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Dry matter and harvest index as production indicators in cassava accessions

Lily Lorena Luna-Castellanos [1]
Isaac Meneses-Márquez [2, §]
Andrés Vásquez-Hernández [2]

1 Colegio de Postgraduados-Campus Veracruz. Carretera Federal Xalapa-Veracruz km 88.5, Manlio Fabio Altamirano, Veracruz, México. CP. 91690. (luna.lily@colpos.mx).

2 Campo Experimental Cotaxtla-INIFAP. Carretera Federal Veracruz-Córdoba km 34.5, La Esmeralda, Medellín, Veracruz, México. CP. 94992. (vasquez.andres@inifap.gob.mx).

Autor para correspondencia: meneses.isaac@inifap.gob.mx

Abstract

Cassava (*Manihot esculenta* Crantz) is a strategically important crop in Mexico; however, germplasm characterization has been based mainly on fresh root yield, which limits the physiological interpretation of its production. This study aimed to analyze dry matter yield and harvest index as indicators of productive variability among Mexican cassava accessions. A total of 14 accessions were evaluated under field conditions using a completely randomized design, determining root yield, root dry matter content and yield (DM, DMY), starch content and yield (SC, SY) and harvest index. The nonparametric analysis showed highly significant differences among accessions for all variables evaluated ($p< 0.01$). Accession MMCOT07 presented the most outstanding performance, with the highest values of RY (88.01 t ha^{-1}), DMY (34.37 t ha^{-1}) and SY (30.08 t ha^{-1}), associated with high DM (39.39%) and SC (34.46%) contents. Other accessions showed contrasting combinations of yield and quality, reflecting differential biomass partitioning strategies. The correlation analysis confirmed strong associations among RY, DMY and SY (p# 0.98), whereas the harvest index provided complementary information on physiological efficiency. These results demonstrate that DMY and harvest index are key variables for a more accurate functional characterization of Mexican cassava germplasm.

Keywords:

adaptability, biomass production, mycorrhizal fungi, specific gravity, starch.



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Introduction

Cassava (*Manihot esculenta* Crantz) is a strategic crop for food security and tropical production systems due to its ability to adapt to marginal environments and its efficiency in carbohydrate production (De Souza *et al*., 2017).

In recent years, its evaluation has shifted from focusing exclusively on fresh root yield (RY) to incorporating more comprehensive indicators of productive performance and the agro-industrial potential of genotypes (Perez-Fons *et al*., 2023; Phanthanong *et al*., 2025).

In this respect, dry matter yield (DMY) and harvest index (HI) allow for a more comprehensive assessment of the crop. DMY combines yield and root carbohydrate concentration, offering a more robust basis for comparing genotypic performance than RY alone (De Souza *et al*., 2017; Adiele *et al*., 2020; Silva *et al*., 2023).

For its part, HI estimates the efficiency with which the plant allocates biomass to reserve roots and constitutes a functional indicator of productivity (Enesi *et al*., 2022; Menegucci *et al*., 2023).

Nonetheless, many studies continue to use RY as the primary criterion for comparison, limiting a more complete understanding of productive variability among accessions (Onyenali *et al*., 2025).

In Mexico, cassava remains underexploited despite its productive and agro-industrial potential (Del Rosario-Arellano *et al*., 2025; Rebolledo-García *et al*., 2025). Although studies on Mexican germplasm have focused on root dry matter (DM) and RY (Meneses-Márquez *et al*., 2014; González-Valdivia *et al*., 2023), information on the relationship among DMY, HI, and variability among accessions from an ecophysiological perspective remains scarce.

This gap is relevant because this germplasm is part of the Mesoamerican diversity center of the genus *Manihot* and comprises accessions with high DM content and potential yields exceeding 40 t ha^{-1} (Meneses-Márquez *et al*., 2014; Rosas-González *et al*., 2014).

Therefore, this study aimed to analyze DMY and HI as indicators of production variability among Mexican cassava accessions, in order to provide elements to understand the allocation of biomass to reserve roots and to strengthen the characterization of germplasm.

Materials and methods

Study area

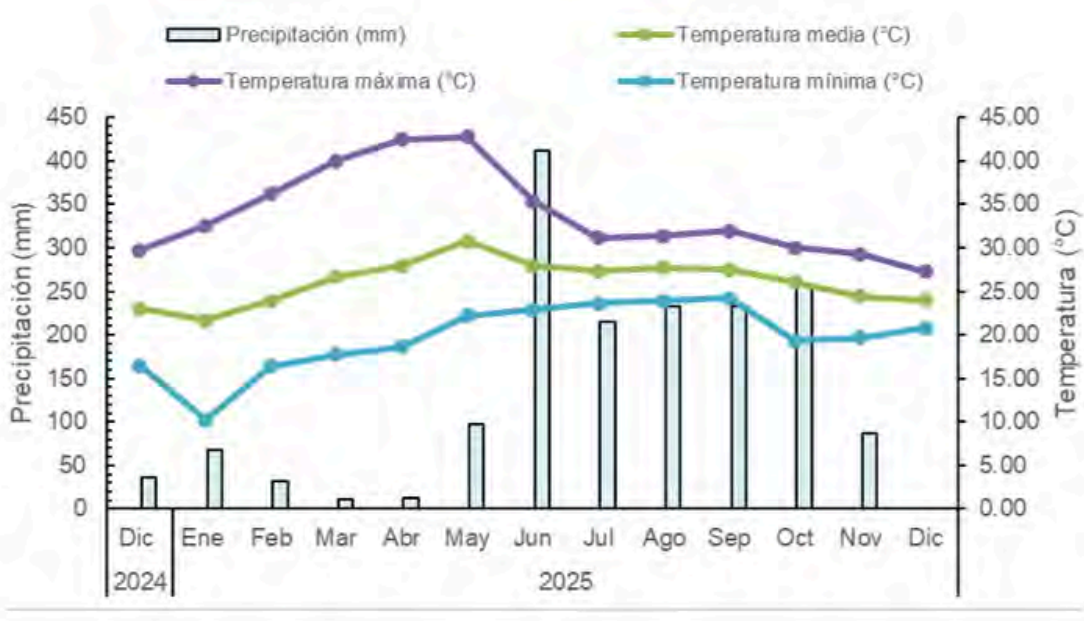
The study was conducted at the Cotaxtla Experimental Field of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP, for its Spanish acronym), located in the municipality of Medellín de Bravo, Veracruz, Mexico, at 18° 56’ 12” north latitude and 96° 11’ 32” west longitude, at an approximate altitude of 20 m.

The climate of the experimental site is warm subhumid (Aw_0). During the evaluation period, the average monthly temperature was 26.34 °C, and the accumulated rainfall was 1 656.58 mm, with 81.4% falling between June and October (Figure 1).



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Figure 1. Precipitation and temperature at the Cotaxtla Experimental Field during the cultivation cycle of 14 cassava accessions.



The soil was a Vertisol of alluvial origin; its physical and chemical characteristics were described and interpreted based on the Official Mexican Standard NOM-021-RECNAT-2000 (2002) and are shown in Table 1.

Table 1. Physical and chemical characteristics of the soil at the Cotaxtla Experimental Field of INIFAP.

Variable	Value	Interpretation
Texture (Bouyoucos)	Sandy loam	-
pH	5.8	Moderately acidic
Organic matter	12 g kg^{-1}	Moderately low
N	11 mg kg^{-1}	Low
P available (Bray-Kurtz 1, method AS-11)	132.8 mg kg^{-1}	High
K available	139 mg kg^{-1}	High
Ca exchangeable	1 800 mg kg^{-1}	Very high
Mg	191 mg kg^{-1}	Suitable

Plant material

A total of 14 Mexican accessions of sweet cassava from the INIFAP-Cotaxtla Germplasm Bank (MMCOT01 to MMCOT14) were evaluated using 20 cm cuttings from physiologically mature plants with eight to ten viable buds (Muktar *et al*., 2024).

Mycorrhizal inoculation, planting and agronomic management

The soil was mechanically prepared by brush clearing, plowing, double cross-harrowing, and furrowing at a height of 0.4 m, with furrows spaced 1 m apart. Before planting, the cuttings were inoculated with the INIFAP® biofertilizer (*Glomus intraradices*) at a dose of 3 kg ha^{-1}, following the recommendations of Durán-Prado *et al*. (2023) as a uniform agronomic management practice rather than as an experimental factor.

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Planting was conducted on December 24, 2024, at a 45° angle (Rosas-González *et al*., 2014). Each experimental plot consisted of four rows with nine plants per row, with a spacing of 1 m between rows and 1 m between plants, which resulted in a useful area of 24 m^2.

Fertilization consisted of 146-46-60 units of N-P_2O_3-K_2O, equivalent to 50% of the conventional recommended dose for the crop; this dose was split into two applications: at the time of planting and 30 days after planting (DAP) (Durán-Prado *et al*., 2023). Weed management included Bentazon at 1.5 L ha^{-1} and two manual and mechanical controls. No insect control was required during the crop cycle.

Data collection

Harvesting was carried out 12 months after planting (MAP). The variables were evaluated on five plants from the central rows of each accession. In each plant, the fresh weights of roots (kg) and aboveground biomass (kg) were recorded.

These measurements were used to estimate RY (t ha^{-1}), DM (%) and HI; in turn, the latter were used to calculate the DM yield (DMY), starch content (SC), and starch yield (SY) using equations 1, 2 and 3, based on Meneses-Márquez *et al*. (2014); Phun-iam *et al*. (2018); Adjebeng-Danquah *et al*. (2020); Rebolledo-García *et al*. (2025):

1

$$\mathrm{DMY}\left(t\mathrm{ha}^{-1}\right)=\mathrm{RY}\left(t\mathrm{ha}^{-1}\right)\times\frac{\mathrm{DM}}{100}$$

2

$$\mathrm{SC}(\%)=\mathrm{DM}(\%)\times 0.875$$

3

$$\mathrm{SY}\left(t\mathrm{ha}^{-1}\right)=\mathrm{RY}\left(t\mathrm{ha}^{-1}\right)\times\frac{\mathrm{SC}(\%)}{100}$$

Data analysis

Data was analyzed under a completely randomized design with five replications per accession. Normality and homoscedasticity were assessed using Shapiro-Wilk and Levene tests. As the variables did not meet these assumptions, differences among accessions were determined with the Kruskal-Wallis test and the multiple comparison of medians with the Dunn test adjusted by Benjamini-Hochberg (α= 0.05).

Associations between variables were analyzed using Spearman correlations. Analyses were performed in RStudio® 4.4.3 (R Core Team, 2020) with the stats, car, FSA, dunn.test, ggplot2 and corrplot packages.

Results and discussion

Productive variability among cassava accessions

The analysis of the productive and physiological parameters showed wide variability among the 14 accessions evaluated (Table 2). MMCOT07 stood out by presenting the highest values of RY (88.01), DMY (34.37), and SY (30.08), associated with high DM (39.39) and SC (34.46) contents. In contrast, accession MMCOT11 had the lowest values for most of the variables evaluated.

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Table 2. Productive performance of 14 cassava accessions under experimental conditions at INIFAP, Cotaxtla.

Accession	Root yield (t ha^{-1})	Dry matter (%)	Dry matter yield (t ha^{-1})	Starch yield (t ha^{-1})	Starch content (%)	Harvest index
MMCOT01	35.04 ±11.25	31.07 ±0.8	10.9 ±3.49	9.54 ±3.05	27.19 ±0.7	0.49 ±0.03
MMCOT02	38.92 ±5.49	34.26 ±0.62	13.42 ±2.03	11.74 ±1.78	29.98 ±0.54	0.49 ±0
MMCOT03	52.2 ±11.65	31.7 ±0.32	16.52 ±3.66	14.45 ±3.2	27.74 ±0.28	0.4 ±0.02
MMCOT04	61.8 ±20.2	32.29 ±0.23	19.93 ±6.44	17.44 ±5.64	28.26 ±0.2	0.39 ±0.02
MMCOT05	76.62 ±19.93	29.46 ±1.68	22.48 ±6.26	19.67 ±5.48	25.78 ±1.47	0.55 ±0.02
MMCOT06	86.02 ± 20.11	35.5 ±0.47	30.6 ±7.15	26.77 ±6.26	31.06 ±0.41	0.46 ±0.06
MMCOT07	88.01 ±24.3	39.39 ±1.23	34.37 ±8.99	30.08 ±7.87	34.46 ±1.08	0.43 ±0.03
MMCOT08	47.1 ±13.73	29.59 ±3.9	14.79 ±3.91	12.94 ±3.42	25.89 ±3.41	0.39 ±0.09
MMCOT09	40 ±13.6	33.72 ±1.29	13.75 ±5.07	12.03 ±4.43	29.51 ±1.13	0.42 ±0.08
MMCOT10	37.7 ±6.86	31.49 ±2.56	11.67 ±2.18	10.21 ±1.9	27.55 ±2.24	0.49 ±0.03
MMCOT11	8.5 ±3.34	19.82 ±0.55	1.73 ±0.72	1.51 ±0.63	17.34 ±0.48	0.4 ±0.07
MMCOT12	15.5 ±5.95	33.31 ±1.04	5.03 ±1.86	4.4 ±1.63	29.15 ±0.91	0.3 ±0.05
MMCOT13	74.1 ±20.01	32.8 ±2.47	25.82 ±7.82	22.6 ±6.85	28.7 ±2.16	0.52 ±0.03
MMCOT14	71.42 ±19.97	30.01 ±0.98	21.45 ±6.05	18.77 ±5.3	26.26 ±0.85	0.31 ±0.01

The values correspond to the mean ± standard error (SE).

The marked productive heterogeneity among accessions reveals contrasting genotypic strategies of growth, RY, and biomass partitioning between aboveground and underground organs, linked to differences in the efficiency of photoassimilate use and allocation (Burbano-Figueroa *et al*., 2022; Gili *et al*., 2025; Okoma *et al*., 2025).

The nonparametric Kruskal-Wallis analysis confirmed highly significant differences ($p< 0.01$) among accessions for all evaluated parameters (Figure 1), with the greatest contrasts in DM and SC ($\chi^2= 40.32$, $p< 0.001$), traits closely linked to the industrial quality of the root and with high utility for genetic selection (Sampaio-Filho *et al*., 2024; Olayinka *et al*., 2025).

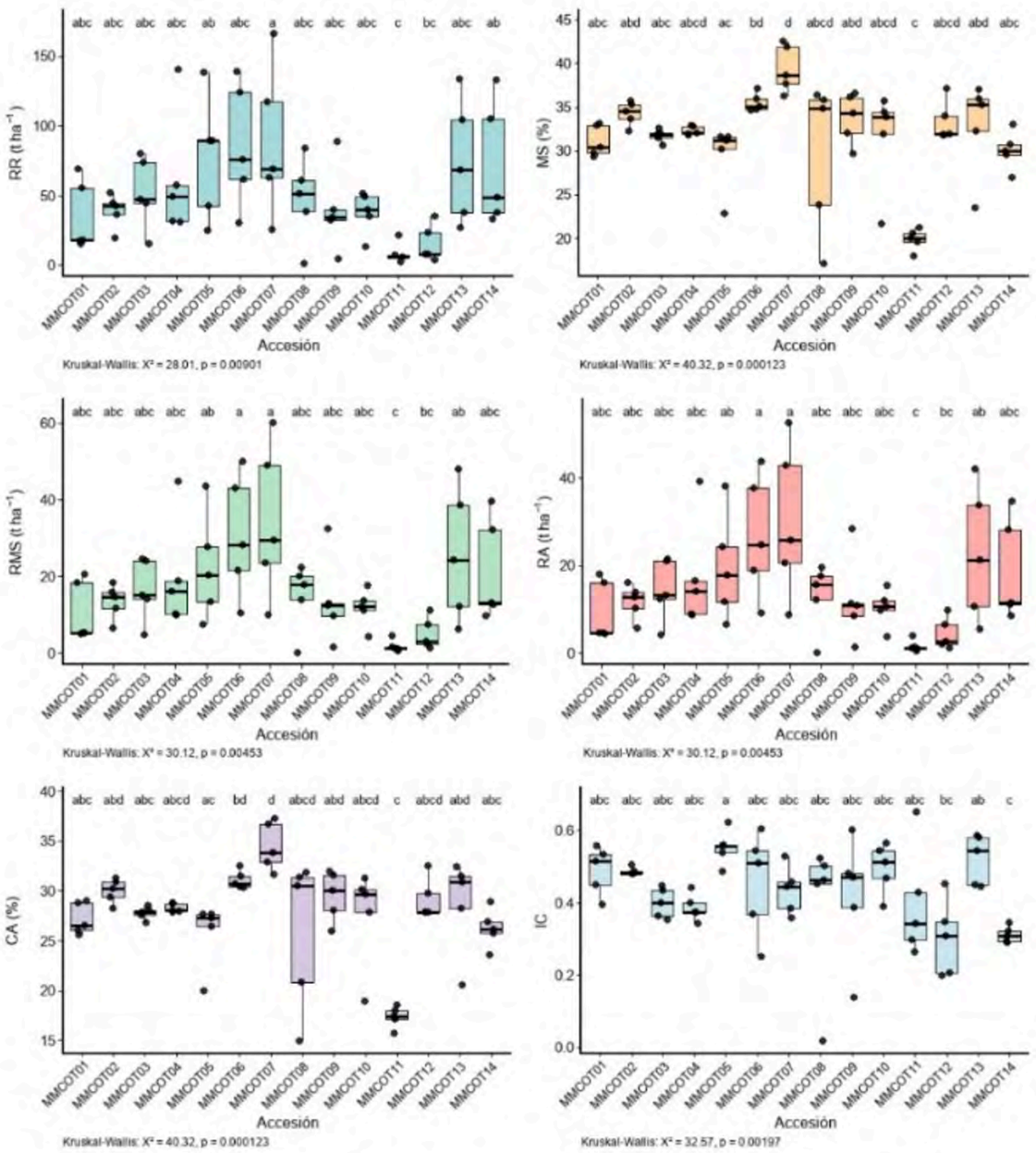
The comparison of means tests corroborated that MMCOT07 was the accession with the greatest agro-industrial potential, given its high performance in yield and root quality (Figure 2). MMCOT05 and MMCOT13 showed HIs greater than 0.50 (Table 2, Figure 2), indicating a preferential allocation of photoassimilates to reserve roots, even without presenting the highest absolute yields, a desirable condition in materials with agro-industrial aptitude (Chaiprasert *et al*., 2022; Gili *et al*., 2025).



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Figure 2. Productive variation among cassava accessions. Root yield (RR= RY); dry matter content (MS= DM); dry matter yield (RMS= DMY); starch yield (RA= SY); starch content (CA= SC); and harvest index (IC= HI). Different letters indicate statistically significant differences among accessions according to Dunn's test with Benjamini-Hochberg correction (p< 0.05).



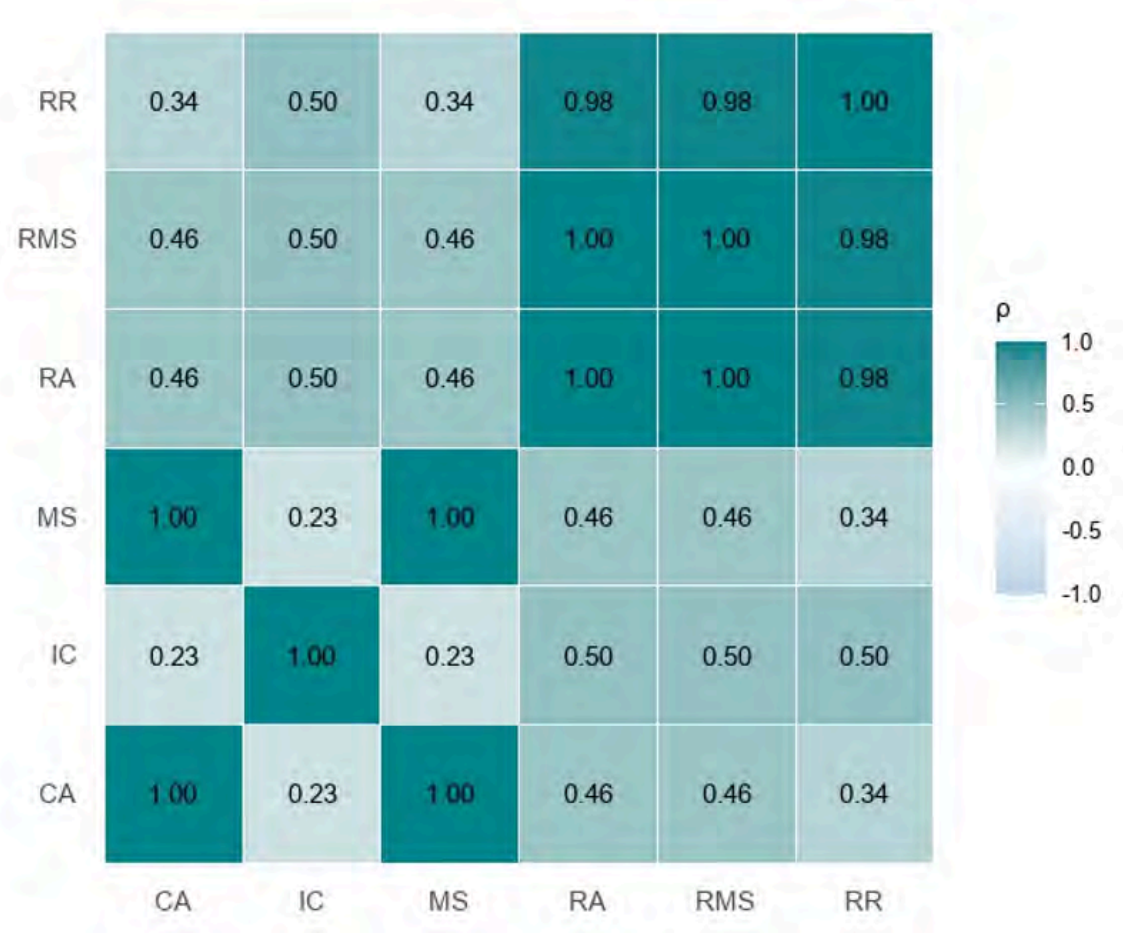
In contrast, MMCOT12 and MMCOT14 showed lower biomass allocation to reserve roots, as indicated by their HI values (0.3 and 0.31), suggesting a strategy more oriented toward aboveground development than toward harvestable organ yield (Table 2, Figure 2). This pattern suggests greater potential for propagation material production or forage use.

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DMY and HI as determinants of yield

Spearman correlation analysis (ρ) confirmed that yield is intrinsically linked to efficiency in assimilate accumulation (Figure 3). The HI showed a moderate positive correlation with RY (ρ= 0.5), which supports its usefulness as a complementary physiological indicator of yield. In turn, DM and SC showed a direct functional relationship (ρ= 1), whereas RY and SY showed a very high positive correlation (ρ= 0.98), indicating that agro-industrial performance depends on the interaction between root biomass and carbohydrate concentration.

Figure 3. Spearman correlation (ρ) between pairs of variables evaluated in cassava accessions. Root yield (RR= RY); dry matter content (MS= DM); dry matter yield (RMS= DMY); starch yield (RA= SY); starch content (CA= SC); and harvest index (IC= HI).



The identified associations confirm that cassava yield depends not only on the volume of roots produced but also on the functional integration among DM, DMY and HI. In this context, DMY acts as an integrative variable of productive performance, while HI remains useful for discriminating contrasting biomass allocation strategies among genotypes (Adjebeng-Danquah *et al*., 2020; Adiele *et al*., 2020; Enesi *et al*., 2022; Menegucci *et al*., 2023; Silva *et al*., 2023; Codjia *et al*., 2025; Onyenali *et al*., 2025).

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Conclusions

Consistent differences were identified between Mexican cassava accessions in RY, DM, SC, and HI. DMY integrated RY with the accumulation of DM in roots, while HI enabled the description of differences in the allocation of biomass to the reserve roots.

These results show that DMY and HI complement RY and strengthen the productive characterization of cassava accessions with differences in root quality.

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mycorrhizal fungi
specific gravity
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