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Morphological Diversity and Genotypic Discrimination in Tomato (*Solanum lycopersicum* L.): Implications for Breeding, Stress Tolerance, and Germplasm Conservation

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Abstract

Understanding the extent and distribution of phenotypic diversity in tomato (*Solanum lycopersicum* L.) is fundamental for cultivar identification, genetic improvement, and the sustainable utilization of germplasm resources. This study evaluated 15 key qualitative morphological traits across nine genetically diverse tomato genotypes to characterize their phenotypic variability and assess its implications for breeding, particularly for stress resilience. The field experiment was conducted under irrigation during the 2024–2025 off-season at two distinct agro-ecological locations in western Ethiopia: Bako Tibe (1560 m.a.s.l.) and Gambella Tare (2697 m.a.s.l.). Significant inter-genotypic variation was observed for all qualitative descriptors. Fruit traits exhibited pronounced diversity, including predominant shapes (ranging from pyriform to cylindrical), shoulder morphology (flat to strongly depressed), cross-sectional outlines (angular, rounded, irregular), and pistil scar patterns (dot, stellate, linear). Notably, 66.66% of genotypes demonstrated high fruit size homogeneity, while angular cross-sections were predominant (55.55%). The prevalence of abiotic stress-related disorders was genotype-dependent: blotchy ripening was observed in 55.55% of genotypes (slight symptoms), sunscald in 44.44% (exposed), and radial cracking in 55.55% (slightly affected), underscoring the interaction between genetic predisposition and environmental factors. Leaf morphological traits, including type (potato, dwarf, Peruvianum) and attitude (drooping, semi-erect, horizontal), further corroborated the substantial genetic diversity. Correlation analysis from the accompanying quantitative trait evaluation revealed that average fruit weight had a strong, positive, and significant genotypic correlation with total marketable fruit yield (rg = 0.35) and fruit yield (rg = 0.716). Our findings align with global studies on tomato landrace diversity and demonstrate that systematic morphological characterization remains a powerful, cost-effective first step for germplasm conservation and for selecting parental lines with desirable agronomic traits, including stress tolerance. The identified genotypes, particularly; 'Cochoro' for yield and 'Melka-salsa' for fruit quality, offer immediate value for breeding programs targeting climate-resilient and market-preferred cultivars.

Keywords: *Abiotic stress, breeding, fruit morphology, genetic diversity, Solanum lycopersicum, qualitative traits.*

Introduction

Tomato (*Solanum lycopersicum* L.), a member of the Solanaceae family, stands as one of the world's most economically significant and nutritionally valuable vegetable crops, playing a pivotal role in global food and nutritional security [1,2]. Its high polymorphism, manifesting as extensive phenotypic diversity in fruit morphology, plant architecture, and physiological responses, has rendered it an exemplary model for studying crop adaptation, domestication, and the genetic basis of complex traits [3, 4]. While the advent of high-throughput molecular markers and genomic tools has revolutionized plant breeding, morphological characterization remains an indispensable and cost-effective foundational step for several critical applications. These include the distinct identification of cultivars, the systematic conservation of germplasm (especially in underutilized local collections), the description of breeding lines for intellectual property protection (Plant Variety Protection), and the initial selection of traits for improvement [5,6].

Fruit-associated qualitative traits such as shape, shoulder type, cross-sectional profile, and pistil scar morphology are primary determinants of marketability, consumer preference, postharvest handling, and transport durability [7, 8]. For instance, cylindrical fruits are often preferred for processing, while heart-shaped or flattened types may be favored in fresh markets. Similarly, fruit shoulder morphology can significantly influence susceptibility to cracking and postharvest water loss [9]. Previous studies have documented substantial variability in these descriptors among heirloom, landrace, and commercial tomato varieties [10, 11]. However, significant gaps remain in understanding the distribution and adaptive significance of these traits within locally adapted genotypes, particularly in under-researched agro-ecologies like the mid- to high-altitude zones of East Africa [12].

Beyond fruit morphology, abiotic stress-related physiological disorders including blotchy ripening, sunscald, and radial cracking pose major challenges to consistent tomato production, leading to substantial postharvest losses and reduced economic returns [13, 14]. The incidence and severity of these disorders are governed by a complex interplay between genetic susceptibility (e.g., genes controlling cuticle development, pigmentation, and calcium transport) and environmental factors such as light intensity, temperature fluctuations, and nutrient availability [15, 16]. A systematic assessment of the genotypic variation in susceptibility to these disorders is a prerequisite for

breeding programs aiming to develop resilient cultivars for stress-prone environments, particularly under the specter of climate change.

Furthermore, leaf architectural traits, including type (e.g., potato leaf, standard, Peruvianum), attitude (e.g., drooping, semi-erect), and foliage density, have direct implications for photosynthetic efficiency, canopy light interception, air circulation, and susceptibility to foliar diseases [17, 18]. For example, potato leaf types have been linked to altered source-sink relationships and yield potential [19], while drooping leaf attitudes may be an adaptation to high light intensity or water stress. Despite their functional significance, comparative analyses of leaf morphology across diverse tomato genotypes are often overlooked in favor of fruit-centric studies.

This study was designed to address these gaps by providing a comprehensive assessment of phenotypic diversity in nine tomato genotypes using a standardized set of 15 qualitative morphological descriptors. The specific objectives were to: (1) comprehensively characterize the phenotypic variability for fruit and leaf traits; (2) identify key diagnostic descriptors that can effectively differentiate among the genotypes for cultivar identification; (3) assess the genotypic variation in the prevalence of common abiotic stress-related disorders; and (4) discuss the implications of this diversity for targeted breeding and germplasm conservation. By integrating detailed morphological trait analysis with agronomic performance data from a parallel quantitative study, this work aims to provide a holistic framework for selecting elite genotypes suitable for sustainable tomato production in the diverse agro-ecologies of western Ethiopia and beyond.

Materials and Methods

Plant Material, Experimental Sites, and Design

Nine tomato (*Solanum lycopersicum* L.) genotypes, including one local check, were evaluated for phenotypic diversity. The genotypes were selected based on their agronomic performance and adaptability to diverse growing conditions. The study was conducted during the 2024–2025 growing season under irrigation at two locations: Bako Tibe (1560 m.a.s.l., clay loam soil, pH 4.99) and Gambella Tare (2697 m.a.s.l., alluvial loam soil). A randomized complete block design (RCBD) with three replications was used. Each plot measured 3 m × 4 m (12 m²), with seedlings transplanted at 45 days after sowing at a spacing of 0.5 m between rows and 0.4 m between plants.

The study evaluated nine tomato (*Solanum lycopersicum* L.) genotypes, comprising eight improved varieties (Melkashola, Cochoro, ILu-Harar, Sire, Melkasalsa, Chali, Gelilema, Komto) and one local check (Table S1). The genotypes were selected based on their reported agronomic performance and adaptability. The field experiment was conducted during the 2024–2025 dry (off-) season under supplemental irrigation at two distinct agro-ecological locations in western Oromia, Ethiopia: (i) Bako Tibe (Bako Agricultural Research Center; 9°06’N, 37°09’E; 1560 m above sea level [m.a.s.l.]; sub-humid, clay loam soil, pH 4.99) and (ii) Gambella Tare (Nint Agri Plc research site in Boneya Boshe District; 9°4’0’’N, 37°01’0’’E; 2697 m.a.s.l.; highland, alluvial loam soil). A detailed description of the climatic and soil characteristics of both sites is provided in the supplementary materials (Appendix Tables S2, S3).

A Randomized Complete Block Design (RCBD) with three replications was employed at each location. Each experimental plot measured 3 m × 4 m (12 m²), with 0.5 m between rows and 0.4 m between plants. Seedlings were raised in a nursery for 45 days before being transplanted. Standard agronomic practices for irrigated tomato production were uniformly followed across both sites, including drip irrigation, fertilization (100 kg ha^{-1} DAP at transplanting and 250 kg ha^{-1} urea split into three applications), staking, and integrated pest management using recommended fungicides (Mancozeb, Bravo) and insecticides (Karate).

Qualitative Trait Evaluation

Data for 15 qualitative morphological descriptors were recorded on a plot basis from five randomly selected and tagged competitive plants per genotype, at appropriate growth stages (e.g., vegetative, anthesis, and fruit ripening). The descriptors were adopted from the International Plant Genetic Resources Institute (IPGRI) guidelines for tomato [20]. The traits assessed, their codes, and scoring scales are detailed in Table 1. Observations were made between 08:00 and 10:00 AM to standardize assessments, particularly for leaf color and turgor.

Quantitative Trait Data (for Correlation Context)

To contextualize the qualitative findings, data from a parallel study on quantitative traits were used. Sixteen agronomic traits were recorded, including days to 50% flowering (DF), days to maturity (NDM), plant height (PH), number of fruits per plant (NFSP), average fruit weight (AFW), total marketable fruit yield (TMFY, t ha^{-1}), fruit length (FL), fruit diameter (FD), and fruit pericarp thickness (FPTH), following standard protocols [20]. The analysis of these quantitative traits was conducted using SAS 9.0, with ANOVA and mean separation via Fisher's LSD ($p \leq 0.05$). Genotypic correlation coefficients (rg) among key traits were calculated using variance and covariance components [21].

Table 1: List of qualitative morphological descriptors, codes, and scoring scales used for tomato genotype characterization (based on IPGRI [20]).

Trait	*Descriptor*	*Code*	*Scoring Scale / Class*
PFSh	Predominant Fruit Shape	1-8	1. Flattened (oblate); 2. Slightly flattened; 3. Rounded; 4. High rounded; 5. Heart-shaped; 6. Cylindrical; 7. Pyriform; 8. Ellipsoid (plum-shaped)
FshSH	Fruit Shoulder Shape	1,3,5,7	1. Flat; 3. Slightly depressed; 5. Moderately depressed; 7. Strongly depressed
FCSH	Fruit Cross-sectional Shape	1,2,3	1. Round; 2. Angular; 3. Irregular
FsH	Fruit Size Homogeneity	3,5,7	3. Low; 5. Intermediate; 7. High
ShPS	Shape of Pistil Scar	1,2,3,4	1. Dot; 2. Stellate; 3. Linear; 4. Irregular
FBESH	Fruit Blossom End Shape	1,2,3	1. Indented; 2. Flat; 3. Pointed
FrF	Fruit Firmness	3,5,7	3. Soft; 5. Intermediate; 7. Firm
BER	Blossom End Rot Incidence	3,5,7	3. Few; 5. Moderate; 7. Many
BR	Blotchy Ripening	3,5,7	3. Slight; 5. Intermediate; 7. Severe
Ss	Sun Scald	3,5,7	3. Slight; 5. Intermediate; 7. Severe
Rc	Radial Cracking	1,3,5,7	1. Corky lines; 3. Slight; 5. Intermediate; 7. Severe
RUWP	Ripening Uniformity (Whole Plot)	3,5,7	3. Poor; 5. Intermediate; 7. Good
LT	Leaf Type	1-6	1. Dwarf; 2. Potato leaf; 3. Standard; 4. Peruvianum; 5. Pimpinellifolium; 6. Hirsutum
LA	Leaf Attitude	3,5,7	3. Semi-erect; 5. Horizontal; 7. Drooping
Fod	Foliage Density	3,5,7	3. Sparse; 5. Intermediate; 7. Dense

Results

Phenotypic Diversity in Qualitative Traits

The evaluation of 15 qualitative traits across the nine tomato genotypes revealed substantial morphological diversity, with the frequency of phenotypic classes ranging from 11.11% to 77.77% (Table 2). Fruit-related descriptors proved to be the most powerful for differentiating between genotypes.

Fruit Morphological Diversity

A wide range of fruit shapes was observed. The most common shapes were cylindrical (long oblong) and pyriform, each exhibited by 22.22% of the genotypes. Other shapes, including slightly flattened, rounded, high-rounded, heart-shaped, and ellipsoid, were each observed in 11.11% of the genotypes. The flattened (oblate) shape was absent in this germplasm (Table 2; Figure 1). Fruit shoulder morphology also varied considerably, with slightly depressed shoulders being the most prevalent (44.44% of genotypes), followed by flat and moderately depressed types (22.22% each), and strongly depressed shoulders being rare (11.11%).

For cross-sectional shape, angular was the dominant form, observed in over half (55.55%) of the genotypes, while rounded and irregular shapes each accounted for 22.22% (Figure 2). Notably, 66.66% of the genotypes exhibited high fruit size homogeneity, a trait highly desirable for uniform harvest and marketing (Table 2).

Figure 1: Prevalent Fruit Forms Observed in the Evaluated Cultivars (source: own study)

Figure 2: Cross-Sectional Morphology of Fruit in the Investigated Varieties (source: own study)

Pistil scar morphology was predominantly a simple dot (55.55% of genotypes), with stellate and linear scars each present in 22.22%. Irregular scars were not observed. Regarding fruit blossom end shape, the indented form was most common (55.55%), followed by pointed (33.33%) and flat (11.11%) (Table 2). Fruit firmness varied, with soft and firm textures being most frequent (44.44% and 33.33% of genotypes, respectively), while intermediate firmness was less common (22.22%).

Prevalence of Stress-Related Disorders

The incidence of abiotic stress-related disorders was genotype-dependent, indicating a genetic basis for susceptibility (Table 2). Blotchy ripening (BR) was predominantly slight (55.55% of genotypes), though 22.22% each showed intermediate and severe symptoms (**Figure 3b**). Sunscald (Ss) susceptibility showed a different pattern, with 44.44% of genotypes exhibiting intermediate exposure symptoms, 33.33% slight, and 22.22% severe (**Figure 3a**). Radial cracking (Rc) was predominantly slight (55.55% of genotypes), but 22.22% each showed intermediate and severe cracking. Blossom end rot (BER) was minimal (few symptoms) in the majority of genotypes (66.66%), with only a few showing moderate (22.22%) or many (11.11%) symptoms.

Figure 3: Manifestations of Sunscald (a) and Blotchy Ripening (b) in the Evaluated Tomato Cultivar (source: own study).

Leaf Morphological Diversity

Substantial variation was also observed in leaf morphology. The potato leaf type was most common (33.33% of genotypes), followed equally by dwarf and Peruvianum types (22.22% each). The *Pimpinellifolium* and *Hirsutum* leaf types were each observed in a single genotype (11.11% each), and the standard leaf type was absent (Table 2). Leaf attitude was predominantly drooping (44.44% of genotypes), with semi-erect (33.33%) and horizontal (22.22%) also present. Foliage density was most frequently sparse (44.44%), followed by dense (33.33%) and intermediate (22.22%) (Table 2).

Table 2: Percentage frequency distribution of 15 qualitative morphological traits among nine tomato genotypes evaluated in western Ethiopia.

Trait	*Class (Code)*	*Frequency (%)*
PFSh (Fruit Shape)	Slightly flattened (2); Rounded (3); High rounded (4); Heart-shaped (5); Ellipsoid (8)	11.11 (each)
	Cylindrical (6); Pyriform (7)	22.22 (each)
FshSH (Shoulder Shape)	Flat (1); Moderately depressed (5)	22.22 (each)
	Slightly depressed (3)	44.44
	Strongly depressed (7)	11.11
FCSH (Cross-section)	Round (1); Irregular (3)	22.22 (each)
	Angular (2)	55.55
FsH (Size Homogeneity)	Intermediate (5)	33.33
	High (7)	66.66
ShPS (Pistil Scar)	Stellate (2); Linear (3)	22.22 (each)
	Dot (1)	55.55
FBESH (Blossom End)	Flat (2)	11.11
	Pointed (3)	33.33
	Indented (1)	55.55
FrF (Firmness)	Intermediate (5)	22.22
	Firm (7)	33.33
	Soft (3)	44.44
BER (Blossom End Rot)	Moderate (5); Many (7)	22.22; 11.11
	Few (3)	66.66
BR (Blotchy Ripening)	Intermediate (5); Severe (7)	22.22 (each)
	Slight (3)	55.55
Ss (Sun Scald)	Slight (3); Severe (7)	33.33; 22.22
	Intermediate (5)	44.44
Rc (Radial Cracking)	Intermediate (5); Severe (7)	22.22 (each)
	Slight (3)	55.55
RUWP (Ripening Uniformity)	Intermediate (5); Good (7)	33.33; 22.22
	Poor (3)	44.44
LT (Leaf Type)	Dwarf (1); Peruvianum (4)	22.22 (each)
	Pimpinellifolium (5); Hirsutum (6)	11.11 (each)
	Potato leaf (2)	33.33
LA (Leaf Attitude)	Horizontal (5)	22.22
	Semi-erect (3)	33.33
	Drooping (7)	44.44
Fod (Foliage Density)	Intermediate (5)	22.22
	Dense (7)	33.33
	Sparse (3)	44.44

Key:- *PFSh: Predominant Fruit shape, FshSH: Fruit shoulder shape, FCSH: Fruit cross-sectional shape, FsH: Fruit Size Homogeneity, ShPS: Shape of pistil scar, FBESH: Fruit blossom end shape, FrF: Fruit firmness, BER: Blossom end rot, BR: Blotchy Ripening, Ss: Sun Scald, Rc: Radial cracking, RUWP: Ripening uniformity of the whole plot, LT: Leaf type, LA: Leaf Attitude, Fod: Foliage density.*

Correlation of Qualitative with Quantitative Performance

The observed qualitative diversity was reflected in the quantitative agronomic performance of the genotypes (Table 3). For instance, the genotype 'Cochoro', which exhibited a firm fruit texture (FrF=7) and high fruit size homogeneity (FsH=7), also recorded the highest total marketable fruit yield across both locations (91.5 t ha^{-1} at Bako, 84.3 t ha^{-1} at Gambella). Conversely, 'Geli-Lema', which had a soft fruit texture (FrF=3) and poor ripening uniformity (RUWP=3), produced the lowest yield at Gambella (42.2 t ha^{-1}). Genotypic correlation analysis from the quantitative study (Table 4) revealed that average fruit weight (AFW) was strongly, positively, and significantly correlated with total marketable fruit yield ($r_g = 0.35$, $p < 0.05$) and fruit yield ($r_g = 0.716$, $p < 0.01$), highlighting the direct contribution of fruit size to overall productivity.

Table 3: Mean performance for key quantitative traits of nine tomato genotypes grown at two locations (Bako Tibe and Gambella Tare).

Genotype	*TMFY (t ha⁻¹)*	*AFW (g)*	*NFSP*	*PH (cm)*	*Key Qualitative Traits*
Cochoro	91.5 (Bako) / 84.3 (Gambella)	146.1	36.0	76.1	Firm fruit, high size homogeneity
Melka-shola	77.2 / 73.3	62.3	42.2	93.5	Indented blossom end, soft fruit
Chali	69.6 / 51.4	102.4	45.8	73.6	Rounded shape, pointed blossom end
Melka-salsa	60.9 / 55.3	51.4	75.4	78.5	Cylindrical fruit, high ascorbic acid
Geli-Lema	61.3 / 42.2	87.2	42.8	93.2	Soft fruit, poor ripening uniformity
LSD (5%)	17.2 / 16.4	19.0 / 33.9	13.5 / 12.1	6.9 / 9.5	

Key: TMFY: Total Marketable Fruit Yield; AFW: Average Fruit Weight; NFSP: Number of Fruits per Plant; PH: Plant Height.

Table 4: Estimates of genotypic correlation coefficients (rg) among key quantitative traits for nine tomato genotypes (combined across two locations).

Trait	*AFW*	*FY*	*FD*	*FPTH*
NFSP	-0.606*	-0.359	-0.312	-0.775*
AFW	-	0.716**	0.778*	0.806**
TMFY	0.735*	0.99***	0.457	0.495
PH	-0.603*	-0.369	-0.716*	-0.148

Key: AFW: Avg. Fruit Weight; FY: Fruit Yield; FD: Fruit Diameter; FPTH: Fruit Pericarp Thickness; NFSP: Number of Fruit Sets per Plant; TMFY: Total Marketable Fruit Yield; PH: Plant Height. *, **, *** indicate significance at $p<0.05$, $p<0.01$, and $p<0.001$, respectively.

Discussion

This study successfully delineated the substantial phenotypic diversity present within a panel of nine tomato genotypes using a robust set of qualitative morphological descriptors. The frequency of phenotypic classes varied widely (11.11% to 77.77%), demonstrating the utility of this approach for discriminating between cultivars, as has been shown in diverse germplasm collections globally [6, 22]. The significant variation observed in key traits, particularly those related to fruit morphology and stress disorder susceptibility, has direct and important implications for targeted breeding, germplasm conservation, and the development of climate-resilient varieties.

Fruit Morphology as a Tool for Cultivar Differentiation and Market Suitability

Our results confirm that fruit morphological descriptors are among the most powerful for distinguishing tomato genotypes [5, 23]. The observed variation in fruit shape from pyriform to cylindrical to heart-shaped is not merely cosmetic but has functional significance for different market segments and uses. For instance, cylindrical (long-oblong) fruits, like those of 'Melka-salsa', are often preferred by the processing industry for producing sauces and pastes due to higher solids content and ease of peeling [7]. In contrast, heart-shaped or slightly flattened fruits may be more appealing for fresh market consumption [24]. The absence of the flattened (oblate) shape in our germplasm suggests a specific genetic background in these locally adapted lines, diverging from some commercial varieties.

The predominance of angular cross-sectional shapes (55.55%) and high fruit size homogeneity (66.66%) are particularly noteworthy. Angular shapes have been associated with specific genetic markers linked to cell wall development and fruit firmness [25]. High size homogeneity is a critical trait for commercial producers, as it reduces sorting costs and ensures a more uniform, high-value product [26]. The significant positive genotypic correlation we observed between average fruit weight and both marketable yield (rg = 0.35) and total yield (rg = 0.716) underscores the economic importance of selecting for larger, more homogenous fruits. This finding is consistent with studies showing that fruit weight is a major component of yield in tomato [27, 28].

Genotypic Variation in Abiotic Stress-Related Disorders

The genotype-dependent variation in the incidence of physiological disorders like blotchy ripening (BR), sunscald (Ss), and radial cracking (Rc) provides crucial insights for breeding programs. Our finding that 55.55% of genotypes showed only slight BR symptoms suggests that some of these lines harbor tolerance mechanisms. BR is often linked to imbalances in potassium and calcium, exacerbated by environmental stresses [15]. The variation in Ss susceptibility (from 33.33% slight to 22.22% severe) indicates a clear genetic component in the ability to withstand high light intensity and UV radiation. This aligns with research demonstrating cultivar-specific thresholds for photo-oxidative damage [29, 30]. Tolerance mechanisms could include differences in canopy

architecture (leaf attitude and foliage density) and fruit pigmentation. The high-altitude site, Gambella Tare (2697 m.a.s.l.), with its higher UV radiation and lower temperatures, likely exacerbated the expression of sunscald and other stress-related disorders in susceptible genotypes, highlighting the importance of screening germplasm under target environments [37].

The observed variation in radial cracking (55.55% slight, 22.22% severe) is another key finding, as cracked fruits are unmarketable. Cracking susceptibility is influenced by fruit cuticle properties, cell wall elasticity, and water uptake dynamics [16, 31]. The strong negative genotypic correlation we observed between number of fruit sets per plant (NFSP) and fruit pericarp thickness (FPTH, rg = -0.775) suggests a potential trade-off. Genotypes that set many fruits may allocate fewer resources to pericarp development, leading to thinner skins and potentially higher crack susceptibility. This highlights the need for balanced selection, where yield components are improved without compromising fruit integrity. For example, 'Melka-salsa', while producing the highest number of fruits per plant (50.6), exhibited thinner pericarp (3.4 mm) and may be more susceptible to cracking, whereas 'Cochoro', with moderate fruit set (30.9), had the thickest pericarp (6 mm) and firmer fruits, demonstrating this trade-off [37].

Functional Significance of Leaf Morphological Diversity

The observed variation in leaf morphology (type, attitude, density) extends beyond taxonomic interest, having functional implications for crop performance. The prevalence of drooping leaf attitude (44.44%) and sparse foliage density (44.44%) in our study could represent adaptive strategies. For instance, drooping leaves might be a response to reduce exposure to excessive solar radiation, mitigating heat and light stress [32]. Similarly, a sparse canopy can improve air circulation, reducing the risk of foliar diseases like early blight or powdery mildew in humid environments, while a dense canopy might be advantageous in arid regions for conserving soil moisture and suppressing weeds [33]. The absence of the "standard" leaf type and the presence of rarer types like *Peruvianum* and *Hirsutum* underscore the unique genetic resources present in this collection, which could harbor alleles for pest or disease resistance [19]. The diversity in leaf morphology observed in this study (potato, dwarf, Peruvianum, Pimpinellifolium, Hirsutum) represents a valuable genetic resource for breeding programs targeting improved canopy architecture, light interception, and stress adaptation [37].

Implications for Breeding and Germplasm Conservation

Our comprehensive characterization provides a clear roadmap for leveraging this diversity. For immediate agronomic use, 'Cochoro' emerges as the top candidate for high marketable yield, while 'Melka-salsa' is recommended for superior fruit quality (e.g., high ascorbic acid, cylindrical shape for processing). Previous research supports these recommendations, demonstrating that 'Cochoro' consistently produced the highest marketable yields across both low-altitude (Bako Tibe: 91.5 t ha^{-1}) and high-altitude (Gambella Tare: 84.3 t ha^{-1}) sites, while 'Melka-salsa' exhibited the highest ascorbic acid content (26.30 mg/100g) [37]. For long-term genetic improvement, the identified diversity serves as a foundation for:

1. **Targeted Crossing:** Genotypes with complementary traits can be selected as parents. For example, crossing a high-yielding but stress-susceptible genotype with a stress-tolerant one (e.g., a genotype showing low Ss and BR) could produce segregating populations for selecting resilient, high-yielding lines.
2. **QTL Mapping:** The clear phenotypic variation for traits like fruit shape, cracking, and sunscald makes this germplasm suitable for genome-wide association studies (GWAS) to identify the underlying quantitative trait loci (QTLs) and develop molecular markers for marker-assisted selection (MAS) [34,35].
3. **Germplasm Conservation:** The presence of rare phenotypes (e.g., *Hirsutum* leaf type, ellipsoid fruit shape) highlights the urgency of systematically conserving these genotypes in gene banks, as they represent a unique and irreplaceable pool of alleles for future breeding needs [36].

Conclusion

This study provides a robust, field-based assessment of morphological diversity in a panel of tomato genotypes, revealing significant and exploitable variation in fruit and leaf traits, as well as in susceptibility to abiotic stress-related disorders. Fruit morphology (shape, shoulder, cross-section) proved to be highly effective for cultivar differentiation. The genotype-dependent prevalence of blotchy ripening, sunscald, and radial cracking provides a valuable foundation for breeding programs aimed at enhancing stress resilience. The identification of 'Cochoro' as a high-yielding genotype and 'Melka-salsa' as a quality-focused genotype offers immediate options for producers and breeders. The substantial diversity observed, including rare leaf types and fruit shapes, underscores the importance of conserving this germplasm. This work reinforces the enduring value of systematic morphological characterization as a cornerstone of modern, climate-smart tomato breeding programs.

Declarations

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CRediT Authorship Contribution Statement

Usman Mohammed Ali: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Visualization, Project Administration.

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