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The impact of potato chips waste addition on fermentation and *in vitro* digestibility of corn silage

Besime Doğan Daş

Harran University, Faculty of Veterinary Medicine, Department of Animal Nutrition and Nutritional Disease, Şanlıurfa, Türkiye

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ABSTRACT

Background: The use of potato peels, stems, and leaves in the production of silage has been reported to enhance the process of nutrient recycling and mitigate the issue of food waste. The objective of this study was to investigate the impact of incorporating potato chips waste (a byproduct derived from the food processing industry) into corn silage on the quality of the silage, fermentation characteristics, and *in vitro* digestibility.

Methods: The silage was prepared by adding 0.5, 1, and 2% potato chips waste (PCW), whereas no addition of PCW was regarded as control. Data relating to dry matter, crude ash, acid detergent fiber, neutral detergent fiber, metabolic energy, methane, organic matter digestibility, fermentation characteristics, i.e., pH, ammonia nitrogen, total yeast-mold and carbon dioxide were recorded.

Results: The addition of PCW significantly altered crude protein and *in vitro* organic matter digestibility, whereas dry matter, crude ash, acid detergent fiber, neutral detergent fiber, metabolic energy, and methane remained unaffected. The *in vitro* organic matter digestibility increased with the addition of PCW, and the highest value was recorded for 0.5% PCW. Similarly, fermentation characteristics, i.e., pH, ammonia nitrogen, total yeast-mold and carbon dioxide were significantly affected by the addition of PCW to corn silage. However, lactic acid bacteria remained unaffected by PCW addition. Silage pH range was 3.61–3.66. The ammonia nitrogen, total yeast mold, and CO_2 production values linearly decreased with increasing amount of PCW compared to no PCW addition.

Conclusion: The results of the study revealed that PCW (particularly 2%) exerted positive effects on silage quality and fermentation. Therefore, PCW and can be used as additive to improve quality and *in vitro* digestibility of corn silage.

1. Introduction

Livestock sector plays a crucial role in the Turkish economy (Akbay and Boz, 2005). The use of silage as a livestock feed in recent years has contributed to a decrease in feed costs and an improvement in animal health (Aslim and Daniş, 2021). The expense associated with feeding livestock is the most significant financial burden in the country (Boğa and Çevik, 2012). One of the most challenging aspects pertaining to feed expenses is in the exorbitant cost associated with quality roughage (Cakan and Tıpı, 2023).

Approximately 50 % of the global potato harvest is consumed in its fresh form, while the remaining is processed into various products such as potato chips, French fries, potato flour, potato starch, potato seed, and animal feed (Mickiewicz et al., 2022). A substantial proportion of the potatoes processed by the starch industry is disposed away as waste (Oda et al., 2002). Consequently, there exists significant potential for feed production by recycling this waste material into animal feed (Pen et al., 2006). The potato industry in Türkiye has seen significant growth in recent years, resulting in an increased range of potato products available to customers, such as potato chips and frozen potatoes (Çapoğlu and Özden, 2023). The by-products derived from potato business, i.e., chips products, frozen potato products, and potato skins, exhibit varying compositions on a dry matter basis. These compositions generally consist of starch ranging from 3 % to 55.9 %, neutral detergent fiber ranging from 20 % to 40.7 %, and acid detergent fiber ranging from 6.2 % to 31.2 %. Based on available information, the crude oil contents of these byproducts range from 2.9 to 6.9 % (Aibibula et al., 2007; Nelson, 2010).

Various studies have been carried out on alternative feed sources in the world and in Türkiye during recent years (Jalal et al., 2023; Şenyüz and Karsli, 2022). Industrial by-products should also be evaluated as an alternative feed source. Industrial by-products that contain enough

E-mail addresses: bdogandas@outlook.com, bdas@harran.edu.tr.

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nutrients and have a certain production capacity are important for the nutrition of ruminants (Charmley et al., 2006; Şenyüz and Karsli, 2022; Yani et al., 2015). Several industrial by-products are used successfully in animal nutrition in Türkiye. One of the most important agricultural and industrial wastes is potato waste and residues (Doğan Daş et al., 2023; Kara et al., 2023). These products appear as agricultural waste during the production phase and as shells, splinters, and pulp, which are produced because of processing in industry. Potatoes and potato waste have low protein and high energy values, which depend on the type of waste, the time spent cleaning, the amount of residue remaining in the wash water and the amount of skin residue the potato contains. In addition, the wastes of products such as potato flakes, French fries, and chips, which are produced during the processing of dried potato products, have a good nutrient content, and are easily used in beef cattle feed (Hinman and Sauter, 1978).

The objective of this study was to investigate the impact of incorporating PCW into corn silage on the quality of the silage, fermentation characteristics, and *in vitro* digestibility.

2. Materials and Methods

2.1. Study design and silage preparation

Corn byproduct was used as the primary component of silage in this study. The study used a control group comprising of the corn product without any supplementary ingredients, alongside three experimental groups consisting of the corn product mixed with varying proportions (0.5 %, 1 %, or 2 %) of PCW. To ensure uniformity, the samples from each group were tightly packed into six glass jars with a capacity of 1.5 L. The silages were kept under full darkness until they were opened.

2.2. Fermentation profile

The silages were unsealed after 60 days fermentation period. The uppermost portion of opened jars, ranging from 3 to 5 cm, was discarded. The contents of each jar were unsealed, and a total of 25 g of silage was mixed with 100 ml of distilled water.

The pH of each silage sample was determined by measuring the pH of the resultant filtrate using a pH meter. The silage filtrates were placed into centrifuge tubes with a volume of 10 ml. To quantify the concentration of ammonia nitrogen, 0.1 ml of 1 M hydrochloric acid (HCl) was added to each tube. Broderick and Kang (1980) were followed to determine the NH_3-N contents of the silage samples. Ashbell et al. (1991) were followed evaluate CO_2 production after five-day aerobic stability.

Dry matter, crude ash, and crude protein content of the silage samples were analyzed according to the procedures of AOAC (2005). The ADF and NDF content of the silages were analyzed according to Van Soest et al. (1991). ***In vitro*** organic matter digestibility (IVOMD) and metabolizable energy were determined by following Menke and Steingass (1988). Similarly, Menke and Steingass (1988) were followed to quantify *in vitro* methane (CH_4) production by silages. The yeast and mold were analyzed according to the procedure of Filya (2001). Lactic acid bacteria (LAB) in silage were determined according to Gney and Ertürk (2020).

2.3. Statistical analysis

The collected data were analyzed by One-Way Analysis of Variance (ANOVA) (Steel et al., 1997). The normality in the data was inspected prior to the analysis and data were normally distributed. The data satisfied the normality assumption for ANOVA; therefore, original data were analyzed. The comparison of group means was conducted using Duncan's multiple comparison test. The analyses were conducted to IBM (2012).

3. Results

Table 1 displays the results of the nutritional analyses performed on the corn plant material used as silage and PCW included as an additive in the research. Table 2 displays the nutritional contents and values of IVOMD, ME, and *in vitro* CH_4 generation for silages generated by the incorporation of PCW at different rates (0.5 %, 1 %, and 2 %).

The statistical analysis of the CP and IVOMD values of the silages shown in Table 2 demonstrated significant group differences at a significance level of $p < 0.05$. Nevertheless, the levels of DM, CA, ADF, NDF, ME, and CH_4 did not exhibit any statistically significant changes ($p > 0.05$). The examination of the CP values of the silages revealed that the addition of PCW resulted in an increase in CP levels. Table 3 presents the fermentation characteristics of the silages generated in this study using CPW.

Statistically significant differences ($p < 0.05$) were seen across groups when analyzing the fermentation parameters (pH, NH_3-N, total yeast-mold, and CO_2) of silages made by including varying quantities of PCW. However, no significant difference was identified in LAB values ($p > 0.05$). The control group exhibited the greatest pH value (3.66), whereas the silage group with the addition of 2 % PCW had the lowest pH value (3.61) ($p < 0.05$) during the pH testing of the silages.

4. Discussion

The addition of PCW significantly improved the quality and fermentation of corn silage in the current study. The easily soluble carbohydrates included in PCW might potentially serve as a source of energy for microorganisms in the silage. This process enhanced the fermentation process and reduced the chances of spoiling (Doğan Daş et al., 2023). The properties of fermentation in silage were significantly impacted by the addition of PCW. For example, the acids in the leftover PCW cause the pH of the silage to drop more quickly. These acids efficiently preserve the feed by preventing the growth of dangerous microorganisms (Doğan Daş et al., 2023). The PCW may be used to form an impervious barrier on the surface of silage pits, thus inhibiting bacterial development and the decomposition of the stored feed. This strategy is efficient and does not need additional storage space. The acidic properties of PCW inhibit the growth of undesirable microorganisms, hence enhancing the preservation of silage.

Yakişir and Aksu (2019) reported that insufficient preservation of silages might result in the denaturation of protein components. Nevertheless, the results of this research demonstrate that the protein levels were increased, indicating that the proteins did not experience denaturation throughout the fermentation process in the present investigation. The potential influence of low-dose PCW application on the absence of discernible disparities in silage ADF and NDF concentrations between the control and experimental cohorts is under scrutiny. The absence of a discernible increase in ambient LAB activity resulting from PCW addition led to the inability of the cell wall components in the silages to undergo degradation. Consequently, this lack of degradation contributed to the absence of any significant disparity in ADF and NDF values between the control and experimental groups.

Significant enhancements in *in vitro* organic matter digestibility (IVOMD) values were seen across all experimental groups in comparison to the control group. The control group had the lowest IVOMD value.

Table 1
The nutrient analyses of the corn plants used as silage material in the current study.

	DM (%)	CA (%)	CP (%)	ADF (%)	NDF (%)
Chips	88.5	2.80	7.45	3.48	9.83
Corn plant	24.45	7.80	7.50	32.20	55.08

DM: Dry matter, %; **CA:** Crude ash DM%; **CP:** Crude protein, DM%; **ADF:** Acid detergent insoluble fiber, %DM; **NDF:** Neutral detergent insoluble fiber, %DM.

Table 2
The nutrient analyses, IVOMD, ME and *in vitro* CH_4 values of corn silage prepared by adding potato chips waste.

	DM	CA	CP	ADF	NDF	IVOMD	ME	CH_4
(%)								
Control	26.15	7.31	7.87^b	32.46	59.41	56.48^b	8.62	9.76
0.5 % chips waste	26.76	7.12	8.05^b	31.31	59.74	63.75^a	9.53	12.55
1 % chips waste	26.21	6.90	8.40^a	31.32	61.72	57.74^b	8.61	8.62
2 % chips waste	27.08	7.10	8.51^a	30.46	60.31	63.61^a	9.40	10.21
SEM	0.546	0.328	0.083	0.400	0.353	1.159	0.165	0.996
P	0.935	0.385	**0.005**	0.398	0.081	**0.016**	0.059	0.606

a-c: Values with different letters in the same column were found to be different ($P < 0.05$); **DM:** Dry matter, %; **CA:** Crude ash DM%; **CP:** Crude protein, DM%; **ADF:** Acid detergent insoluble fiber, %DM; **NDF:** Neutral detergent insoluble fiber, %DM; **IVOMD:** *In vitro* organic matter digestion %, **ME:** Metabolic energy, **CH_4:** *In vitro* methane gas (%).

Table 3
Fermentation characteristics of the silages prepared by adding different concentrations of potato chips waste.

	pH	NH_3-N/TN	Total Yeast-Mold cfu/g	CO_2	LAB
Control	3.66^a	10.63^a	8.45^a	3.72^a	7.37
0.5 % chips waste	3.64^a	8.16^{ab}	7.10^b	2.62^b	7.31
1 % chips waste	3.63^{ab}	7.78^b	6.98^b	2.60^b	7.19
2 % chips waste	3.61^b	6.67^b	6.96^b	1.66^c	6.72
SEM	0.006	0.540	0.218	0.201	0.332
P	**0.010**	**0.044**	**0.019**	**0.000**	0.917

$^{a,b,c,d,e:}$ Values with different letters in the same column were found to be different ($P < 0.05$); **NH_3-N/TN:** Ammonia nitrogen, **CO_2:** Carbondioxide formation g/kg DM; **Total Yeast-Mold:** log10/cfu/gr, **LAB:** Lactic acid bacteria cfu/g.

Conversely, the group that received an addition of 0.5 % PCW demonstrated the highest IVOMD value. The potential cause for the observed rise in IVOMD values is believed to be the readily soluble carbohydrate content found in PCW. Lactic acid (LA) serves as the primary fermentation product in silages, and it undergoes fermentation in the rumen before being assessed by ruminant animals. Consequently, an elevation in IVOMD values would be logically consistent with this relationship. The current study's results are corroborated by a work conducted by (Şenyüz and Karsli, 2021, 2022), which demonstrated that the inclusion of potato pulp silage as a substitute for corn silage in dairy cow diets resulted in increased organic matter digestibility at different levels.

No significant differences were seen in the ME and CH_4 levels of the silages when comparing the groups. The lack of a noticeable difference between the two groups was attributed to the inclusion of a small number of PCW.

It has been shown that the ideal pH range for silage falls between 3.5 and 4.2 (Rondahl et al., 2011). Upon examination of the NH_3-N values of the silages, it was observed that the control group exhibited the highest value (10.63), whilst the group supplemented with 2 % PCW had the lowest value (6.67). There are two significant adverse processes that take place in the plant when the material intended for silage is shredded to the appropriate sizes and then compressed into the silo. Respiration and protein catabolism are two instances of metabolic processes. Plant proteases are enzymes that catalyze the hydrolysis of proteins, resulting in the formation of smaller peptide and amide molecules. These molecules are then subjected to further degradation processes, leading to the production of amino acids and ammonia. Elevations NH_3-N concentrations inside silage may arise, perhaps attributable to the process of proteolysis.

The consumption and productivity of animals that are fed silages containing a significant degree of protein breakdown resulting from proteolysis are diminished (Filya, 2001). A significant decrease in the overall yeast and mold levels of the silages was seen when comparing the control group to the experimental groups. In a study conducted by Özüretmen (2019), it was shown that the transformation of easily soluble sources of carbohydrates into lactic acid (LA) and acetic acid (AA) resulted in a reduction in pH levels of silage. This reduction in pH levels was attributed to the antibacterial properties of AA, which effectively prevented the growth of yeast and mold in silages. The CO_2 levels observed in the silages were determined to be comparatively lower when compared to the control samples. The occurrence of high levels of carbon dioxide in silages serves as an indication of the aerobic degradation of the silages. Additionally, the presence of residual sugars following the fermentation process diminishes the capacity of silages to withstand aerobic conditions when they are opened for feeding and exposed to unrestricted air intake (Filya, 2002).

5. Conclusion

This study examined the effects of varying amounts of PCW addition on quality, fermentation process, IVOMD, and *in vitro* gas generation in corn silage. The inclusion of 2 % PCW had beneficial impacts on the fermentation characteristics, overall quality, and *in vitro* digestion of organic matter. This research concluded that PCW may be considered a suitable silage supplement due to its beneficial impact on both the quality of the silage and its fermentation characteristics.

CRediT authorship contribution statement

Besime Doğan Daş: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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