Changes in Biochemical and Microbiological Quality of Silage Produced with the Use of Innovative Films

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Abstract: A common method of silage production in Europe is based on the use of cylindrical bales wrapped with polyethylene films. In this study, several modifications of composition of these films were tested for their impact on the microorganisms involved in the ensiling process. Different additives, including nanosilver particles and microcellulose, were analyzed upon the first stage of the experiment. In the second stage, the usability of recycled polyethylene as a film component was assessed. The forage value after ensiling was determined during storage, based on analyses of the content of crude fiber, nitrate nitrogen, total protein, sugars, acids (lactic, acetic, butyric and propionic), pH and dry matter. Microbial forage quality was evaluated by analyses of growth of lactic acid bacteria (LAB) compared to the number of undesirable aerobic bacteria, yeasts and molds. Film properties were also characterized. No statistically significant (\( p < 0.05 \)) differences were shown for the tested film formulae as compared to standard commercial films. In the second experimental stage, an elevated pH and a slightly higher content of acids were observed for the tested films than for the control sample. In addition, for standard PE film supplemented with nanosilver, a higher number of LAB was detected on the inner surface of the film and in the ensiled material.

Keywords: ensiling; forage conservation; nanosilver additive; baling films

1. Introduction

In order to optimize methods of silage production, we have recently launched research studies based on testing new film formulae, for wrapping bales, that enable obtaining of high-quality forage. The experimental results regarding innovative films enriched with microcellulose and nanosilver particles were first shown during the 1st International Electronic Conference on Agronomy and published in Biology and Life Sciences Forum as a proceeding paper [1]. In this article, we provide an extended version of the contribution with some new, complementary information.

Ensiling as a method of forage conservation is one of the most common ways of supplying a source of energy and essential nutrients for livestock [2–4]. The source material for silage production can be almost any type of crop plant [2]. Silage preparation has been gaining popularity in Europe since the 21st century, exceeding production of hay and allowing better conservation and longer storage time of fodder [2,5–7]. At first, the fermentation process was carried out in tightly sealed bunker silos, but then the technology of round bales was implemented. The big-bale conservation and packaging method was a milestone that enabled silage collection in the field and its easy transport to the storage site [2,8]. Bales were initially placed into giant polyethylene (PE) sacks tied at the neck until automatic wrappers were invented. Nowadays, bales are typically wrapped in PE stretch film [8].
Suitable stretch film for wrapping should have some important features: thickness, extensibility, UV and damage resistance and water and air impermeability. High strength is also desirable to protect bales from damage until the feeding-out phase, ensuring proper conditions for good quality silage production and storage [3,4,9]. Any tears on the film surface may disturb the proper conditions established for the fermentation process inside the bale and lead to the aerobic deterioration of silage [10,11]. Note that standard PE films have relatively high permeability to oxygen (over 7000 cm$^3$ per m$^2$ per day), which increases further during sunny days [12].

Although film airtightness can be improved by the use of multiple film layers (4–8), this approach would generate even higher disposal costs and a stronger negative impact on the environment [10,12]. Oxygen barrier films were proposed as alternatives to standard PE-based products, providing better air impermeability as well as reducing material usage and costs of wrapping [10,12,13].

Higher susceptibility to film biodegradation could be achieved with the use of additives of natural origin, such as chitosan, cellulose, starch, casein and fatty acids, as well as synthetic aliphatic and aromatic polyesters [7]. However, with those modifications, original film strength and durability would have been reduced significantly, which would have resulted in problems during wrapping of bales and later caused deterioration of material during storage [14].

The PE films could not have been reused in their original form because of the high number of residues adsorbed onto their surface [3,14–18]. After fermentation, films are also often fragmented in a way that prevents their repeated use [19]. An additional problem for farmers is the long-term storage of used film, which in practice is not properly managed or stored at municipal landfill sites but rather is burned or buried, resulting in environment pollution with toxic oxides, furans and dioxins [3,7].

Korol et al. [20] estimated that nowadays, no more than 30% of agricultural films are being recycled. The percentage of recycled silage and stretch films in different parts of the world varies. For example, in Germany in 2021, about 30,200 tons of used films, that is, 56% of the total amount present on the market, were collected and recycled [21]. These films were mostly multilayered, combining either polymeric or non-polymeric materials, which may have been added to improve the properties, functionality and age-resistance of the resultant product [22,23]. In order to reduce thermo-oxidative degradation and maintain recyclate quality during further reprocessing, it is desirable to add stabilizers to PE. This type of treatment improves the quality of recyclate and limits thermooxidation during recycling [24].

The fermentation process in silage is initiated by natural plant microbiota belonging to the lactic acid bacteria group (LAB) [5,6], followed by microbial species succession. The final result of ensiling depends on these microorganisms and their metabolism products [5]. The presence of undesirable microorganisms such as aerobic bacteria, molds and yeasts may become a severe issue, since it can lead to silage quality loss [5,13,25,26]. For that reason, different PE film modifications have been considered to improve both mechanical strength and oxygen barrier properties. In this context, the admixture of various components is regarded as a solution that promotes growth of beneficial LAB strains while blocking the development of unfavorable microbiota.

The present study focused on monitoring microbial population changes and silage parameters during the storage of ensiled forage in bales wrapped with modified PE film containing different innovative additives. The possibility of use of recycled PE was also considered. The main research hypothesis was that the films containing tested additives might be used in silage fermentation, providing proper conditions for the process.

2. Materials and Methods

2.1. Plant Material Source and Bale Preparation

The experiment was performed at the Pedigree Breeding Center in Osiek (Nidek, Malopolska voivodeship, Poland; 49°54′ N, 19°19′ E). The plant material was a mixture of
Grasses and legumes consisting of Italian ryegrass (*Lolium multiflorum*), perennial ryegrass (*Lolium perenne*), red fescue (*Trifolium pratense*), rough bluegrass (*Poa trivialis*) and white clover (*Trifolium repens*), as well as other dicotyledon species. The dry mass composition of the forage was 80–85% grasses, 10–15% legumes and up to 5% of other dicotyledons. The meadow was mowed in July at the first shoot, when Italian ryegrass reached its heading phase [27]; then the forage was dried to about 50% content of dry mass (DM) through the method of wilting on swathes [28]. The dry material was collected and cylindrical bales were formed. Having been transported to the place of storage, the material was wrapped in the tested films with the use of an automatic wrapper, in at least 16 repetitions (bales) for each film. During the experiment, bales were stored on the concrete site, fenced and covered with a safety net to protect against damage caused by animals.

Preparation of silage required up to 2 months [10,29]. Initial fermentation was followed by a stability phase, when no significant changes in the ensiled material parameters were observed [29]. The ensiled material analyzed in this study was subjected to long-term storage, i.e., 17 months in the first stage and 10 months in the second experiment, and all obtained results are presented compared to the forage that was fermented with the use of a standard wrapping film.

The analyses in the first stage of experiment were performed after 5, 11 and 17 months of storage. The second experiment, conducted during the next season, was modified considering the previous results, and all analyses were carried out after 4 and 10 months of storage. At each time of testing, four bales were opened for sample collection for each experimental variant analyzed at both stages.

### 2.2. Tested Films

The recipes for the innovative multi-layer films used in the experiment were developed by the Central Mining Institute (GIG) in Katowice, Poland. The film manufacturer was ERG Bierun Folie, Bierun, Poland. Nanosilver particles were incorporated at 400 ppm onto the silica carrier to the vinyl ethylene and vinyl acetate copolymer (EVA) and used as an external sticky layer to improve antimicrobial properties of film. To modify film biodegradation properties, three types of microcellulose with different particle sizes were used at 5% concentration. For the production of those bio-composites, microcellulose particles were introduced at 15% mass content to the metalloocene linear low-density PE (mLLDPE). Each film consisted of three layers: external (made of EVA), middle and internal (both made of PE). The recycled PE of the middle film layer, used in the second experimental stage, was prepared with the previously established protocol. The first stage of the recycling was sorting, pre-grinding and cleaning. Next, the process of washing and grinding was conducted with the use of mills, centrifuges, dynamic washers, flotation tanks, hydraulic presses and an electric drying system. The product of the first stage, a clean and dry plastic in form of flakes, was next re-granulated with the use of cutting compactors, extruders, mass filtration systems, cutting heads and granulate dryers. The final product, a dry granulate, was used in further film production processes.

During the first stage, the following combinations were tested: (P1) film with the addition of nanosilver to the external layer, (P2) film with the addition of nanosilver to the external layer and microcellulose type 1 to the middle layer, (P3) film with the addition of nanosilver to the external layer and microcellulose type 2 to the middle layer, (P4) film with the addition of microcellulose type 1 to the middle layer, (P5) film with the addition of microcellulose type 2 to the middle layer, (P6) film with the addition of microcellulose type 3 to the middle layer and (P7) control, commercial film.

The second stage of the experiment aimed to test the possibility of use of recycled PE together with nanosilver for film preparation. The combinations were as follows: (PR1) film with the middle layer made of the recycled PE and nanosilver added to the external layer, (PR2) film with the middle layer made of a standard PE and nanosilver added to the external layer and (PR0) control, commercial film.
In both experiments, a commercially available standard film (ERG Bieruń Folie, Bieruń, Poland) was used as a control.

2.3. Microbiological Analyses

Microbial cell population frequency changes in the ensiled material were monitored with a modified Koch surface-plating method [30] of silage aqueous suspension prepared after cutting the material in short fragments, then adding sterile water and shaking on a rotary shaker for 4 h. To determine the total number of aerobic bacteria, the appropriate suspension dilutions were placed onto enriched agar (2.5%, Biomaxima, Lublin, Poland) and incubated for 72 h at 20 °C. The number of LAB was estimated after plating on MRS (deMan, Rogosa, Sharpe) Broth (Biomaxima) prepared with 2% bacteriological agar (Biomaxima) and incubation for 72 h at 37 °C. To isolate molds and yeasts, a Sabouraud–dextrose medium (6.5%, Biomaxima) with 1% bacteriological agar was used and the incubation conditions were 96 h at 30 °C. After a given time, the number of colonies grown on the medium surface was counted, then the number of colony-forming units (cfu) in 1 mL of silage dry matter (DM) [30]. Please note that for the case of microbial frequency evaluation, i.e., Figures 1–3 and 7–9, the logarithmic mode was used for data visualization; however, all the statistical analyses were enacted on original numeric values.

The degree of surface colonization of ensiling film with microorganisms was analyzed with two methods: (1) microbiological imprints of square fragments cut out from the tested films on plates containing the appropriate media, in which the colonization was estimated on a 4-point scale (see: text below); and (2) plating directly onto microbiological media of suspensions obtained after slow washing of the content of the film surface with distilled sterile water, in which the number of microorganisms was determined in 1 mL of suspension and then recalculated as per 1 cm² of a given film. Both the microbiological media and cultivation conditions were as described elsewhere [30].

2.4. Analyses of Silage Biochemical Properties

Chemical characterization of silage quality requires determination of basic parameters such as pH, content of dry matter, total protein, sugars and crude fiber. The standard drying procedure (24 h at 105 °C) was used for DM content assessment, whereas a potentiometric method was employed for pH determination [31]. The content of total sugars was estimated with the Bertrand protocol while the total protein level was calculated based upon total nitrogen content measurement with the Kjeldahl method [31]. Ammonia nitrogen was assessed with the Conway method [27] and crude fiber content was determined as leftovers after hydrolysis [31]. Lactic, acetic, butyric and propionic acids, serving as indicators of the fermentation processes’ progress in each bale, were determined with gas chromatography [27].

2.5. Statistical Analyses

The results were analyzed with Statistica 13.0 (TIBCO Software Inc., Palo Alto, CA, USA) software. Two-way ANOVA followed by a post-hoc Tukey test was used to evaluate differences at p < 0.05. If no statistical differences in changes of a parameter in time were observed for the sample, the “time” variable was neglected and one-way ANOVA was performed. Four biological repetitions (objects) were analyzed for each experimental combination (group).
Figure 1. Lactic acid bacteria (LAB) population changes in silage during the first experimental stage. Storage time: 5, 11 and 17 months. Bars marked with the same letter indicate no statistical difference ($p < 0.05$); n.d.—not detectable.

Figure 2. Aerobic bacteria population changes in silage during the first experimental stage. Storage time: 5, 11 and 17 months. Bars marked with the same letters indicate no statistical difference ($p < 0.05$); n.d.—not detectable.

Figure 3. Mold and yeast population changes in silage during the first experimental stage. Storage time: 5, 11 and 17 months. Bars marked with the same letters indicate no statistical difference ($p < 0.05$); n.d.—not detectable.
3. Results and Discussion

3.1. Nanosilver and Microcellulose Addition to the Wrapping Film

Previous studies revealed that the number of LAB decreased during the stability phase as compared to the fermentation stage [5] and the references therein. In our experiment, we showed that in most of the studied variants, i.e., P1, P5, P6 and control (P7), the number of LAB still tended to increase during storage (Figure 1). However, a significant increase of the population of unfavorable microorganisms was also typically observed, in particular for variants P4 and P5 (Figures 2 and 3). Possible aerobic silage deterioration may have occurred if the number of yeasts and molds exceeded $10^5$ cfu·g$^{-1}$ [5], which was observed for samples P3–P5 after 11 months of storage. These results suggest that ensiled fodder should be used before a year of storage to prevent possible mycotoxin poisoning as an effect of intense mold growth [5,12,25,26]. That observation was the main reason for implementing a modification involving bale storage shortening in the second stage of the presented studies.

To obtain the best-quality product, a high number of LAB should be observed together with the relatively low number of molds, yeasts and aerobic strains [6,32]. Among the tested variants, formula P6 seemed to fulfill the above requirements, especially due to the high LAB number after 17 months, although there were no statistical differences between P6 and the control sample, P7. For the P3, P4 and P5 variants, the frequency of LAB was still high (Figure 1), but undesirable molds, yeasts and aerobic bacteria were also observed (Figures 2 and 3). In turn, the application of formulae P1 and P2 tended to inhibit the growth of hazardous microorganisms, as was also observed for P6 and P7. For sample P1, after 10 months of storage, no microbial presence in silage was observed, which may have resulted from inappropriate sample maintenance before analysis. Silages are very often problematic samples with a high risk of compromising before the analysis in the laboratory. Therefore, possible differences between the result and the real composition of the sample right after collection may occur and should be considered [29].

During analysis of the film internal surface microbial colonization, the most important observed parameter was low frequency of molds combined with the presence of LAB in the silage. It was assumed that innovative additives would inhibit the growth of unfavorable strains on the film and at the same time remain non-toxic to the lactic acid bacteria in the material. The presence of LAB on the internal film layer was desired but not essential. Considering such assumptions, the best results were obtained for variants P1, P2 and P6 as well as the control sample (Table 1). The great variability of microbial frequency observed during the experiment on the external surface may have been a result of changeable weather conditions.

### Table 1.
The degree of microbial surface colonization of film variants after storage for 5, 11 and 17 months. Scale: -, no colonization; * or +, low colonization; ** or ++, medium colonization; *** or ++++, intense colonization. An asterisk (*) symbol was used for the external and a plus (+) for the internal film layer.

| Sample Variant | Lactic Acid Bacteria | Aerobic Bacteria | Molds and Yeasts |
|----------------|----------------------|------------------|-----------------|
|                | 5 11 17              | 5 11 17          | 5 11 17         |
| P1             | **/++ **/- **/-     | **/++ **/- **/- | **/++ **/- **/- |
| P2             | **/++ **/- **/-     | **/++ **/- **/- | **/++ **/- **/- |
| P3             | **/++ **/- **/-     | **/++ **/- **/- | **/++ **/- **/- |
| P4             | **/++ **/- **/-     | **/++ **/- **/- | **/++ **/- **/- |
| P5             | **/++ **/- **/-     | **/++ **/- **/- | **/++ **/- **/- |
| P6             | **/++ **/- **/-     | **/++ **/- **/- | **/++ **/- **/- |
| P7 (control)   | **/+++ **/- **/-    | **/+++ **/- **/- | **/+++ **/- **/- |

Chemical analyses revealed no significant differences between material ensiled with tested modified films and the control (Figures 4–6, Table 2). Avila and Carvalho [5] showed in their study that the dry mass of ensiling material decreased as a result of the fermentation
process. In our study, the DM of forage was 52% and decreased significantly during the first months of storage in all the variants except for P2 and P4. However, it was found that later, a slight DM increase could be observed for most combinations, and in final silages, DM ranged from 41% to 52% depending on a tested variant (Figure 4). Many authors have suggested that the DM content in silage should be above 30%, since in wetter forages, the risk of secondary clostridial fermentation is elevated [10,27,28]. However, as pointed out by some researchers, if the forage is too dry (DM > 40%), bale porosity may increase due to problems with packing and thus anaerobic conditions would be harder to obtain, which in turn could lead to non-optimal fermentation [10,27]. On the other hand, it was found that DM was also dependent on forage composition and increased in material with a high content of legumes [10]. Note that in our case, the content of legumes was relatively high (approx. 15%), and therefore, despite the high value of DM, the fermentation process during silage formation proved to be efficient.

The acidity of material after 5 months of ensiling ranged between pH 4.4 and 4.7 (Figure 5), which proves that proper acidic conditions for LAB growth were maintained in each type of bale. A slight decrease in pH was observed over time; however, this observation was not significant. These values seem to be in line with the results obtained by other authors [6,27,28]. A pH decrease was also documented by Kung [29] after 165 d and 365 d of storage.

![Figure 4](image_url)

**Figure 4.** Silage dry mass [%] changes during bale storage for 5, 11 and 17 months. Bars marked with the same letters indicate no statistical difference ($p < 0.05$).

![Figure 5](image_url)

**Figure 5.** Silage pH value changes upon storage for 5, 11 and 17 months.
In most cases, the quality of silages prepared with the use of innovative films was similar to the control (Table 2). It is known that high sugar content in forage (determined in our experiment as 14.75%) ensures proper conditions for LAB metabolic activity [33], whereas its decrease in silage provides evidence of efficient bacterial fermentation. The expected chemical characteristics of silage produced from meadow species should be as follows: total protein, up to 18%; crude fiber, 20–26%; ammonia nitrogen, as low as possible but no more than 5–11% of total nitrogen [6,27,28]. Slight disparities in crude fiber content (Table 2) may be associated with different compositions of forage [10]. The ammonia nitrogen concentration was below 10% of total N in all the samples (data not presented).

The concentration of lactic acid in the tested samples was between 2.1–9.3% of DM (Figure 6). Although many authors have suggested that lactic acid content in silage should remain within 2–5% of DM [5,6,28,29], a higher value can also be accepted because in such a case, the stability of the product in air is prolonged during the later feed-out phase [2]. The acetic acid content should range from 1% to 3% [2,6,29], but again, slightly higher values may be regarded as beneficial due to better product stability after the bale is opened. The level of propionic acid should be kept below 0.1% [29], whereas butyric acid is undesirable and not detected in well-fermented silages [28,29]. However, it should be stressed that the lactic-to-acetic acid ratio is one of the most important parameters of silage quality, and lactic acid should contribute more than 70% of total acids [2,12,28]. In two cases tested in this study, i.e., variants P1 and P3, after 11 months of storage, the abovementioned ratio was lower than 72%. In addition, for samples P1 and P5 after 11 months of storage, the presence of propionic acid was also detected (Figure 6). A significant decrease of determined total acids during storage was observed for most combinations. This change may have been connected to the growth of yeast and acetic acid bacteria activity in silage [5,29].

Our experiment revealed that all tested formulae were safe to use and did not negatively affect the abundance of LAB nor the final silage quality. During the storage, a
decrease of content of sugar as well as lactic and acetic acids was observed along with an increase of DM content. Desirable results as compared to the control were obtained for the variant containing microcellulose type 3 in the middle film layer (P6). The formulae with the addition of nanosilver (P1 and P2) should also be considered promising.

3.2. Preparation of Films with Recycled PE

The number of LAB in the silage in variants PR1 and PR2 ranged between $10^4$ and $10^6$ cfu·g$^{-1}$ DM and did not change significantly during the storage (Figure 7). For the bales wrapped with the control film, PR0, a significant decrease in the number of undesirable strains as well as LAB was observed. For all tested silages except PR0 after 4 months of storage, the number of yeasts and molds was below $10^6$ cfu·g$^{-1}$ (Figure 7). These results suggest proper conservation of material and preservation of anaerobic conditions in the silage environment [5]. In addition, the frequency of aerobic bacteria was low, which confirmed observations of Cai et al. [6], who proved that after the fermentation phase, the number of aerobic microorganisms decreases to $10^6$ cfu·g$^{-1}$.

![Figure 7](image.png)

**Figure 7.** Microbial population changes during the second stage of the experiment. Storage time: 4 and 10 months. Bars marked with the same letters indicate no statistical difference ($p < 0.05$); results were analyzed separately for each group of microorganisms.

Assuming, as previously, that the best wrapping film should not be extensively colonized with microorganisms on the surface of a bale cover, any undesired microbe adhesion on the tested films should be limited, especially on the inner sides. Accordingly, a relatively low frequency of strains was observed on the internal layer of films (Figure 8). A greater variability in microbial frequency was observed on the external surfaces of films (Figure 9); this may reflect changeable weather conditions.

The resultant silage produced during the second stage of tests was of very good quality. The obtained pH values (Table 3) were slightly but not significantly higher for the tested samples after 4 months of storage than for the control (PR0) and were similar to the optimal values suggested in the literature [6,27–29]. A significant pH decrease was only observed in the PR1 variant, but this result was possibly caused by a greater DM content loss compared to that of the other samples. That negative change in DM content may have resulted in an undesirable process such as clostridial fermentation [10,27,28].

A decrease of the sugar content in samples PR1 and PR2 was observed (Figure 10); this may imply an active microbial metabolism. For sample PR1, a significant increase of total protein content and ammonia nitrogen, which may have been linked to degradation of plant tissues [9,28,29] and disruption of the covering film structure, was observed at the end of the experiment (Figure 10). Small but statistically significant differences in crude fiber content were observed.

The concentrations of lactic and acetic acids (Figure 11) were similar to the values described in the literature [2,5,6,28,29]. The contribution of lactic acid in the total acids
content was above 77% after 4 months of storage and then decreased to 54–68% after 10 months. In sample PRI, after 10 months of storage, high levels of both acetic and lactic acids were detected (Figure 11), along with butyric (0.05% of DM) and propionic (0.02% of DM, not shown) acids. The presence of butyric acid should not be detected in properly ensiled forage [29].

**Figure 8.** Microbial colonization of inner film surfaces during the second experimental stage. Storage time: 4 and 10 months. Bars marked with the same letters indicate no statistical difference (p < 0.05); results were analyzed separately for each group of microorganisms; n.d.—not detectable.

**Figure 9.** Microbial colonization of outer film surfaces during the second experimental stage. Storage time: 4 and 10 months. Bars marked with the same letters indicate no statistical difference (p < 0.05); results were analyzed separately for each group of microorganisms; n.d.—not detectable.

**Table 3.** Dry mass content and pH changes in silage during storage for 4 (t1) and 10 (t2) months. Values marked with the same letters indicate no statistical difference (p < 0.05).

| Sample          | Dry Mass [%] | pH         |
|-----------------|--------------|------------|
|                 | 4            | 10         | 4          | 10          |
| PR0 (control)   | 39.14 ± 1.50 b | 42.79 ± 1.64 bc | 4.69 ± 0.06 b | 4.85 ± 0.06 bc |
| PR1             | 46.59 ± 1.78 c | 32.32 ± 1.24 a  | 4.82 ± 0.06 b | 4.32 ± 0.06 a  |
| PR2             | 38.98 ± 1.49 b | 41.14 ± 1.57 b  | 4.83 ± 0.06 b | 5.01 ± 0.06 c  |
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Prepared with PE films with the addition of nanosilver in the external layer had similar, or even better, parameters compared to those of the control sample: a variant of the second stage of the experiment showed that silage produced and stored in bales were significantly better, parameters compared to those of the control sample: a variant of high-quality silages. Those innovative films were used to form bales and test forage ensiling.

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Figure 10. Silage parameters in the second stage of the experiment during storage for 4 and 10 months. Bars marked with the same letters indicate no statistical difference (p < 0.05); results were analyzed separately for each parameter. * for ammonia nitrogen the concentration was presented as % of total nitrogen.

Figure 11. Content of organic acids in tested silages after 4 and 10 months of storage. Bars marked with the same letters indicate no statistical difference (p < 0.05); statistical significance analysis was performed for the sum of organic acids.

4. Conclusions

The results of the presented work proved that microcellulose or nanosilver may be successfully used as additives to obtain novel, multilayered films for the production of high-quality silages. Those innovative films were used to form bales and test forage ensiling. The resultant silages were then characterized with regard to their chemical content and microbiological colonization. The quality of the final product did not change significantly during 17 months of storage. However, after 11 storage months, intensification of growth of unfavorable strains was observed. Therefore, it is recommended to store bales for no longer than 1 year.

The second stage of the experiment showed that silage produced and stored in bales prepared with PE films with the addition of nanosilver in the external layer had similar, or even better, parameters compared to those of the control sample: a variant wrapped in standard PE film. The addition of nanosilver to the film had no negative impact on the conditions required for proper fermentation. This observation suggests that the...
films used in agriculture may be successfully admixed with nanosilver, which could be supplemented as an antimicrobial agent.

The use of recycled PE in the second stage yielded properly conserved silage of a quality comparable to the control, but after 10 months of storage, some undesired processes occurred that resulted in detection of butyric acid and dry mass content loss. It is therefore suggested that this type of film may be used in formation of bales only for short-time storage purposes. Reduced production costs and a positive environmental impact are strong arguments supporting the use of modified films in agricultural practice.

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