

Nutrient contents and in vitro digestibility of different parts of corn plant

T. Ayaşan^{1#}, N. Cetinkaya², S. Aykanat³ & C. Celik²

¹Osmaniye Korkut Ata University, Kadirli Academy of Applied Sciences, Osmaniye, Turkey

²Ondokuz Mayıs University, Faculty of Veterinary Medicine, Department of Animal Nutrition and Nutritional Diseases.
55139, Atakum, Samsun, Turkey

³East Meditarreanean Agricultural Research Institute, Adana, Turkey

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Abstract

The objective of this study was to assess the nutrient contents and in vitro true digestibility (IVTD) of parts of the corn plant. The corn used in the study was P2088, a variety that is grown widely in Turkey. It had matured and was harvested 140 days after planting. Four replicate plants were separated into nine parts, namely lower stalk, central stalk, upper stalk, corn ear stalk, corn ear shuck, kernels, corn cob, leaf, tassel, plus the entire plant. The samples were dried and ground for analysis. Nutritional values were determined in the laboratory and in vitro digestibility was assessed. Significant differences in nutrient content were observed among parts of the corn plant. The highest crude protein (CP) content was found in the leaf (12.41%), followed by the grain (12.37%). Dry matter (DM) varied from 91.25% to 96.07%. The highest ether extract (EE) was in the grain (2.84%), and the upper stalk contained the least EE (0.29%). The parts also differed in their contents of crude cellulose (CS) and crude ash (CA) ($P < 0.001$). Most organic matter (OM) was found in the corn cup (94.27%). The highest in vitro dry matter digestibility (IVDMD) was in the kernels (79.06%) and the lowest was in the lower stalk (38.13%). In terms of in vitro true organic matter digestibility (OMD) values of the corn plant and its 9 parts, the highest values were found in the kernels and the lowest in the lower stalk.

Keywords: crude nutrients, in vitro true digestibility, parts of corn plant

Corresponding author: tayasan@gmail.com

Introduction

Quality roughage and concentrate feeds are the most important input in livestock farming, so there is a need for procuring this feed, increasing its production, and meeting the requirements of the livestock industry. Feed prices are a major factor that affects the economic viability of farmers. Therefore, efforts dedicated to reducing feed costs would be of direct benefit to them. In this regard, using corn residues after harvest is one practice that reduces feed expenses, and lowers the cost of animal production.

Corn, an annual warm-season cereal crop, can be grown in tropical, subtropical, and temperate climate zones. It occupies 25.7% of the land area that is used in cereal cultivation (Açar *et al.*, 2015). Although it is used primarily as human food and animal feed (Tandzi & Mutengwa, 2020), corn is an industrial raw material. It has particular importance in human nutrition in less developed countries. Cereal grain production totals 2.7 billion tons worldwide, of which corn amounts to 1 038 281 thousand tons or 38.1% of total cereal production. Corn ranks third after wheat and rice in cultivation area and first in the amount produced in the world. In Turkey, grain corn and corn silage account for 68% and 32% of the area planted to corn, respectively (Turkish Grain Board, 2014).

The kernels constitute approximately 46% of the dry matter of a corn plant, with the stalk, leaf, cob and husk collectively constituting the remaining 54% (Pordesimo *et al.*, 2004). Kowalik *et al.* (2013) stated that the DM, chemical composition and energy values for the corn stalk differed, depending on the variety and the cutting height of the plant at harvest. Corn stover (stalk and leaf) can be used effectively in ruminant feeding (Li *et al.*, 2014; Feedipedia, 2016; Mourtzinis *et al.*, 2016).

Studies on the nutrient analysis and *in vitro* digestibility of the parts of corn are scarce in the scientific literature. Therefore, this study was designed to examine the variations in nutrient composition of the ten parts that make up the corn plant using the *in vitro* gas production technique.

Materials and Methods

Rumen fluid for use in measuring *in vitro* digestibility was collected at Florya Company Slaughter House (Samsun, Turkey) from freshly slaughtered animals. These beef cattle had been kept for commercial meat production at Florya Company's farm. They were fed dried grass (83 g CP/kg DM; 6 MJ ME/kg DM) *ad libitum* and 8 kg concentrate feed (120 g/kg CP and 10.80 MJ ME/kg DM). Immediately after collection, the rumen fluid was transported to the Ruminant Feed Evaluation Laboratory. Ruminant content was strained through three layers of cheesecloth and kept at 39 °C in a CO₂ atmosphere until it was used in an *in vitro* digestibility assay.

Table 1 Chemical analysis of soil samples collected from corn fields at Dogankent

Saturation, %	Soil type	pH	Salt	Lime %	OM	P ₂ O ₅ kg/dekare	K ₂ O	Zn	Fe	Cu mg/kg	Mn
72	Clayey	8.10	0.02	15.96	2.38	4.69	150.97	0.35	7.28	1.23	4.86

OM: Organic matter, P₂O₅: phosphorus pentoxide, K₂O: potassium oxide, Zn: zinc, Fe: iron, Cu: copper, Mn: manganese

During the corn growing season, 155.6 mm of precipitation were received. Seasonal climate values of main product corn are shown in Table 2. Because of insufficient precipitation, drip irrigation was provided once a week during the growing season and for ten times in total. The weather temperature values in the first half of June did not affect pollination negatively. That is, the kernel set, and seeds extended the full length of the cob. In short, during the fertilization weeks, there was an ideal climate for the corn. The highest average value for relative humidity was observed in June at 76.27%. Relative humidity increased with temperature and irrigation of the crop. This created an environment that was conducive to the emergence of fungal diseases, but chemical treatments were not carried out because the severity of the northern leaf blight and rust diseases was below the economic damage threshold.

Table 2 Weather during the growing season for corn at Dogankent from 27 March to 13 August 2018

Month	Days	Air temperature, °C			Relative humidity, %			Rainfall, mm
		Minimum	Maximum	Mean	Minimum	Maximum	Mean	
March	5	10.4	24.78	17.04	33.18	94.38	68.68	18.80
April	30	13.00	27.93	19.90	35.06	96.88	69.49	44.20
May	31	16.81	31.10	23.20	36.82	95.43	70.36	80.6
June	30	19.68	32.29	25.36	46.08	98.10	76.27	11.4
July	31	22.54	34.08	27.89	47.57	97.07	75.76	0.60
August	13	23.04	35.02	28.37	44.47	96.24	74.30	0.00
Total	140							155.6

The production area was tilled to make it ready for sowing. Ridges, 70 cm apart, that had been created in the autumn were tilled again in January because of weed growth. Just before sowing, the base dressing was applied, and the ridges were prepared for planting. The corn planter was adjusted to ensure a planting depth of 5 - 6 cm and seeds were spaced 20 cm apart on the ridges. Germination was completed 15 days after

planting. Diammonium phosphate fertilizer was applied at 22.5 kg/dekare during planting and 67.5 kg urea/dekare was applied as a top dressing when the plants were 40 - 50 cm tall.

The plants were first cultivated for weed control when they reached the height of 10 - 15 cm, and again when they reached a height of 40 - 50 cm. During the corn growing season, a pesticide was used once for protection from corn borers. Immediately after being cultivated for the second time, a drip irrigation system was installed, and the plants were watered. Irrigation continued once a week for the remainder of the growing season.

The corn reached harvest maturity after 140 days and was harvested on 13 August 2018. Four randomly selected replicate plant samples were collected. These plant samples were separated into nine parts (Figure 1), and the fractions were dried and ground for nutrient analyses.

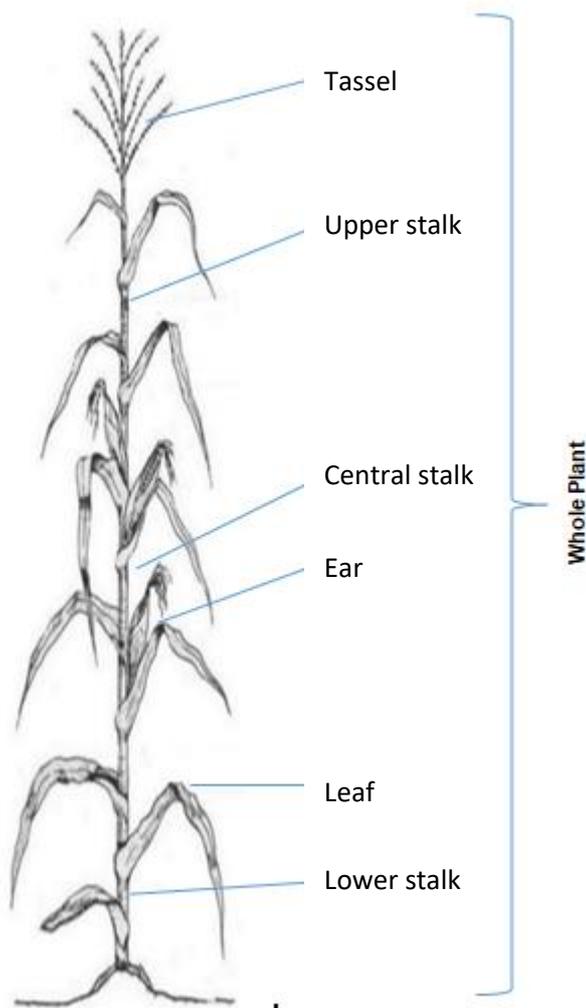


Figure 1 Morphological schematic of a corn plant illustrating its parts

The total corn plant and lower stalk, central stalk, upper stalk, corn ear stalk, corn ear shuck, kernels, corn cob, leaf, tassel of the corn plant were sampled. There were four replicate samples from the total plant and each of the nine parts were analysed individually. Samples were milled to pass through a 1-mm sieve. Milled feed samples were then analysed chemically using AOAC methods for dry matter (DM), crude protein (CP), ether extract (EE), crude cellulose (CC), and crude ash (CA) (AOAC, 2006). An *in vitro* Ankom Daisy fermentation device (Ankom Technology Corp. Fairport, NY, USA) was used to estimate the true digestibility of samples of corn plant and each of its ten parts. Again, the quadruple samples from each part of the plant were used to estimate IVTD. The method of determining IVTD was described by Czerkawski and

Breckenridge (1977). Buffer solutions were prepared as specified for Ankom Daisy in vitro fermentation equipment

The weighed sample bags were placed in four digestion jars. Then 1600 mL buffer solution and 400 ml rumen fluid were poured into each jar. The jars were removed from their chambers after 48 hours of incubation at 39 °C. Bags were rinsed with cold running tap water, then dried at 105 °C for 12 hours and burned in an ashing oven at 550 °C for 4 - 6 hours. The DM and ash contents of each sample were calculated. Finally, in vitro true digestibility (D) was calculated for DM and OM using the equation given by Ozcan and Kiliç (2018):

$$D = 100 - \frac{((W3 - (W1 \times C1))}{W2}$$

Where: W1 = weight of F57 bag,
W2 = dried sample or nutrient (DM or OM),
W3 = nutrient left in residue after incubation, and
C1 = weight of blank bag after incubation.

Analysis of variance was used to test differences among parts of the corn plants. Duncan's multiple comparison test was used to separate means when significant differences were observed.

Results and Discussion

In Çukurova region, the early maturing (105 - 115-day) varieties (FAO 650-750) are preferred as the main crop and the 120 - 135-day varieties (FAO 550-650) are considered a secondary crop (FAO, 2014). If the corn is sown as the main crop, it is the best to sow it between March and mid April. If it is the secondary plant, it should be sown immediately after the wheat harvest and by the beginning of July at the latest. In both cases, the harvest time is between late September and early October.

Corn kernels are commonly used in animal feeding as a source of energy (Li *et al.*, 2014). On the top of the stalk of corn, there are male flowers in the shape of a mixed cluster (tassel). Female flowers grow in the shape of an ear in the axil on the middle part of the stalk. Each plant has one to three ears. A corn plant produces three to five million pollen grains. Blooming starts on the tassel one to three days before the silk grows out. Almost immediately after coming into contact with the silk, pollen grains start the growth of the pollen tube, which ultimately enters the female flower or ovule. Each ovule is a potential kernel and a well-developed ear should have 750 - 1000. Li *et al.* (2014) stated that the tassel consisted of 92.26% DM, 6.60% CP, 1.4% CF, 71.49% NDF, 37.80% ADF, and 5.78% ADL. All chemical constituents varied among the parts of the corn plant ($P < 0.001$). The chemical compositions of the entire corn plant and its parts are shown in Table 3.

Table 3 Chemical composition of total corn plant and its ten parts

Parts	DM %	CP %	EE %	CF %	CA %
Lower stalk	94.05 ^{bc}	6.05 ^c	0.41 ^{de}	38.96 ^a	5.31 ^{de}
Central stalk	92.92 ^{cd}	6.30 ^c	0.43 ^{de}	29.23 ^{cde}	5.14 ^{de}
Upper stalk	91.61 ^{de}	4.37 ^d	0.29 ^e	29.61 ^{cd}	6.88 ^c
Ear stalk	92.73 ^{cd}	5.03 ^{cd}	0.56 ^{cde}	27.04 ^e	4.70 ^e
Ear shuck	95.13 ^{ab}	4.30 ^d	0.79 ^{bc}	32.32 ^b	6.03 ^{cd}
Kernels	92.56 ^{de}	12.37 ^a	2.84 ^a	2.60 ^g	0.82 ^g
Cob	96.07 ^a	4.00 ^d	0.31 ^{de}	32.50 ^b	1.80 ^f
Leaf	92.80 ^{cd}	12.41 ^a	1.03 ^b	22.17 ^f	17.90 ^a
Tassel	91.25 ^e	11.03 ^a	0.60 ^{cd}	30.32 ^{bc}	10.86 ^b
Entire plant	92.22 ^{de}	9.03 ^b	0.40 ^{de}	27.84 ^{de}	5.02 ^e

^{a-e} within columns means with a common superscript do not differ at $P=0.05$

DM: dry matter, CP: crude protein, EE: ether extract, CF: crude fibre, CA: crude ash

With the development of silage technology, the entirety of the corn plant has become one of the most important feedstuffs for animals in the world.

Corn stalk is generally classified as low-quality roughage. In recent years, it has emerged as a competitor to corn straw. It has become a product and is baled, not left on the field. The main problem with the use of corn stalks in animal feeding is their physical condition. Before giving them to animals as feed, they should be chopped and added to the total mixed ration (TMR). Ming-yuan *et al.* (2015) found that the DM content of the lower stalk, middle stalk, and top stalk were 79.1%, 73.7%, and 64.0%, respectively, and the DM content of the whole stalk was 75.7%. Ayaşan *et al.*, (2019) found that DM contents were 90.92%, 91.54%, and 90.54%, respectively, with an average of 91.00%. In another study, it was found that the nutrient contents of corn stalks differed depending on the levels of added enzyme. The structure of the corn stalk without enzyme additive contained 87.90% DM, 2.02% CF, 35.06% CC, 61.63% NDF, 43.16% ADF, and 9.79% ADL (Gado *et al.*, 2017).

In the present study, the leaf contained 92.80% DM, 12.41% CP, 1.03% CF, 22.17% CC, and 17.90% CA. However, Ayaşan *et al.* (2019) found that the leaf contained 87.76 % DM, 13.09% CP, 66.98% NDF, 40.87% ADF, and 0.88% ADL.

The DM content varied significantly among the morphological structures of the corn plant. Dry matter content was highest in the cob with 96.07% and lowest in the tassel with 91.25%. Ndukwe *et al.* (2015) found the DM ratio of corn was 88.62 - 90.15%, Ayaşan *et al.* (2019) found the DM ratio in seven parts of corn was 87.76 - 91.54%. Ayaşan *et al.* (2019) reported that the top stalk had the highest DM and the leaf had the lowest DM. In another study, it was found that the corn cobs contained 88.52 - 90.83% DM (Kanengoni *et al.*, 2015). Based on 2015 data, Pioneer 2088 contained 85.98% DM, 7.51% CP, 3.84% CF, 23.47% CC, and 1.20% CA (Variety Registration and Seed Certification Centre, 2016).

The second largest constituent of the kernel was CP. In terms of the entire plant, CP was greatest in the leaf (12.41%) and grain (12.37%), while the cob (4.00%) and the husk (4.30%) had the lowest CP. Ansah *et al.* (2012), Olagunju *et al.* (2013), and Abubakar *et al.* (2016) reported that the cob had 3.50%, 3.42%, and 4.19% CP, respectively.

With about 6% CP, corn stover has a higher nutritional content than most straws (Feedipedia, 2016). Daud *et al.* (2013) reported that the corn stalk contained 24.9% ash, 42.0% hemicellulose, 7.3% moisture and 7.3% lignin. Chea *et al.* (2015) found the DM, CP, OM, ash and CF ratio of corn stover was 45, 6.41, 85.12, 0.35, and 22.30%, respectively. However, Terler *et al.* (2019) indicated that the stover percentage and DM content of corn differed significantly between varieties. Corn cob is that part of the ear that is composed of a lignocellulose biomass characterized by close intertwining of cellulose (45 to 55%), hemicellulose (25% to 35%), and lignin (20% to 30%). It holds the kernels. Abubakar *et al.* (2016) reported that the corn cob had 2.49% ash, 33.33% cellulose, 4.72% fat, 6.00% moisture, and 4.19% protein. He *et al.* (2019) asserted that the corn leaves and corn stalk differed in terms of chemical composition and CP content in particular.

Another study examined the nutrient content of the whole plant and the stover of four silage corn varieties. In evaluating whole-plant corn silage, He *et al.* (2020) found that DM ranged from 39.7% to 50.1% and averaged 42.7%, CP averaged 7.0%, CA averaged 3.4%, and CF, NDF, ADF, and ADL averaged 3.0%, 40.1%, 22%, and 1.5%, respectively. As for the stover of these varieties DM, CP, CA, and CF were 32.9%, 4.9%, 6.0%, and 1.3%, respectively, and NDF, ADF, and ADL were 70.2%, 42.6%, and 3.2%, respectively (He *et al.*, 2020).

Ayaşan *et al.* (2019) reported that the CP ratio in Pioneer 2088 was within the range of 3.72 - 14.45%. The highest CP was found in the ear, with 14.45%, followed by the leaf with 13.09%, and the lower stalk had the lowest CP with 3.72%. Ullah *et al.* (2010) reported that the CP values for various corn varieties were within the range of 7.71 - 14.60%. Ndukwe *et al.* (2015) found the CP content of corn was 10.72 - 12.33%. The average CP content (7.49%) obtained in the current study was in line with that observed (7.31%) by Lee *et al.* (2014). However, it was lower than the observations (10.67 - 11.27%, 9.80%, and 8.82%) of Ijabadeniyi and Adebolu (2005), Sumbo and Victor (2014), and Kılınc *et al.* (2018), and greater than the ratio (7.10%) that was reported by Vaswani *et al.*, (2016). These discrepancies might be due to differences in variety, genotype, ecological conditions of the place where the study was carried out, and the total precipitation and temperature during the harvest time and vegetation. In previous studies, it was reported that the kernels protein content showed variation owing to the genotype, and to fertilizer applications with nitrogen (Hafez & Abdelaal, 2015) and zinc (Dumral Çağlayan, 2015), ecological conditions (Sweley *et al.*, 2012), whether the genotype was local (Aliu *et al.*, 2012), line or hybrid (Khan & Dubey, 2015), sowing time and sowing frequency (Karaşahin & Sade, 2011), stress conditions (Ali *et al.*, 2010), and harvest time (Kalkan & Sade, 2009; Karaşahin & Sade, 2011).

The greatest CF content was found in the lower stalk and the lowest in the kernel. Sumbo and Victor (2014) found the CF content of maize meal (i.e. ground kernels) was 4.50%. Similarly, Amodu *et al.* (2014) and Vasmani *et al.* (2016) reported that the CF of corn kernels ranged from 6.8% to 7.6% and from 0.89% to 2.07% (1.64% on average), respectively. In a study that examined the quality and yield of grain-corn varieties, the CF average was 3.54% (3.33 - 4.00%) with statistically significant differences between varieties

(Kılınç *et al.*, 2018). In a study that examined the nutrient composition of corn from various countries, Lee *et al.* (2016) found the average CF content was 3.62% ($P < 0.05$). Ansah *et al.* (2012) found 0.60% CF in the structure of the corn kernels, and Abubakar *et al.* (2016) found it was 4.72%. Kowalik *et al.* (2013) found the sections of the corn stalk between 15 and 55 cm and above 55 cm had CF contents of 0.46% and 0.76%, respectively, which was higher than the values that were found in the present study. On the other hand, Ming-Yuan *et al.*, (2015) reported that the CF contents of the bottom, middle, and top stalk were 0.66 - 0.87%, 0.80 - 1.28%, and 0.86 - 1.32%, respectively.

Crude cellulose (CC) is the fourth largest constituent of the corn kernel after the carbohydrate, protein, and ether extract (fat) contents. Statistically significant differences existed between the parts of the corn plant, which varied between 2.60% and 38.96%. Ijabadeniyi and Adebolu (2005) and Ullah *et al.* (2010) found the CC content was 2.07 - 2.77% and 0.80 - 2.32%, respectively. Amodu *et al.* (2014) found the CC content was between 23.0% and 27.8%. Vasmani *et al.* (2016) found it was between 31.65% and 40.06%. Ansah *et al.* (2012) found the corn cob was composed of 35.50% CC, which was confirmed by the 33.3% found by Abubakar *et al.* (2016), and 35.03% and 31.36%, depending on whether the cutting height was 15 - 55 cm or above 55 cm (Kowalik *et al.*, 2013). Ming-Yuan *et al.* (2015) reported that the CC contents of the bottom, middle, and top stalk of the corns were 35.4 - 42.8%, 29.8 - 35.8%, and 26.7 - 32.3%, respectively, values which were higher than those found in the present study.

Minerals are an important consideration in animal feeding and in corn (Ahmad *et al.*, 2012; Khan *et al.*, 2014). In terms of proximate analysis of plant materials, minerals are found in the crude ash (CA) fraction. The CA content in the current study was between 0.82% and 17.90%, and averaged 1.008%. However, the mineral content depends on plant variety (Ullah *et al.*, 2010). Amodu *et al.* (2014) found the CA content was 4.9 - 5.1%. Olagunju *et al.* (2013) revealed that the CA content varied from 31.65% to 40.06% in the cob. In another study, it was asserted that the difference in the cutting heights (15 - 55 cm or above 55 cm) affected the average CA contents (8.54 or 8.10%) in the corn stalk (Kowalik *et al.*, 2013).

Differences among mean OM, IVOMD, and IVDMD values of component parts of the corn plant were highly significant (Table 4). The OM level was found to be the highest in the cob (94.27%) and the lowest in the leaf (74.90%). In their study, which examined organic matter digestibility (OMD) in some corn varieties, Vasmani *et al.* (2016) asserted that the OM content of corn was within the range of 91.00% to 93.69%. However, in the present study, the estimates were more variable among the parts, that is, between 74.90% and 94.27%. As with the results from the proximate analysis, variations resulted from differences in varieties and lines, maturity level at harvest, and the regions where the corn was grown. Gado *et al.* (2017) reported that the OM content in the corn stalk was between 75.65% and 90.27%. Olagunju *et al.* (2013) stated that the corn cob had 95.34% OM content. In the current study, the OM content in the shank and husk was observed to be 88.04 - 89.10%. In a study to determine the nutrient content of the tassel, the OM content was found to be 93.05% (Li *et al.*, 2014).

Table 4 Mean organic matter content and in vitro digestibilities of organic matter and dry matter of total corn plant and its nine component parts

Parts	OM, %	IVDMD, %	IVOMD, %
Lower stalk	88.75 ^{cd}	48.13 ^e	34.90 ^d
Central stalk	87.78 ^{cd}	50.50 ^c	50.07 ^b
Upper stalk	84.75 ^e	52.19 ^c	48.28 ^{bc}
Ear stalk	88.04 ^{cd}	49.98 ^c	47.34 ^{bc}
Ear shuck	89.10 ^c	53.44 ^c	51.05 ^b
Kernels	91.77 ^b	79.06 ^a	78.90 ^a
Cob	94.27 ^a	44.43 ^d	43.41 ^c
Leaf	74.90 ^g	60.83 ^b	51.40 ^b
Tassel	80.32 ^f	52.14 ^c	45.60 ^{bc}
Entire plant	87.20 ^d	51.57 ^c	48.64 ^{bc}

^{a-e} Within columns means with a common superscript do not differ at $P = 0.05$

OM: organic matter, IVDMD: in vitro dry matter digestibility, IVOMD: in vitro organic matter digestibility

In general, *in vitro* digestibility is the value calculated from gas measurements taken from the *in vitro* gas production system. *In vitro* true digestibility is the value calculated by the rumen simulation technique. *In vitro* digestibility may be calculated using the 24-hour gas production. On the other hand, IVTD is calculated after 48-hour incubation of the feed in the bags using the rumen simulator. In this study, there was a statistically significant difference between the parts of the corn in terms of IVDMD, which was the highest in the kernel with 79.06% and the lowest in the lower stalk 38.13%. On the other hand, IVOMD was found to be within the range of 34.90% to 78.90%. Wattanaklang *et al.* (2016) stated that the DM and OM of corn stover had digestibilities of 47.71% and 46.78%, respectively. The same researchers found that DM, CP, EE, CF, and ash contents of corn stover were 99.28, 4.25, 9.64, 32.79, and 1.68%, respectively. Terler *et al.*, (2019), who investigated corn stover, observed that the potential and effective degradability of OM, CP, and neutral detergent fibre were influenced significantly by variety and harvest date.

Conclusions

Morphological parts of the corn plant differ in their nutrient content. Being able to apply these results in animal feeding depends on the ability to separate the plant material into its component parts as is now done in harvesting the grain. Further development of technology may allow the separation of more nutrient rich parts for the corn stover from those parts that are less nutritious. Such technology may be beneficial to livestock production.

Authors' Contributions

TA contributed to the project idea, design and execution of the study. TA, NÇ, SA and CÇ conducted the laboratory analyses. TA and NÇ supervised the project and wrote the manuscript.

Conflict of Interest Declaration

There is no conflict of interest.

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