.2A	6.7C	1.6C	15.4A	9.8C	4.7C
CMR35-91-63 (G5)	0.21B	1.29A	1.50C	2.6B	12.2A	2.1B	6.5E	9.8C	7.3B
CM523-7 (G6)	0.14D	0.65B	1.51C	2.7B	5.6D	2.5B	12.8B	12.0B	9.56
F-test	**	**	**	**	**	**	**	**	**
G x W									
W1 x G1	0.04E	0.55B-E	4.70A	3.5B	6.8D	3.7A	5.8E	7.0GH	14.5A
W1 x G2	0.13D	0.64B-E	3.03C	3.1BC	7.1CD	0.3E	7.2DE	8.2FG	12.2B
W1 x G3	0.32A	0.30E	2.34D	1.1FG	4.9E	1.1CD	12.2B	19.9A	9.3C
W1 x G4	0.15CD	0.87BC	4.05B	3.4B	4.9E	0.8DE	13.1B	13.6BC	4.8EF
W1 x G5	0.30A	0.80BC	1.75E	4.3A	7.7C	3.6A	5.8E	12.4CD	13.1AB
W1 x G6	0.16B-D	0.38DE	1.50EF	2.8CD	4.8E	2.8B	7.3D	9.3EF	12.5AB
W2 x G1	0.11D	0.89B	1.41EF	1.6EF	9.1B	2.8B	8.4D	18.0A	7.0C-E
W2 x G2	0.04E	0.63B-E	1.57E	1.9E	4.9E	2.3B	10.4C	15.0B	7.8CD
W2 x G3	0.20B	0.78B-D	0.84F	2.9B-D	5.1E	1.6C	7.7D	11.0DE	2.2G
W2 x G4	0.20BC	0.51C-E	0.15G	3.1BC	8.4B	2.5B	17.7A	5.9H	4.5F
W2 x G5	0.12D	1.77A	1.19EF	1.0G	16.8A	0.7DE	7.2DE	7.2GH	1.5G
W2 x G6	0.11D	0.92B	1.51E	2.5D	6.4D	2.2B	18.2A	14.7B	6.6D-F
F-test	**	**	**	**	**	**	**	**	**
C.V. (%)	14.74	11.87	19.87	13.13	7.51	21.69	9.95	10.43	18.50

5 *Note:* Different letters in the same column represent significant differences (least significant
 6 difference test). NS, *, ** = non-significant, significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level,
 7 respectively.
 8

Table 3(on next page)

Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes under two water treatments in the 2021/2022 growing season.

Each data point indicates the average performance of six cassava genotypes under two water treatments in the 2021/2022 growing season.

1 **Table 3:**
 2 **Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes**
 3 **under two water treatments in the 2021/2022 growing season.**

Treatment	CGR (g m ⁻² day ⁻¹)			RGR x 10 ⁻² (g day ⁻¹)	
	90–150	150–180	180–360	90–150	150–360
	DAP	DAP	DAP	DAP	DAP
Water treatment (W)					
Drought (W1)	14.7	18.1B	9.1A	2.2	0.49A
Irrigation (W2)	15.3	40.6A	3.6B	2.7	0.39B
F-test	NS	**	**	NS	*
C.V. (%)	5.25	6.75	13.04	30.60	16.77
Genotype (G)					
Kasetsart 50 (G1)	11.4D	32.4AB	6.4B	2.0B	0.41B
Rayong 9 (G2)	17.8B	18.0D	8.1A	2.8A	0.62A
Rayong 72 (G3)	18.4B	28.4C	5.6BC	2.6A	0.28D
CMR38-125-77 (G4)	19.7A	32.6AB	8.5A	2.4AB	0.34C
CMR35-91-63 (G5)	13.0C	35.3A	5.1BC	2.1B	0.64A
CM523-7 (G6)	9.6E	29.5BC	4.5C	2.8A	0.34C
F-test	**	**	**	**	**
G x W					
W1 x G1	10.1E	39.2B	5.8E-G	2.0	0.45C
W1 x G2	10.6E	2.8G	11.1AB	2.6	0.94A
W1 x G3	24.4A	28.0D	8.1CD	2.6	0.26FG
W1 x G4	17.2C	5.5G	12.3A	1.6	0.43CD
W1 x G5	12.4D	14.0F	9.6BC	2.2	0.62B
W1 x G6	13.3D	19.2E	7.8C-E	2.2	0.25FG
W2 x G1	12.7D	25.6D	6.9D-F	2.1	0.36DE
W2 x G2	25.0A	33.3C	5.2F-H	3.0	0.31EF
W2 x G3	12.3D	28.7CD	3.2HI	2.6	0.31EF
W2 x G4	22.1B	59.7A	4.6GH	3.2	0.24G
W2 x G5	13.5D	56.7A	0.7J	2.1	0.67B
W2 x G6	5.8F	39.8B	1.11IJ	3.4	0.42CD
F-test	**	**	**	NS	**
C.V. (%)	6.35	11.15	11.12AB	18.35	8.82

4 Note: Different letters in the same column represent significant differences (least significant
 5 difference test). NS, *, ** = non-significant, significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level,
 6 respectively.

Table 4(on next page)

Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index (HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two water treatments in 2021/2022 growing season .

Each data point indicates the average performance of six cassava genotypes under two water treatments in the 2021/2022 growing season.

1 **Table 4:**
 2 **Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index**
 3 **(HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two**
 4 **water treatments in 2021/2022 growing season.**

Treatment	Storage root fresh weight (t ha ⁻¹)	Storage root dry weight (t ha ⁻¹)	Total dry weight (t ha ⁻¹)	HI	Starch yield (t ha ⁻¹)
Water treatment (W)					
Drought (W1)	26.1A	9.7	12.8A	0.77A	250.2A
Irrigation (W2)	23.8B	8.2	11.9B	0.68B	192.0B
F-test	*	NS	*	**	**
C.V. (%)	9.13	19.72	7.04	2.36	9.52
Genotype (G)					
Kasetsart 50 (G1)	23.6B	8.9BC	13.4A	0.67D	249.0A
Rayong 9 (G2)	23.2B	8.5C	11.3C	0.71C	212.8B
Rayong 72 (G3)	25.7AB	10.0A	12.7B	0.80A	252.3A
CMR38-125-77 (G4)	25.9AB	9.7AB	12.5B	0.78AB	260.8A
CMR35-91-63 (G5)	23.7B	8.3C	11.1C	0.75B	223.5B
CM523-7 (G6)	27.4A	8.3C	13.1AB	0.64E	128.0C
F-test	*	**	**	**	**
G x W					
W1 x G1	24.4B-D	9.8B	13.9BC	0.73D	296.7A
W1 x G2	26.3A-C	9.8B	11.1EF	0.83A	254.5B
W1 x G3	25.7A-C	9.9B	12.7D	0.81A	285.6A
W1 x G4	29.2A	11.2A	15.1A	0.76B-D	309.7A
W1 x G5	24.6B-D	8.9BC	11.9DE	0.76B-D	218.8C
W1 x G6	26.4A-C	8.6B-D	11.9DE	0.73D	135.8E
W2 x G1	22.8CD	8.1CD	12.9CD	0.61E	201.3C
W2 x G2	20.2D	7.2D	11.4E	0.59EF	171.1D
W2 x G3	25.8A-C	10.0AB	12.7D	0.79A-C	219.1C
W2 x G4	22.6CD	8.2CD	9.9G	0.80AB	211.9C
W2 x G5	22.8CD	7.7CD	10.2FG	0.75CD	228.2BC
W2 x G6	28.3AB	8.0CD	14.4AB	0.56F	120.3E
F-test	*	**	**	**	**
C.V. (%)	11.73	8.85	5.46	4.09	8.92

5 *Note:* Different letters in the same column represent significant differences (least significant
 6 difference test). NS, *, ** = non-significant, significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level,
 7 respectively.

Table 5(on next page)

Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate (SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava genotypes under two water regimes in the 2022/2023 growing season.

Each data point indicates the average performance of six cassava genotypes under two water regimes in the 2022/2023 growing season.

1 **Table 5:**
 2 **Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate**
 3 **(SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava**
 4 **genotypes under two water regimes in the 2022/2023 growing season.**

Treatment	LGR (g day ⁻¹)			SGR (g day ⁻¹)			SRGR (g day ⁻¹)		
	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP
Water treatment (W)									
Drought (W1)	1.01A	0.32B	0.21A	0.3B	2.5B	0.4B	1.6A	4.4A	2.8B
Irrigation (W2)	0.95B	0.73A	0.13B	0.6A	7.0A	0.5A	1.1B	2.6B	3.6A
F-test	*	**	**	**	**	**	**	**	**
C.V. (%)	5.08	17.51	11.01	24.50	24.45	8.48	10.53	20.12	15.39
Genotype (G)									
Kasetsart 50 (G1)	1.32B	0.50B	0.07D	0.2D	6.9A	0.4C	0.8E	4.4B	2.1D
Rayong 9 (G2)	0.64E	0.30C	0.21AB	0.3C	1.7D	0.6B	0.6E	2.2D	2.3CD
Rayong 72 (G3)	0.79D	0.33C	0.23A	0.8A	2.7C	0.6B	2.5A	3.7C	1.3E
CMR38-125-77 (G4)	1.63A	0.60B	0.16C	0.5B	6.6A	0.2D	2.1B	2.1D	3.6B
CMR35-91-63 (G5)	0.99C	0.95A	0.15C	0.3C	6.7A	0.7A	1.0D	6.3A	7.0A
CM523-7 (G6)	0.52F	0.49B	0.19B	0.7A	4.0B	0.2D	1.3C	2.1D	2.7C
F-test	**	**	**	**	**	**	**	**	**
G x W									
W1 x G1	2.02B	0.18E	0.06EF	0.2DE	3.0E	0.3E	1.2D	6.0BC	1.6F
W1 x G2	0.24G	0.45C	0.26C	0.2DE	1.0FG	0.7C	0.6FG	3.3D	1.5F
W1 x G3	0.14G	0.19E	0.43A	0.1G	0.1G	0.9B	4.5A	6.5B	0.4G
W1 x G4	2.74A	0.27DE	0.04FG	0.5C	4.5CD	0.1G	1.2D	1.3F	4.0C
W1 x G5	0.50EF	0.43CD	0.14D	0.1G	3.5DE	0.4E	0.8EF	7.6A	7.5A
W1 x G6	0.45F	0.43CD	0.32B	0.7B	2.9E	0.2F	1.6C	1.6EF	1.6F
W2 x G1	0.63E	0.81B	0.08E	0.1G	10.8A	0.5D	0.4G	2.8D	2.6DE
W2 x G2	1.04D	0.16E	0.16D	0.3D	2.4EF	0.5D	0.7E-G	1.2F	3.1CD
W2 x G3	1.43C	0.47C	0.02G	1.4A	5.4C	0.3E	0.4G	0.9F	2.1EF
W2 x G4	0.50EF	0.93B	0.28C	0.5C	8.7B	0.3E	3.0B	2.8D	3.3CD
W2 x G5	1.49C	1.47A	0.16D	0.4C	9.8A	1.1A	1.3CD	5.0C	6.4B
W2 x G6	0.59EF	0.54C	0.07EF	0.8B	5.2C	0.3E	1.0DE	2.6DE	3.8C
F-test	**	**	**	**	**	**	**	**	**
C.V. (%)	11.57	21.29	10.46	16.48	14.75	7.83	12.77	15.22	14.53

5 *Note:* Different letters in the same column represent significant differences (least significant
 6 difference test). ** = significant at $p \leq 0.01$ level, respectively.

Table 6(on next page)

Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes under two water treatments in the 2022/2023 growing season.

Each data point indicates the average performance of six cassava genotypes under two water treatments in the 2022/2023 growing season.

1 **Table 6:**
 2 **Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes.**
 3 **under two water treatments in the 2022/2023 growing season.**

Treatment	CGR (g m ⁻² day ⁻¹)			RGR x 10 ⁻² (g day ⁻¹)	
	90–150	150–180	180–360	90–150	150–360
	DAP	DAP	DAP	DAP	DAP
Water treatment (W)					
Drought (W1)	1.7B	31.0B	7.2A	0.58	0.87A
Irrigation (W2)	2.8A	38.3A	2.6B	0.62	0.66B
F-test	**	**	**	NS	**
C.V. (%)	7.42	0.50	3.43	7.74	11.13
Genotype (G)					
Kasetsart 50 (G1)	1.0E	28.6C	5.2C	0.49C	0.78B
Rayong 9 (G2)	1.7D	21.0D	7.1A	0.12E	0.77BC
Rayong 72 (G3)	1.0E	17.0E	6.5B	0.35D	0.89A
CMR38-125-77 (G4)	3.6B	42.0B	3.5D	0.48C	0.71C
CMR35-91-63 (G5)	4.4A	71.7A	0.7E	1.41A	0.57D
CM523-7 (G6)	2.1C	27.6C	6.3B	0.74B	0.87A
F-test	**	**	**	**	**
G x W					
W1 x G1	0.8F	18.2G	8.3C	0.72D	0.81C-E
W1 x G2	0.2G	19.0G	9.5B	0.04H	0.83B-D
W1 x G3	0.4G	10.3H	12.0A	0.18G	0.71F
W1 x G4	3.7B	40.3D	5.2E	0.73D	1.11A
W1 x G5	2.7D	75.1A	0.7G	0.85C	0.85BC
W1 x G6	2.5D	23.0F	7.3D	0.96B	0.90B
W2 x G1	1.1F	39.0D	2.2F	0.25F	0.72D-F
W2 x G2	3.1C	22.9F	4.6E	0.20FG	0.73D-F
W2 x G3	1.5E	23.7F	1.0G	0.51E	0.72EF
W2 x G4	3.4C	43.7C	1.8F	0.23FG	0.66F
W2 x G5	6.1A	68.3B	0.7G	1.98A	0.28G
W2 x G6	1.7E	32.2E	5.2E	0.52E	0.83BC
F-test	**	**	**	**	**
C.V. (%)	8.77	3.46	10.34	6.65	7.76

4 Note: Different letters in the same column represent significant differences (least significant
 5 difference test). NS, ** = non-significant and significant at $p \leq 0.05$, respectively.
 6

Table 7(on next page)

Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index (HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two water treatments in the 2022/2023 growing season .

Each data point indicates the average performance of six cassava genotypes under two water treatments in the 2022/2023 growing season .

1 **Table 7:**
 2 **Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index**
 3 **(HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two**
 4 **water treatments in the 2022/2023 growing season.**

Treatment	Storage root fresh weight (t ha ⁻¹)	Storage root dry weight (t ha ⁻¹)	Total dry weight (t ha ⁻¹)	HI	Starch yield (t ha ⁻¹)
Water treatment (W)					
Drought (W1)	26.3A	9.8A	13.3A	0.76A	265.2A
Irrigation (W2)	24.1B	6.9B	10.2B	0.68B	176.6B
F-test	**	**	**	*	**
C.V. (%)	2.88	7.14	6.24	8.57	5.63
Genotype (G)					
Kasetsart 50 (G1)	22.9D	8.6BC	11.7B	0.78A	249.9A
Rayong 9 (G2)	20.9E	8.0C	11.7B	0.71BC	213.7B
Rayong 72 (G3)	30.1A	6.9D	10.1C	0.65D	198.0C
CMR38-125-77 (G4)	25.9C	9.7A	12.9A	0.75AB	245.1A
CMR35-91-63 (G5)	23.4D	8.7B	12.3AB	0.70C	210.8B
CM523-7 (G6)	27.9B	8.4BC	11.7B	0.72BC	207.8EC
F-test	**	**	**	**	**
G x W					
W1 x G1	21.8D	9.6BC	12.8BC	0.80A	309.0A
W1 x G2	24.3C	9.2CD	13.4B	0.76AB	247.0C
W1 x G3	29.6A	10.3B	13.4B	0.77AB	280.6B
W1 x G4	30.4A	11.4A	14.9A	0.77AB	296.8A
W1 x G5	25.8B	9.6BC	13.3B	0.73BC	259.7C
W1 x G6	25.9B	8.7DE	11.9CD	0.73BC	198.0E
W2 x G1	24.1C	7.6FG	10.6EF	0.75AB	190.8EF
W2 x G2	17.5E	6.7G	10.0F	0.67C	180.3F
W2 x G3	30.5A	3.5H	6.8G	0.53D	115.4H
W2 x G4	21.5D	7.9EF	10.9D-F	0.72BC	193.5EF
W2 x G5	21.0D	7.7F	11.4DE	0.67C	161.8G
W2 x G6	29.8A	8.1EF	11.4DE	0.71BC	217.5D
F-test	**	**	**	**	**
C.V. (%)	3.41	7.41	6.61	5.65	4.66

5 Note: Different letters in the same column represent significant differences (least significant
 6 difference test). *, ** = significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level, respectively.

Figure 1

Weather data at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand for the experiment from August 2021 to August 2022 and from August 2022 to August 2023. (A) 2021/2022 and (B) 2022/2023.

Weather data at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand.

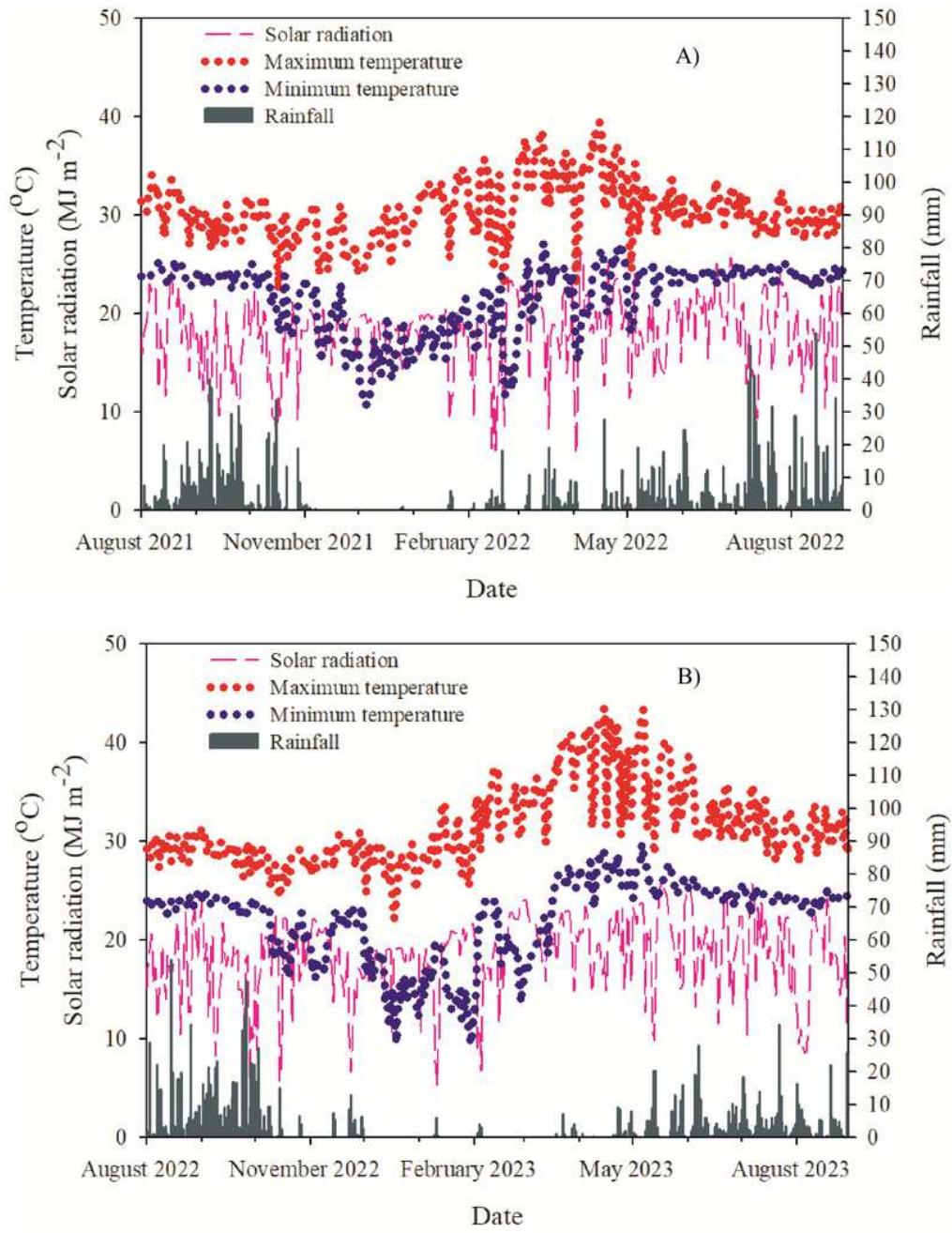


Figure 2

Soil moisture content of rainfed treatment (drought treatment) and irrigation treatment. (A) soil depth 0–30 cm in 2021/2022. (B) 30–60 cm in 2021/2022. (C) 0–30 cm in 2022/2023. (D) 30–60 cm in 2022/2023.

Soil moisture content of rainfed treatment (drought treatment) and irrigation treatment.

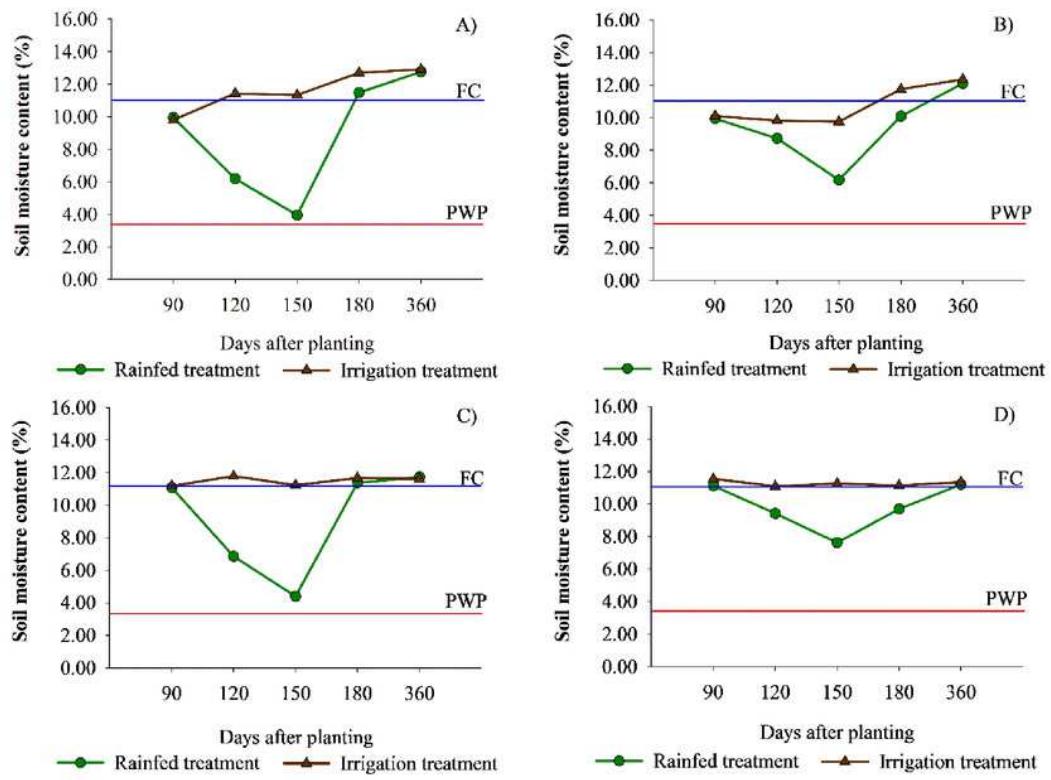


Figure 3

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for drought and irrigation treatment. (A) during 2021/2022 and (B) 2022/2023. Different letters in the same days after planting represent significant differences.

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for drought and irrigation treatment.

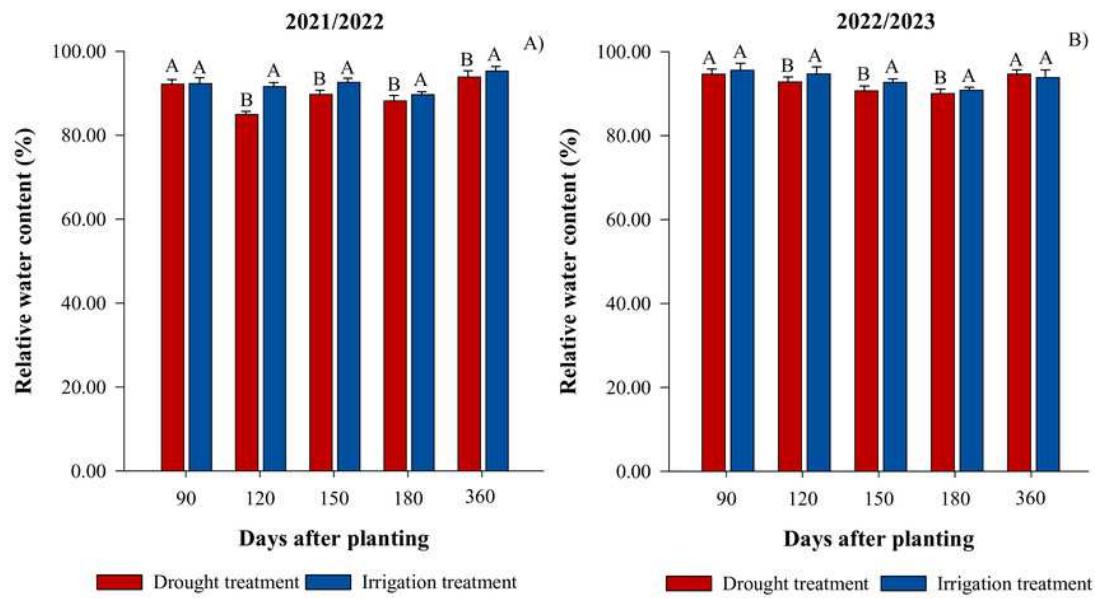


Figure 4

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for six cassava genotypes. (A) during 2021/2022 and (B) 2022/2023. Different letters in the same days after planting represent significant differences.

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for six cassava genotypes.

