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Determining Quality Properties, Nutrient Content, and Relative Feed Value of Tomato Harvest Waste Silage

Mahmoud O. A. Elfaki* and Unal KILIC

Department of Animal Science, Faculty of Agriculture, Ondokuz Mayis University, Samsun, Turkiye
Corresponding author e-mail: mahmoudosman03@gmail.com

***Abstract*—The nutrient contents and silage quality of the green parts remaining in the field after the harvest of the tomato (*Solanum lycopersicum*) were investigated for its usability as a roughage source for ruminants. Tomato harvest wastes (THW) were evaluated as silage with and without roots. Silage quality, chemical content, energy, and relative feed values (RFV) were determined. The data were analyzed by using a t-test. The THW silage with roots exhibited higher ash, NDF, ADF, ADL, and CEL content, while the silage without roots showed higher CP, OM, and NFE content ($P<0.05$). No significant differences were observed in EE and HCEL content among the two silages ($P>0.05$). The higher TDN, ME, and NE were observed in THW silage without roots, while silage with roots had a higher NE_L value. The THW silage without roots exhibited higher gas and water losses compared to those with roots. Both silages maintained appropriate pH levels and sensory and Flieg scores qualities, with no significant differences observed ($P>0.05$). Feed quality indicators, including DMD, DMI, and RFV, were significantly higher in the silage without roots ($P<0.05$), categorizing it as "Good" compared to the "Fair" rating for silage with roots. The results highlight the potential of THW silages as livestock feed, with root inclusion enhancing fiber content and silage without roots offering superior energy values and feed quality. Furthermore, ensiling THW with additions is recommended to improve its potential feed value. *In vivo* studies are also suggested to assess the feed value of THW silages further.**

***Keywords*—Feed value, harvest waste, metabolizable energy, ruminant, tomato, silage.**

INTRODUCTION

Roughage plays a critical role in the nutritional requirements of ruminants. However, ensuring a consistent supply of high-quality roughage throughout the year poses challenges due to inadequate forage crop cultivation areas. Expanding cultivation areas for forage crops, enhancing pasture management, and repurposing industrial by-products and field harvest wastes as alternative roughage sources for ruminant nutrition is imperative to address this limitation. These waste materials harbor significant nutritional potential, and understanding their feed values is paramount to their effective utilization in animal production. This knowledge stands to make substantial contributions to incorporating these waste products as alternative feed sources in the context of animal husbandry, thereby mitigating the roughage deficit [1, 2].

Inappropriate use of harvest waste and its use as garbage can cause economic and environmental problems. Tomato harvest wastes - THW (leaves, stems, and other green parts) are used as a biomass energy source or mixed with manure in biogas production. These wastes are incorporated into the soil as fertilizer after breaking down or used in compost production. In addition, these harvested wastes are burned in the field, causing environmental pollution and economic waste. The amount of pesticides and chemical fertilizers left in the harvest wastes pollute the groundwater and the rainwater [3]. Additionally, these wastes are tried to be disposed of by throwing them into rivers, stream beds, and landfills. The use of harvest wastes as fertilizer and their random disposal into the environment cause the contamination of pathogens and pests. Considering global warming and climate change, preventing the damages that may arise when these wastes are left in the environment is important. Economic and environmental contributions can be achieved if this waste is used as animal feed [4]. It is stated that 88.52% of the wastes left after the harvest in the farms and greenhouses are evaluated in a way that will harm nature and the atmosphere [5].

There are applications for using these wastes as animal feed in fresh form, hay, or silage. It is predicted that THW will significantly contribute to meeting the roughage deficiency seen, especially in the winter months. Since hay, silage, and pellets are made, it is seen that animals prefer to consume THW, their digestibility has increased, and they have an essential share in closing the roughage deficit [6, 7]. The evaluation of THW as animal feed is important in preventing the damages that may occur when these wastes are left in the environment.

Tomato harvest wastes that cannot be used effectively; studies about its use as an alternative feed source for ruminants have recently intensified. Besides the production of alternative feed crops, drying and ensilage of roughages are emphasized in terms of their usability in winter to close the roughage gap. In different studies, some differences have been observed in the case of feeding fresh, dried, and ensiled tomato plants. It has been determined that if lactating dairy cattle are fed the same amount of fresh or dried tomato stalks, milk yield is not affected, but if tomato stalks are ensiled with mushrooms or yeast, milk yield increases [8]. Additionally, it has been observed that dried tomato wastes do not cause health problems or affect live weight in cattle diets when used as a replacement for wheat straw, a low-quality roughage source [9].

It is believed that ruminants can consume these residues after making silage. One of the most significant advantages of silage production is that it makes bitter plants palatable with an aromatic taste that livestock can consume voluntarily. This study aims to produce silage using discarded tomato harvest wastes and assess the resultant silage's quality, nutrient content, and relative feed value.

MATERIAL AND METHODS

A. *Silage materials*

Tomato harvest wastes were obtained from the green parts (leaves, stems, and branches) remaining after harvesting fruits from the tomato plants (*Solanum lycopersicum*) grown under greenhouse conditions at Ondokuz Mayıs University, Faculty of Agriculture, Samsun Province, Turkiye. The experiment categorized THW into two groups: with roots and without roots. The buffering capacity was determined in the sample before silage preparation [10].

B. *Silage preparation*

The green parts of the collected THW were shredded using a chopping machine, with an average length of 2-3 cm. Silages were prepared according to silage techniques, using laboratory-type PVC silos manufactured to prevent air ingress (2.5 liters, 10 cm diameter, and 30 cm length), in three parallel repetitions, according to Filya [11] and Kilic [12]. No additives were introduced to the THW during the silage preparation. Silos were stored under room temperature (20-25°C) in the laboratory.

C. *Silage quality parameters*

The prepared silages were opened after a fermentation period of 60 days. The acidity of the silage was determined using a digital pH meter (Hanna Instruments 1332 model pH meter) with samples taken from different locations within the silages in three replicates [13]. The Flieg score was calculated using the formula: Flieg score = 220 + (2 × % dry matter – 15) – 40 × pH.

Required pH (RpH) values for silages were determined according to Meeske [14] using the formula: RpH = 0.00359 × dry matter (g/kg) + 3.44. The values were compared with the pH values measured experimentally. The physical evaluation (sensory analysis) of silages, including color, structure, odor, and total score, was conducted as reported by Kilic [15].

D. *Chemical analysis*

The silages were dried in a forced-air oven at 55°C for 72 hours. Then, dried silages were milled in a hammer mill through a 1 mm sieve for chemical analyses. The samples were analyzed for dry matter (DM), ash, and crude protein (CP) contents according to the AOAC [16] procedure. Kjeldahl N and CP were calculated by multiplying N by 6.25. The neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and crude fiber (CF) analyses were done according to the method of Van Soest et al. [17] using Ankom^{2000} semi-automated fiber analyzer (Ankom Technology). The ether extract (EE) content was determined using the Ankom^{XT15} analyzer [18]. The organic matter (OM), nitrogen-free extract (NFE), cellulose (CEL), and hemicellulose (HCEL) were determined by calculation. All chemical analyses of samples were carried out in triplicate.

E. *Energy values*

The total digestible nutrient (TDN), metabolizable energy (ME), net energy lactation (NE_L), and net energy (NE) of the THW silages were calculated using the following formulas [19, 20, 21].

TDN (%) = 4.898+(89.796×(1.0876–(0.0127×ADF)))

ME (MJ/kg DM) = (0.17 × %DMD) – 2

NE_L (Mcal/kg DM) = 1.085 + (0.0124 × ADL)

NE (Mcal/kg DM) = (0.0307 × TDN) – 0.764

NE_L and NE values were converted to MJ/kg DM (1 calorie = 4.184 joules).

F. *Relative feed value*

The relative feed value (RFV) was used to determine the forage quality of the THW silages by calculating dry matter digestibility (DMD) and dry matter intake (DMI, body weight %) according to Rohweder et al. [22]:

DMD, % = 88.9 – (0.779 × ADF%)

DMI, body weight % = 120 / (NDF%)

RFV, % = (DMD × DMI) / 1.29

According to the quality grading standard assigned by the hay marketing task force of the American Forage and Grassland Council, the RFVs were assessed as roughages based on prime >151, 1 (premium) 151-125, 2 (good) 124-103, 3 (fair) 102-87, 4 (poor) 86-75, 5 (reject) < 75.

G. *Statistical analysis*

The data obtained from the study were analyzed using the SPSS 20.0 software package by Ondokuz Mayis University. Nutrient content and silage quality data of the silages investigated in this study were analyzed by using a t-test, controlling for normality and variance homogeneity.

RESULTS AND DISCUSSION

The nutrient content of the silage material (THW) used in the experiment is given in Table 1. The initial DM content of fresh THW exhibited a value of 18.41% with roots and 17.38% without roots. This observed range was marginally lower compared to the value reported by Tekin and Kara [23].

The silage materials' CP contents were slightly higher in THW without roots than in THW with roots. Notably, the ash content was higher in THW with roots than in THW without roots. Tomato harvest waste with roots had higher fiber fractions (NDF, ADF, ADL, CEL, HCEL) and lower OM, EE, and NFE compared to THW without roots. These differences indicate that the presence of roots affects the nutritional quality of the THW.

Buffer capacity plays a pivotal role in silage preparation, influencing the resistance of plants to acidification. In this context, it is noteworthy that the buffer capacity of THW with roots was observed to be lower than THW without roots (Table 1). This disparity is attributed to soil in the root segment, contributing to a reduction in buffering capacity. It is crucial to acknowledge that the activities of plant proteins predominantly influence the buffering capacity. Consequently, the non-root portions of THW exhibit a higher protein content. Notably, both rooted and rootless wastes are deemed more amenable to ensiling, as their buffering capacity falls below the 350 meq/kg DM threshold, signifying a favorable condition for the ensiling process.

Table 1. Nutrient content, cell wall component, and buffer capacity of silage materials (DM%)

Parameters	THW with roots	THW without roots
Dry matter*	18.41	17.38
Organic matter	79.87	84.06
Ash	20.13	15.94
Crude protein	9.14	9.76
Ether extract	1.48	1.64
Crude fiber	38.59	37.74
Nitrogen-free extracts	22.76	26.42
Neutral detergent fiber	59.30	51.99
Acid detergent fiber	42.47	37.03
Acid detergent lignin	12.22	8.55
Cellulose	30.25	28.47
Hemicellulose	16.83	14.96
Buffer capacity (meq NaOH / kg DM)	37.8	60.4

THW: tomato harvest waste, *: natural form.

The results of this study reveal significant differences in quality parameters between THW silages with and without roots (Table 2). The gas loss was significantly lower in THW silage with roots compared to THW silage without roots (*P*=0.002). In the THW silage without roots, not only gas loss but also water loss was observed. The reason for the water loss in the silage is due to the low initial DM content of the silage material. However, the significantly lower gas loss observed in THW silage with roots compared to silage without roots indicates better fermentation efficiency when roots are included. This aligns with studies suggesting that the inclusion of root biomass may enhance fermentation stability by providing more readily fermentable carbohydrates and buffering capacity, thereby minimizing fermentation losses [24].

The measured pH values (MpH) showed no significant difference between treatments (*P*=0.113), and the required pH values (RpH) were significantly higher in THW silage with roots compared to silage without roots (*P*=0.025). In terms of the MpH values, the THW silages with and without roots showed appropriate pH values.

Sensory quality parameters (organoleptic properties), evaluated subjectively by criteria such as odor, structure, and color, showed no significant differences in odor, structure, or total score between the two silage types. Both silages received an organoleptic score of "Good." However, color scores were significantly lower (indicating better color quality) in THW silage with roots compared to silage without roots (*P*=0.025). This finding corroborates with studies like those of Weinberg and Ashbell [25], which noted that organoleptic qualities, especially color, often correlate with lactic acid content and the presence of chlorophyll degradation products in silages.

The Flieg point, a critical indicator of silage quality, was higher in THW silage without roots (*P*=0.047). This could be due to differences in dry matter or nutrient composition, as the inclusion of roots may alter the balance of structural carbohydrates to fermentable sugars, slightly affecting microbial dynamics. Classified according to sensory analyses and Flieg scores, the THW silages with and without roots were found to be in the "good" quality class, aligning with benchmarks set for practical silage use [26].

Table 2. Quality parameters of tomato harvest waste silages

Parameters	THW silage with roots	THW silage without roots	*P* values
Gaz loss, %	0.93±0.09^{b}	6.81±0.78^{a}	0.002
MpH	4.09±0.03	4.15±0.01	0.113
RpH	4.13±0.01^{a}	4.09±0.01^{b}	0.025
Odor	13.27±0.42	13.33±0.30	0.898
Structure	3.20±0.22	3.40±0.21	0.522
Color	1.40±0.13^{b}	1.80±0.11^{a}	0.025
Total score	17.53±0.49	17.87±0.42	0.310
Organoleptic score	Good	Good	-
Flieg point	75.03±0.72^{b}	79.73±1.63^{a}	0.047
Flieg score	Good	Good	-

THW: tomato harvest waste, MpH: measured pH value, RpH: required pH value, a,b: means with different superscripts in the same row were significantly different ($P \leq 0.05$). The standard error of means is presented as"±" in the table.

The nutrient content of THW silages with and without roots on a DM basis is presented in Table 3. The DM content was significantly higher ($P<0.05$) in THW silage with roots compared to THW silage without roots. Higher DM in silages with roots suggests improved preservation characteristics, potentially due to reduced water content, which aligns with findings by Muck and Shinners [27] that emphasize the importance of optimal DM for silage stability. Organic matter content followed an opposite trend, with THW silage without roots recording a significantly higher value ($P<0.001$) than silage with roots. Conversely, ash content was higher in THW silage with roots compared to without roots ($P<0.001$). As it is known, ash includes natural inorganic substances in the feed (macro and trace minerals) as well as materials such as dust, soil, and sand that might have mixed with the feed. Since the root part is underground, some soil may remain even after cleaning, which is why the THW silage with roots showed a higher ash content. This is consistent with reports that plant roots contribute to higher ash content due to soil and mineral uptake [28, 29].

Crude protein content was significantly higher in THW silage without roots than in silage with roots ($P<0.05$). This difference may reflect variations in the protein content of root and shoot components, as discussed by Dewhurst et al. [30], who observed similar patterns in forage crops. Also, ensiling had a significant effect on the CP content of the silages. However, there was a decrease in the CP content compared to the initial material, which can be attributed to ammonia loss during fermentation, leading to a reduction in the CP value. The ensiling of rootless THW showed the same effect.

Nitrogen-free extracts and CF were significantly higher in silage without roots compared to silage with roots ($P<0.05$). The NDF, ADF, ADL, and CEL contents were all significantly higher in THW silage with roots compared to silage without roots ($P<0.001$). However, no significant difference was observed in EE and HCEL content between the two silages ($P>0.05$). These differences underscore the potential impact of root inclusion on the nutritional quality and fiber content of THW silages.

Table 3. Nutrient content and cell wall component of tomato harvest waste silages (DM%)

Parameters	THW silage with roots	THW silage without roots	*P* values
Dry matter*	19.17±0.25^{a}	18.08±0.21^{b}	0.029
Organic matter	82.51±0.02^{b}	85.62±0.16^{a}	<0.001
Ash	17.49±0.02^{a}	14.38±0.16^{b}	<0.001
Crude protein	9.02±0.02^{b}	9.47±0.08^{a}	0.007
Ether extract	1.66±0.05	1.62±0.18	0.813
Crude fiber	34.32±0.26^{b}	35.74±0.05^{a}	0.006
Nitrogen-free extracts	30.70±0.38^{b}	32.31±0.22^{a}	0.022
Neutral detergent fiber	54.14±0.08^{a}	47.97±0.47^{b}	<0.001
Acid detergent fiber	40.41±0.21^{a}	35.19±0.01^{b}	<0.001
Acid detergent lignin	10.75±0.05^{a}	6.86±0.02^{b}	<0.001
Cellulose	29.66±0.26^{a}	28.33±0.03^{b}	0.007
Hemicellulose	13.73±0.28	12.78±0.48	0.166

THW: tomato harvest waste, *: natural form, a,b: means with different superscripts in the same row were significantly different ($P \leq 0.05$). The standard error of means is presented as"±" in the table.

The energy values of the THW silages with and without roots displayed significant differences ($P \leq 0.05$) across all parameters (Table 4). The THW silage without roots had higher TDN, ME, and NE compared to the silage with roots ($P<0.001$). Conversely, NE_L was higher in the THW silage with roots than in silage without roots ($P<0.001$). These findings highlight a trade-off in energy characteristics: silage without roots offers superior digestible and metabolizable energy, while silage with roots is more suitable for lactating animals due to its higher NE_L values. The energy values of THW silages are higher than those reported by Tekin and Kara [23]. This may be attributed to differences in the fermentation process, microbial activity, or substrate composition, which can influence the digestibility and energy content of the silage. Additionally, variations in environmental conditions, such as temperature and humidity, during the silage preparation could also contribute to the observed discrepancies in energy values.

Table 4. Energy values of tomato harvest waste silages

Parameters	THW silage with roots	THW silage without roots	*P* values
TDN, %	56.47 ± 0.23^b	62.43 ± 0.01^a	<0.001
ME, MJ/kg DM	7.62 ± 0.03^b	8.32 ± 0.01^a	<0.001
NE_L, MJ/kg DM	5.10 ± 0.01^a	4.90 ± 0.01^b	<0.001
NE, MJ/kg DM	4.06 ± 0.03^b	4.82 ± 0.01^a	<0.001

THW: tomato harvest waste, TDN: total digestible nutrient, ME: metabolizable energy, NE_L: net energy lactation, NE. Net energy, MJ: megajoule, DM: dry matter, a,b: means with different superscripts in the same row were significantly different ($P \leq 0.05$). The standard error of means is presented as”±” in the table.

Table 5 evaluates the RFV and forage quality parameters of the THW silages with and without roots. Significant differences ($P \leq 0.05$) were observed for all parameters. Dry matter digestibility was significantly higher in THW silage without roots compared to with roots ($P<0.001$). This finding suggests that the absence of roots in silage improves the digestibility of the feed, likely due to the lower structural fiber content (as evidenced by lower NDF and ADF levels in Table 3). Similarly, DMI was higher in silage without roots than in silage with roots ($P<0.05$). This aligns with the findings of Oba and Allen [31], who observed that higher DMD correlates positively with increased DMI, as animals are more likely to consume feeds that are more digestible and energy-rich.

The RFV, a comprehensive index of forage quality, was significantly higher in THW silage without roots compared to silage with roots ($P<0.001$). Based on RFV categorization, silage without roots was classified as "Good," while silage with roots was categorized as "Fair". These classifications are consistent with established RFV benchmarks, where a score of 100 or above denotes high-quality forage suitable for dairy cattle or other high-producing animals [32-35]. These findings suggest that the exclusion of roots improves the feed quality of THW silages, as evidenced by higher DMD, DMI, and RFV values. The superior RFV of silage without roots positions it as a more suitable option for livestock feed, particularly where high forage quality is required.

Table 5. Relative feed value and forage quality of tomato harvest waste silages

Parameters	THW silage with roots	THW silage without roots	*P* values
DMD, %	56.61 ± 0.16^b	60.68 ± 0.01^a	<0.001
DMI, %BW	2.22 ± 0.01^b	2.50 ± 0.02^a	0.006
RFV	97.27 ± 0.13^b	117.70 ± 1.14^a	<0.001
RFV Quality	Fair	Good	-

THW: tomato harvest waste, DMD: dry matter digestibility, DMI: dry matter intake, BW: body weight, RFV: relative feed value, a,b: means with different superscripts in the same row were significantly different ($P \leq 0.05$). The standard error of means is presented as”±” in the table.

CONCLUSION

Based on the findings of this study, the initial DM content of THW exhibited low levels. Despite this and the low buffering capacity of the silage material, successful ensiling was achieved. THW silages without roots exhibited higher gas and water losses compared to those with roots. Both types of silages showed appropriate pH values and were classified as good quality. To enhance silage quality, it is recommended to increase the initial DM content to the optimal range of 30–35%, which can be achieved by incorporating fillers such as barley, straw, or sugar beet pulp. By improving the DM content, it can potentially reduce the losses during fermentation, maintain a more stable pH, and enhance the overall quality of the silage. The inclusion of these fillers also provides additional nutrients, such as energy and fiber, which can further enhance the feeding value of the silage.

The findings also demonstrate that excluding roots from THW silage improves its nutritional quality by enhancing digestibility and intake potential. This could be due to the lower lignin and structural carbohydrate content observed in root-free silage, which supports the efficient degradation of fiber by ruminal microbes. Additionally, the inclusion of additives (such as molasses, urea, lactic acid bacteria, etc.) during ensiling is suggested to enhance the feed value of THW silage further. Future research should focus on evaluating the effects of these silages on animal performance metrics, such as milk production, growth rates, and feed conversion efficiency, to better assess their practical applications.

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