

Research Article

Performance evaluation of groundnut (*Arachis hypogaea* L.) varieties for grain yield and yield-related traits at Fogera district, northwestern Ethiopia

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Abstract - Groundnut (*Arachis hypogaea* L.) is a key oilseed and food crop in Ethiopia, but productivity remains below potential due to low-yielding varieties, suboptimal management, and environmental stresses. This study evaluated the performance of improved groundnut varieties in terms of phenology, growth, and yield traits to identify promising genotypes for northwestern Ethiopia. Field experiments were conducted in Fogera District during the 2022 and 2023 main cropping seasons using a randomized complete block design with three replications. Data on phenological, growth, and yield traits were analyzed using combined ANOVA, correlation analysis, and mean performance comparisons. Significant variation ($P \leq 0.01$) was observed among varieties for most traits, including days to maturity, plant height, number of primary branches, seeds per pod, biomass yield, pod yield, harvest index, unshelled yield, and hundred-grain weight, while shelling percentage showed a non-significant difference. Pod yield ranged from 1,208.7 kg ha⁻¹ (Senaf) to 3,221.6 kg ha⁻¹ (Werer961), with Babile4 and BaHaGudo also showing above-average yields combined with high biomass. Harvest index varied from 28.1% (Bulki01) to 59.1% (Babile 4). Correlation analysis indicated that days to maturity were positively associated with plant height and biomass yield but negatively correlated with harvest index, while pod yield was moderately correlated with harvest index and strongly with

unshelled yield. The study revealed substantial genetic variability and identified Werer961, Babile2, and Derib as promising varieties for improving groundnut productivity in northwestern Ethiopia.

Keywords: Groundnut, pod yield, yield-related traits, genetic variability, adaptability

1. Introduction

Groundnut (*Arachis hypogaea* L.), a tetraploid species ($2n = 4x = 40$), is an important global legume crop that originated in South America and is now widely cultivated in tropical and subtropical regions (Radhakrishnan et al., 2022; Jivani, 2022). Groundnuts are grown on more than 28 million hectares with an average yield of 1.8 t ha^{-1} , and they supply around 30% of the world's edible oil and 20% of the daily protein needs in underdeveloped nations (Khan et al., 2021a; Arya et al., 2016). The major producers, accounting for a substantial portion of global output, are China, India, and Nigeria (Tadesse & Nepir, 2024; United States Department of Agriculture, Foreign Agricultural Service, 2024). It is planted on more than 87,616 hectares in Ethiopia, with the yielding 144,525 tons of pods with an average productivity of 1.65 t ha^{-1} (Khan et al., 2021a; Tadesse & Nepir, 2024).

Groundnut is a significant food and oilseed crop in Ethiopia that is mostly grown in lowland regions under rain-fed conditions. It is rich in minerals needed to form bones due to the presence of calcium, magnesium, and phosphorus, and also very good for human health and would probably prevent high blood pressure because the sodium-potassium ratio is less than one, which is very important in the body for the prevention of high blood pressure (Desire et al., 2021; Galani et al., 2022). Despite its importance, the potential yield of improved varieties ($>2.5 \text{ t ha}^{-1}$) and national groundnut production still differ by more than 0.85 t ha^{-1} . This discrepancy demonstrates how productivity could be raised by employing

high-yielding varieties and better agronomic practices.

To overcome these limitations, a study on the adaptation of groundnut varieties was carried out in the Fogera district, northwest Ethiopia. The performance and adaptability of improved groundnut varieties under regional environmental circumstances are assessed through field trials. Ethiopian groundnut productivity is limited by a number of variables. These include the widespread use of low-yielding varieties, restricted availability to high-quality seeds, suboptimal agronomic techniques, and vulnerability to both biotic (diseases and insect pests) and abiotic (drought, irregular rainfall, and extreme temperatures) (Tadesse & Nepir, 2024; Mesfin et al., 2016).

Additionally, farmers lack knowledge about the benefits of modern management practices and better varieties. These variables need to be addressed to ensure sustainable groundnut production and close the productivity gap (Tadesse & Nepir, 2024; Gelaye & Luo, 2024; Sime, 2018). To overcome these constraints, focused research is required to evaluate stable and productive groundnut varieties in Ethiopia's distinct agro-ecological zones (Wondaferew et al., 2024; Abady et al., 2019b). Therefore, the objective of this study was to evaluate enhanced groundnut varieties' growth, yield, and adaptation in the Fogera district, northwest Ethiopia. It is anticipated that the results would help to identify and suggest varieties that enhance food security, increase productivity, and improve smallholder farmers' lives in Ethiopia's appropriate production zones.

2. Materials and methods

2.1 Description of experimental site

The experiment was conducted at Fogera district, northwestern Ethiopia,

for two consecutive cropping seasons, 2022 and 2023. The description of the experimental location is presented in Table 1.

Table 1. Description of the experimental locations.

Location	Altitude (m. a. s. l)	Geographical Location	Geographical Location	weather data	weather data	Soil type
		Latitude	Longitude	Rainfall (mm)	Temperature (°C)	Black clay soil
Fogera district	1806.4	110 56 59 °N	37 34 59 °E	1730	21.6	Black clay soil

Note: Source = Climatic and edaphic information was obtained from their respective Fogera district administrative office.

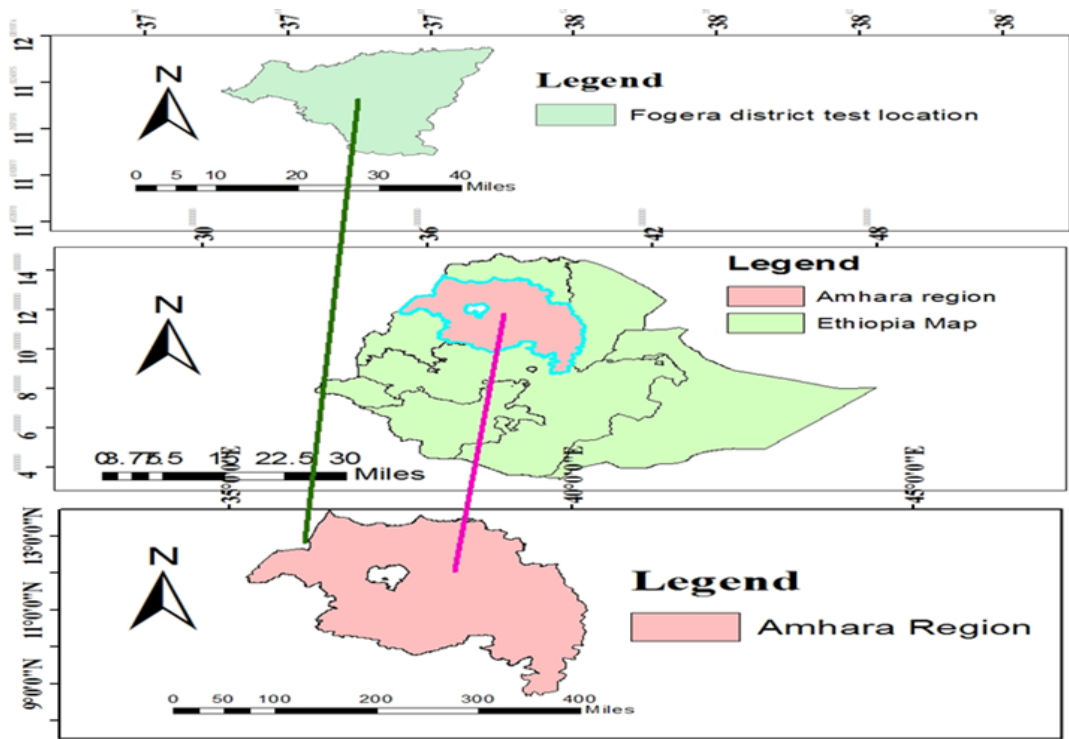


Figure 1. Mapping of the study area.

2.2 Experimental materials

The planting materials were initially obtained from Haramaya University,

Ethiopia. Wondaferew et al. (2024) evaluated groundnut varieties, which are presented in Table 2.

Table 2. Released groundnut varieties used for field evaluation.

Variety	Pedigree	Productivity in the research area (ton/ha)	Released center
Babile1	ICGV-98412	2.4	HU
Roba	ICG-7794	6.8	WARC
Senaf	ICG-9097	1.7-2.4	BARC
Shulamit	NA	5.8	ARC/EIAR
Werer961	ICGV-87108	5.5	WARC
Babile2	ICGV-98404	2.002	HU, PARC and WARC
Babile4	ICGV-95469	1.86	PARC
Babile5	ICG67XBIG SEED	2.1	HU
BaHa Gudo	ICGV-88357	1.97	HU
BaHa Jidu	NC-AC-2748 X CHIO	2.02	HU
Bulki01	ICGV-88424	6.5	WARC
Derib	ICGV-97164	2.2	Assosa and Pawe ARC
Milkaye	PI-158850	2.2	MARC

Note: Source: [Ethiopian Agriculture Authority \(2022\)](#), and the Amara Regional Research Office (ARAR) and Ethiopian Institute of Agricultural Research (EIAR). Where: Alt: altitude, m. a. s. l: meter above sea level, RF: rainfall, long: Longitude, lati: Latitude, NA=not available, WARC= Werer agricultural research center, HU=Haromaya university and MARC=Mechera agricultural research center.

2.3 Experimental design and crop management

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each groundnut variety was planted in five rows, each 2 m in length, with a spacing of 60 cm between rows and 10 cm between planting holes. Two seeds were sown per hole and later thinned to one plant per hole two weeks after emergence. The gross plot size was 6 m², while the net harvested plot area was 3.6 m², consisting of the three central rows, each measuring 2 m in length, to minimize border effects. Weeding was carried out manually twice per growing season. All other agronomic practices, including planting, fertilizer application, and crop protection measures, were conducted in accordance with the recommendations of the Ethiopian National Agricultural Research System.

2.4 Data collection and trait measurement

Data were collected on both plot- and plant-basis for ten agronomic and yield-related traits. Plot-based data were recorded from all plants grown in the central rows of each plot, excluding one border row on each side to minimize border effects. Plant-based data were collected from five randomly selected plants taken from the central rows of each plot, and the mean values of these samples were used for statistical analysis. The traits days to 90% maturity, pod yield, hundred-grain weight, biomass yield, unshelled yield, shelling percentage, and harvest index were recorded on a plot basis. In contrast, plant height, number of primary branches, number of pods per plant, and number of seeds per pod were recorded on a plant basis. The mean values of the five randomly sampled

plants were used to estimate the performance of each variety and for the analysis of individual traits within each plot.

2.4.1 Trait descriptions

Days to 90% maturity: Recorded as the number of days from sowing to physiological maturity, when approximately 90% of plants in a plot exhibited light-yellow coloration of stems, leaves, and floral branches. **Plant height (cm):** Measured from the ground level to the tip of the main stem from ten randomly selected plants in the central rows of each plot, and the average value was calculated. **Number of primary branches per plant:** Counted from five representative plants per plot, and the mean number of primary branches was computed. **Number of pods per plant:** Determined by counting the total number of pods from the five sampled plants and calculating the average. **Number of seeds per pod:** Estimated by randomly selecting ten pods from the sampled plants, counting the number of seeds per pod, and calculating the mean value. **Biomass yield (kg ha⁻¹):** Aboveground biomass was harvested from the net plot area, sun-dried to a constant weight, and converted to kilograms per hectare. **Pod yield (kg ha⁻¹):** The weight of air-dried pods harvested from the net plot area was recorded and converted to kilograms per hectare. **Unshelled yield (kg ha⁻¹):** Total weight of grains obtained after shelling the harvested pods, expressed on a hectare basis. **Shelling percentage (%):** Calculated as the ratio of unshelled (grain) yield to pod yield, expressed as a percentage:

Shelling percentage (%)

$$= \frac{\text{Unshelled yield}}{\text{Pod yield}} \times 100$$

Harvest index (%): Computed as the ratio of pod yield to total biomass yield, expressed as a percentage:

$$\text{Harvest index (\%)} = \frac{\text{Pod yield}}{\text{Biomass yield}} \times 100$$

2.5 Statistical analysis

Prior to conducting the combined analysis, homogeneity of error variances across years was tested for each trait using Levene's test. Since the variances were homogeneous, a combined analysis of variance (ANOVA) across years was performed using a linear mixed model approach. The statistical model used for the combined ANOVA was:

$$Y_{ijk} = \mu + g_i + e_j + b_{k(j)} + (ge)_{ij} + \varepsilon_{ijk}$$

where:

Y_{ijk} = observed value of a trait for the i^{th} variety grown in the k^{th} block of the j^{th} year,

μ = overall (grand) mean,

g_i = effect of the i^{th} variety,

e_j = effect of the j^{th} year,

$b_{k(j)}$ = effect of the k^{th} block (replication) nested within the j^{th} year,

$(ge)_{ij}$ = interaction effect between the i^{th} variety and the j^{th} year,

ε_{ijk} = random error associated with the observation.

In the mixed model, varieties were considered as fixed effects, while years, blocks within years, and error terms were treated as random effects. All measured quantitative traits were subjected to analysis of variance using R software (version 4.4.2) to assess the significance of differences among varieties. When significant differences were detected, mean separation was performed using the Least Significant Difference (LSD) test at the 5% probability level

3. Results and discussion

3.1 Combined analysis of variance

The combined analysis of variance revealed highly significant ($P \leq 0.01$) differences among groundnut varieties for days to maturity, number of primary branches, plant height, seeds per pod, biomass yield, pod yield, harvest index, unshelled yield, and hundred-grain weight (Table 3), indicating the presence of substantial genetic variability for these

traits. Such variability provides opportunities for selection and genetic improvement of groundnut varieties across different agro-ecological conditions.

The effect of year was also highly significant ($P \leq 0.01$) for days to maturity, plant height, biomass yield, pod yield, harvest index, and hundred-grain weight, demonstrating the influence of seasonal climatic variability, particularly rainfall and temperature, on crop growth and productivity. The variety $\times$ year interaction was highly significant ($P \leq 0.01$) for days to maturity, seeds per pod, biomass yield, pod yield, harvest index, and unshelled yield, indicating differential varietal responses across years. This suggests variation in adaptability among the evaluated varieties, with some showing broader adaptation and others performing better under specific environmental conditions (Williams et al., 2008; Eskezia et al., 2025). Similar results have been reported in earlier studies on groundnut, which documented significant genotype $\times$ environment interactions for yield and yield-related traits (Gelaye & Luo, 2024; Khan et al., 2021b; Yadawad & Bhat, 2025). The observed variability among varieties is consistent with reports by Çalışkan et

al. (2008) and Abady et al. (2021), who identified significant differences in days to maturity, plant height, and pod yield, and by Mekonnen (2024), who emphasized the importance of genetic variability for improving yield potential and adaptability through selection. However, contrasting findings have been reported by Abady et al. (2019a), who observed limited genetic variation among improved groundnut varieties in Ethiopia, likely due to the use of related parental lines in breeding programs. In addition, Nigussie et al. (2019), who indicated that variability observed under certain environments may be strongly influenced by environmental factors, particularly under rainfed conditions with variable rainfall. These findings underscore the importance of multi-year and multi-environment evaluations to distinguish genetic effects from environmental influences and to identify stable, high-performing groundnut varieties.

The coefficients of variation for most traits were within acceptable ranges, indicating satisfactory experimental precision and reliability of the results (Rashid et al., 2017; Habib et al., 2024).

Table 3. Mean squares from combined analysis of variance for yield and other traits of groundnut varieties evaluated over two years (2022 and 2023) at Fogera district.

SOV	Variety (V)	Year (Y)	V $\times$ Y	MSE
DF	12	1	12	48
DM	152.96**	14080.82**	106.79**	16.19
PRB	2.78**	31.09**	1.78ns	0.98
PH	33.65**	5276.75**	6.63ns	9.86
SPP	0.11**	0.93**	0.05*	0.025
BY	7835354.64**	289333697.82**	3881588.20**	577857.54
PY	2007958.23**	15362718.73**	928849.35**	181276.09
HI	810.83**	1563.55**	82.460**	29.46
USY	364938.83**	3854944.56**	270243.19**	109534.99
SHP	168.61ns	1.59ns	127.32ns	104.56
HGW	633.26**	8667.25**	117.25ns	71.44

Note: Sov =source of variation, ** = significant at 0.01, and * =0.05 probability levels, respectively and ns=non-significant difference, DF=degree of freedom, MSE= mean square error, DM=days to maturity, PRB=number of primary branches per plant, PH (cm)=plant height, SPP= number of seeds per pod, BY (kg ha⁻¹) =biomass yield, PY (kg ha⁻¹)=Pod yield, HI (%)=harvest index, USY (kg ha⁻¹) = unshelled seed -yield, SHP (%)=shelling percentage, HGW (g) =hundred grain-weight.

3.2 Phenological and growth traits

3.2.1 Days to maturity (DM)

Days to maturity of the evaluated groundnut varieties ranged from 147.5 days for Babile4 to 162.2 days for Shulamit, with a mean value of 155.7 days (Table 4), indicating the presence of both early- and late-maturing genotypes. This variation reflects differences in phenological development and provides options for adaptation across diverse agro-ecological conditions. Early-maturing varieties, such as Babile4 (147.5 days) and Milkaye (148.7 days), are suitable for environments with short growing periods or limited rainfall, as they can escape terminal drought stress. In contrast, late-maturing varieties, including Shulamit (162.2 days) and Senaf (162.0 days), are better suited to areas with longer growing seasons or supplemental irrigation, where extended moisture availability supports prolonged growth and development. These results agree with previous studies [Alemayehu et al. \(2025\)](#) and [Mengistu et al. \(2024\)](#), which reported that days to maturity is a key trait influencing groundnut adaptation and yield stability under Ethiopian conditions. However, other studies [Beebe et al. \(2008\)](#), have indicated that delayed maturity does not consistently result in higher yield, particularly in lowland areas where mid-season drought may limit crop performance.

3.2.2 Plant height (PH)

Plant height varied significantly among the evaluated groundnut varieties, ranging from 28.45 cm in Shulamit to 35.83 cm in Werer961, with a mean value of 31.95 cm (Table 4). This variation reflects differences in vegetative growth and adaptation among genotypes. Taller varieties, such as Werer961 (35.83 cm) and Derib (34.96 cm), may enhance light interception and biomass accumulation, potentially contributing to improved pod and biomass yields. In contrast, shorter varieties, including Shulamit (28.45 cm) and Senaf (28.67 cm), may be advantageous

under high plant density or mechanized production systems due to improved lodging resistance. These findings are consistent with earlier reports that documented significant genotypic variation in plant height among groundnut varieties grown in Ethiopia ([Mekonnen, 2024](#); [Bekele et al., 2023](#)). However, other studies have indicated that shorter genotypes may perform better under low-input conditions, highlighting the importance of matching plant architecture with specific production environments ([Bekele et al., 2023](#); [Berhanu et al., 2020](#)).

3.2.3 Number of primary branches per plant (PRB)

In the combined analysis, the number of primary branches per plant varied among the evaluated groundnut varieties, ranging from 5.03 in Milkaye to 7.40 in Bulki01, with a mean of 6.37 branches per plant (Table 4). This variation reflects genotypic differences in plant architecture and growth habit. Varieties such as Bulki01, Babile2, and Roba exhibited higher branching capacity, which may increase the number of pod-bearing sites and contribute to yield potential. In contrast, Milkaye and Babile4 produced fewer primary branches, possibly indicating adaptation to environments with limited resources. Similar variation in branching among groundnut varieties has been reported in earlier studies, where branching pattern was identified as an important contributor to yield component diversity ([Giayetto et al., 2013](#); [Ghodke, 2021](#)).

3.3 Yield-related traits

3.3.1 Pod yield (PY)

Pod yield varied markedly among the evaluated groundnut varieties, ranging from 1,208.7 kg ha⁻¹ in Senaf to 3,221.6 kg ha⁻¹ in Werer961, with a mean of 2,250.1 kg ha⁻¹ (Table 4). The highest-yielding variety, Werer961, demonstrated superior pod production, likely reflecting efficient assimilate partitioning. Other

high-performing varieties included Derib (2,775.6 kg ha⁻¹), Babile2 (2,712.8 kg ha⁻¹), and Babile1 (2,701.3 kg ha⁻¹), whereas Senaf and Shulamit recorded the lowest yields. In 2022, pod yield ranged from 1,090.2 kg ha⁻¹ (Milkaye) to 3,627.9 kg ha⁻¹ (Werer961), with top performance by Werer961, Babile2, and Babile4. In 2023, the highest pod yields were recorded for Derib (3,806.3 kg ha⁻¹), BaHaGudo (3,686.6 kg ha⁻¹), and Babile2 (3,066.7 kg ha⁻¹), while Bulki01 (1,768.1 kg ha⁻¹) and Senaf (1,280.6 kg ha⁻¹) remained the lowest. The observed variation indicates substantial genetic potential for pod yield improvement. These results are consistent with previous findings, which reported superior performance of derived genotypes under Ethiopian rainfed conditions (Tsegaye, 2023). However, pod yield expression is strongly influenced by environmental factors, emphasizing the importance of multi-location and multi-year evaluations to identify stable, high-performing varieties (Kumar et al., 2016). Varieties such as Babile2, Derib, and BaHaGudo performed consistently across years, suggesting broad adaptability to Fogera's agro-ecology. Observed differences are attributed to genotypic variation, soil fertility, and climatic factors, particularly rainfall distribution during critical growth stages. These results align with previous reports highlighting significant genotype × environment interactions in Ethiopian groundnut production (Kumar et al., 2016; McIlveen, 2025; Parvin, 2019; Tsegaye, 2023), confirming Werer961, Babile2, and Derib as promising candidates for yield improvement and production expansion in similar agro-ecological zones.

3.3.2 Biomass yield (BY)

Biomass yield of the evaluated groundnut varieties ranged from 3,667.3 kg ha⁻¹ in Milkaye to 7,579.9 kg ha⁻¹ in Babile5, with a mean of 5,843.7 kg ha⁻¹ (Table 4). Varieties such as Werer961, Babile2, and BaHaGudo combined high biomass production with substantial pod

yield, making them suitable for mixed crop-livestock systems, where groundnut residues serve as valuable livestock feed. These findings are consistent with previous reports highlighting the importance of dual-purpose groundnut varieties for both grain and fodder production (Fouillet et al., 2021; Atta-Krah et al., 2021). However, excessive vegetative growth may reduce assimilate allocation to pods, indicating a potential trade-off between biomass and pod yield (Tsegaye, 2023; Chirwa et al., 2024).

3.3.3 Harvest index (HI)

Harvest index varied among the evaluated groundnut varieties, ranging from 28.1% in Bulki01 to 59.1% in Babile4, with a mean of 41.2% (Table 4). High-HI varieties, such as Babile4 (59.1%) and Babile1 (58.0%), exhibited efficient translocation of assimilates from vegetative tissues to pods, a key trait for yield improvement. In contrast, Bulki01 and Senaf recorded lower harvest index values, indicating less efficient biomass partitioning. These findings align with previous reports documenting significant genotypic differences in harvest index among Ethiopian groundnut varieties (Atemkeng-Nkoumki, 2015; Liu et al., 2025). However, harvest index may also be influenced by environmental factors, including moisture and nutrient availability (Gayosso Barragán et al., 2025).

3.3.4 Hundred grain- weight (HGW)

Hundred-grain weight varied among the groundnut varieties, ranging from 36.9 g in Milkaye to 68.1 g in Babile2, with a mean of 49.5 g (Table 4). Large-seeded varieties, such as Babile2 and Babile1, are preferred in Ethiopian markets and suitable for processing, whereas medium- to small-seeded varieties, including Milkaye and Babile4, may be advantageous where seed multiplication efficiency and higher pod number are prioritized. These results are consistent with previous reports indicating strong market demand

for large-seeded groundnut in Eastern Amhara (Gayosso Barragán et al., 2025). However, medium-seeded types may achieve higher yield due to more efficient

pod filling, suggesting a potential trade-off between market preference and productivity (McIlveen, 2025).

Table 4. Mean separation from combined analysis of variance for yield and other traits of groundnut varieties evaluated over to 2022 and 2023 cropping seasons.

Variety	DM	PRB	PH	SPP	BY	PY	HI	USY	SHP	HGW
Babile1	156.50	6.03	33.78	1.90	4739.79	2701.28	57.99	1464.1	53.32	65.35
Roba	156.00	7.00	30.58	1.70	5966.74	1832.56	30.95	939.07	50.44	48.31
Senaf	162.00	6.41	28.67	1.67	5329.49	1208.74	26.85	708.52	58.56	62.24
Shulamit	162.17	6.07	28.45	1.83	5364.13	1846.02	34.48	980.38	54.88	44.73
Werer961	148.50	6.70	35.83	2.13	6038.04	3221.63	54.14	1494.77	46.24	48.46
Babile2	156.17	7.20	31.95	1.93	7348.45	2712.83	37.77	1435.76	52.45	68.13
Babile4	147.50	5.67	34.43	1.87	4459.67	2631.19	59.09	1035.43	41.01	37.43
Babile5	159.00	6.67	30.48	1.80	7579.9	1973.27	29.51	882.97	47.75	43.32
BaHaGudo	158.00	5.83	33.05	1.87	6086.9	2676.59	45.59	1310.51	48.14	47.58
BaHaJigu	156.33	6.87	29.82	1.90	7037.81	2220.14	34.27	1188.36	52.35	55.91
Bulki01	161.00	7.40	31.08	1.80	6542.07	1698.7	28.10	1011.2	59.40	42.73
Derib	152.50	5.93	34.96	2.10	5808.42	2775.6	49.33	1214.11	45.68	42.59
Milkaye	148.67	5.03	32.23	2.01	3667.33	1752.64	47.72	961.52	54.97	36.91
V	**	**	**	**	**	**	**	**	ns	**
Y	**	**	**	**	**	**	**	**	ns	**
V x Y	**	ns	ns	*	**	**	**	**	ns	ns
Mean	155.72	6.37	31.95	1.89	5843.75	2250.09	41.21	1125.13	51.17	49.52
CV (%)	2.58	15.57	9.83	8.38	13.01	18.92	13.17	29.42	19.98	17.07

Note: CV (%) =coefficient of variation, MSE=mean square error, DM=days to maturity, PRB=number of primary branches per plant, PH (cm)=plant height, SPP= number of seeds per pod, BY (kg ha⁻¹) =biomass yield, PY (kg ha⁻¹)=Pod yield, HI (%)=harvest index, USY (kg ha⁻¹) = unshelled seed -yield, SHP (%)=shelling percentage, HGW (g) =hundred grain-weight.

Table 5. Mean separation from separate analysis for yield and yield-related traits of groundnut varieties evaluated at Fogera district in the 2022 cropping season.

Varieties	DM	PRB	PH	SPP	BY	PY	HI	USY	SHP	HGW
Babile1	140.67	6.27	24.60	2.07	3480.57	2120.62	60.88	1034.6	48.8	50.75
Roba	144.67	7.53	21.93	1.80	3776.58	1185.85	31.24	552.33	47.46	38.97
Senaf	143.33	6.68	19.67	1.80	3100.64	1136.92	36.34	702.75	61.77	41.28
Shulamit	147.67	6.67	19.60	1.93	3447.7	1206.62	34.82	698.02	58.53	36.4
Werer961	141.00	8.27	27.33	2.00	5626.79	3627.98	64.43	1627.65	44.82	41.39
Babile2	140.00	8.00	25.33	2.00	5679.33	2359	41.22	1106.95	47.59	54.43
Babile4	138.00	5.80	27.07	1.93	3723.65	2237.38	59.81	1100.07	49.66	28.85
Babile5	140.67	7.53	23.00	1.93	4505.63	1715.29	37.78	874.02	51.48	34.47

Varieties	DM	PRB	PH	SPP	BY	PY	HI	USY	SHP	HGW
BaHaGudo	140.67	6.60	23.47	2.13	3400.19	1666.54	48.85	789.96	46.66	41.63
BaHaJigu	143.33	7.73	22.07	2.00	4245.26	1761.12	41.33	849.78	48.76	44.51
Bulki01	145.00	9.07	21.67	2.00	4398.03	1629.35	36.15	909.62	57.35	37.89
Derib	141.33	5.87	28.67	2.20	3259.95	1744.95	53.18	938.01	53.01	27.93
Milkaye	143.33	5.00	24.00	2.13	2286.64	1090.2	47.97	552.88	51.16	28.17
V	ns	**	**	ns	***	**	***	***	ns	***
MSE	10.65	1.18	6.40	0.02	248877.29	148020.36	34.93	43339.84	43.93	33.69
Mean	142.28	7.00	23.72	1.99	3917.77	1806.29	45.69	902.82	51.31	38.97
CV (%)	2.29	15.51	10.66	7.21	12.73	21.30	12.94	23.06	12.92	14.89

Note: MSE=mean square error, CV (%) =coefficient of variation, DM=days to maturity, PRB=number of primary branches per plant, PH (cm)=plant height, SPP= number of seeds per pod, BY (kg ha⁻¹) =biomass yield, PY (kg ha⁻¹)=Pod yield, HI (%)=harvest index, USY (kg ha⁻¹) = unshelled seed -yield, SHP (%)=shelling percentage, HGW (g) =hundred grain-weight.

Table 6. Mean separation from separate analysis for yield and yield-related traits of groundnut varieties evaluated at Fogera district in the 2023 cropping season.

Variety	DM	PRB	PH	SPP	NPP	BY	PY	HI	USY	SHP	HGW
Babile1	172.33	5.80	42.97	1.73	32.13	5999.01	3281.94	55.09	1893.6	57.84	79.94
Roba	167.33	6.47	39.23	1.6	34.27	8156.89	2479.28	30.65	1325.81	53.43	57.65
Senaf	180.67	6.13	37.67	1.53	28.2	7558.33	1280.56	17.35	714.28	55.35	83.19
Shulamit	176.67	5.47	37.3	1.73	36.33	7280.56	2485.42	34.15	1262.75	51.23	53.06
Werer961	156.00	5.13	44.33	2.27	49.47	6449.29	2815.28	43.85	1361.89	47.67	55.54
Babile2	172.33	6.40	38.57	1.87	27.8	9017.56	3066.66	34.31	1764.5	57.32	81.84
Babile4	157.00	5.53	41.8	1.8	37.4	5195.69	3025.00	58.37	970.79	32.37	46.01
Babile5	177.33	5.80	37.97	1.67	29.47	10654.17	2231.25	21.23	891.91	44.01	52.17
BaHaGudo	175.33	5.07	42.63	1.6	32.6	8773.61	3686.64	42.34	1831.06	49.62	53.54
BaHaJigu	169.33	6.00	37.57	1.8	35.53	9830.36	2679.17	27.22	1526.94	55.94	67.32
Bulki01	177	5.73	40.5	1.6	37.93	8686.11	1768.06	20.04	1112.78	61.45	47.57
Derib	163.67	6.00	41.25	2.00	39.3	8356.9	3806.25	45.48	1490.21	38.35	57.26
Milkaye	154	5.07	40.47	1.89	42.07	5048.01	2415.08	47.48	1370.17	58.78	45.65
V	**	ns	ns	**	**	**	**	**	*	ns	**
MSE	21.74	0.79	13.33	0.03	32.00	906837.7	214531.8	23.98	175730.1	165.19	109.20
Mean	169.15	5.74	40.17	1.78	35.58	7769.73	2693.89	36.74	1347.44	51.03	60.06
CV (%)	2.76	15.46	9.09	9.63	15.90	12.26	17.19	13.33	31.11	25.19	17.40

Note: CV (%) =coefficient of variation, MSE=mean square error, DM=days to maturity, PRB=number of primary branches per plant, PH (cm)=plant height, SPP= number of seeds per pod, BY (kg ha⁻¹) =biomass yield, PY (kg ha⁻¹)=Pod yield, HI (%)=harvest index, USY (kg ha⁻¹) = unshelled seed -yield, SHP (%)=shelling percentage, HGW (g) =hundred grain-weight.

3.4 Correlation among phenological, growth, and yield traits

Correlation analysis revealed significant associations among phenological, growth, and yield-related traits of groundnut varieties. Days to maturity (DM) was strongly and positively correlated with plant height ($r = 0.75^{***}$) and biological yield ($r = 0.812^{***}$), indicating that late-maturing genotypes tend to produce taller plants with greater biomass accumulation (Bhattacharya, 2022). Conversely, DM exhibited a moderate but significant negative correlation with harvest index ($r = -0.55^{***}$), suggesting that prolonged vegetative growth may reduce the efficiency of dry matter partitioning toward economic yield (Figure 2). Pod yield-related traits, including shelling percentage and hundred-grain weight, showed moderate to weak correlations with most yield components. Hundred-grain weight was positively associated with

biological yield ($r = 0.59^{***}$) and plant height ($r = 0.56^{***}$), indicating that increased seed size contributes to overall plant vigor and biomass production. Pod yield exhibited a moderate positive correlation with harvest index ($r = 0.41^{***}$) and a strong positive association with unshelled pod yield ($r = 0.80^{***}$), highlighting the importance of efficient assimilate translocation and seed filling in yield determination (Bhattacharya, 2022; Gelaye, 2025). Overall, the observed relationships suggest that selection for late-maturing, taller genotypes with higher biomass production and improved harvest index may enhance groundnut productivity. Additionally, the weak correlations among certain traits, such as shelling percentage and pod number per plant, indicate opportunities for independent selection to improve quality traits without negatively affecting yield performance.

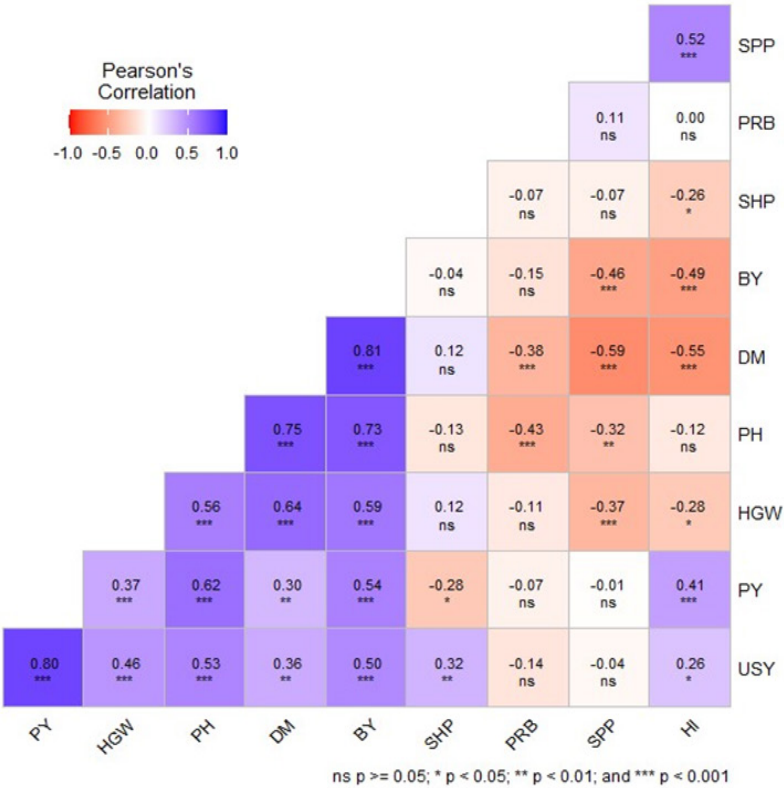


Figure 2. Pearson’s correlation coefficients among groundnut traits.

4. Conclusion

The study demonstrated significant genetic variability among the 13 groundnut varieties evaluated in the Fogera district over two cropping seasons. The combined analysis of variance revealed highly significant differences ($P \leq 0.01$) for key traits, including days to maturity, pod yield, and biomass yield, indicating the potential for selecting superior genotypes. The significant genotype $\times$ environment interaction observed suggests that environmental factors, particularly seasonal rainfall and temperature variations, strongly influence varietal performance. Among the tested genotypes, Werer961, Babile2, and Derib exhibited the highest pod yields and stability, while correlation analysis confirmed that harvest index and unshelled yield are critical determinants of pod yield.

Based on these findings, varieties Werer961, Babile2, and Derib are recommended for wider cultivation in the Fogera district and similar agro-ecologies to enhance productivity. For integrated crop–livestock farming systems, Werer 961, Babile2, and BaHaGudo are identified as ideal dual-purpose varieties due to their combination of high pod yield and substantial biomass. Future breeding programs should prioritize traits such as harvest index, unshelled yield, and hundred-grain weight, given their strong association with yield performance. Finally, to ensure broad adaptability and effective dissemination, multi-location evaluations across diverse agro-ecologies and strengthened extension services are recommended to facilitate farmer adoption.

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Conflict of interest

We declare that there are no potential conflicts of interest regarding this research, authorship and publication of this article. This statement emphasizes our commitment to ethical standards in research and ensures that the findings presented are free from any unjustified influence or bias.

Author contributions statement

AA: Conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; writing original draft; writing, revise and editing. DBF: Data curation; formal analysis; investigation; methodology; software; supervision; validation; writing. SSS: revise and edit.

References

- Abady, S., Shimelis, H., & Janila, P. (2019a). Farmers' perceived constraints to groundnut production, their variety choice and preferred traits in eastern Ethiopia: Implications for drought-tolerance breeding. *Journal of Crop Improvement*, 33(4), 505–521. <https://doi.org/10.1080/15427528.2019.1625836>
- Abady, S., Shimelis, H., Janila, P., & Mashilo, J. (2019b). Groundnut (*Arachis hypogaea* L.) improvement in sub-Saharan Africa: A review. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, 69(6), 528–545. <https://doi.org/10.1080/09064710.2019.1601252>
- Abady, S., Shimelis, H., Janila, P., Yaduru, S., Shayanowako, A. I. T., Deshmukh, D. B., Chaudhari, S., & Manohar, S. S. (2021). Assessment of the genetic diversity and population structure of

- groundnut germplasm collections using phenotypic traits and SNP markers: Implications for drought tolerance breeding. *PLoS ONE*, 16(11), e0259883. <https://doi.org/10.1371/journal.pone.0259883>
- Alemayehu, L., Kebede, M., & Wada, E. (2025). AMMI analysis of elite bread wheat (*Triticum aestivum* L.) selections for genotype by environment interaction and stability of grain yield in Southern Ethiopia. *PLoS ONE*, 20(1), e0318559. <https://doi.org/10.1371/journal.pone.0318559>
- Arya, S. S., Salve, A. R., & Chauhan, S. (2016). Peanuts as functional food: a review. *Journal of Food Science and Technology*, 53(1), 31-41. <https://doi.org/10.1007/s13197-015-2007-9>
- Atemkeng-Nkoumki, M. F. (2015). *Genetic analysis of traits related to biological nitrogen fixation in cowpea [Vigna unguiculata(L.) Walp] under low soil phosphorus* [Doctoral dissertation, University of Ghana]. Semantic Scholar. <https://api.semanticscholar.org/CorpusID:88867864>
- Atta-Krah, K., Chotte, J.-L., Gascuel, C., Gitz, V., Hainzelin, E., Hubert, B., Quintero, M., & Sinclair, F. L. (Eds.). (2021). *Agroecological transformation for sustainable food systems: Insight on France-CGIAR research* (Les dossiers d'Agropolis International, No. 26). Agropolis International. <https://doi.org/10.23708/fdi:010082500>
- Beebe, S. E., Rao, I. M., Cajiao, C., & Grajales, M. (2008). Selection for drought resistance in common bean also improves yield in phosphorus-limited and favorable environments. *Crop Science*, 48(2), 582-592. <https://doi.org/10.2135/cropsci2007.07.0404>
- Bekele, G., Birhanu, T., & Terefe, F. (2023). Growth, yield, yield components, and grain qualities of groundnut (*Arachis hypogaea* L.) as affected by liming and phosphorus rates in southwest Ethiopia. *Oil Crop Science*, 8(3), 165-173. <https://doi.org/10.1016/j.ocsci.2023.07.001>
- Berhanu, H., Hunduma, A., Dalasa, M., & Getachew, A. (2020). Performance evaluation of groundnut varieties in eastern parts of Ethiopia. *Food Science and Quality Management*, 102, 28-33. <https://doi.org/10.7176/FSQM/102-04>
- Bhattacharya, A. (2022). Effect of low temperature on dry matter, partitioning, and seed yield: A review. In A. Bhattacharya (Ed.), *Physiological processes in plants under low temperature stress* (pp. 629-734). Springer. https://doi.org/10.1007/978-981-16-9037-2_7
- Çalışkan, S., Çalışkan, M. E., & Arslan, M. (2008). Genotypic differences for reproductive growth, yield, and yield components in groundnut (*Arachis hypogaea* L.). *Turkish Journal of Agriculture and Forestry*, 32(5), 415-424.
- Chirwa, P. W., Araia, M., AvanaTientcheu, M. L., Muledi, J. I., Syampungani, S., Akinnifesi, F. K., et al. (2024). Trees in multifunctional landscapes: Definition, classification, systems, structure, functionality, examples in Africa. In P. W. Chirwa, S. Syampungani, & T. M. Mwamba (Eds.), *Trees in a Sub-Saharan multi-functional landscape: Research, management, and policy* (pp. 9-40). Springer. https://doi.org/10.1007/978-3-031-69812-5_2
- Desire, M. F., Blessing, M., Elijah, N., Ronald, M., Agather, K., & Tapia, Z. (2021). Exploring food fortification potential of neglected legume and oilseed crops for improving food and nutrition security among smallholder farming communities: A systematic review. *Journal of Agriculture and Food Research*, 3, 100117. <https://doi.org/10.1016/j.jafr.2021.100117>
- Eskezia, A., Nakachew, K., Tadesse, M., & Kassa, M. (2025). Genotype-by-

- environment interaction and yield stability of Kabuli chickpea (*Cicer arietinum* L.) in Northern Ethiopia. *Legume Science*, 7(2), Article 70038. <https://doi.org/10.1002/leg3.70038>
- Ethiopian Agriculture Authority. (2022). *Crop variety register: Plant variety release, protection and seed quality control directorate* (Issue No. 25). Ethiopian Agriculture Authority.
- Galani, Y. J. H., Orfila, C., & Gong, Y. Y. (2022). A review of micronutrient deficiencies and analysis of maize contribution to nutrient requirements of women and children in Eastern and Southern Africa. *Critical Reviews in Food Science and Nutrition*, 62(6), 1568–1591. <https://doi.org/10.1080/10408398.2020.1844636>
- Gayosso Barragán, O., Acosta Gallegos, J. A. A., Alcalá Rico, J. S. G. J., Jiménez Hernández, Y., Chávez Aguilar, G., Chávez Díaz, I. F., & Aranda Lara, U. (2025). Genotype × environment interaction and yield stability of “Pinto” bean (*Phaseolus vulgaris* L.) lines in a semi-arid region of Mexico. *Agriculture*, 15(20), 2150. <https://doi.org/10.3390/agriculture15202150>
- Gelaye, Y. (2025). Intercropping of pepper (*Capsicum annuum* L.) and black cumin (*Nigella sativa* L.) optimizes crop performance and system productivity in Ethiopia: Systematic review. *Cogent Food & Agriculture*, 11(1), Article 2451057. <https://doi.org/10.1080/23311932.2025.2451057>.
- Gelaye, Y., & Luo, H. (2024). Optimizing peanut (*Arachis hypogaea* L.) production: Genetic insights, climate adaptation, and efficient management practices: Systematic review. *Plants*, 13(21), 2988. <https://doi.org/10.3390/plants13212988>
- Ghodke, S. R. (2021). *Morpho-physiological characterization of summer groundnut (Arachis hypogaea L.)* [Master's thesis]. Mahatma Phule Krishi Vidyapeeth <https://krishikosh.egranth.ac.in/server/api/core/bitstreams/548e02b5-4521-4cfd-a4f9-95ed3a2c67ac/content>
- Giayetto, O., Morla, F. D., Fernandez, E. M., Cerioni, G. A., Kearney, M., Rosso, M. B., & Violante, M. G. (2013). Temporal analysis of branches pod production in peanut (*Arachis hypogaea*) genotypes with different growth habits and branching patterns. *Peanut Science*, 40(1), 8–14. <https://doi.org/10.3146/PS12-10.1>
- Habib, M. A., Azam, M. G., Haque, M. A., Hassan, L., Khatun, M. S., Nayak, S., Abdullah, H. M., Ullah, R., Ali, E. A., Hossain, N., Ercisli, S., & Sarker, U. (2024). Climate-smart rice (*Oryza sativa* L.) genotypes identification using stability analysis, multi-trait selection index, and genotype-environment interaction at different irrigation regimes with adaptation to universal warming. *Scientific Reports*, 14, 13836. <https://doi.org/10.1038/s41598-024-64808-9>
- Herrmann, L., Fouillet, E., Nguyen, T. T., Nguyen, H. T. T., Atieno, M., Zhong, S., & Lesueur, D. (2021). Positive impacts of a cowpea-cassava intercropping system on soil biodiversity in Northern Vietnam (Yen Bai Province). In K. Atta Krah et al. (Eds.), *Transformations agroécologiques pour des systèmes alimentaires durables: Panorama de la recherche France-CGIAR* (p. 18). Agropolis International. <https://doi.org/10.23708/fdi:010083985>
- Jivani, J. M. (2022). *Genetic diversity analysis in groundnut (Arachis hypogaea L.) based on molecular markers and biochemical parameters* [Master's thesis, Junagadh Agricultural University]. Krishikosh. <https://krishikosh.egranth.ac.in/server/api/core/bitstreams/d7741276-ea9d-446e-873c-e6812501d86e/content>

- Khan, M. M. H., Rafii, M. Y., Ramlee, S. I., Jusoh, M., & Al-Mamun, M. (2021a). Bambara groundnut (*Vigna subterranea* L. Verdc): A crop for the new millennium, its genetic diversity, and improvements to mitigate future food and nutritional challenges. *Sustainability*, 13(10), Article 5530. <https://doi.org/10.3390/su13105530>
- Khan, M. M. H., Rafii, M. Y., Ramlee, S. I., Jusoh, M., & Al Mamun, M. (2021b). AMMI and GGE biplot analysis for yield performance and stability assessment of selected Bambara groundnut (*Vigna subterranea* L. Verdc.) genotypes under the multi-environmental trials (METs). *Scientific Reports*, 11, 22791. <https://doi.org/10.1038/s41598-021-01411-2>
- Kumar, C. V. S., Wani, S. P., Nagesh Kumar, M. V., Rao, P. J., Saxena, K. B., Hingane, A. J., Sudhakar, C., Pushpavalli, S. N. V. C. L., Yamini, K. N., Shruthi, H. B., Saxena, R. K., & Varshney, R. K. (2016). Hybrid technology—a new vista in pigeonpea breeding. *The Journal of Research PJTSAU*, 44(4), 1–13. <http://oar.icrisat.org/id/eprint/10763>
- Liu, X., Wang, X., Zhao, K., Zhang, C., Zhang, F., Yuan, R., Lamlo, S. F., Ren, H., & Zhang, B. (2025). Improvement of premium oil soybean variety Heinong 551 with integrating conventional hybridization and gamma radiation. *Life*, 15(10), 1616. <https://doi.org/10.3390/life15101616>
- McIlveen, E. (2025). *Evaluating seed treatments and soybean cyst nematode (Heterodera glycines Ichinohe) reproduction on dry bean (Phaseolus vulgaris L.) market classes and cultivars* [Master's thesis]. University of Guelph. <https://atrium.lib.uoguelph.ca/bitstreams/2c0b0ba4-5412-4403-bd2c-92a23590b9ba/download>
- Mekonnen, A. B. (2024). *Adoption of climate-smart agricultural practices among smallholder farmers and implications for climate change adaptation in Southern Ethiopia* [PhD thesis]. University of Nairobi. <https://erepository.uonbi.ac.ke/handle/11295/166736>
- Mengistu, D. K., Terefe, H., Teshome, T., Garamu, T., Lakew, B. F., & Fadda, C. (2024). Chickpea production restored through upscaling crowdsourcing winner varieties and planting date adjustments in the Ada'a district, East Shoa zone, Ethiopia. *Heliyon*, 10(11), e32269. <https://doi.org/10.1016/j.heliyon.2024.e32269>
- Mesfin, H. M., Ahmed, M. H., & Abady, S. (2016). Determinants of multiple groundnut technology adoption in eastern Ethiopia. *Review of Agricultural and Applied Economics*, 19(2), 51–60. <https://doi.org/10.15414/raae/2016.19.02.51-60>
- Nigussie, D., Mulugeta, W., Molla, A., Bishaw, Z., & Biradar, C. (2019). GIS-based multi-criteria land suitability mapping for scaling faba bean varieties in Ethiopia. *African Crop Science Journal*, 27(4), 687–708. <https://doi.org/10.4314/acsj.v27i4.10>
- Parvin, S. (2019). *Biochemical and physiological mechanisms of legume nitrogen fixation under higher atmospheric CO₂ concentrations* [Master's thesis]. The University of Melbourne. <https://rest.mars-prod.its.unimelb.edu.au/server/api/core/bitstreams/7dd9a24a-a658-5181-aa8d-8cfa89c3d02f/content>
- Radhakrishnan, T., Kona, P., Ajay, B. C., & Kumar, N. (2022). Groundnut breeding. In D. K. Yadava, H. K. Dikshit, G. P. Mishra, & S. Tripathi (Eds.), *Fundamentals of field crop breeding* (pp. 837–906). Springer Singapore. <https://doi.org/10.1>

007/978-981-16-9257-4_16

- Rashid, M. M., Nuruzzaman, M., Hassan, L., & Begum, S. N. (2017). Genetic variability analysis for various yield attributing traits in rice genotypes. *Journal of the Bangladesh Agricultural University*, 15(1), 15–19. <https://doi.org/10.3329/jbau.v15i1.33525>
- Sime, G., & Aune, J. B. (2018). Sustainability of improved crop varieties and agricultural practices: A case study in the central Rift Valley of Ethiopia. *Agriculture*, 8(11), 177. <https://doi.org/10.3390/agriculture8110177>
- Tadesse, M., & Nepir, G. (2024). Review on groundnut (*Arachis hypogaea* L.) breeding, production and challenges, and opportunities in Ethiopia. *Discover Plants*, 1, 53. <https://doi.org/10.1007/s44372-024-00064-5>
- Tsegaye, A. (2023). *Livestock feed resource availability, their quality and utilization practice in selected district of North Wollo Zone, Ethiopia* [Master's thesis]. Woldia University.
- United States Department of Agriculture, Foreign Agricultural Service. (2024, May 10). Oilseeds: World Markets and Trade. <https://www.fas.usda.gov/sites/default/files/2024-05/oilseeds.pdf>
- Williams, R. M., O'Brien, L., Eagles, H. A., Solah, V. A., & Jayasena, V. (2008). The influences of genotype, environment, and genotype × environment interaction on wheat quality. *Australian Journal of Agricultural Research*, 59(2), 95–111. <https://doi.org/10.1071/AR07185>
- Wondaferew, D., Mullualem, D., Bitewlgn, W., Kassa, Z., Abebaw, Y., Ali, H., Kebede, K., & Astatkie, T. (2024). Cultivating sustainable futures: Multi-environment evaluation and seed yield stability of faba bean (*Vicia faba* L.) genotypes by using different stability parameters in Ethiopia. *BMC Plant Biology*, 24, 1108. <https://doi.org/10.1186/s12870-024-05829-4>
- Yadawad, A., & Bhat, R. (2025). Genotype and environment interaction analysis for yield stability and resistance to *Aspergillus flavus* in groundnut (*Arachis hypogaea* L.) advanced lines. *Bangladesh Journal of Botany*, 54(3), 611–617. <https://doi.org/10.3329/bjb.v25i3.84337>