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Effect of maize (*Zea mays* L.) genotypes, harvesting stages and ensiling periods on fermentation and nutritional value of silage

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Abstract

The current study was aimed at evaluating the effect of genotypes (G), harvesting stages (HS), and ensiling periods (EP) on fermentation quality, nutritional value, and *in vitro* digestibility of organic matter in maize silage. Three factors were studied in a 3 × 2 × 3 factorial randomized complete block design: G (Kuleni, Jibat, and Kolba), HS (milk and dough stage), and EP (4, 6, and 8 weeks). Color, aroma, texture, temperature, pH, mold, and dry matter loss of the maize silage showed significant variation ($p < 0.05$) in the G × HS × EP interaction effect. The Jibat variety harvested at the dough stage and ensiled for 6 weeks had better ($p < 0.05$) color, aroma, and texture silage quality. The Kuleni variety harvested at the dough stage and ensiled for 4 and 8 weeks had a higher ($p < 0.05$) pH value and dry matter loss of the silage, respectively. The G × HS × EP interaction has a significant ($p < 0.05$) effect on partial dry matter (PDM), ash, crude protein (CP), and metabolizable energy, but neutral detergent fiber, acid detergent fiber, and organic matter digestibility showed no significant variation ($p > 0.05$). The PDM was higher ($p < 0.05$) in the Kuleni variety harvested at the dough stage and ensiled for 4 weeks, while the value of the CP was higher ($p < 0.05$) in the Kolba variety harvested at the milk stage and ensiled for 8 weeks. Jibat and Kolba are the two varieties of maize that are suitable for silage. As the ensiling period increased, the *in vitro* digestibility of organic matter improved, but ensiling for 4 weeks is important to avoid dry matter losses.

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Introduction

Maize is the most important cereal crop in Ethiopia, and is primarily grown for human use. The crop was grown on 2,526,212.36 hectares of land in Ethiopia[1]. In a mixed agricultural system, crop residues serve as the primary source of animal feed, in particular during the dry seasons[2,3]. Most authors reported that variety differences affect the stover yield and quality traits[2−4]. In addition, the digestibility of maize silage is significantly affected by hybrids and harvesting time[5,6]. Leafy corn hybrids used for silage had a positive effect on animal performance[7] but Darby & Lauer observed that the hybrid did not affect stover yield and silage quality[8].

The type of forage crop and the ensiling conditions are crucial elements that influence the silage's fermentation process and cause a rapid pH drop[9]. Similarly, the length of the ensiling period (2–6 weeks) has an impact on silage quality. The silage is stable once the pH is about 4.0, until it is opened for feeding and exposed to air[10]. On the other hand, there is proof that some microbial activity also takes place during the stable stage of the ensiling process[11]. From the entire amount of maize produced for food, 25% was collected in the green stage[12]. Green maize stover is a highly palatable animal feed but during the dry season the quality becomes low. Dry stover is less interesting for cattle feeding and has inferior nutrition (3.7% crude protein (CP) as opposed to 8.8% in green stover)[13].

Feed shortage during the dry season and poor quality for dry maize stover are the main constraints of livestock production[2,3], but making silage is an important option to conserve green maize stover without affecting their nutritional quality and can be alternatively used in the dry season[14]. The fermentation quality, nutritional composition (ash and CP) and organic matter digestibility of the maize stover silage is highly dependent on harvesting stage and ensiling period[5,6,15]. The fermentation parameters of legume silage were affected by the ensiling length and storage temperature were determined until 75 d[16], but other research showed no significant difference in silage digestibility ensiled and exposed to air for different periods[10,17].

In Ethiopia, maize is primarily sown for grain production, and green maize is commonly sold in the market. The green stover is dried on the land, which leads to some nutritional losses, but the green stover can be used for silage production. The changes in nutritional and fermentation quality and digestibility of the silage from different maize genotypes with different harvesting stages and ensiling periods have not been evaluated under such conditions. Therefore, the current study was designed to evaluate fermentation quality, nutritive value, metabolizable energy, and digestibility (*in vitro*) of maize silage prepared from different cultivars/genotypes that were harvested at different stages, and ensiled for different periods.

Materials and methods

Experimental design and silage preparation

The highland maize varieties (Kuleni, Jibat, and Kolba) were grown at the Holetta agricultural research center, which is located 29 km west of Addis Ababa, Ethiopia. The center is located at 9°03'28.82" E latitude and 38°30'17.59" E longitude and at an elevation of 2,400 m above sea level. The region receives 1,144 mm of rain on average each year, and the average daily temperature ranges from 6 to 21 °C.

A factorial randomized complete block design containing three factors, including varieties, cultivars, and genotypes (Kuleni, Jibat, and Kolba), harvesting stage (milk and dough stage), and length of ensiling periods (4, 6, and 8 weeks) with each combination replicated five times, was used to evaluate the quality of the silage.

Maize planting was made on a gross plot size of 15 m^2 (3 m × 5 m) with a recommended space of 0.75 m between rows, followed by 0.25 m between plants. The space between plots and blocks was 1 and 1.5 m, respectively. A fine seedbed with good soil moisture content was used for planting. Two seeds were inserted into each hole before being filled with fine soil. During the sowing season, diammonium phosphate (200 $kg \cdot ha^{-1}$) was used. To maintain the ideal plant population, undesirable plants were removed after 15 d of planting. Additionally, urea (120 $kg \cdot ha^{-1}$) was administered *via* sprinkling during the growing season and top-dressing at the knee-high stage. The maize was harvested above the ground (10–15 cm). The part of the block in each variety was harvested at the milking stage (after 75 d of growing), and the remaining biomass was harvested at the dough stage (after 120 d of growing) after removing the cob or grain for human consumption.

For adequate compaction and consolidation, the biomass obtained at both harvesting stages was chopped (1–3 cm). For simultaneous compacting purposes, the chopped biomass was weighed, put into a plastic bag (20 cm × 30 cm), and put into a 4-L plastic bucket. By hand and intermittent tamping with a wooden stick, all plastic bags were filled to the same packing density (1,000 g per plastic bag on a fresh matter basis). The plastic bags were immediately sealed within the buckets after being neatly packed. A heavy load was placed on top of the plastic bag and incubated at room temperature to eliminate oxygen from the materials that had been ensiled.

Silage fermentation parameters

After the ensiling periods (4, 6, and 8 weeks), the corresponding small silos were opened for the sensory parameter evaluation of the silages. As soon as the silage was opened, the thermometer was put into the silos, and then the silage temperature was recorded. The pH meter (Hanan Benchtop pH meter) was calibrated with buffer solutions (pH 4 and 7), and it was used to measure the pH values of the silage. Following a mold inspection, the silage was well mixed, and representative samples were collected and refrigerated to evaluate the pH and chemical composition of the silage. To measure the pH of the silage, a 20-g sample was taken into a beaker, mixed with 100 mL of distilled water, blended with a glass stirrer, and kept for 1 h.

Total dry matter loss was calculated as (DM of forage – DM of silage)/DM forage × 100)/DM of forage weight loss in the silage.

Physical characteristics/sensory evaluations

The physical characteristics (colour, smell, texture, and moldiness) were assessed immediately after the silo was opened and appraised subjectively by a panel of five individuals with experience assessing the quality of silage. Before starting the real review, the panelists who were from the department of animal feeds and nutrition research program were given an introduction to the criteria (Table 1) and given an exercise. On a scale of 1–4, the silage's physical quality criteria were graded[18].

Chemical composition

The chemical composition and *in vitro* digestibility of maize silages were determined at the Holetta agricultural research center in the animal nutrition laboratory. Representative samples were taken after each ensiling period. The samples were dried in an oven at 60 °C for 72 h. The dried samples were ground to pass through a 1 mm sieve in a Wiley mill. Dry matter, crude protein, and ash contents of the silage were determined with the AOAC (1990) procedure[19]. Neutral detergent fiber, acid detergent fiber, and acid detergent lignin were determined by Van Soest et al.[20].

In vitro digestibility

The *in vitro* digestibility of the feed was determined by using the two-stage method of Tilley & Terry[21]. Rumen liquor was collected and transported to the laboratory using thermos flasks and pre-warmed to 39 °C before the daily meal of the three cannulated Boran-Friesian steers. The steers were 42 months old and weighed 590 kg. The steers were fed natural pasture hay (6% CP, on a DM basis) *ad libitum* and a 2-kg concentrate (19.86% CP, on a DM basis) per day/head every morning. The sample (0.5 g) was incubated in a test tube at 39 °C for 48 h with 10 mL of rumen fluid and 50 mL of buffer solution. After the microbiological digestion, the enzymatic digestion with acid pepsin solution (i.e., 5 mL per tube) was continued for another 48 h. Blank samples were also incubated in duplicate with buffered rumen fluid for correction of *in vitro* organic matter digestibility. Digestible organic matter in the dry matter (DOMD) was determined after drying and burning the residues. Estimated metabolizable energy (ME) was calculated by using ME (MJ/kg) = 0.16*g DOMD/kg DM[22].

Statistical analysis

Data was analyzed by using the statistical analysis system, version 9.3[23]. A 3 × 2 × 3 factorial randomized block design containing three factors such as variety (Kuleni, Jibat and Kolba) harvesting stage (milking and dough stage), and length of ensiling periods (4, 6 and 8 weeks) were subjected to analysis.

Table 1. Sensory evaluations and fermentation characteristics.

Sensory parameters	Rating scale			
	1	2	3	4
Color	Dark	Olive yellow	Light olive green	Olive green
Smell/aroma	Offensive	Moderately pleasant	Pleasant	Very pleasant
Texture	Slimy	Soft	Fairly firm	Firm
Mold coverage	Highly moldy	Moderately moldy	Scattered mold spot	No mold

1 = Bad, 2 = Moderate, 3 = Good, 4 = Excellent.

Significances of differences among treatments were determined by using Tukey tests ($p < 0.05$). The following statistical model was used Yijkl = μ + Vi + Pj + Hk + VPHijk + Eijkl, Where, Yijkl = the dependent variable, μ = overall mean, Vi = effect of variety (i = 1, 2, 3), Pj = effect of ensiling period (j = 1, 2, 3), Hk = effect of harvesting stage (k = 1, 2), VPHijk = interaction effect, Eijkl = experimental error.

Results

Physical characteristics and fermentation quality

The sensory and fermentation quality of the maize silage, including colour, aroma, texture, temperature, pH, mold and dry matter loss, showed significant variation ($p < 0.05$) with the interactional effect of variety × harvesting stage × ensiling period (Table 2). The Jibat maize variety harvested at the dough stage and ensiled for 6 weeks has a better ($p < 0.05$) silage quality (colour, aroma, and texture). However, the Kuleni variety harvested at the dough stage and ensiled for 4 and 8 weeks had a higher ($p < 0.05$) pH value and dry matter loss of the silage, respectively. The total dry matter loss of the silage in the Kuleni variety was higher than the silage prepared from the Jibat and Kolba maize varieties. As the incubation period increased, dry matter loss in the silage increased, but its pH value decreased. The silage prepared from Jibat and Kolba cultivars has a superior textural quality than the Kuleni cultivar.

Chemical composition and *in vitro* digestibility

The interaction effect of genotype × harvesting stage × ensiling period has a significant variation ($p < 0.05$) on partial dry matter (PDM), ash, crude protein (CP), and metabolizable energy, but neutral detergent fiber (NDF), acid detergent fiber (ADF), and *in vitro* organic matter digestibility in the dry matter (DOMD) showed no significant variation ($p > 0.05$) (Table 3). The PDM was higher ($p < 0.05$) in the Kuleni variety harvested at the dough stage and ensiled for 4 weeks, while the value of the CP was higher ($p < 0.05$) in the Kolba variety harvested at the milk stage and ensiled for 8 weeks. As the ensiling period lengthened, the fiber fractions of the silage declined, but the digestibility of the silage increased. The NDF, ADF, and acid detergent lignin contents of silage made up of the Jibat and Kolba maize cultivars were lower than those of silage prepared from the Kuleni maize variety, but the values of DOMD in the silage prepared from Jibat and Kolba cultivars were higher than the silage made up of the Kuleni cultivar. The higher ash and crude protein contents and the lower fiber fractions in Jibat and Kolba maize variety silages demonstrate that they are

Table 2. Effect of variety × harvesting stage × ensiling period on sensory and fermentation characteristics of the maize silage.

Variety	HS	EP (weeks)	Colour	Aroma	Texture	Mold	pH	T^{0}	TDML
Kuleni	Milk	4	3.24^{h}	3.08^{j}	3.48^{j}	3.72^{g}	4.04^{g}	19.84^{d}	11.13^{p}
		6	3.44^{f}	3.40^{h}	3.64^{h}	4.00^{a}	3.98^{i}	20.40^{b}	16.40^{k}
		8	2.28^{j}	2.48^{k}	2.60^{l}	2.60^{i}	3.80^{l}	19.54^{f}	20.07^{e}
Jibat		4	3.36^{g}	3.08^{j}	3.60^{i}	3.72^{g}	4.00^{h}	19.46^{g}	6.30^{r}
		6	3.72^{c}	3.84^{b}	3.88^{c}	3.80^{e}	3.88^{k}	21.58^{a}	12.05^{o}
		8	3.56^{d}	3.52^{g}	3.76^{f}	3.84^{d}	3.70^{n}	19.68^{e}	16.59^{j}
Kolba		4	3.00^{i}	3.20^{i}	3.64^{h}	3.72^{g}	4.00^{h}	20.06^{c}	7.36^{q}
		6	3.00^{i}	3.80^{c}	3.84^{d}	3.92^{b}	3.74^{m}	20.40^{b}	13.20^{m}
		8	3.00^{i}	3.08^{j}	3.32^{k}	3.60^{h}	3.70^{n}	19.38^{h}	17.52^{h}
Kuleni	Dough	4	3.36^{g}	3.60^{f}	3.76^{f}	3.76^{f}	4.38^{a}	18.70^{k}	16.76^{i}
		6	3.36^{g}	3.60^{f}	3.72^{g}	3.88^{c}	4.16^{d}	18.74^{j}	20.64^{d}
		8	3.56^{d}	3.64^{e}	3.72^{g}	3.84^{d}	4.04^{g}	18.74^{j}	22.15^{a}
Jibat		4	3.52^{e}	3.20^{i}	3.84^{d}	3.80^{e}	4.24^{b}	18.66^{l}	13.10^{n}
		6	4.00^{a}	4.00^{a}	4.00^{a}	4.00^{a}	4.06^{f}	18.60^{n}	18.09^{g}
		8	3.76^{b}	3.84^{b}	3.88^{c}	3.88^{c}	2.90^{o}	18.60^{n}	20.87^{b}
Kolba		4	3.00^{i}	3.20^{i}	3.80^{e}	4.00^{a}	4.22^{c}	18.62^{m}	14.32^{l}
		6	3.00^{i}	3.68^{d}	3.88^{c}	3.80^{e}	4.10^{e}	19.14^{i}	19.16^{f}
		8	3.00^{i}	3.80^{c}	3.92^{b}	3.84^{d}	3.96^{j}	19.14^{i}	20.67^{c}
LSD			0.006	0.006	0.006	0.004	0.006	0.005	0.006
SEM			0.01	0.02	0.01	0.005	0.01	0.02	0.01
Overall average		Kuleni	3.20	3.30	3.48	3.63	4.06	19.32	17.85
		Jibat	3.65	3.58	3.82	3.84	3.79	19.43	14.50
		Kolba	2.99	3.30	3.73	3.81	3.94	19.45	15.37
		4	3.24	3.22	3.68	3.78	4.14	19.22	11.49
		6	3.42	3.72	3.82	3.90	3.98	19.81	16.59
		8	3.19	3.39	3.53	3.60	3.68	19.18	19.64
Statistical effect		V	***	***	**	***	**	***	***
		HS	***	***	***	***	***	***	***
		EP	***	***	***	***	**	***	***
		V × HS	***	***	**	***	***	***	***
		V × EP	***	*	***	***	***	***	***
		HS × EP	***	***	**	***	***	***	***
		V × HS × EP	***	***	***	***	**	***	***

$^{a-r}$ Means with different superscripts within the same column are significantly different ($p < 0.05$); V = variety, HS = harvesting stage, EP = ensiling period, LSD = least significance difference, T^{o} = silage temperature; TDML = total dry matter loss; SEM = Standard error of the mean * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Table 3. Effect of variety × harvesting stage × ensiling period on chemical composition (%, DM basis) and metabolizable energy (MJ/Kg DM) of the maize silage.

Variety	HS	EP (weeks)	PDM	Ash	CP	NDF	ADF	ADL	DOMD	ME
Kuleni	MS	4	20.50^{k}	7.98^{n}	4.43^{d}	60.78	33.97	3.54^{def}	54.76	8.80^{i}
		6	19.28^{n}	10.31^{i}	4.24^{ef}	59.65	32.68	3.40^{fg}	56.46	9.00^{h}
		8	18.82^{o}	11.12^{f}	3.64^{h}	59.99	32.74	3.36^{gh}	57.36	9.20^{f}
Jibat		4	22.35^{h}	11.96^{d}	4.88^{b}	59.97	31.75	3.26^{ghi}	57.28	9.20^{f}
		6	20.98^{j}	12.52^{b}	5.28^{a}	59.28	31.15	3.06^{kl}	58.70	9.40^{c}
		8	19.89^{m}	13.31^{a}	4.28^{ef}	58.70	30.24	2.73^{m}	59.90	9.60^{a}
Kolba		4	21.54^{i}	9.76^{j}	4.19^{f}	60.35	31.42	3.16^{ijk}	56.74	9.10^{g}
		6	20.17^{l}	10.33^{i}	4.69^{c}	59.23	30.94	3.01^{l}	57.92	9.30^{e}
		8	19.22^{n}	10.89^{g}	5.14^{a}	58.89	30.43	3.11^{jkl}	58.35	9.30^{e}
Kuleni	DS	4	27.05^{d}	4.58^{q}	3.93^{g}	61.28	34.47	4.04^{a}	54.46	8.70^{j}
		6	25.79^{f}	5.74^{p}	3.74^{h}	60.15	33.18	3.90^{ab}	56.16	9.00^{h}
		8	24.71^{g}	6.07^{o}	3.14^{i}	60.49	33.24	3.86^{b}	57.06	9.10^{g}
Jibat		4	28.75^{b}	8.28^{m}	4.38^{de}	60.47	32.25	3.76^{bc}	56.98	9.10^{g}
		6	27.10^{d}	8.98^{l}	4.78^{bc}	59.78	31.65	3.56^{de}	58.40	9.35^{d}
		8	25.93^{f}	9.38^{k}	3.78^{h}	59.20	30.74	3.23^{hij}	59.60	9.50^{b}
Kuleni		4	29.51^{a}	10.49^{h}	3.69^{h}	60.85	31.92	3.66^{cd}	56.44	9.00^{h}
		6	27.84^{c}	12.36^{c}	4.19^{f}	59.73	31.44	3.51^{ef}	57.62	9.20^{f}
		8	26.85^{e}	11.36^{e}	4.64^{c}	59.39	30.93	3.61^{de}	58.05	9.30^{e}
LSD			0.15	0.15	0.13	0.15	0.14	0.12	0.16	0.15
SE			0.02	0.01	0.03	0.04	0.02	0.03	0.03	0.01
Overall average		Kuleni	22.69	7.63	3.85	60.39	33.38	3.68	56.04	8.97
		Jibat	24.17	10.74	4.56	59.57	31.30	3.27	58.48	9.34
		Kolba	24.19	10.87	4.42	59.74	31.18	3.34	57.52	9.20
		4	24.95	10.36	4.25	60.62	32.63	3.57	56.11	8.98
		6	23.53	10.04	4.49	59.64	31.84	3.41	57.54	9.21
		8	22.57	8.84	4.10	59.44	31.39	3.32	58.39	9.33
Statistical effect		V	***	***	***	***	***	***	***	***
		HS	***	***	***	***	***	***	***	***
		EP	***	***	***	***	***	***	***	***
		V × HS	***	***	NS	NS	NS	NS	NS	NS
		V × EP	***	***	***	***	***	***	***	***
		HS × EP	***	***	NS	NS	NS	NS	NS	**
		V × HS× EP	**	***	*	NS	NS	**	NS	***

$^{a-r}$ Means with different superscripts within the same column are significantly different ($p < 0.05$); V = variety, HS = harvesting stage, EP = ensiling period, LSD = least significance difference, T° = silage temperature; TDML = total dry matter loss; SEM = Standard error of the mean * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, NS = Non significance, DS = Dough stage, MS = Milk stage, neutral detergent fiber (NDF), and acid detergent fiber (ADF).

potential ruminant fodder because increasing the concentration of cell wall compounds limits feed intake and energy availability of forages in ruminants.

Discussion

Physical characteristics and fermentation quality

Maize silages prepared from three maize varieties (Kuleni, Jibat and Kolba) and harvested at dough and milk stage and ensiled for different periods have different sensory and fermentation characteristics. In agreement with the current finding, the previous report confirms that harvesting stage and variety has a significant effect on silage quality[24−26]. The maize stover silages made from the two maize accessions (West Atlantic Seed Alliance 1 and Shika tagged) and the Arganie variety (a hybrid of Wonchi and Kulani) which were harvested at 95, 105, and 109 d after sowing and ensiled for three ensiling durations (4, 6 and 8 weeks), are comparable with the present silag physical and sensory qualities[6,25−27]. A leafy texture, soft touch, yellowish-brown, mild, and pleasant smell are the main characteristics of quality silage[28].

A lower value of pH in the maize silage is an indicator of increased lactic acid concentration, thereby implying better fermentation during the ensiling period; the pH value of the silage in the current study was found between 3.70 and 4.20 which is comparable with the previous reports[28,29]. In line with the current finding, when the ensiling period began to increase, the value of pH was going to decrease[22,29], but when the ensiling period increased from 30 to 120 d, the pH value increased from 3.97 to 4.01 in maize and Faba bean-based silage and the silage prepared from pearl millet (*Pennisetum americanum*) accessions (Mokwa, Bunkure, and Kankara) which were harvested at the growing, flowering and milk stages, had higher pH values (4.3–4.5)[24,30], this difference might be due to the dry matter and less water soluble carbohydrate concentrations of the pre-ensiled maize varieties harvested at the dough stage. As documented in other researcher works, the value of pH in the silage is significantly affected by the dry matter and water soluble carbohydrate contents of the forage and harvesting stages[22,31]. In agreement with our findings, earlier studies have reported the value of pH in the maize silage which ranges from 3.6 to 4.2[27,32].

Our observation with regard to dry matter loss is associated with the maturity stage and ensiling period, which is in line with the findings of another researcher who documented a different dry matter loss of the silage in different harvesting stages and ensiling periods[33,34]. The silage dry matter loss is completely related to sugar and starch reduction, which are directly associated with the removal of cobs and grain from the recently harvested maize varieties. The reduction in pH value in the silage and the silage exposed to air during feeding phase is responsible for dry matter loss[35,36].

The higher temperatures in silage do not always promote optimal silage fermentation since they decrease the silage's quality, accelerate protein breakdown, and slow down the pH's quick reduction for effective degradation[36−38]. The amount of temperature (18.6–21.58 °C) in maize silage that is reported in the present study is higher than the amount of temperature (16.62–19.52 °C) in maize stover silage prepared from the Arganie variety[6]. In contrast with our findings, earlier studies have reported a higher amount of silage temperature (27–40 °C)[33,39], this variation might be related to the climate condition under which the silage trials were done.

Chemical composition and *in vitro* digestibility

The dry matter (DM), and ash contents of the maize silage reported in the present study are lower than the DM and ash values of the silage which were done by other researchers[34,40], but the silage prepared from the two maize accessions by Hayashi et al.[41] had a similar amount of ash content with the present finding. The higher (4.5%–5.5%) level of the ash in maize stover silage was reported previously[40,42]. The current finding is confirmed by the previous reports, which stated that harvesting stage and variety have a significant effect on silage fiber fraction crude protein, and *in vitro* organic matter digestibility[25,27,43].

Our finding with regard to the variation of nutritional qualities of the silage, which are strongly associated with maturity stage and ensiling periods, is in line with the findings of other researchers, who noted that length of ensiling period and maturity stages are the major factors that affect the nutritional composition of the silage made from maize and sorghum crops[44−48]. The proportion of leaves, stalks, and grain content has a significant effect on the partial dry matter content of maize silage[33,49]. A little decline in reducing sugars, which was observed in sweet sorghum and corn silage, could be used to explain the drop in partial dry matter. This decrease may also be attributed to the need to maintain the microbial population in the maize silage[28,50].

The nutrient concentration in the maize crop decreases with grain filling in the parent material used to make silage, variations in crude protein (CP) content observed with the stage of harvest are expected[41,50]. The CP content of the silage obtained from the current study is within the range of 4.5% to 8.5 %, which has been reported by other studies[51]. In contrast with our findings, earlier studies have reported higher CP values (6.4%–8%) among different maize genotypes[45,52]. Additionally, the CP content of the silage prepared from the three maize varieties (Kuleni, Jibat, and Kolba) in the current trial was less than the minimal amount of CP (8%) required for rumen microbe growth[22,53]. As opposed to the current findings, previous findings have reported a positive change in CP content as the silage has been incubated for various ensiling periods[49,54], but the ensiling length did not affect CP concentration in sorghum silage[16].

The fiber fractions of the silage are significantly affected by the stage of harvesting, and management of ensiled crops due to different fermentation quality and losses from ensiled materials[30,51]. The neutral detergent fiber (NDF), and acid detergent fiber (ADF) contents of the silage decreased as the ensiling period increased, which is in line with previous findings from other researchers[36,42,54]. The NDF content in maize silage which is reported in the present study is marginally lower than the values of NDF in maize stover silage prepared from the Arganie variety[6,34]. In agreement with our findings, earlier studies have reported equal amount of lignin and ADF in silage made from different maize accessions[45,36], but the silage prepared from Arganie maize variety has the higher ADF and lignin contents[6,34].

Cellulase and hemicellulase activity of bacterial enzymes and the generation of organic acids during fermentation may be responsible for the reduction in fiber concentration of silage[54]. In contrast with our findings, earlier studies have reported the lower NDF values of the silage (41.5 to 47.1 g/100 g DM) prepared from different maize genotypes[26,52,55], this variation might be due to the differences in leaf and steam ratios in maize stover.

The amount of metabolizable energy (ME) in maize silage obtained from the current finding is comparable with the level of ME in maize and sorghum stover based silage which is reported by other researchers[25,28,47]. In line with the current finding, *in vitro* digestibility of corn silage is affected by hybrids (normal and brown mid-rib) which were stored for 270 d[44,47]. In contrast with our findings, other researchers reported that the ensiling period and areas had no effect on the digestion and fermentation of the silage[10,56]. The possible reason for the variation in nutritional composition and *in vitro* organic matter digestibility of maize silage might be related with genotype, harvesting stage, and agronomic practices of the land used to sow the crop.

Conclusions

The results of this experiment clearly demonstrate that the maize genotype, harvesting stage, and ensiling period have a significant effect on silage fermentation quality, nutritional value, and *in vitro* organic matter digestibility. As the ensiling period lengthened, the fiber fractions of the silage declined and the digestibility of the silage increased, but to minimize dry matter loss, the maize varieties should be ensiled for 4 weeks. It was concluded that Jibat and Kolba are the most suitable maize genotypes for silage production in terms of physical characteristics, *in vitro* digestibility, nutritional quality, and fermentation quality under the environmental conditions of Ethiopia. However, lactic acid, volatile fatty acids, and ammonia-N levels in the silage should be verified, and a feeding trial is required to confirm this finding.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Terefe G, Kitaw G; data collection: Terefe G, Faji M, Mengistu G; analysis and interpretation of results: Dejene M, Kehaliu A, Fekadu D, Mekonnen B, Walelegne M; draft manuscript preparation: Terefe G, Kitaw G. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflict of interest

The authors declare that they have no conflict of interest.

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