Agro-morphological characterization, phenotypic trait analysis, and breeding potential of horned melon (Cucumis metuliferus) germplasm for enhanced food security

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Background to the study

Global Context: Climate change and food insecurity drive interest in indigenous and underutilized crops as sustainable, climate-resilient alternatives (Mmbando, 2025; Olarewaju et al., 2025).
Crop Importance: Horned melon is a nutrient-rich, drought-tolerant species native to sub-Saharan Africa, showing high adaptability to low-input farming systems
Research Gaps: Despite its potential, limited data exist on its agro-morphological traits, genetic diversity, and phenotypic associations, hindering improvement and commercialization
Research Focus: The study evaluates phenotypic and agro-morphological diversity among accessions from Mashonaland East, using correlation and regression analyses to identify key yield determinants.
Significance: Findings will support climate-smart breeding, genetic conservation, domestication, and commercial valorization of *C. metuliferus*, strengthening sustainable agriculture in sub-Saharan Africa.

Materials and Methods

Study Area and Experimental Design
Location: Midlands State University, Gweru (19°45'S, 29°84'E), Natural Region III, Zimbabwe (2024/2025 season).
Climate & Altitude: Mean annual rainfall ~674 mm; average temperature 18°C; altitude 1428 m a.s.l.
Soils: Sandy loams (fersialitic group, kaolinite dominant); slightly acidic (pH 5.9) with organic C 1.54%, nitrate-N 6.23 ppm, and N:C ratio 0.25.

Germplasm Collection and Preparation
Samples: 24 accessions collected from natural and cultivated populations in Mashonaland East Province.
Seed extraction: Wet method — ripened fruits softened at room temperature, pulp squeezed in water, jelly removed using mutton cloth, seeds washed, shade-dried, and stored.
Rationale: Ensured high-quality, mature, and contamination-free seed stock for experimental use.

Experimental Procedure
Seed Germination: Conducted under controlled lab conditions on moistened filter paper in petri dishes (5 replicates × 100 seeds/accession).
Field Establishment: Pre-germination by soaking seeds in warm water (12 h), planted in pots (35 cm × 16 cm) with 5 kg soil + 300 g cattle manure + 10 g Compound D (7:14:7 NPK).
Design: Randomized Complete Block Design (RCBD) with three replicates.
Data collection: Agro-morphological traits recorded throughout the growth cycle:

Days to germination-GE, Days to emergence-DE, Vine length (cm) -VL, Number of branches-NB, Days to female flower-DFF, Days to male flower-DMF, Days to Maturity-DM, Fruit length (cm)-FL, Fruit width (cm)-FW, Fruit weight (cm)-FWT, Number of Fruits-NF, Number of thorns-NT, Number of seeds-NS, 100-seed weight (g)-100-WT, Yield plant-1 (kg)-YD,

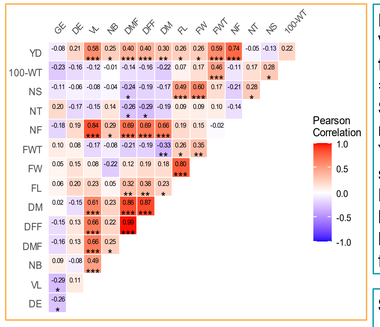
Analyses performed:
One-way ANOVA to assess differences among landraces.
Tukey's post-hoc test ($p \leq 0.05$) to identify significant mean differences.
Linear regression and Pearson correlation to determine trait relationships and yield associations.
Visualization: Graphical outputs and trend analysis generated using R Studio.

Results and Key findings

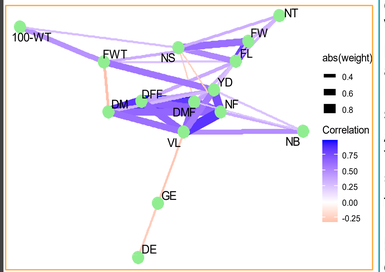
Summary of Agro-Morphological Variability in Horned Melon
Highly significant variation ($p < 0.001$) observed across 15 traits among 24 horned melon accessions.
Early growth performance varied widely, with *Acc8, Acc2,* and *Acc11* showing superior germination and *Acc18* and *Acc17* producing the longest vines.
Flowering and maturity timing ranged broadly, from early (*Acc1, Acc3*) to late (*Acc6, Acc16, Acc24, Acc8, Acc14*) accessions.
Fruit traits showed marked diversity in size, weight, and fruit number, with *Acc20* and *Acc5* outperforming others.
Seed yield and quality differed significantly, with *Acc20* and *Acc23* producing the most seeds and *Acc16* and *Acc17* showing the heaviest seed weights.

Table 1. The quantitative agro-morphological attributes of horned melon (*C. metuliferus)* for the Combined Seasons. Abbreviations (see Data collection section)

Acc No.	GE	DE	VL	NB	DFF	DMF	DM	FL	FW	FWT	NF	NT	NS	100-WT	YD
Acc1	92.83^{gh}	7.0^{abc}	241.7^{abc}	12.11^{ef}	54.67^{a}	52.83^{a}	112.8^{a}	10.39^{jkl}	6.60^{bcde}	385.8^{jk}	7.50^{a}	58.00^{defgh}	349.8^{cd}	0.947^{defg}	2.877^{bcde}
Acc2	95.87^{gh}	8.2^{abcde}	260.6^{fgh}	14.39^{klm}	69.50^{i}	67.33^{m}	137.8^{mn}	13.01^{efgh}	8.03^{ghij}	372.5^{jk}	12.67^{cdef}	58.67^{defgh}	370.3^{defghi}	1.147^{ghi}	4.738^{gh}
Acc3	86.20^{f}	7.1^{abcd}	248.7^{hcd}	14.22^{jkl}	57.33^{b}	56.83^{bc}	118.3^{bcd}	8.26^{a}	4.97^{a}	198.7^{ab}	6.94^{a}	35.75^{b}	305.0^{b}	0.867^{cdef}	1.427^{a}
Acc4	72.97^{a}	10.0^{e}	237.4^{a}	12.78^{fg}	58.50^{b}	56.83^{bc}	115.8^{ab}	10.86^{hcd}	7.03^{bcdefg}	309.3^{fg}	7.66^{a}	67.25^{hi}	358.5^{cdef}	1.052^{fghi}	2.849^{bcde}
Acc5	72.73^{a}	9.0^{abcde}	278.3^{kl}	13.50^{ghij}	61.33^{de}	59.33^{cdef}	121.7^{def}	9.46^{abb}	6.23^{b}	402.0^{k}	15.44^{fg}	38.50^{b}	300.3^{b}	1.112^{ghi}	6.235^{j}
Acc6	76.20^{abc}	7.5^{abcde}	266.6^{ghij}	12.17^{f}	72.17^{j}	71.00^{n}	141.0^{no}	11.75^{cdefg}	6.52^{bc}	282.7^{def}	14.22^{efg}	58.83^{defgh}	307.2^{b}	1.127^{ghi}	4.00^{defgh}
Acc7	78.83^{bcd}	7.9^{abcde}	251.8^{def}	15.00^{klm}	60.83^{cde}	57.83^{bcd}	121.7^{def}	13.78^{ij}	6.58^{bcd}	267.0^{cde}	7.28^{a}	48.67^{cd}	370.5^{defghi}	0.825^{bcdef}	1.933^{ab}
Acc8	97.57^{h}	7.7^{abcde}	275.3^{kl}	14.00^{hijk}	65.50^{gh}	63.17^{hij}	142.0^{o}	13.23^{ijkl}	8.15^{hij}	310.9^{fg}	16.33^{g}	64.33^{ghi}	309.9^{b}	0.700^{abc}	5.045^{h}
Acc9	91.57^{g}	9.7^{cde}	283.7^{lm}	15.22^{lmn}	62.33^{ef}	60.67^{efgh}	124.7^{efgh}	13.84^{kl}	7.90^{ghij}	285.7^{def}	14.83^{fg}	56.75^{defg}	367.6^{defgh}	0.843^{bcdef}	4.293^{fgh}
Acc10	92.50^{gh}	8.2^{abcde}	240.7^{abc}	13.11^{fgh}	63.83^{fg}	61.33^{ghi}	127.5^{ghi}	13.01^{efgh}	7.82^{fghij}	280.0^{def}	8.28^{abb}	49.75^{cde}	350.7^{cde}	0.780^{bcde}	2.387^{abc}
Acc11	94.57^{gh}	7.8^{abcde}	240.0^{ab}	10.61^{bcd}	61.33^{de}	58.00^{bcde}	125.2^{fgh}	12.36^{defgh}	8.00^{ghij}	283.7^{def}	7.11^{a}	62.75^{ghi}	377.0^{fghi}	0.967^{defgh}	2.019^{abc}
Acc12	75.50^{ab}	7.1^{abcd}	258.6^{efg}	10.95^{cd}	62.50^{ef}	60.33^{defg}	131.3^{ij}	11.51^{cdef}	7.68^{efghij}	277.6^{def}	9.44^{abc}	50.00^{cde}	373.0^{efghi}	1.273^{i}	2.689^{bcd}
Acc13	79.53^{bcde}	6.6^{a}	281.8^{l}	14.94^{klm}	66.00^{gh}	63.50^{ij}	140.8^{no}	11.21^{bcde}	7.80^{ghij}	258.5^{cd}	14.50^{efg}	64.00^{ghi}	372.2^{defghi}	0.783^{bcde}	3.739^{defg}
Acc14	83.88^{def}	6.8^{ab}	271.3^{jk}	10.61^{bcd}	65.00^{gh}	62.83^{ghij}	142.0^{o}	10.68^{bcd}	6.75^{bcde}	162.4^{a}	12.33^{cdef}	53.67^{cdef}	351.4^{cde}	0.638^{ab}	2.056^{abc}
Acc15	79.47^{bcde}	7.6^{abcde}	281.0^{l}	16.17^{no}	66.50^{h}	64.50^{ijk}	136.7^{lm}	12.88^{efgh}	7.77^{fghij}	266.9^{cde}	14.11^{efg}	71.00^{i}	384.5^{ghi}	1.017^{fgh}	3.746^{defg}
Acc16	84.53^{ef}	10.2^{e}	267.2^{ghij}	10.22^{bcd}	68.83^{i}	67.00^{lm}	132.2^{ij}	11.85^{cdefg}	7.03^{bcdefg}	236.8^{bc}	13.28^{efg}	68.83^{i}	270.7^{a}	0.550^{a}	3.129^{cdef}
Acc17	74.77^{ab}	8.1^{abcde}	292.2^{mn}	16.50^{o}	68.83^{i}	66.83^{lm}	136.3^{klm}	13.05^{ijkl}	7.63^{defghij}	253.5^{cd}	15.55^{fg}	53.17^{cdef}	338.2^{c}	1.275^{i}	4.000^{efgh}
Acc18	76.83^{abc}	9.1^{abcde}	293.0^{n}	15.44^{mno}	68.83^{i}	66.33^{klm}	132.5^{ik}	10.99^{bcd}	6.43^{b}	204.1^{b}	15.39^{fg}	64.17^{ghi}	366.0^{defgh}	0.650^{abc}	3.166^{cdef}
Acc19	72.87^{a}	9.1^{abcde}	268.6^{hij}	9.89^{bc}	65.83^{gh}	64.00^{ijk}	128.0^{hi}	13.92^{kl}	7.93^{ghij}	301.6^{efg}	12.33^{cdef}	67.83^{hi}	389.2^{hij}	0.995^{efgh}	3.750^{defg}
Acc20	73.33^{a}	9.7^{cde}	282.2^{l}	13.28^{ghi}	69.00^{i}	66.83^{lm}	133.0^{ijkl}	15.66^{l}	9.32^{k}	352.9^{hij}	13.00^{defg}	54.83^{cdefg}	418.2^{k}	0.828^{bcdef}	4.571^{gh}
Acc21	77.73^{abc}	8.6^{abcde}	262.6^{ghi}	9.55^{ab}	59.17^{bcd}	56.00^{b}	117.2^{bc}	13.45^{ijkl}	8.72^{ijk}	332.2^{ghi}	11.22^{bcde}	53.17^{cdef}	402.3^{jk}	1.180^{hi}	3.746^{defg}
Acc22	74.70^{ab}	9.8^{de}	249.8^{cde}	11.00^{d}	58.67^{bc}	56.17^{b}	123.7^{efg}	10.47^{bc}	7.60^{cdefghi}	229.6^{bc}	9.61^{abcd}	45.00^{bc}	365.0^{defg}	0.833^{bcdef}	2.252^{abc}
Acc23	81.30^{cdef}	7.5^{abcde}	239.6^{ab}	8.5^{a}	59.17^{bcd}	56.83^{bc}	121.0^{cde}	12.34^{defgh}	8.65^{ijk}	336.3^{ghi}	8.00^{ab}	70.08^{i}	392.3^{ij}	1.052^{fghi}	2.711^{bcd}
Acc24	74.40^{ab}	9.4^{bcde}	277.9^{kl}	11.05^{de}	72.00^{j}	69.00^{mn}	138.8^{mno}	11.73^{cdefg}	7.28^{bcdefgh}	260.0^{cd}	14.28^{efg}	0.00^{a}	309.1^{b}	0.742^{abcd}	3.695^{defg}
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
$LSD_{0.05}$	2.710	1.436	4.788	0.570	1.215	1.467	2.121	0.952	0.569	20.505	1.820	5.201	11.678	0.119	0.6132



Abbreviations (see Data collection section)
Asterisks denote statistical significance: * indicates significance at $p < 0.05$ ** at $p < 0.01$ *** at $p < 0.001$
Figure 1. A pairwise Pearson correlation analysis among 15 agro-morphological traits of horned melon (C. metuliferus) accessions.



Abbreviations (see Data collection section)
Figure 2. Trait correlation network for 15 agro-morphological traits of horned melon (C. metuliferus) accessions.

Breeding Implications
Vine length (VL), fruit weight (FWT), and fruit number (NF) strongly determine yield ($R^2 = 0.93$).
Synchronized flowering ($r = 0.99$) enhances reproductive efficiency and uniform maturity.
Yield prediction: VL, NF, and FWT are reliable selection indices.
Early traits (GE, DE) show weak yield links—lower breeding priority.
Integrated selection for vegetative vigor and fruit traits supports climate-smart breeding.

Summary: Key Findings on *C. metuliferus*

High genetic diversity ($p < 0.001$) among 24 accessions highlights strong potential for breeding climate-resilient, high-yielding cultivars.
Vegetative traits (vine length, branching) and **phenological variation** influence yield and adaptability to diverse environments (
Elite accessions (Acc5, Acc8, Acc2, Acc20) showed superior yield and fruit traits, while Acc24's thornlessness improves handling.
Yield correlated strongly with fruit number ($r = 0.76$**) and weight ($r = 0.59$**); synchronized flowering ($r = 0.99$**) enhances fruit set.
Breeding focus: prioritize vine vigor, fruit biomass, and reproductive synchrony to develop climate-smart, marketable horned melon cultivars.

Conclusion

Yield strongly correlated with vine length, branch number, fruit number, and synchronized flowering.
- **Early growth traits** had weak yield correlations but are crucial for good crop establishment.
- **Fruit weight and width** were better predictors of yield than fruit length.
- **Seed traits** had minimal effect on yield, suggesting potential for separate improvement.
- **High-performing accessions** (Acc5, Acc8, Acc1, Acc24) show strong potential for breeding resilient, nutrient-rich cultivars