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Communication

Nutritional Characteristics of Corn Silage Produced in Campania Region Estimated by Near Infrared Spectroscopy (NIRS)

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Abstract: In formulating balanced rations for ruminants, knowing the chemical composition of forage and feeds in general is crucial to create adequate nutritional plans that meet animals' feed requirements. From July to December of 2020, a total of 175 samples of corn silage hybrid PR31Y43 grown (135 days of maturity class) in three sites (Piana del Sele, Vallo di Diano and Caserta) of the Campania region (South Italy) were collected and analysed by using a portable Near Infrared Spectroscopy (NIRS). The area of cultivation/storage of corn silage highly ($p < 0.05$) affected the nutritional characteristics of the analysed samples. The silages produced in the Vallo di Diano showed the significantly highest ($p < 0.05$) DM content compared to those from the other sites (349.3 vs. 323.4 and 328.1 g/kg as feed from Caserta and Piana del Sele, respectively). The structural carbohydrates were significantly higher ($p < 0.05$) in Piana del Sele feed than those in both Caserta and Vallo di Diano feeds (420.1 vs. 396.7 and 397.6 g/kg as feed), whereas the non-fibrous carbohydrates were significantly higher in Caserta and Vallo di Diano feeds ($p < 0.05$; 469.6 and 471.8 g/kg as feed); intermediate values were registered in the corn silages produced in Piana del Sele (446.6 g/kg as feed). No differences were detected for protein levels. The NIRS technology could be useful to obtain fast and accurate picture of silage quality. The knowledge of the nutritional characteristics of silages can improve the formulation of balanced rations, contributing to guarantee animal welfare and good productive performances.

Keywords: silages; corn silage; ruminants' feeding; NIRS technology

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1. Introduction

Corn (*Zea mays* L.) is one of the most widespread and cultivated cereals in the world; its uses range from human to zootechnical nutrition. Corn has great agronomic characteristics [1] and a high concentration of nutrients; moreover, due to high levels of soluble sugars, it is easy to ensile [2]. In ruminant feeding, corn is used as: (i) whole plant, chopped and ensiled; (ii) cob or grain mash, due to its high palatability, good digestibility and low cost; (iii) corn grains (whole or flour, flaked, extruded), due to its high energy content [3]. Corn silage is produced by shredding the entire corn plant, harvested when the grain is waxy; then, it is compressed in the silo where anaerobic fermentations take place allowing its conservation. The nutritional characteristics of corn silage, however, can be very variable as the factors that modify its chemical composition are several (i.e., harvesting, compression, storage). Indeed, its nutritional value greatly varies in relation to the time of harvesting; in particular, an early harvesting can cause an excessive loss of nutrients from silo runoff, and also, poor starch development in the grains can lead to a low energy concentration. By contrast, as the ripening progresses, there is a reduction in the nutritive value, characterized by low protein and high crude fiber content [4]. Due to its great variability in terms of chemical composition, there could be a risk of formulating diets with an untruthful nutritional value when specific chemical analyses are not carried out, which might affect the increasing share of much more expensive concentrate feeds when balancing diets for ruminants.

In Italy, corn is cultivated over an area of 578,417 ha, with a total production of 52,237,540 q [5], and about 86% of corn and its derivatives are used to feed livestock, a sector characterized by a strong orientation towards high quality and certified products [6]. Dairy products are the first Italian food compartment, reaching more than 12% of the total income from national food, with a value of production up to 14.5 billion euros. Every year, Italian companies produce one million tons of cheeses—460,000 of which are DOP products. In Italy, Lombardy represents the region with the highest number of dairy cattle farms, about 27% of the total, while Campania is the region with the largest number of buffaloes, 72% of the total, mainly reared for producing the Mozzarella di Bufala DOP (www.mozzarelladop.it, accessed on 5 September 2022) and, at a lower extent, buffalo meat [7]. Corn silage is the main forage in the diets of dairy cows, particularly reared in the Po Valley (with the exception of the Parmigiano Reggiano area, where the use of silage is forbidden by the production specification), as well as in those of dairy buffaloes [8], thanks to a high dry matter (DM) yield and high concentration of net lactation energy [9]. Therefore, knowing the nutritional characteristics of corn silage is necessary for formulating diets that meet the animals' feeding requirements, to avoid losses into the environment and to ensure an economical sustainability of livestock. In fact, it has been estimated that, for the production of 100 kg of milk, feed has an impact of 45% of the total costs, and this value is subject to fluctuations over the years because it depends on the availability of the raw materials [10] and the changes in the prices, especially of concentrates [11]. The conserved forages have lower nutritive values when compared to the fresh ones, but the losses can be reduced if the production processes are carefully performed [12]. The utilization of high-quality forages in the formulation of diets for ruminants, thanks to the improvement of rumen fermentation characteristics [13–16], guarantees animal well-being [17,18] and high quality of animal-based food as well [19–22]. During the last few years, the use of Near Infrared Spectroscopy (NIRS) technology has been proposed in livestock farms and could be useful for forages, as well as for silages evaluation [23–26]. The benefits of NIRS use are rapidity, multiplicity of analyses, a low sample size and reduced cost. In this research, the chemical characteristics of 175 samples of corn silages produced in three sites (Piana del Sele, Vallo di Diano and Caserta) of Southern Italy (Campania region) were investigated by using a portable NIRS device. For this purpose, a NIRS portable device was used on the barn directly, thus saving time, providing the ability to correct the feeding plan and giving the opportunity to the farmer to carry out self-control analyses. The hypothesis was that the field knowledge of actual nutritional characteristics of silages can improve the formulation of balanced rations, contributing to guarantee animal welfare and good productive performances.

2. Materials and Methods

2.1. Sample Collection

From July to December of 2020, a total of 175 samples of corn silage were collected. All the samples were produced in the farm, wherein the corn plant (hybrid PR31Y43, Pioneer Hi-Bred Italia, S.r.l., Gadesco Pieve Delmona, Cremona, Italy) was grown on the area located in three sites of Campania region (in the South Italy), according to the distribution reported in Figure 1:

- Caserta—plain area
- Piana del Sele (Salerno province)—plain area
- Vallo di Diano (Salerno province)—hilly area

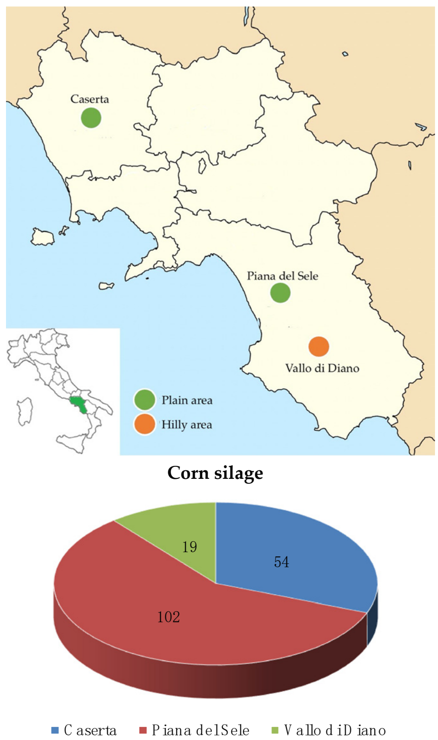

Figure 1. Classification of the silages according to the experimental sites.

The experimental design was to compare the nutritional characteristics of the corn silages produced in the three sites, which were characterized by different geographic coordinates and climate.

In Table 1, the environment features of the testing sites are depicted.

Table 1. Features of the sites.

Site	Longitude	Latitude	Altitude *	Temperature **	Rainfall
	°E	°N	m	°C	mm
Caserta	14°33	41°07	68	15.2	1153
Piana del Sele	14°97	40°50	10	16.8	988
Vallo di Diano	15°39	40°31	450	10.0	1192

*: a.s.l.: at sea level. **: annual mean value.

2.2. Corn Cultivation

According to the differences in climate conditions registered in the three sample sites, the corn was sown between early and mid-April. As far as fertilization is concerned and depending on the soil endowment, P_2O_5 was used at a dose between 150 and 250 kg/ha (maintenance + enrichment) and K_2O at a dose between 200 and 300 kg/ha (maintenance + enrichment). Two weeding interventions were carried out during the harvesting phase of the crop.

The plants were cut when the grain had a moisture content around 30–35%, after 130–145 days of harvest, in function of the different climate conditions registered in the sampling sites. Mowing was carried out between 15 and 20 cm from the ground in order to reduce the possibility of contamination with the soil and with a shredding length not exceeding 1 cm. The silo loading was completed within one week by carrying out an adequate compression of the forage. No additives were added in all farms.

2.3. NIRS Analysis

A NIRS portable device (AgriNIR™, Dinamica Generale, Poggio Rusco, Mantova, Italy) was used for the analysis of corn silage samples. NIR™ Trace management software allows the analysis of forage and cereals. The corn silages were sampled as follow: 7–10 days after the opening of the silo using a loader bucket (Oakfield Apparatus, Wisconsin, USA), the samples were carefully scraped at a depth of 46 cm on the cutting face (either vertically or horizontally depending on how you are feeding) to create a pile of silage on the bunker floor. The spoiled material from the top of the silo was discarded. From five to eight hand grab samples of the pile scraped were mixed thoroughly, and a representative sample was taken for analysis.

Samples in the raw state (about 0.5–1.0 g) were pressed into the case utilized for the analysis to remove air. As suggested by the manufacturer, in order to have homogeneous materials, it was important to cut the silages in pieces of 2–3 cm. Energy in this spectral range was directed on to the sample, and energy reflected (I) was measured by the device. Energy I was stored as the reciprocal logarithm (log 1/R), and the spectra were elaborated for providing information on the chemical composition of the sample [27]. The model/calibration was done using a regression method (partial least squares, PLS), a full-spectrum regression methodology, largely used for feed quality laboratory calibrations that allows having a careful wavelength selection that improves the field applications' predictive accuracy. The dataset was constructed by associating the laboratory value to each spectrum and determining the LIB files (containing the scores) and the PCA, containing the eigenvectors necessary to transform the spectra of the wavelength-absorbance space into the hyperspace, determined by the principal components. Calibration took place in the 1100–1800 nm range; treatments such as SNV 1441 were applied to the spectra.

The chemical bonds associated with absorbance in the silage samples supported the evaluation of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and ether extract (EE) [27]. Non-structural carbohydrates (NSC) were calculated as follows: 100-(NDF+CP+EE+Ash) [28]. The NIRS calibration parameters of the manufacturer are depicted in Table 2.

Table 2. NIRS calibration and validations of the technique utilized for silage analysis.

	Calibration		Validation				
Nutrient	**RMSSECV**	**R^2**	**Nr.**	**RMSEP**	**R^2**	**BIAS**	**SLOPE**
DM	1.519	0.892	44	1.9	0.9	1.18	1.07
Starch	1.366	0.788	44	1.9	0.82	−0.55	1.2
CP	0.213	0.689	44	0.48	0.75	0.37	0.8
NDF	0.830	0.785	44	1.3	0.69	1.04	1.05
ADF	0.605	0.627	44	0.5	0.78	0.38	1.15
EE	0.121	0.665	44	0.25	0.55	−0.02	1.13
Ash	0.179	0.429	44	0.45	0.62	0.38	0.65

RMSECV: root means square standard error of calibration; R^2: coefficient determination; RMSEP: root mean square error of prediction; N: number of samples after outlier removal; RMSEP: root means square standard error of performance. Slope and bias correction factors were calculated as: y_{corr} = bias + slope x y, where y is the predicted value of validation samples measured on the slave instrument and y_{corr} is the corrected value of validation samples measured on the slave instrument. DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; EE: ether extract.

2.4. Statistical Analysis

ANOVA was used for the data analysis using the following equation:

$$Yij = \mu + \alpha i + \varepsilon ij \quad (1)$$

where:

(1) y represent the experimental data;
(2) μ is the general mean;

(3) α is the production site (Caserta, Piana del Sele and Vallo di Diano);
(4) εij is the error term.

The Post-hoc Tukey test was used for comparing the means. The JMP software (JMP®, Version 14 SW, SAS Institute Inc., Cary, NC, USA, 1989–2019) was utilized for the statistical procedures. The level of significance was $p < 0.05$.

3. Results

Table 3 shows the chemical composition of the analyzed corn silages, and in Figure 2, CP, NDF and NSC of silages are depicted. With the exception of CP and ash, all parameters were affected by the sampling site. The silages produced in the Vallo di Diano had significantly the highest ($p < 0.05$) DM content compared to those from the other sites (349.3 vs. 323.4 and 328.1 g/kg as feed of Caserta and Piana del Sele, respectively). The structural carbohydrates (NDF and ADF) were significantly higher ($p < 0.05$) in Piana del Sele than those from both Caserta and Vallo di Diano (420.1 vs. 396.7 and 397.6 g/kg as feed). Lipid fraction was highest ($p < 0.05$) in the Caserta site compared to that from the Piana del Sele one (33.47 vs. 31.34 g/kg as feed), whereas the non-fibrous carbohydrates were significantly higher in Caserta and Vallo di Diano ($p < 0.05$; 469.6 and 471.8 g/kg as feed) and intermediate values were registered in the corn silages produced in Piana del Sele (446.6 g/kg as feed).

Table 3. Chemical composition (mean ± SD) of corn silages according to the sampling site.

Corn Silages (nr 175)	DM	CP	NDF	ADF	Ash	EE	NSC
Sampling Site	**g/kg as Feed**						
Caserta	323.4 ± 29.4 b	67.36 ± 3.50	396.7 ± 15.9 b	214.9 ± 21.5 b	32.92 ± 4.52	33.47 ± 3.00 a	469.6 ± 24.0 a
Piana del Sele	328.1 ± 33.4 b	67.87 ± 4.43	420.1 ± 23.8 a	229.5 ± 34.2 a	33.99 ± 7.49	31.34 ± 3.25 b	446.6 ± 41.2 b
Vallo di Diano	349.3 ± 56.5 a	66.76 ± 2.92	397.6 ± 24.4 b	213.5 ± 36.9 b	31.09 ± 5.88	32.71 ± 3.35 ab	471.8 ± 42.6 a

DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; EE: ether extract; NSC: non-structural carbohydrates. Along the column, different letters indicate statistically significant differences at 5%.

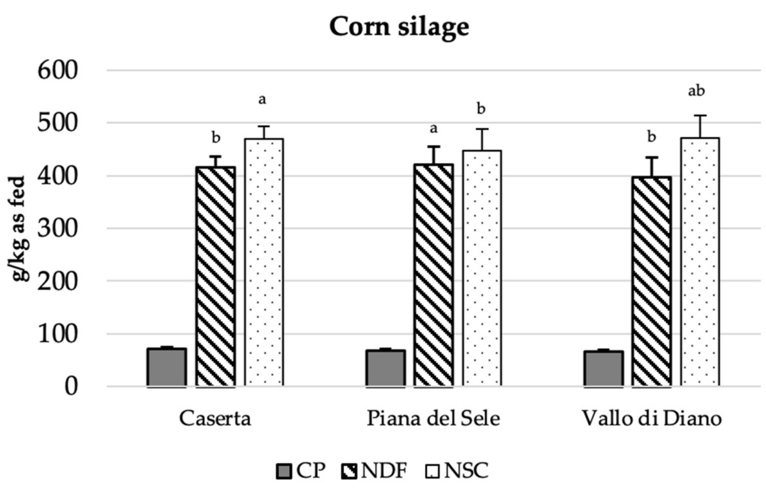

Figure 2. Crude protein, neutral detergent fiber and non-structural carbohydrates of silages. CP: crude protein; NDF: neutral detergent fiber; NSC: non-structural carbohydrates. Different letters indicate statistically significant differences at 5%.

4. Discussion

Concerning the chemical composition, differences in the variable ripening stage at the time of harvesting are highlighted. In the silage produced in the Piana del Sele site, despite a lower value recorded for dry matter, a higher grain content also led to an increase in structural carbohydrates. One of the most important parameters that can influence the nutritional characteristics of corn silage is the moisture content at the time of harvesting.

Ideally, crop yields are maximized near 65% moisture and when losses during feeding, storage and harvesting are minimized.

Regarding the carbohydrates, both structural and non-structural ones, delaying harvesting can reduce both fiber and starch digestibility as the plant becomes more lignified and the grains overripe and become harder and less digestible if left intact after ensiling. In fact, the proportion of structural carbohydrates with a higher percentage of lignin would increase as yield increases, causing a decrease in nutritive value [29]. Therefore, in practice, it is not necessary to pursue the maximization of the yield, but to improve the agronomic efficiency; thus, the equilibrium between yield and quality should be optimal. For guaranteeing the farm's competitiveness, it is common to produce forages on the farm, reduce feeding expenses and increase the farm's economic autonomy [30]. In Italy, corn silage is a large part of the total fiber present in the diet, especially in dairy farms, because of various favorable conditions such as soil fertility, climate and high yield/ha [31]. Consequently, many dairy farms producing corn silage are self-sufficient for energy needs, but it is a different matter for protein sources, which are purchased on the market and this exposes farmers to market volatility. Another critical point is represented by the choice of the correct moment to harvest that is not always feasible for the farmer. In particular, this is mainly ascribable in recent years to the climatic stress registered in the regions that are Mediterranean-type, characterized by less frequent rainfall as well as a change during the year in the distribution of rainfall [32]. This condition certainly also influences the chemical characteristics of forage growth. The chemical composition and, therefore, the nutritional value of ensiled forages can greatly vary according to climatic trends, and corn is particularly susceptible to water stress. In general, all the factors that reduce the availability of carbohydrates, such as starch and sugars, or of digestible fibrous fractions (NDF) represent a direct cost for the farmer, due to the reduction of the energy value of the forage, which must be integrated with a higher share of cereals or feeds purchased on the market. In recent years, several studies underlined the higher irrigation demand of Mediterranean crops because of the changing climate [33–35]. As reported by the IPCC [35], high temperatures and less water availability are recognized as the main responsible factors of the crop growth and yield. Long-lasting droughts associated with an increasing number of extreme events have led to hydrological imbalances such as water scarcity, especially in the southern regions of the EU.

Concerning the non-fibrous carbohydrates, corn silages from the Piana del Sele site showed lower contents, probably because of the climate situation (less rainfall and higher temperature) registered in the last years that may have affected grain maturation. In particular, starch content, especially for corn silage and autumn/winter cereals, depends on the grain content and the ripening stage of the plant, which determines the level of starch accumulation in the kernels. Corn grains comprise 30–52% of plant biomass [36] and starch accounts for 70–75% of dry weight [37]. The grains and the vegetative part of the plant have very different compositions, particularly in non-structural carbohydrates (high and low concentrations, respectively); the kernels' percentage in corn plant greatly affects the nutritional value of the silage.

In a study comparing two different areas over two years, Ferreira et al. [38] reported that, in regions of South America where the temperatures are greater than 35 °C for a long period, delaying the time of sow during grain development to avoid drought and heat stress or selecting corn hybrids characterized by early maturity could be useful choices.

As reported by Ettle and Schwarz [39], the statistical differences found for fat content between the silages produced in the three analyzed sampling sites could be due to the different type of cultivated corn rather than the time of mowing of the plant. In a study by Zhao et al. [40], the yield in dry matter appears negatively correlated with the quality parameters of corn silage (i.e., CP and EE). This commitment between yield and nutritive value is probably due to the dilution effect [41] and was previously reported in other crop production [42,43].

5. Conclusions

In this study, 175 samples of corn silages were evaluated, providing a useful picture about corn silages produced in Southern Italy. The studied silages showed a rather variable chemical composition; environment features, the sampled area and probably the choice of the period of mowing were able to affect silages' quality. It is really important to know these features and how to improve them, as it is useful for the farmers to formulate optimal rations that are able to guarantee animals' health and the quality of animal-based product. This research confirms the usefulness of a NIRS portable device, which can save time and help in correcting the feeding plan; additionally, it is an easy self-control analysis that can be performed by the farmer himself.

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