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Evaluation of Biomass Yield and Nutritional Composition of Soybean (*Glycine max* (L.) Merrill) Varieties Grown in Lowland Areas of Eastern Amhara, Ethiopia

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Abstract

This study was conducted to identify the best-performing soybean varieties for biomass yield, chemical composition, haulm and seed yield, and other agronomic characteristics under rain-fed conditions in the lowland areas of Eastern Amhara, Ethiopia. The experiment took place at three locations: Jari, Chefa, and Sirinka. A randomized complete block design with three replications was employed. Twelve released soybean varieties “Afgat”, “Belesa-95”, “Boshe”, “Cheri”, “Dhidhessa”, “Gishama”, “Gizo”, “Korme”, “Pawe-03”, “Katta”, “Wegayen”, and “Wollo” served as treatments. Seeds were sown with a spacing of 40 cm between rows and 10 cm between plants. Each plot measured 3.2 m × 4 m, with 0.5 m and 1 m separating plots and blocks, respectively. Combined analyses across Jari and Sirinka indicated that the varieties “Afgat”, “Gishama”, “Gizo”, “Pawe-03”, “Wegayen”, and “Wollo” produced higher dry matter yields than others. “Gishama”, “Gizo”, “Pawe-03”, and “Wegayen” also had superior haulm yields. For seed yield, “Pawe-03”, “Gizo”, “Afgat”, “Gishama”, “Wollo”, and “Wegayen” outperformed the other varieties. Notably, the “Wollo” variety exhibited the highest protein content at both Jari and Sirinka. Based on these results, “Afgat”, “Pawe-03”, and “Wollo” are recommended for cultivation in the Jari, Chefa, and Sirinka zones. These varieties demonstrate strong potential for delivering high dry matter, haulm, and seed yields, as well as providing a valuable protein supplement for ruminants. Further research is recommended to investigate their optimal application in livestock feeding systems.

Keywords: “Afgat”, crude protein, dry matter, haulm, Jari

Introduction

Several factors contribute to the low productivity of Ethiopian livestock, with feed availability being the most significant constraint. The current supply of livestock feed in the country does not meet the nutritional requirements of the animals. Natural pastures remain the primary source of feed; however, they are limited to fallow croplands, degraded shallow uplands and highlands, and areas with soils unsuitable for cropping due to flooding and waterlogging. These grasslands typically provide feed for only four to five months of the year, and their productivity is generally low. Moreover, grazing lands have been shrinking for decades due to the rapid expansion of cultivated land, which is aimed at feeding the growing human population (Feyissa et al., 2022; Tesfaye and Gutema, 2022). This continual loss of grazing areas has led to a scarcity of adequate feed to support the existing livestock population. Therefore, it is critically important to select high-yielding, high-quality forage varieties and to develop improved forage production strategies to address the feed shortage and enhance livestock productivity in Ethiopia.

Ethiopia has conducted extensive research and development over the past 40 years to test and assess the performance and adaptation of various forage species in different agro-ecological zones. Numerous prospective species of browse trees, legumes, and grasses have been chosen for development initiatives. The chosen species outperformed the naturally existing swards in terms of yield and quality. The introduction and development of selected forage species into the farming system was expected to help solve the severe forage deficit that the country is presently facing (Feyissa et al., 2022). During the dry season, when crop residues, hay, and grazing are insufficient to sustain animal productivity, supplementation with forage legumes boosts animal productivity. The introduction and adoption of soybean

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forage is one possible source of legumes for feed (Feyissa et al., 2022).

In addition to being a significant legume crop farmed for its oil- and protein-rich seeds, soybeans (*Glycine max* (L.) Merrill) also provide excellent hay, silage, and forage for grazing. When it grows to a height of 60 cm, it can be grazed for the first time. Soybean serves as a globally significant protein source for both human consumption and animal feed (Qin et al., 2022). It is an annual herbaceous plant with rapid growth that originated in Asia. It is today cultivated worldwide. It is a leguminous plant that stands upright and can reach a height of 1.3 meters. Soybean forage offers numerous beneficial qualities as fodder, just like other forage legumes. Soybean leaves and stems can be grazed by livestock. Ensiled or dried to make hay. Studies confirm that soybean foliage and silage offer cattle key benefits, including high nutritional content, strong digestibility, high palatability, and cost-effective production (Pereira et al., 2022; Aster et al., 2023).

In Ethiopia, soybean forage is most suited for winter crops, as it can withstand droughts and flourish in situations where other legumes, such as alfalfa, are scarce. According to Zaeem et al. (2021), forage soybeans can be sown alone or in conjunction with other forage species, such as corn. It should be sown on a well-prepared seedbed once the average temperature is higher than 10°C. According to An et al. (2024), it grows swiftly and can produce 8.97 to 14.68 $t.ha^{-1}$ DM.

The nutritive value of the soybean plant can be comparable to early bloom alfalfa (which shows high protein content and is very digestible to mature ruminant animals). When fed alfalfa forage or soybean hay, growing heifers and lactating dairy cows can exhibit similar performance. Unless the forage is dusty or moldy, palatability is usually not an issue when feeding soybean forage. In three to four months after seeding, it produces cut hay equal in quality to alfalfa cut hay (Ghizzi et al., 2020).

With a protein content ranging from 11% to more than 22% of the dry matter (DM), soybean forage is comparatively high, at 24.7%. Additionally, the amount of fiber varies greatly, with ADF making up anywhere from 20% to over 45% of the DM (Sun et al., 2024). It is relatively poor in lignin (about 6% DM). Harvest ripeness is the primary determinant of soy forage quality. While fiber content fluctuates in the opposite direction, protein concentration increases during pod formation and declines during blooming. As the pod and seed components increase, the proportion of stems and leaves on the plant decreases. Because the seeds contain oil, the mature forage's lipid content can account for up to 10% of the dry matter (Ghizzi et al., 2020).

Haulms are plant material above the ground level, harvested, dried, and used for feeding livestock. In small-scale mixed agricultural systems, grain legume haulms are also an important source of fodder for ruminant feeding. Belete et al. (2021) reported that a trend growing among smallholder farmers in Ethiopia's highlands is the use of grain legume haulms as animal feed. In small-scale mixed crop-livestock farming areas, soybean haulms (residue) have already established themselves as significant parts of the diet of ruminants. Soybean haulms had also been found to have values of 89.18%, 5.10, 2.85%, 96.90%, 80.80%, 63.20%, and 13.00% for DM, CP, EE, OM, NDF, ADF, and ADL contents, respectively (Maheri-Sis et al., 2011). The dry matter yield of soybean haulm was 3.54 $t.ha^{-1}$ harvested with application of 100% RDF (60 kg N + 30 $kg.ha^{-1}$ P_2O_5), 3.59 $t.ha^{-1}$ with 100% RDF + FYM (5 $t.ha^{-1}$) (Durgeshwari et al., 2022) and 3.23 $t.ha^{-1}$ with fertilizer in (Sisay, 2017). Soybeans are a typical short-day crop sensitive to photoperiod response; it is essential to select suitable varieties for forage purposes carefully (Zhang et al., 2020). This study was conducted to select the best-performing varieties in terms of biomass yield, chemical composition, haulm yield, seed yield, and other agronomic characteristics of *Glycine max* (L.) Merrill grown under rain-fed conditions in lowland areas of Eastern Amhara.

Materials and Methods

Description of the Study Area

The study was conducted in 2018 and 2019 at three locations in Eastern Amhara. The locations were Jari, Chefa, and Sirinka. Jari is situated at 11°21′00″ N latitude and 39°38′00″ E longitude, located approximately 435 km North of Addis Ababa, the Capital City of Ethiopia. It lies at an altitude of 1680 meters above sea level. The area receives an average annual rainfall of 1204.6 mm and a mean range temperature of 11.2-25.6°C. There are two types of soil: black and clay. Chefa is about 355 km North of Addis Ababa, the Capital City of Ethiopia. It lies at an altitude of 1,450 meters above sea level. The area receives an average annual rainfall of 850 mm and a mean range temperature of 21-36°C. There are two types of soil: black and clay. Sirinka is located 508 km North of Addis Ababa, the capital city of Ethiopia. The area is situated at an altitude of 1850 masl with the geographical coordinates of 11°45′00″ N and 39°36′36″ E. The rainfall pattern is bimodal, with two distinct rainfall seasons: 'Belg' (February-April) and

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‘Meher’ (June-October). The mean annual rainfall is 950 mm. Months are classified as June to August as the main rainy seasons; months of September to February are considered dry seasons, while March to May are a short rainy season (Zeleke et al., 2020).

Experimental Procedures and Design

Using a randomized complete block design, the experimental fields were divided into three blocks, and the twelve treatments were randomly assigned to the plots in each block. As a treatment, twelve varieties of soybeans were employed. Planting was done right after the onset of the rainy season. On a 3.2 m × 4 m plot with eight rows per plot, seeds were sown 40 cm apart between rows and 10 cm apart within each row. There were 0.5 and 1 meters between plots and blocks, respectively. The seed rate was 60 $kg.ha^{-1}$. During seeding, 100 $kg.ha^{-1}$ of NPS fertilizer was applied. Only the complete three rows were harvested at 50% of the blooming stage to estimate the biomass yield; the remaining three rows were used to produce seed and haulm yields. The soybean varieties are listed in Table 1.

Data Collection

Forage growth parameters and yield

Plot coverage, vigor, and leafiness score were collected on a given labeled scale (1-9). Plant height was measured at the 50% flowering stage. The distance between the soil surface and the tip of each plant was recorded for ten randomly selected plants from each plot, excluding those on the borders. Biomass yield was taken when the plant reached the optimum harvesting stage (50% flowering), and the fresh green weight of the sample and the extra yield per hectare of land were measured. The dry matter content was determined based on the fresh green weight, which was dried in a forced-draft oven for 72 hours at 65°C until a constant weight was achieved. The sample yield per hectare was then calculated by multiplying the dry matter percentage by the sample yield per hectare. Haulm yield was measured after the soybeans were threshed. Haulm is the crop residue of soybeans.

Soybean seed yield and yield components

Seed yield and other agronomic characteristics were collected. The data that were collected were estimated for the three sampled rows and then extrapolated to a hectare of land. Ten plants, excluding those on the borders, were taken randomly and measured for plant height at maturity and the number of pods per plant. Plant height at maturity was measured at 90% physiological maturity, which was the distance between the soil surface and the tip of each plant. The number of pods per plant was taken at 90% physiological maturity, and seed yield was also taken at 90% plant physiological maturity.

Chemical analysis of soybean forage

Chemical analysis of soybean varieties in the experiment was conducted in the laboratory. Representative samples of forage were taken to the Debre Birhan Agricultural Research Center Animal Nutrition Laboratory for chemical analysis. The

Table 1. Backgrounds of soybean varieties used as a treatment

No.	Variety name	Year of release/ register	Released from	Altitude (masl)	Maturity group
1	“Afgat”	2007	Awassa Agricultural Research Center (AwARC)	520-1800	Medium
2	“Belesa-95”	2003	Areka Agricultural Research Center (ARARC)	520-1800	Late
3	“Boshe”	2008	Bako Agricultural Research Center (BARC)	1200-1900	Medium
4	“Cheri”	2003	Bako Agricultural Research Center(BARC)	1300-1850	Midium
5	“Dhidhessa”	2008	Bako Agricultural Research Center(BARC)	1200-1900	Medium
6	“Gishama”	2010	Pawe Agricultural Research Center (PARC)	520-1800	Medium
7	“Gizo”	2010	Pawe Agricultural Research Center (PARC)	520-1800	Medium
8	“Korme”	2011	Bako Agricultural Research Center(BARC)	1200-1900	Medium
9	“Pawe-03”	2016	Pawe Agricultural Research Center (PARC)	520-1800	Late
10	“Katta”	2011	Bako Agricultural Research Center(BARC)	1200-1900	Medium
11	“Wegayen”	2010	Pawe Agricultural Research Center (PARC)	520-1800	Late
12	“Wollo”	2012	Sirinka Agricultural Research Center (SARC)	520-1800	Medium

Source: MoANR, 2016.

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samples were dried in a forced-draft oven at 65°C for 72 hours and then ground to pass through a 1 mm screen sieve using a mill. The ground sample was stored in an airtight plastic bag pending chemical analysis. Dry matter (DM) was determined by drying samples overnight at 105°C in a forced-draft oven. Ash concentrations were determined by combusting the sample at 550°C for 3 hours, and total N concentrations were determined using the micro Kjeldahl method. Crude protein (CP) contents were calculated as N × 6.25. The samples were analyzed using the AOAC method (1990). Organic matter (OM) was calculated as the amount of ash deducted from 100. The neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) of the samples were determined using the method of Van Soest and Robertson (1985).

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedures of the Genstat computer software program (Version 18). Treatment means were separated using Duncan's multiple range test (DMRT) when the F-value showed significant differences. Statistical significance was established when the probability was ≤ 0.05 level of significance.

The model used for analysis was:
$Yijk = \mu + Ti + Lj + (TL)ij + Bk(j) + eijk$
Where:
Yijk = the measured response of treatment i in block k of location j,
μ = the grand mean,
Ti = the effect of treatment i,
J = the effect of location
TL= the treatment and location interaction,
Bk(j) = the effect of block k in location j and
Eijk = the random error effect of treatment i in block k of location j

Results and Discussions

Dry Matter Yield and Other Morphological Characteristics of Soybean Varieties

The combined mean (Table 2) showed that there was highly significant variation (P<0.001) between varieties in all parameters. There was a significant difference (P<0.05) among locations in plot coverage, days to 50% flowering, and biomass yield, but no significant difference (P>0.05) between locations under vigor, leafiness score, dry matter yield, and plant height at the 50% flowering stage. However, there was no significant difference (P>0.05) in variety by location interactions, except for days to 50% flowering, which showed a significant difference (P<0.05) in the interaction effect.

The combined analysis across locations (Jari and Chefa) for the year 2018 revealed that varieties "Afgat", "Gizo", "Pawe-03", and "Wollo" had higher dry matter yields compared to other soybean varieties. The "Afgat", "Gishama", "Gizo", "Pawe-03", and "Wollo" varieties had higher biomass yield as compared to other soybean varieties. The dry matter yield of "Afgat" was 6.54 $t.ha^{-1}$, lower than 7.34 $t.ha^{-1}$ reported by Suzan et al. (2004) and 6.72 $t.ha^{-1}$ reported by Assaeed et al. (2000). However, the current result was sufficient to support livestock production in the existing environment.

The combined analysis of variance over two years at Jari for plant vigor, leafiness score, days to 50% flowering, biomass yield, dry matter yield and plant height at 50% flowering (Table 3) showed that there were highly significance difference (P<0.01) between varieties. Still, there was no significant difference (P>0.05) on plot coverage. There were significant differences (P<0.05) among years in leafiness score, days to 50% flowering, biomass yield, dry matter yield, and plant height at 50% flowering, except that plot coverage and vigor showed no significant differences (P>0.05) between years. Plot coverage, vigor, days to 50% flowering, and plant height at 50% flowering showed a significant difference (P<0.05) among varieties due to the year interaction effect. However, the leafiness score, biomass yield, and dry matter yield showed no significant difference (P>0.05) due to the interaction effect of variety and year. The presence of significant interactions by year indicated inconsistent performance of the varieties for this character over the years. However, the presence of no significant interaction indicates that the consistent performance of the variation over the years.

The mean biomass yield of varieties "Afgat", "Gizo", "Pawe-03", and "Wollo" was significantly higher, at 17.2 $t.ha^{-1}$, 16.1 $t.ha^{-1}$, 16.7 $t.ha^{-1}$, and 16.71 $t.ha^{-1}$, respectively, compared to other varieties. Additionally, the mean dry matter yields of varieties "Afgat", "Gizo", "Pawe-03", "Wogayen", and "Wollo" were significantly higher at 4.99 $t.ha^{-1}$, 4.34 $t.ha^{-1}$, 4.64 $t.ha^{-1}$, 4.19 $t.ha^{-1}$, and 4.79 $t.ha^{-1}$, respectively, compared to other varieties. The dry matter yield of "Afgat" was 4.99 $t.ha^{-1}$, which is lower than the 7.34 $t.ha^{-1}$ reported by Suzan et al. (2004) and the 6.72 $t.ha^{-1}$ reported by Assaeed et al. (2000).

The combined mean (Table 4) revealed a highly significant variation (P<0.001) between varieties in all parameters. There were highly significant differences

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(P<0.001) among locations in day to 50% flowering, plant height at 50% flowering, biomass yield, dry matter yield, and haulm yield, but no significant difference (P>0.05) between locations under vigor. There was a significant interaction between variety and location (P<0.05) in terms of vigor, days to 50% flowering, plant height at 50% flowering, and biomass yield. However, dry matter and haulm yield showed no significant difference (P>0.05) due to the interaction effect.

The combined analysis across locations showed that varieties “Afgat”, “Gishama”, “Gizo” “Pawe-03”, “Wogayen”, and “Wollo” had higher dry matter yield as compared to the other soybean varieties. But, there was low yield in this cropping season (2019) as compared with the first year (2018) because, unfortunately, in this cropping season, there was heavy rain intensity with ice during the early stage of growing at Sirinka. The dry matter yield of “Pawe-03” was 2.39 $t.ha^{-1}$, lower than 7.34 $t.ha^{-1}$ reported by Suzan et al. (2004) and 6.72 $t.ha^{-1}$ reported by Assaeed et al. (2000). The combined analysis across locations showed that varieties “Gishama” (3.97 $t.ha^{-1}$), “Gizo” (3.60 $t.ha^{-1}$), “Pawe-03” (4.04 $t.ha^{-1}$), and “Wogayen” (3.36 $t.ha^{-1}$) had higher haulm yield as compared to the other soybean varieties. The haulm yield of “Pawe-03” (4.04 $t.ha^{-1}$) is higher than the 3.23 $t.ha^{-1}$ reported by Sisay (2017) and 3.54 $t.ha^{-1}$ reported by Durgeshwari et al. (2022).

Seed Yield and Other Agronomic Characteristics of Soybean Varieties

The combined mean (Table 5) showed that there was highly significant variation (P<0.001) between varieties in all parameters. There were significant differences (P<0.05) among locations in date of maturity, plant height at maturity, seed yield, and thousand seed weight, but no significant differences (P>0.05) between locations in the number of pods per plant. There was a significant difference (P<0.05) in variety by location interaction for date of maturity, plant height at maturity, and thousand seed weight.

Table 2. The combined mean of dry matter yield and other related characteristics of soybean varieties over locations (Jari and Chefa) in 2018

Variable	N	PC	Vg	LS	DF50%	BY ($t.ha^{-1}$)	DMY ($t.ha^{-1}$)	PH50% (cm)
Variety	72							
“Afgat”	6	8.833^{a}	8.5^{a}	8.833^{a}	65.83^{c}	14.68^{a}	6.541^{a}	81.13^{ab}
“Belessa-95”	6	7.667^{bcde}	6.833^{d}	7.167^{c}	68.67^{b}	9.76^{de}	4.525^{de}	71.52^{cd}
“Boshe”	6	7.5^{cde}	7.0^{d}	7.0^{c}	62.00^{d}	8.43^{e}	4.646^{cde}	64.90^{e}
“Cheri”	6	8.0^{abcd}	8.0^{abc}	7.0^{c}	68.33^{b}	10.59^{cd}	5.323^{bcde}	77.16^{bc}
“Dhedessaa”	6	7.167^{de}	7.167^{cd}	6.833^{c}	69.67^{b}	9.07^{de}	4.290^{e}	70.28^{de}
“Gishama”	6	7.667^{bcde}	8.333^{a}	8.167^{ab}	69.50^{b}	12.62^{ab}	5.315^{bcde}	79.25^{ab}
“Gizo”	6	8.5^{abc}	8.5^{a}	8.333^{ab}	69.33^{b}	13.25^{ab}	5.879^{ab}	78.28^{ab}
“Korme”	6	7.833^{abcd}	7.333^{bcd}	7.167^{c}	69.33^{b}	9.03^{de}	4.500^{de}	70.91^{de}
“Pawe-03”	6	8.5^{abc}	8.167^{ab}	8.0^{b}	72.33^{a}	13.05^{ab}	5.939^{ab}	77.20^{bc}
“Kata”	6	6.833^{e}	7.0^{d}	7.167^{c}	69.33^{b}	9.46^{de}	4.266^{e}	70.61^{de}
“Wogayen”	6	8.0^{abcd}	8.5^{a}	8.0^{b}	65.50^{c}	12.11^{bc}	5.467^{bcd}	83.87^{a}
“Wollo”	6	8.667^{ab}	8.5^{a}	8.833^{a}	65.83^{c}	13.24^{ab}	5.698^{abc}	81.16^{ab}
Gmean		7.931	7.819	7.708	67.97	11.27	5.199	75.52
SEM		0.111	0.112	0.105	0.382	0.306	0.123	0.862
CV		9.6	9.4	7.8	2.00	14.30	15.7	6.5
SL V		***	***	***	***	***	***	***
SL LO		**	ns	ns	***	***	ns	ns
SL VX LO		ns	ns	ns	**	ns	ns	ns

Notes: PC (%)= plot coverage; Vg= Plant vigor; LS= leafiness score of plant; DF (50%)=date at 50% flowering stage; PH (50%)= plant height; BY= biomass yield; DMY= dry matter yield; N= number of observation; SEM= standard error of mean; CV= coefficient of variation; SLV= significant level of variety; SL LO= significant level of location; SL VX LO= Significant level of variety by location interaction; ns= non significant at P>0.05; **= significant at P<0.01; *** =significant at P<0.001; means with the same super script in columns are not significantly different.

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However, the number of pods per plant and seed yield showed no significant difference (P > 0.05) due to the interaction effect.

The combined analysis across locations showed that variety "Pawe-03" (2951 kg.ha^{-1}), "Gizo" (2862 kg.ha^{-1}), "Afgat" (2859 kg.ha^{-1}), "Gishama" (2654 kg.ha^{-1}), "Wollo" (2461 kg.ha^{-1}) and "Wogayen" (2404 kg.ha^{-1}) had higher seed yield as compared to the other soybean varieties. The seed yield of "Pawe-03" was 2951 kg.ha^{-1}, greater than 2880 kg.ha^{-1} reported by Agegn et al. (2022).

Chemical Composition of Soybean Varieties

The mean protein and ash composition of soybean varieties are shown in Table 6. The mean CP content at Chefa ranges from "Boshe" (21.30%) to "Gizo" (33.60%). The CP content of "Gizo" is the highest compared to "Boshe", making it a good source of protein supplement for various production systems. The crude protein content of "Gizo" (33.60%) was comparatively higher than the mean of CP 20.01% reported by Assaeed et al. (2000).

The mean CP content at Jari ranges from "Korme" (17.20%) to "Wollo" (35.56%). The numerical values showed that the CP content of "Wollo" was the highest compared to others, indicating it was a good source of protein supplement for various production systems. The average CP content at Sirinka varies from 14.59% for "Korme" to 27.66% for "Wollo". The numerical value showed that the CP content of "Wollo" was the highest compared to others, indicating it was a good source of protein supplement for various production systems. This indicated that variety "Wollo" could have high crude protein content and digestible nutrients that can support animal production over the maintenance requirements of animals. It was used as a supplement to roughage feed sources used as animal feed.

Table 3. The combined mean of dry matter yield and other related characteristics of soybean varieties over the years (2018 and 2019) at Jari

Variable	N	PC	Vg	LS	DF50%	BY (t.ha^{-1})	DMY (t.ha^{-1})	PH50% (cm)
Variety	72							
"Afgat"	6	8.5	8.667^{a}	8.5^{a}	63.33^{e}	17.20^{a}	4.993^{a}	71.77^{a}
"Belessa-95"	6	8.17	7.167^{cd}	7^{c}	66.83^{c}	9.45^{c}	3.159^{cd}	58.97^{bc}
"Boshe"	6	8.0	7.167^{cd}	7.333^{bc}	60.67^{f}	8.14^{c}	3.026^{cd}	56.75^{bc}
"Cheri"	6	8.17	7.833^{abc}	7^{c}	66.5^{c}	10.41^{c}	3.676^{bcd}	61.99^{b}
"Dhedessaa"	6	8.0	7.333^{cd}	7^{c}	66.83^{c}	9.80^{c}	3.038^{cd}	59.63^{bc}
"Gishama"	6	7.5	8.167^{ab}	7.667^{abc}	69.17^{b}	13.63^{b}	3.813^{bc}	69.45^{a}
"Gizo"	6	8.5	8.5^{a}	8.167^{ab}	67.67^{bc}	16.10^{ab}	4.335^{ab}	70.27^{a}
"Korme"	6	8.17	7.333^{bcd}	7.5^{bc}	67.33^{bc}	9.56^{c}	3.364^{cd}	59.19^{bc}
"Pawe-03"	6	8.5	7.5^{bcd}	7.333^{bc}	74.83^{a}	16.70^{a}	4.635^{a}	71.70^{a}
"Kata"	6	7.67	6.667^{d}	7^{c}	67^{c}	8.63^{c}	2.888^{d}	56.11^{c}
"Wogayen"	6	8.33	8.333^{a}	7.667^{abc}	65.5^{cd}	13.36^{b}	4.189^{ab}	71.77^{a}
"Wollo"	6	9.0	8.667^{a}	8.167^{ab}	64de	16.71^{a}	4.787^{a}	74.61^{a}
Gmean		8.21	7.778	7.528	66.64	12.47	3.825	65.18
SEM		0.115	0.119	0.108	0.535	0.545	0.192	1.473
CV		10.7	8.4	9.6	2.5	18.6	16.8	6.8
SL V		ns	***	**	***	***	***	***
SL Y		ns	ns	*	***	***	***	***
SL VXY		*	*	ns	**	ns	ns	*

Notes: PC (%)= plot coverage; Vg= Plant vigor; LS= leafiness score of plant; DF (50%)=date at 50% flowering stage; PH(50%)= plant height; BY= biomass yield; DMY= dry matter yield; N= number of observation; SEM= standard error of mean; CV= coefficient of variation; SLV= significant level of variety; SL Y= significant level of year; SL VXY=Significant level of variety by year interaction; ns= non significant at P> 0.05; *=significant at P<0.05;**= significant at P<0.01; *** =significant at P<0.001; means with the same super script in columns are not significantly different.

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Chefa's superior protein may stem from favorable agro-climatic conditions (e.g., soil nitrogen, temperature) supporting protein synthesis. Sirinka's lower CP could relate to nutrient leaching or heat stress, consistent with Masuda et al. (2021), who noted protein reduction in soybeans under high temperatures. Sirinka's high ash suggests mineral-rich soils or environmental factors promoting mineral uptake. "Kata's" 13.40% ash in Sirinka aligns with findings by Duan et al. (2022), where soil micronutrients elevated ash content.

"Wollo" and "Afgat" showed broad adaptability, performing well across locations. "Wollo"'s CP dominance in Jari (35.56%) indicates genotype-environment (G×E) synergy. "Korme's" poor performance in Sirinka and Jari highlights varietal sensitivity to environmental stressors. The crude protein content of variety "Wollo" (35.56%, 27.66% at Jari and Sirinka, respectively) was comparatively higher than the mean of CP 20.01% detailed by Assaeed et al. (2000). Therefore, it possible to generalize that all varieties in all three locations used as protein supplement for growing and lactating animals where soybean varieties can be accessible to producers.

The mean fiber composition of soybean varieties is shown in Table 7. The mean NDF content at Chefa ranges from "Cheri" (28.79%) to "Belessa-95" (58.57%), ADF from "Cheri" (19.78%) to "Afgat" and "Belessa-95" (35.16%), and ADL from "Cheri" (4.56%) to "Afgat" and "Belessa-95" (8.94%). The NDF content of "Belessa-95" was the highest compared to "Cheri", making it more fibrous than "Cheri" and other varieties. The ADF content of "Afgat" and "Belessa-95" was the highest compared to "Cheri", indicating that "Afgat" and "Belessa-95" had the highest lignocellulose content among "Cheri" and other soybean varieties. The ADL content of "Afgat" and "Belessa-95" was highest compared to "Cheri" and other varieties. This indicated that "Afgat" and "Belessa-95" had the highest lignin content as compared to "Cheri" and other varieties.

Table 4. The combined mean of dry matter yield and other related characteristics of soybean varieties over locations (Jari and Sirinka) 2019

Variable	N	Vg	DF (50%F)	PH (50%F)	BY ($t.ha^{-1}$)	DMY ($t.ha^{-1}$)	HY ($t.ha^{-1}$)
Variety	72						
"Afgat"	6	8.17^{a}	59.33^{ef}	52.07^{b}	13.08^{a}	2.19^{ab}	3.28^{bc}
"Belessa-95"	6	7.42^{b}	62.00^{cd}	45.73^{c}	7.19^{b}	1.41^{c}	2.29^{d}
"Boshe"	6	7.25^{b}	58.17^{f}	46.77^{c}	7.12^{b}	1.53^{c}	1.85^{d}
"Cheri"	6	7.42^{b}	61.00^{cde}	44.00^{c}	8.30^{b}	1.67^{bc}	2.38^{d}
"Dhedessaa"	6	7.42^{b}	60.50^{cdef}	45.13^{c}	7.81^{b}	1.52^{c}	2.09^{d}
"Gishama"	6	8.42^{a}	67.67^{b}	57.73^{a}	13.56^{a}	2.38^{a}	3.97^{ab}
"Gizo"	6	8.25^{a}	63.00^{c}	52.93^{ab}	13.34^{a}	2.08^{ab}	3.60^{abc}
"Korme"	6	7.25^{b}	61.17^{cde}	44.90^{c}	7.78^{b}	1.41^{c}	1.94^{d}
"Pawe-03"	6	7.08^{b}	75.17^{a}	52.58^{ab}	13.88^{a}	2.39^{a}	4.04^{a}
"Kata"	6	6.83^{b}	61.50^{cde}	42.20^{c}	6.66^{b}	1.31^{c}	2.30^{d}
"Wogayen"	6	8.17^{a}	61.17^{cde}	56.87^{ab}	11.37^{a}	2.15^{ab}	3.36^{abc}
"Wollo"	6	8.25^{a}	60.00^{def}	55.53^{ab}	13.37^{a}	2.32^{a}	3.09^{c}
Gmean		7.66	62.56	49.70	10.29	1.86	2.85
SEM		0.10	0.6	1.12	0.69	0.11	0.13
CV		7.3	3.1	8.2	21.6	22.4	20.3
SL V		***	***	***	***	***	***
SL LO		ns	***	***	***	***	***
SL VXLO		*	*	***	***	ns	ns

Notes: Vg= Plant vigor; DF (50%)= date at 50% flowering stage; PH(50%)= plant height; BY= biomass yield; DMY= dry matter yield; HY= haulm yield; N= number of observation; SEM= standard error of mean; CV= coefficient of variation; SLV= significant level of variety; SL LO= significant level of location; SL VX LO= Significant level of variety by location interaction; ns= non significant at P> 0.05; *significant at P<0.05; *** significant at P<0.001; means with the same super script in columns are not significantly different.

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Table 5. The combined mean of seed yield and other agronomic characters of soybean varieties over locations (Jari and Sirinka) 2019

Variable	N	DM	PHM (cm)	NPPP	SY (kg.ha^{-1})	1000swt (gm)	Variable
Variety	72						
"Afgat"	6	136de	59.6^{bcd}	65.3^{b}	2859^{a}	134.3^{abc}	136de
"Belessa-95"	6	147.17^{abc}	69.5^{b}	38.9^{de}	1539^{bc}	137.4^{abc}	147.17^{abc}
"Boshe"	6	129.33^{f}	54.6^{cd}	37.3^{de}	1256^{c}	94.9^{g}	129.33^{f}
"Cheri"	6	136.5^{de}	50.9^{d}	38.4^{de}	1337^{bc}	114.9^{ef}	136.5^{de}
"Dhedessaa"	6	140.33^{cd}	70.6^{b}	41.9^{de}	1406^{bc}	118.3^{de}	140.33^{cd}
"Gishama"	6	152.5^{a}	89.1^{a}	62.1^{bc}	2654^{a}	131.1^{abcd}	152.5^{a}
"Gizo"	6	146.33^{abc}	67.7^{bc}	66.4^{b}	2862^{a}	139.9^{ab}	146.33^{abc}
"Korme"	6	142.5^{bcd}	59.9^{bcd}	36.6^{de}	1465^{bc}	124^{cde}	142.5^{bcd}
"Pawe-03"	6	148.83^{ab}	71.1^{b}	88.8^{a}	2951^{a}	104.1^{fg}	148.83^{ab}
"Kata"	6	143.5^{bc}	65.4^{bc}	35.7^{e}	1841^{b}	133.8^{abc}	143.5^{bc}
"Wogayen"	6	147.17^{abc}	71.3^{b}	49^{cde}	2404^{a}	129.2^{bcd}	147.17^{abc}
"Wollo"	6	131.5^{ef}	58.9^{bcd}	51.0^{c}	2461^{a}	145^{a}	131.5^{ef}
Gmean		141.81	65.7	50.9	2086	125.6	141.81
SEM		1.17	3.02	2.26	100.6	2.21	1.17
CV		3.8	16.8	22.3	20.9	8.9	3.8
SL V		***	***	***	***	***	***
SL LO		***	***	ns	***	**	***
SL VXLO		*	***	ns	ns	*	*

Notes: DM= date of maturity; PHM= plant height at maturity; NPPP= number of pod per plant; SY= seed yield; swt= seed weight; N= number of observation; SEM= standard error of mean; CV= coefficient of variation; SLV= significant level of variety; SL LO= significant level of location; SL VX LO= Significant level of variety by location interaction ns= non significant at P>0.05; *=significant at P<0.05;**= significant at P<0.01; *** =significant at P<0.001; means with the same super script in columns are not significantly different.

Table 6. Protein and Ash composition of soybean varieties (% DM basis)

Location		Chefa			Jari			Sirinka		
Variable	N	DM%	Ash %	CP %	DM%	Ash %	CP %	DM%	Ash %	CP %
Variety	36									
"Afgat"	3	91	9.89	29.68	91	10.99	32.46	96	10.42	26.56
"Belessa-95"	3	91	10.99	24.89	91	10.99	20.98	96	6.25	18.09
"Boshe"	3	91	10.99	21.30	91	9.89	18.80	97	12.37	17.81
"Cheri"	3	91	9.89	23.20	90	10	20.12	97	12.37	17.88
"Dhedessaa"	3	90	11.11	22.23	91	9.89	17.68	95	12.63	20.31
"Gishama"	3	91	10.99	29.12	91	10.99	29.24	97	11.34	23.06
"Gizo"	3	91	9.89	33.60	91	9.89	23.40	97	10.93	26.03
"Korme"	3	89	11.24	24.92	91	9.89	17.20	96	12.50	14.59
"Pawe-03"	3	91	8.79	27.50	91	10.99	30.49	97	11.34	25.09
"Kata"	3	91	10.99	28.69	90	11.11	20.40	97	13.40	18.53
"Wogayen"	3	91	10.99	27.34	92	9.78	27.63	97	11.34	18.13
"Wollo"	3	94	13.83	31.60	91	9.89	35.56	97	11.34	27.66
Overall mean		91	10.80	27.01	91	10.36	24.50	96.58	13.02	21.15

Notes: N= number of observation; DM= dry matter; Cp= crude protein.

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The mean NDF content at Jari from “Boshe” (28.79%) to “Belessa-95” (58.57%), ADF from “Wogayen” (19.57%) to “Kata” (40%), and ADL from “Boshe” (4.56%) to “Kata” (10%). The NDF content of “Belessa-95” was the highest compared to other varieties, making it more fibrous than the others. The ADF content of “Kata” was the highest compared to other varieties, indicating that “Kata” had the highest lignocellulose content among other soybean varieties. The ADL content of “Kata” is the highest compared to other varieties. This indicated that “Kata” has the highest lignin content as compared to other varieties. The variety of “Kata” could not be easily digested and absorbed by animals that were relatively high in crude fiber and low in total digestible nutrients and protein.

The average NDF content at Sirinka varies from 40.8% for “Wollo” to “Belessa-95” 56.14%; the average ADF varies from “Wollo” (24.74%) to “Gishama” (35.05%); and the average ADL varies from 9.1% for “Korme” to 7.27% for “Gizo” and “Wollo”. The NDF content of “Belessa-95” was the highest compared to other varieties, making it more fibrous than the others. The ADF content of “Gishama” was the highest compared to other varieties, indicating that “Gishama” had the highest lignocellulose content among other soybean varieties. Compared to other varieties, “Gishama” and “Korme” have the highest ADL content. This showed that “Gishama” and “Korme” had the greatest lignin content.

Sirinka’s elevated NDF and ADL suggest environmental factors (e.g., soil fertility, temperature, or water stress) may promote lignification, reducing forage digestibility. However, its lower ADF at Chefa and Jari implies higher hemicellulose content, potentially improving energy availability. Chefa and Jari similarity in NDF and ADF indicates comparable growing conditions, though Jari’s marginally higher ADL could stem from subtle differences in soil pH or harvest timing.The varieties “Cheri” and “Wogayen” are ideal for high-digestibility forage, especially in ruminant diets. “Kata” and “Belessa-95” are less optimal for feed.

Table 7. Fiber composition of soybean varieties (% DM basis)

Location		Chefa			Jari			Sirinka		
Variable	N	NDF%	ADF%	ADL%	NDF%	ADF%	ADL%	NDF%	ADF%	ADL%
Variety	36									
“Afgat”	3	47.67	35.16	8.94	41.35	30.77	7.67	44.32	27.08	7.32
“Belessa-95”	3	58.57	35.16	8.94	58.57	35.16	8.94	56.14	31.25	8.74
“Boshe”	3	43.79	32.97	7.61	28.79	19.78	4.56	45.38	28.87	8.12
“Cheri”	3	28.79	19.78	4.56	33.33	22.22	5.55	45.38	28.87	8.15
“Dhedessaa”	3	44.44	31.11	7.77	44.68	32.97	8.64	45.00	29.47	8.64
“Gishama”	3	44.68	32.97	7.67	43.59	32.97	7.67	55.62	35.05	9.10
“Gizo”	3	44.68	32.97	8.64	47.39	35.16	8.94	44.29	26.80	7.27
“Korme”	3	46.71	33.71	8.74	42.15	30.77	7.67	50.20	33.33	9.10
“Pawe-03”	3	31.75	21.98	4.72	50.00	39.56	9.82	50.15	32.99	8.40
“Kata”	3	45.79	32.97	4.61	52.22	40.00	10.00	45.50	30.93	8.31
“Wogayen”	3	37.59	26.37	5.79	30.24	19.57	4.68	45.38	28.87	8.15
“Wollo”	3	46.82	34.04	8.64	45.75	32.97	7.61	40.80	24.74	7.27
Overall mean		43.44	30.77	7.47	43.17	30.99	7.65	47.35	29.85	8.21

Notes: N= number of observation; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin.

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Conclusions

The results indicated significant differences among soybean varieties in terms of dry matter yield, haulm yield, seed yield, and other agronomic traits. The varieties in their combined analysis showed that "Afgat", "Pawe-03", and "Wollo" gave better results in most of the important parameters than other varieties. The CP content of all varieties exceeded the optimal level for use as a protein supplement in livestock nutrition. Specifically, "Wollo" and "Gizo" varieties gave higher crude protein content in three locations than the others. The crude protein content of these varieties indicates that they can be used as a supplementary feed for livestock production. Therefore, varieties "Afgat", "Pawe-03", and "Wollo" were recommended for the given areas of Jari, Chefa, Sirinka, and similar environments, as they are suitable for optimal forage dry matter, haulm, and seed production. In addition, it is used as a supplement for the growth and production of ruminants. In addition, it is used as a supplement for the growth and production of ruminants. Thus, further research is needed to investigate the utilization of livestock and the response of varieties on production.

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