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Morphological traits of fruits and seeds of *Ziziphus* tree species growing in different land uses in Ethiopia

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ABSTRACT

The practice of gathering and utilizing Ziziphus tree fruits serves as a key strategy to enhance nutrition and livelihoods employed by rural communities across various regions worldwide. Despite a burgeoning interest in and comprehension of their significance, there remains a dearth of information concerning the morphological attributes of both fruits and seeds essential for bolstering resistance against pests and diseases through breeding efforts. In this regard, comprehensive data pertaining to fruit dimensions (length, width, weight, and maturity level) and seed characteristics (length, width, and 100-seed weight) across three distinct land use types (LUT)—farmland (FL), home garden (HG), and roadside (RS)—were systematically gathered to ascertain the variability in traits among *Ziziphus* tree species in the Bosset and Bati districts of Ethiopia. Significant disparities in fruit and seed morphological traits were evident among different populations inhabiting the aforementioned LUTs. Notably, the most substantial mean measurements for fruit length (16 mm), width (18 mm), and weight (28 g), as well as seed width (6 mm), were documented within the farmland setting of Bosset. The highest mean seed length (7 mm) and 100-seed weight (5 g) were observed within farmland and home garden environments in Bati. Furthermore, a significant and positive correlation was determined between fruit length and width ($r = 0.78$), alongside the weight of ten fruits and width ($r = 0.65$). Ffruit maturity levels exhibited a negative correlation with weight but not with length and width dimensions. Similarly, seed length and width demonstrated a significant correlation ($r = 0.88$), while 100-seed weight exhibited a modest correlation with seed dimensions. Overall, findings suggest that the Bosset district boasts superior morphological traits, thereby indicating its potential for harboring robust stands and candidate trees conducive to selection for breeding programs aimed at enhancing resistance against insect pests and diseases.

1. Introduction

The collection and utilization of fruit trees stand as integral components within the multifaceted livelihood strategies upheld by

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rural households across diverse regions globally [1,2]. For generations, communities residing in or adjacent to forests have relied upon the gathering and utilization of indigenous fruit trees (IFTs) alongside other forest resources [3]. Even amidst droughts and crop failures, these trees serve as vital resources, offering emergency sustenance and serving as coping mechanisms, particularly among rural populations, especially the impoverished, to alleviate hunger and generate income [3,4]. Presently, with an increasing appreciation and comprehension of their intrinsic worth, these resources are garnering more attention than ever before [1,5,6].

In Ethiopia, numerous IFTs, including Ziziphus trees, significantly contribute to the food and nutrition security, as well as the health and economic well-being, of rural communities [7–12]. Flourishing in arid and semi-arid regions, *Ziziphus* tree species serve various purposes, predominantly catering to the needs of rural inhabitants. Fruit pulp finds extensive consumption and market demand, whether as fresh produce, dried fruits, or processed into juices, jams, and assorted products [13]. Communities discern fruits based on their size (large and small), color (yellow and red), and flavor (sour and sweet) [4]. Environmental and genetic variations contribute to the morphological diversity observed in these fruits [14–16].

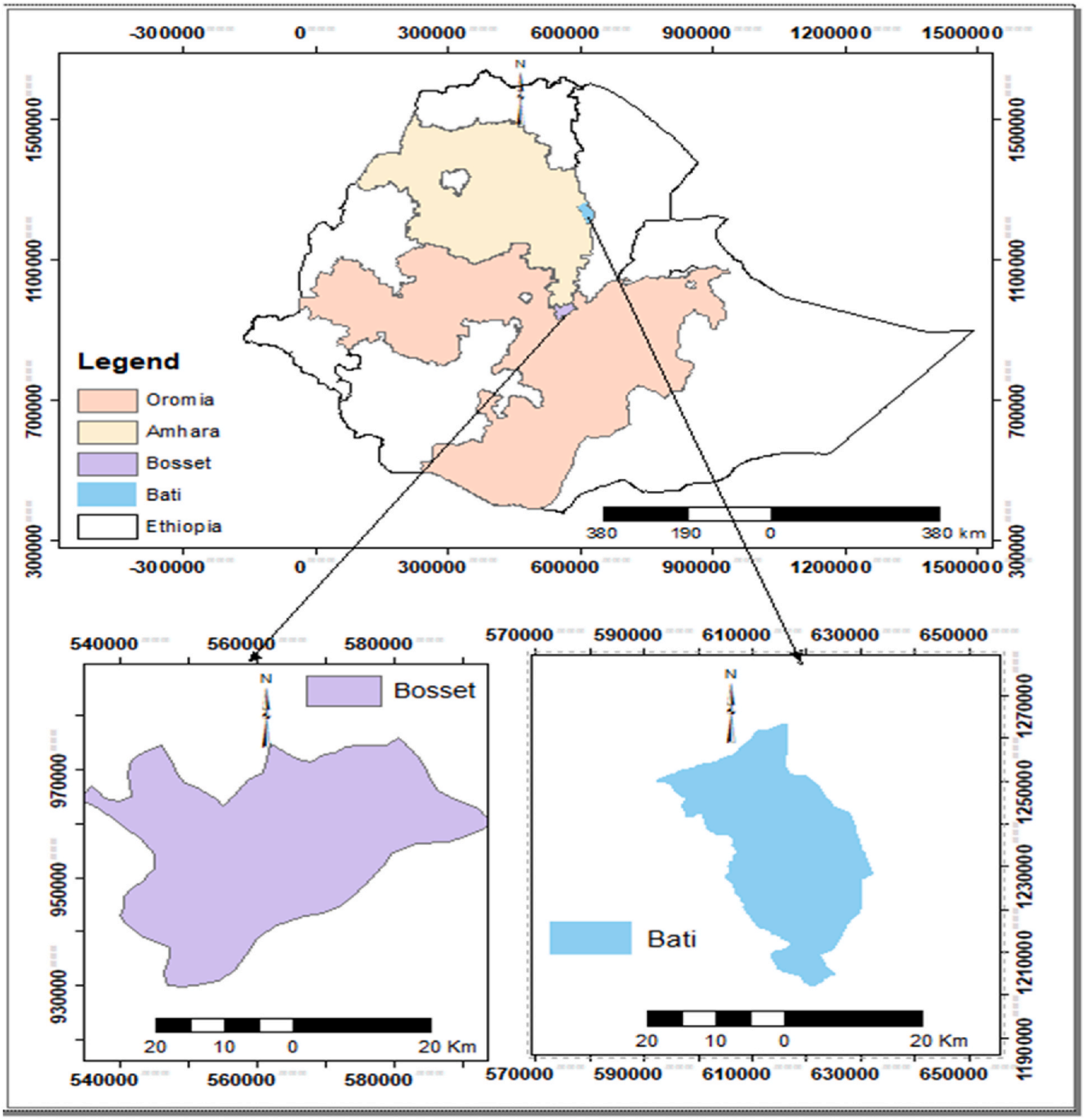

Fig. 1. Location map of the study sites in Ethiopia.

Ziziphus species hold a prime position among the fruit trees prioritised for agroforestry endeavours and are frequently earmarked for domestication across tropical and subtropical nations [17]. When managed adeptly, they wield considerable potential to enhance the livelihoods of communities, particularly those grappling with poverty. Consequently, the conservation and promotion of efficacious harvesting and utilization practices related to *Ziziphus* species assume paramount importance, offering manifold benefits to local populations [18].

Moreover, enhancing production through selective breeding aimed at bolstering resistance against insect pests and diseases [18] emerges as a pivotal and prominent strategy for realising the aforementioned advantages. Additionally, the meticulous selection of optimal candidate trees stands as a prerequisite for the successful execution of domestication initiatives targeting these socioeconomically significant tree species [1,19].

However, prior to embarking on endeavours related to breeding for disease and pest resistance, and domestication, a thorough understanding of fruit and seed morphological traits is indispensable [16,20,21]. While the ecological, environmental, and socioeconomic benefits of *Ziziphus* tree species have been documented in studies exploring woody species diversity in Ethiopia [5,7–12], crucial information regarding fruit and seed morphological traits, pivotal for identifying optimal candidate trees for breeding resistance against insect pests and diseases, remains elusive in the Ethiopian context. Hence, identifying land use types (LUTs) harboring superior candidate trees assumes significance, facilitating the selection of premium fruits and seeds for breeding programmes aimed at enhancing resistance against insect pests and diseases, thereby ensuring enhanced utilization and production of *Ziziphus* fruits by local communities.

The imperative to furnish comprehensive insights into *Ziziphus* tree species, coupled with the nation's commitment to augmenting the production of Indigenous Fruit Trees (IFTs), including *Ziziphus* species, underscores the necessity for conducting this study. Herein, we scrutinise the variability in morphological traits of fruits and seeds of *Ziziphus* species thriving naturally across diverse LUTs, namely farmland (FL), home garden (HG), and roadside (RS), within Ethiopia.

2. Materials and methods

2.1. Study sites

The study was conducted in three land use types in Bosset and Bati districts located in Oromia and Amhara Regional States, Ethiopia (Fig. 1; Table 1).

Bosset district falls within three major agro-climatic zones (highlands 1 %, Midlands 20 % and lowlands 79 %) and Bati district falls within two major agro-climatic zones (Midlands, 19 % and the Lowlands 81 %). Meteorological data recorded at Mojo station taken from Addis Ababa National Meteorology Service Agency indicates that Bosset received high rainfall amount between June to August and low rainfall amount from March to May, and the dry season extends from September to February. Similarly, Bati receives high rainfall amount between June to August and low rainfall amount in March and April, and the dry season extends from September to February.

2.2. Sampling

To identify potential land-use types where *Ziziphus* species grow, a reconnaissance field survey, discussions with Zonal natural resource experts and field visits were conducted in North Omo Zone, Konso Zone, East Shewa Zone, Oromia Special Zone and South Wollo Zones, Ethiopia. Thereafter, a three-stage stratified purposive sampling technique was employed to select LUTs. Accordingly, in the first stage, two zones (the East Shewa zone of the Oromia regional state and the Oromia special zone of the Amhara regional state), were selected purposively because of the presence of *Ziziphus* species trees. As a second stage, two suitable districts (Bosset from East Shewa Zone and Bati district of Oromia Special Administrative Zone), were selected. In the third stage, three representative LUTs; FL, HG and RS were selected purposively based on the availability of *Ziziphus* trees from each district.

2.3. Data collection

Six transect lines were established in total, with three lines per district. Each transect line spanned 1 km in length, with plots situated 100 m apart, resulting in 10 plots sampled per transect within each land use type. Transect lines were systematically laid out [22,23] to facilitate data collection. In total, 60 sample plots were surveyed, with 30 plots sampled per district. In each of the sample plots, the individual tree was treated as an independent plot in this study. Within each 10 × 10 m plot, trees were randomly sampled for the collection of fruit and seed traits. Based on this, a total of 60 trees (10 trees from three LUTs from the two districts) were sampled

Table 1
Location and climate of study Districts in Ethiopia.

District	Altitude (m.a.s.l.)	Latitude	Longitude	Rainfall (mm)	Temperature (°C)	Soil type
Bosset	1400–2500	*8° 34′ 59″N*	*39° 28′ 59″ E*	600–900	26–34	Vertisols (heavy clay soils), alluvial (loamy soil to silt clays), cambisol
Bati	1800–2200	11°11′N	40°1′E	550–780	23–30	Sand clay loam, clay, sandy loam, Luvisol, Vertisols

[24].

Fruit collection involved the use of a long stick to shake branches, a conventional method employed across both districts. Care was taken to gather only intact, mature fruits, while small-sized immature fruits, those showing signs of premature drying, and those with damaged pulp were conscientiously avoided [25]. Subsequently, from each color category denoting different stages of fruit maturity (red, yellow, and green), a random selection of 10 fruits was made for the measurement of length, width, and weight per fruit. For seed trait analysis, 75 fruits per tree were randomly chosen and transported to the Forest Pathology and Entomology Laboratory of the Ethiopian Forest Development in Addis Ababa. There, the fruits underwent a drying process in an oven set at 60 °C for 72 h until complete desiccation [26,27]. Following drying, the hard seed coats were carefully opened to record the number of seeds per fruit and measure their length, width, and 100-seed weight. Fruit weights (measured in the field) and seed weights (measured in the laboratory) were determined using a digital balance, while length and width measurements were conducted with an electronic digital caliper.

2.4. Data analysis

A descriptive analysis of morphological variables such as the mean, standard deviation, and minimum and maximum values was conducted. One-way Analysis of Variance (ANOVA) was performed to analyse variations in fruit and seed morphological traits among the studied LUTs. Before ANOVA, normal distributions of the data sets were checked using the Shapiro-Wilk test, and it was considered significant at $P \leq 0.05$. The fruit length data in the Bati district was transformed into log values to reduce skewness and improve homoscedasticity, as they were not normally distributed at $\boldsymbol{\alpha} = 0.01$. Significant means were compared using Tukey's Honestly Significant Difference (Tukey's HSD) post hoc test at $P \leq 0.01$. Pearson's correlation coefficient (r) was used to evaluate the relationships between different fruit and seed morphological traits. All the analyses were conducted with the help of R free software version 4.3.2 [28].

3. Result

3.1. Fruit traits variation among LUTs

Fruit morphological traits varied ($P < 0.01$) among the populations in the three LUTs within and among the two districts (Table 2). The negative correlation of fruit maturity levels with weight indicated that fruit weight decreased as the fruits matured (Table 3).

3.2. Seed variation among LUTs

Seed morphological traits varied significantly ($P < 0.01$) among the populations in the three LUT within and among the two study districts (Table 4).

A significant and positive correlation in seed traits was observed, which could be crucial for conducting further studies such as domestication studies and fruit genetic improvement (Table 5).

Table 2
Variation in fruit morphological traits of *Ziziphus* fruits in the three LUTs.

District	Trait	LUTs	Mean ± SE	SD	CV	Min.	Max.	*P*-value
Bosset	Fruit Length (mm)	HG	15.5(±0.2)^{a}	1.8	2.2	11.9	19.0	0.027
		FL	16(±0.1)^{a}	1.1	3.3	11.9	19.4	
		RS	14.6±(0.2)^{b}	1.3	22.4	8.9	18.5	
	Fruit width (mm)	HG	17.3±(0.2)^{a}	1.5	1.8	12.1	20.6	0.012
		FL	17.7±(0.2)^{a}	1.6	2.4	14.1	21.3	
		RS	16.1(±0.2)^{b}	1.8	8.0	9.0	19.7	
	Fruit weight of ten fruits (g)	HG	28.5(±1.6)^{a}	4.9	2.3	19	35	0.367
		FL	28.5(±0.9)^{a}	2.7	3.1	25	33	
		RS	23.4(±1.0)^{b}	2.9	9.2	20	29	
Bati	Fruit Length (mm)	HG	14.2(±0.2)^{b}	1.9	3.6	8.9	19.2	0.01
		FL	14.4(±0.1)^{ab}	1.4	2.0	11.1	18.1	
		RS	14.8(±0.1)^{a}	1.4	2.0	10.5	18.7	
	Fruit width (mm)	HG	15.3(±2.0)^{b}	2.0	3.9	9.0	20.9	0.004
		FL	15.8(±1.7)^{b}	1.7	2.7	12.7	19.6	
		RS	16.3(±1.6)^{a}	1.6	2.7	11.3	20.3	
	Fruit weight of ten fruits (g)	HG	21.2(±1.4)^{b}	4.6	20.8	15	29	0.731
		FL	20.9(±1.3)^{b}	4.0	15.9	14	26	
		RS	22.3(±1.2)^{a}	3.8	14.7	18	29	

Means followed by a common letter in the same column, within each trait and district are not significantly different at $P < 0.01$, Tukey's HSD Test. SE: standard error of the mean, CV: Coefficient of variation, Min: minimum, Max: maximum. LUTs: Land use types, HG: Home garden, FL: Farm land, RS: Roadside.

Table 3
Pearson correlation coefficients for fruit morphological traits.

Fruit trait	Length (mm)	Width (mm)	weight of 10 fruits (g)
Width (mm)	0.788[a]		
weight of 10 fruits (g)	0.532[a]	0.645[a]	
Maturity level (colours)	0.024	0.011	−0.019

[a] - Significant at $P < 0.01$.

Table 4
Variation in seed morphological traits of *Ziziphus* fruits in the three LUTs.

District	Traits	LUTs	Mean ± SE	SD	CV	Min.	Max.	P-value
Bosset	Seed length (mm)	FL	6.15(±0.06)	0.71	0.502	4.24	7.3	0.19
		HG	6.27(±0.07)	0.79	0.623	4.44	7.57	
		RS	6.36(±0.07)	0.77	0.591	4.43	7.47	
	Seed width (mm)	FL	5.32(±0.06)[b]	0.62	0.378	4.14	6.63	0.005
		HG	5.48(±0.07)[ab]	0.79	0.63	3.54	7.02	
		RS	5.56(±0.06)[a]	0.72	0.525	3.68	7.02	
	100 seeds weight (g)	FL	44.13(±1.91)	4.69	21.96	39.5	52.64	0.541
		HG	45.11(±1.80)	4.03	16.29	39.87	50.73	
		RS	43.55(±0.95)	2.14	4.56	40.28	45.45	
Bati	Seed length (mm)	FL	6.55(±0.06)[a]	0.66	0.43	5.05	7.95	0.001
		HG	6.53(±0.07)[a]	0.77	0.6	4.46	7.95	
		RS	6.25(±0.08)[b]	0.92	0.64	4.43	7.78	
	Seed width (mm)	FL	5.92(±0.05)[a]	0.59	0.34	4.78	7.24	0.006
		HG	5.84(±0.07)[a]	0.73	0.54	4.12	7.03	
		RS	5.49(±0.07)[b]	0.81	0.54	4.02	7.03	
	100 seed weight (g)	FL	44.65(±1.91)	0.01	18.28	39.86	51.3	0.17
		HG	45.51(±2.21)	0.01	24.59	40.93	53.26	
		RS	42.09(±0.69)	0.00	15.19	39.52	43.37	

Means followed by a common letter in the same column, within each trait and district are not significantly different at $P < 0.01$, Tukey's HSD Test. SE: standard error of the mean, CV: Coefficient of variation, Min: minimum, Max: maximum. LUTs: Land use types, HG: Home garden, FL: Farm land, RS: Roadside.

Table 5
Pearson correlation coefficients for seed morphological traits of *Ziziphus* fruit.

Seed morphological traits	Length (mm)	Width (mg)	Weight (mg)
Width (mm)	0.879[a]		
Weight (mg)	0.624[a]	0.648[a]	
100 seeds weight (mg)	0.094	0.169	0.158

[a] - Significant at $P < 0.01$.

4. Discussions

4.1. Fruit and seed morphological traits

4.1.1. Fruit traits

Fruits collected from the three distinct LUTs in Bosset exhibited higher overall mean values for all parameters compared to those in Bati. Notably, farmland and home gardens yielded larger and wider fruits than those from roadside areas, a variance likely attributable to diverse factors such as soil fertility and management practices. The significant and positive correlation observed among morphometric traits across LUTs provides valuable insights, enabling the prediction of other traits based on one, particularly beneficial during periods of - time and financial constraints [25]. It is anticipated that there would be a strong correlation between length, width, and weight, given that larger fruits typically possess greater mass.

In terms of mean fruit dimensions, variations were evident among LUTs in both districts, with Bosset showcasing a higher mean fruit length than Bati. However, it's noteworthy that the mean fruit length reported in this study was smaller than that documented in Ukraine for *Z. mauritiana* (ranging from 31.21 to 45.33 mm) and fell within the range of fruit lengths observed for *Z. spina-christi* (11.16–17.72 mm) [29]. Similarly, the mean fruit width in the current study (15.82 mm in Bati and 17.06 mm in Bosset) was smaller than the width range recorded for *Ziziphus mauritiana* (26.45–39.61 mm), while it fell within the width range for *Z. spina-christi* (11.88–18.43 mm) and *Z. jujube* (16.66–35.60 mm) [30,31].

In the present study, the overall mean fruit weight (26.63 g in Bosset and 21.47 g in Bati) exceeded the reported weight range for other *Ziziphus* fruits, such as *Z. jujube*, which ranges from 2.52 to 19.37 g [30], and the mean weight of *Z. mauritiana* at 0.47 g [18].

Moreover, the mean weight observed in this study falls within the weight range of both *Z. mauritiana* and *Z. jujube* (which weighs between 9 and 37 g) and surpasses the weight range of *Z. spina-christi* (between 0.5 and 0.7g) [31]. The variations in fruit morphological traits can be attributed to a range of factors including geography, climate, ecology, cross-pollination, natural hybridization, gene flow within the same species, and human intervention [20,26,29,32,33].

4.1.2. Seed traits

In all LUTs, two seeds per fruit were consistently observed. However, there were variations in seed morphological traits among the three LUTs. Notably, seed width in Bosset and both seed length and width in Bati exhibited differences across the LUTs, while 100-seed weights did not vary significantly in either district. The overall mean seed lengths were 6.44 mm and 6.26 mm, and the overall mean widths were 5.45 mm and 5.15 mm in Bosset and Bati, respectively. Similarly, akin to fruit traits, higher seed trait values were also recorded across all three LUTs in the Bosset district. Correlation analysis revealed a significant and positive correlation among seed morphological traits. Just like fruits, seed traits are among the most crucial characteristics [34], and it is imperative to consider them during tree selection for domestication and tree improvement [25].

5. Conclusions and recommendations

Variations in fruit and seed morphological traits were observed among populations across the three LUTs. Fruits collected from the LUTs in Bosset exhibited consistently higher overall mean values across all parameters compared to those from Bati. Notably, larger fruit lengths and widths were obtained from FL and HG, while a significant and robust correlation was noted among fruit and seed morphometric traits. Interestingly, fruit length, width, and weight showed no correlation with fruit maturity stages (color types), indicating that fruit can mature regardless of their dimensions. Thus, it can be inferred that substantial morphological diversity exists among fruit and seed traits within and among the LUTs in the districts, likely influenced by a multitude of biotic and abiotic factors including variations in geography, climate, ecology, human interventions, cross-pollination, natural hybridization, seed propagation, and gene flow within the same species. The pronounced variation in fruit and seed morphology among the different LUTs underscores the necessity for further research aimed at enhancing utilization and fruit size, especially given their smaller size compared to other *Ziziphus* species reported from various countries. In conclusion, to facilitate widespread distribution and maximize utilization through domestication and large-scale plantations, future studies should prioritize breeding for resistance against diseases and pests, as well as genetic improvement of the fruits.

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Submission declaration

This study has not been published previously and is not under consideration for publication elsewhere.

Data availability statement

Data will be made available upon reasonable request from the corresponding author. The data associated with the study will be deposited into a publicly available repository upon request.

CRediT authorship contribution statement

Tigabu R. Alle: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Samora M. Andrew:** Writing – review & editing, Supervision. **Miriam F. Karlsson:** Writing – review & editing, Supervision. **Abdella Gure:** Writing – review & editing, Supervision.

Declaration of competing interest

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

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