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Timo Lötjönen
Vesa Joutsjoki

Harvest and storage of moist cereal straw

- experiments 2013 – 2014 and 2015 – 2016

Solution Architect for Global Bioeconomy & Cleantech Opportunities

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Name of the report: Harvest and storage of moist cereal straw - experiments 2013 – 2014 and 2015 – 2016

Key words: round baling, wrapping, preservative, moulds, yeasts, microbiological analyses

Summary

Straw of cereals make up a significant biomass potential in Finland and the other Nordic countries. Usually straw storage is based on low moisture content (15-20 % w.b), which prevents decomposition. In Nordic countries, straw is often difficult to harvest dry enough due to autumn weather conditions. Airtight storage, for example plastic wrapping, can be used to preserve moist materials such as silage. However, it is unknown how this storage method would preserve straw, which is relatively dry, coarse and low-sugar material.

The aim of this study was to identify, how baled moist straw could be conserved by using different amounts of plastic wrapping and preservatives designed for moist straw. To solve these questions, two round bale storage experiments were conducted. The first experiment consisted of the following 12 treatments: two moisture levels*three wrapping levels (0 layers, 3 layers, 6 layers)*two preservative levels (with or without). The bales were stored for 6 or 12 months. The second experiment consisted of the following 6 treatments: three wrapping levels (0 layers, 3 layers, 6 layers)*two preservative levels (with or without). Four replicated bales of every treatment were made and the bales were stored for 6 months.

Round baled straw, the moisture content of which was over 25 % was not preserved well without plastic wrapping. The major reason for failure was moulding. Even a low amount of plastic wrapping (3 layers) maintained straw quality reasonably well over winter (6 months). When straw was stored for 12 months, 6 layers of wrapping seemed to maintain moist straw quality slightly better than 3 layers, but the quality had already decreased, being poorer than after 6 months of storage. The added preservatives (microbial or acid) helped a little to maintain straw quality, even though in these experiments straw moisture content was higher than recommended for use of the preservatives. Propionic acid was quite effective regardless of straw moisture, when it was combined to plastic wrapping.

It can be recommended that moist straw should be wrapped with 3 layers of plastic for over winter storage and with 6 layers for one year storage. The costs of wrapping were estimated to be 5.5 – 13.5 €/ton DM higher than in a system, where the bales are not wrapped but they are stored under thin plastic cover or a tarpaulin.

Preface

This work was carried out in the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program coordinated by CLIC Innovation with funding from the Finnish Funding Agency for Innovation, Tekes.

The first part of this report belongs to BEST research program's Working Package 2 (WP2) "Radical improvement of bioenergy supply chains", and it's Task 2.1 "Raw materials". The second part of report belongs to BEST Updated plan's WP1 "Bio as a part of the solar economy energy system", and it's Task1.2 "Energy storage concepts for maximizing the potential of bioresources".

This report tells about two practical experiments, where moist straw was harvested and stored with different methods. The straw can be used for bioenergy, for raw material for industry or for cattle fodder or bedding. Finally, costs of storage methods are presented.

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Ruukki and Jokioinen, February 2017

CONTENTS

1 INTRODUCTION 7

2 MATERIALS AND METHODS (2013 – 2014 EXPERIMENT) 8

3 RESULTS & DISCUSSION (2013 – 2014 EXPERIMENT) 10

3.1 ORGANOLEPTIC ANALYSES 10
3.2 PHYSICAL CHARACTERISTICS OF THE BALES 12
3.3 MICROBIOLOGICAL ANALYSES 14

4 MATERIALS AND METHODS (2015 – 2016 EXPERIMENT) 19

5 RESULTS & DISCUSSION (2015 – 2016 EXPERIMENT) 20

5.1 ORGANOLEPTIC ANALYSES 20
5.2 PHYSICAL CHARACTERISTICS OF THE BALES 20
5.3 MICROBIOLOGICAL ANALYSES 24
5.4 COSTS OF WRAPPING AND PRESERVATIVES 27

6 CONCLUSIONS 27

7 REFERENCES 28

1 Introduction

Straw of cereals make up a significant biomass potential in Finland and the other Nordic countries (Pahkala & Lotjonen 2012). The demand for biomass will increase in the future, and it is likely that Finnish straw will be used industrially for energy or bio products. At the moment, the straw is mainly used for animal feed, bedding and in some farms for heat production.

Biomass storage is often based on low moisture content, which will prevent microbiological activity. The moisture of straw in bales should be less than 20% (wet basis), in order to prevent decomposition (Bernesson & Nilsson 2005). According to some guidelines, target moisture should be 15 – 16 % in bales (EuBioNet2 2007). Excessively moist straw may begin to mould and warm up, resulting in deteriorating quality of biomass, and part of the dry matter will be lost as a result of decomposition. Moulds can cause health risks to workers dealing with straw (Kotimaa et al. 1991).

If the purpose of use allows a slight decay (e.g. fuel for combustion), the straw may be a bit moister than 20%. The outside air temperature and humidity, as well as the quality and the degree of compression of biomass will define, which is at sufficiently low storage moisture. Details of target moisture are partly based on the experience of different conditions, and there is little research information available.

Airtight storage is based on mostly the fact that biomaterial is compressed and covered with plastic so closely that activity of microbial agents is enough to exhaust the oxygen in biomass (Duniere et al. 2013). In this case, the aerobic microbial activity runs out by itself. Airtight storage can be used for a very wide area of biomass moisture; the moisture can be from 15 to 85%. If biomass is rather dry and coarse, there can be difficulties to compress biomass so that oxygen would not be excessive in the early stages of the preserving process. Such a situation is typical with a bit moist baled and in plastic wrapped straw. Lactic acid fermentation can be used to enhance the success of airtight storage in many biomasses (Duniere et al. 2013). However, lactic acid fermentation is not usually suitable for the storage of cereal straws, because straws have just a little bit of sugar and they are drier than lactic acid fermentation requires.

Microbial preparations have been developed for different kinds of biomaterials and moisture areas to prevent the growth of yeasts and moulds. For example, for baled cereal straw there is a specific microbial inoculum, when the moisture is less or over 22%. So far, the efficacy of the products of this kind has been studied very little. One reason for this is surely that big part of the world's straw can be harvested as sufficiently dry without any problems. Wet autumns are causing problems mainly in Finland, Central and Northern Sweden, Norway and Ireland.

Acids which prevent the growth of yeasts and moulds are one possibility to store moist straw. For example propionic acid has been used to preserve hay and straw, when moisture content has been 20 – 60 % (AIV 2016). Plastic wrapping is recommended together with use of propionic acid.

In Nordic countries, the straw is difficult to harvest dry enough every autumn, in order to maintain the quality of the straw based on low moisture content. On the other hand, some dry autumns straw harvesting does not have any problems. Because of the increasing demand of straw in future, we see it is necessary to study the effectiveness of alternative methods of straw storage. The aims of this study were to identify, how baled moist straw will be conserved: 1) by using different amounts of plastic wrapping film and 2) by using preservatives designed for moist straw.

2 Materials and methods (2013 – 2014 experiment)

The field experiment was conducted in autumn 2013 at Ruukki Research Station in Central Finland (64° 41, N; 25° 05, E) to solve harvesting and storage problems of moist cereal straw. In the experiment moist barley straw material was baled at two different time frames, resulting in different moisture levels. The target moisture contents of bales were about 20 % and about 25 % (wet basis). Attaining of the moisture target rages was monitored by taking preliminary moisture samples from the straw windrows. Barley had been harvested 10.9.2013 and the baling experiment was conducted eight days later, so there was enough time to try finding suitable time frames for baling. The bales were made with an integrated round baler wrapper (McHale Fusion 2) with full bale density setting. Raking was not used; the bales were made directly after combine harvester.

The bales were made either without wrapping or wrapped with a standard plastic film with two different layers of plastic and with or without a storage preservative. The experiment consisted thus of the following 12 treatments: two moisture levels (two harvesting times)*three wrapping levels (0 layers, 3 layers, 6 layers)*2 preservative levels (with or without). Each treatment had two bales, which were stored until March 2014 or until September 2014. Wrapped bales were stored outside and bales without wrapping inside of the barn stacked, but separated by wooden pallets. The bales were weighed before and after storage with a scale with an accuracy of ± 5 kg.

Figure 1. The round bales were made with an integrated round baler wrapper either without wrapping or wrapped with a plastic film.

The used preservative was BioStraw from Biotal Company, in which the active bacterial species is *L.buchneri*. The manufacturer claims that the product maintains straw quality up till 22 % moisture content even without wrapping. On the other hand, wrapping of bales is recommended when storing moist straw. Bacteria-product was mixed to water according to instructions before baling. The preservative liquid was spread directly to baler's pick up by applicator (4 l/fresh ton).

Figure 2. The preservative liquid was applied 4 l/straw fresh ton.

Figure 3. The bales without wrapping were stored inside and wrapped bales outside of the barn.

In 2014, the bales were opened and splitted in half in March (6 months storage) or in September (12 months storage) and an organoleptic analysis were performed immediately. Quality samples were taken by picking straw representatively from splitted bales. Moisture determination was done by oven drying (105 °C, 24 h). Microbiological analyses were performed on straw samples from bales stored for 6 and 12 months, respectively. The set of analyses carried out on each straw sample covered the determination of total microbial count (PCA-medium plates, cultivation at +30°C for 3 days) and the specific determinations for enterobacteria (VRGB-medium plates, cultivation at +37°C for one day), yeasts and moulds (DRBC-medium plates + 50 mg/ml oxitetracycline, cultivation at +25°C for 5 days), and lactic acid bacteria (MRS-medium plates, cultivation at +30°C for 3 days).

3 Results & discussion (2013 – 2014 experiment)

3.1 Organoleptic analyses

Organoleptic analyses after removing the wrapping plastics and splitting the bales showed that the bales without plastics were mouldy. 3 or 6 plastic layers had prevented moulds well when opening the bales stored for 6 months (table 1). In the bales stored for 12 months without wrapping the mould had partially turned to dust. The bales stored for a longer period with wrapping had some wet and mould plots in surface of bales (about 5 cm deep), but not inside. This was a new observation compared to bales stored for 6 months.

Table 1. Treatments in the experiment and results of organoleptic analysis for straw bales stored for 6 and 12 months.

Bale number	Moisture target (w.b)	Plastic layers	Preser-vative	After 6 months storage	After 12 months storage
1	20 %	0		Mould plots	Mouldy and dusty bale
2	20 %	3		Very few mould plots	Some mould in surface, but not inside
3	20 %	6		Well preserved bale	Some mould in surface, but not inside
4	20 %	0	x	Mould plots	Mouldy and dusty bale
5	20 %	3	x	Well preserved bale	Some mould in surface, but not inside
6	20 %	6	x	Well preserved bale	Some mould in surface, but not inside
7	25 %	0		Mould plots	Mouldy and dusty bale
8	25 %	3		Well preserved bale	Some mould in surface, but not inside
9	25 %	6		Well preserved bale	Some mould in surface, but not inside
10	25 %	0	x	Very mouldy bale	Mouldy and dusty bale
11	25 %	3	x	Well preserved bale	Some mould in surface, but not inside
12	25 %	6	x	Well preserved bale	Some mould in surface, but not inside

The colour of straw was the brightest and smell the freshest in the bales wrapped with 6 layers of plastic. The bales which had 3 layers of plastic had smell of ammonia. The bales without wrapping had stuffy and mouldy smell. The preservative didn't seem to help to maintain quality of straw with or without wrapping (table 1).

Figure 4. The round bales were splitted in half for organoleptic analysis.

Figure 5. Straw in the bales after 6 months storage. On the left: bale wrapped with 3 plastic layers, no preservative (bale number 2). On the right: bale without wrapping, preservative was used (bale number 10).

3.2 Physical characteristics of the bales

As seen in Fig. 6, most bales were moister than desired. It also seems that bales without wrapping (1, 4, 7 & 10) had lost some moisture during storage. If moisture was calculated without these bales, average moisture content was 25 % (range 22 – 32 %) when the target was 20 %. Correspondingly, when the target was 25 %, average moisture content was 30 % (range 23 – 38 %). The bales 11 and 12 were particularly wet after 12 months storage, reason for this is unknown (fig. 6). There was a little rain (1.2 mm) between making bales 1 - 6 and 7 - 12, which can explain why the latter bale batch was moister than the first one.

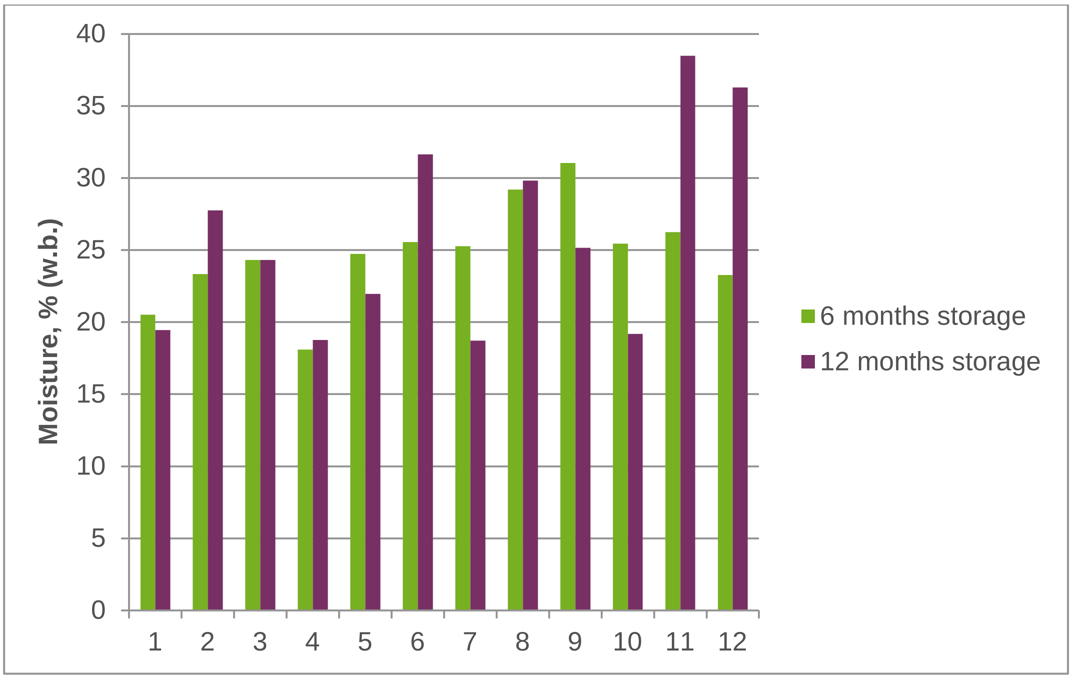


Figure 6. Moisture content (w.b.) of straw bales after 6 or 12 months storage. The treatments are explained in table 1.

Before storing, the bales 1 - 6 weighed on the average 340 kg and bales 7 - 12 weighed 270 kg (fig. 7). Weight loss was the highest in the bales without wrapping, the bales without plastics and stored for 12 months had lost 40 – 65 kg of their weight (fig. 7 & 8). The wrapped bales had lost their weight little, less than 10 kg (fig. 8).

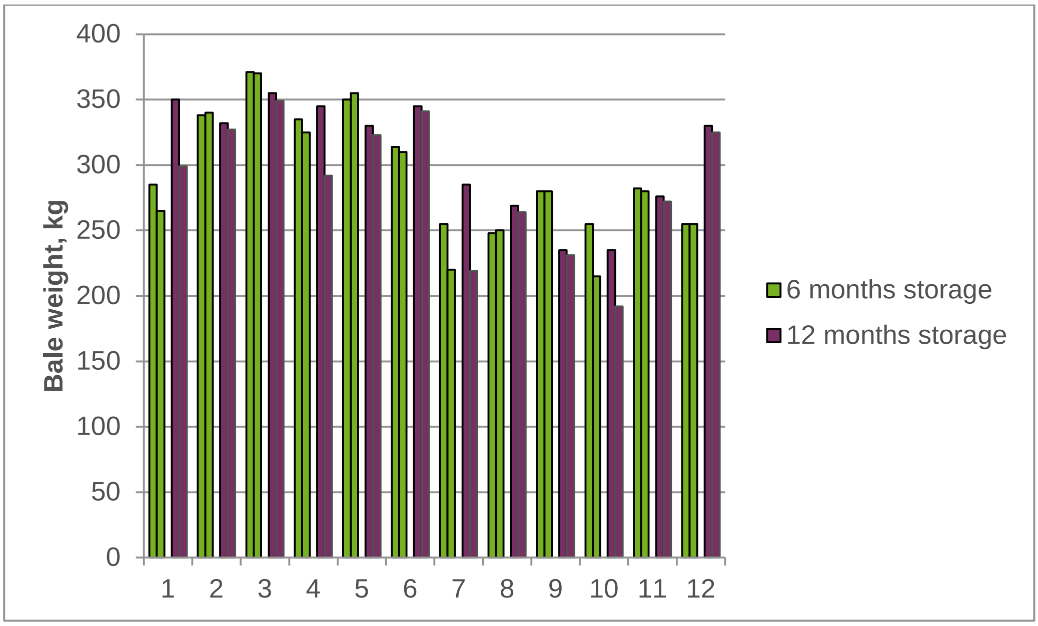


Figure7. Bale weights before storage (first bar) and after 6 or 12 months storage (second bar). The treatments are explained in table 1.

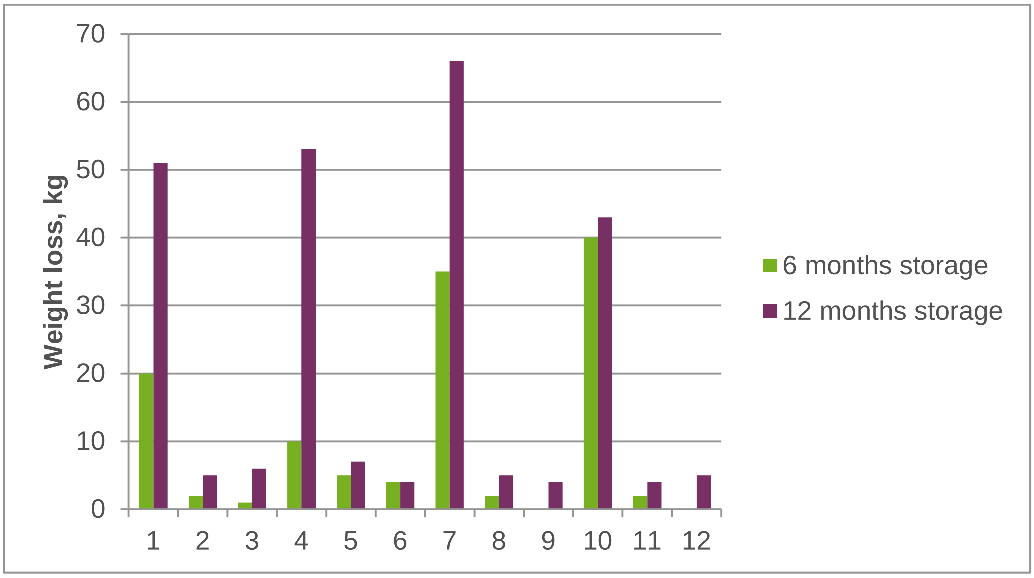


Figure 8. Weight loss of bales during storage. The treatments are explained in table 1.

The moisture content of the bales was not measured before storage, because sampling would have destroyed air tightness of wrapped bales. Thus, we cannot exactly determine, how big part of the weight loss came from moisture loss and how much from dry matter loss. However, it can be calculated that 12 months stored unwrapped bales lost roughly 20 – 30 kg dry matter during storage, which is approximately the same as moisture loss.

The measured bale size was 1.28 m x 1.23 m (diam. x width). Dry matter densities of bales varied between 120 kg DM/m^3 (bales 7- 12) and 160 kg DM/m^3 (bales 1- 6). The bales wrapped with 3 layers plastic film had on the average 680 g film per bale and the bales with 6 layers had 1360 g film per bale. Because one roll of plastic film weighted 24.9 kg, one roll would be enough to wrap 36 bales with 3 layers or 18 bales with 6 layers.

3.3 Microbiological analyses

Fig. 9 suggest, that the number on total bacteria is highest in bales with higher moisture and wrapped in plastic. This is most likely the result of humidity and warmth, which are optimal conditions for most soil micro-organisms. Somewhat surprisingly, the highest counts of lactic acid bacteria were determined in plastic wrapped bales stored for 6 months without the microbial preservative agent (Fig. 10). An explanation could be the presence of some fresh grass in these bales, which provided an additional nutrition source for microbial growth.

In general, the number of lactic acid bacteria seemed to decline when storing was continued till 12 months. The results indicate that freshly baled straw is not an optimal environment for lactic acid bacteria, but the humidity and warmth of baled straw wrapped in plastic and stored for 6 months enhances the growth of lactic acid bacteria from the natural environment. When numbers of lactic acid bacteria and moulds (Fig. 11) are considered in bales, it seems that the bales with high number of lactic acid bacteria harbour a low number of moulds, suggesting that the organic acids produced by lactic acid bacteria (either of natural origin or added as a preservative agent) contribute to the preservation of baled straw from mould contaminations.

With an exception of the bale number 10, the highest number of moulds was observed in the bales without wrapping and stored 6 months (Fig.11). The number of moulds seemed to decrease in these bales after 12 months storing. The wrapped bales stored for 12 months seemed to be slightly more mouldy than those stored for 6 months, suggesting that wrapping in plastic may create conditions favouring fungal growth. These observations are parallel with organoleptic analysis. The level of yeasts and enterobacteria (Fig. 12) did not vary much between bales except for bale number 9, which had high numbers of both microbes. This could be due to the unintended loose structure of the bale, which enabled vigorous microbial growth.

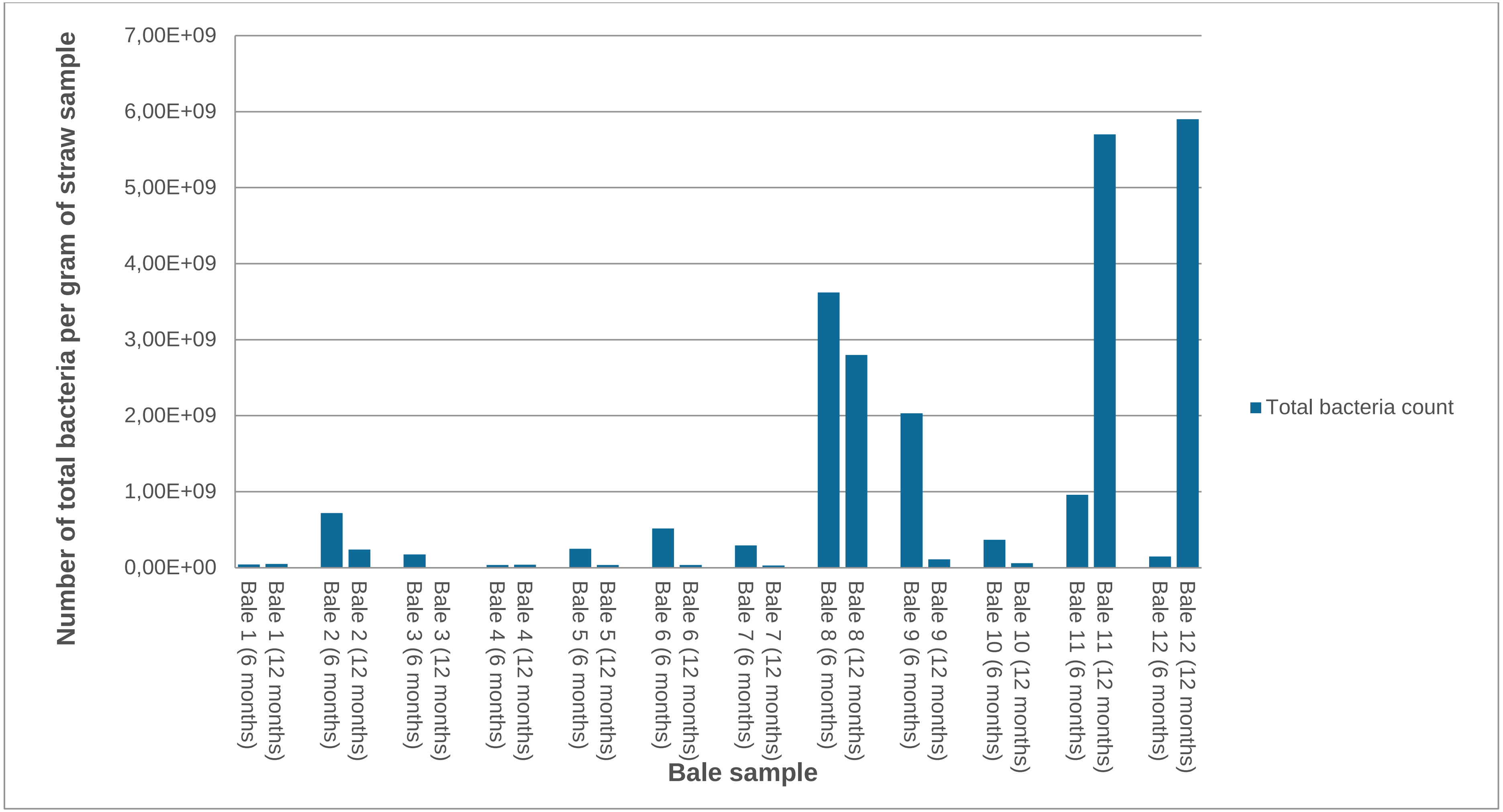


Figure 9. Determination of the number of total bacteria (per gram of straw sample) in the experimental bales. Information on the bales is presented in Table 1.

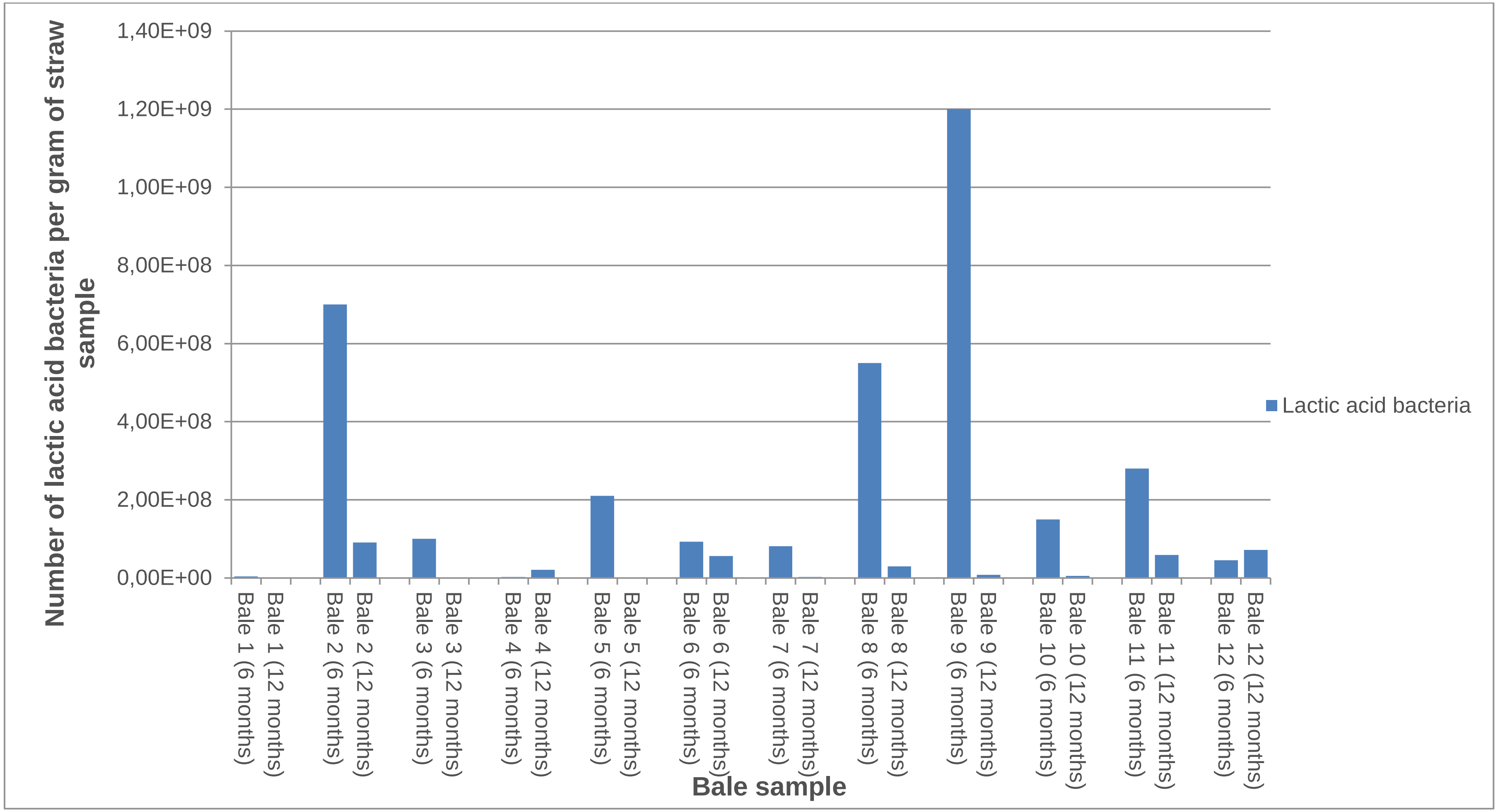


Figure 10. Determination of the number of lactic acid bacteria (per gram of straw sample) in the experimental bales. Information on the bales is presented in Table 1.

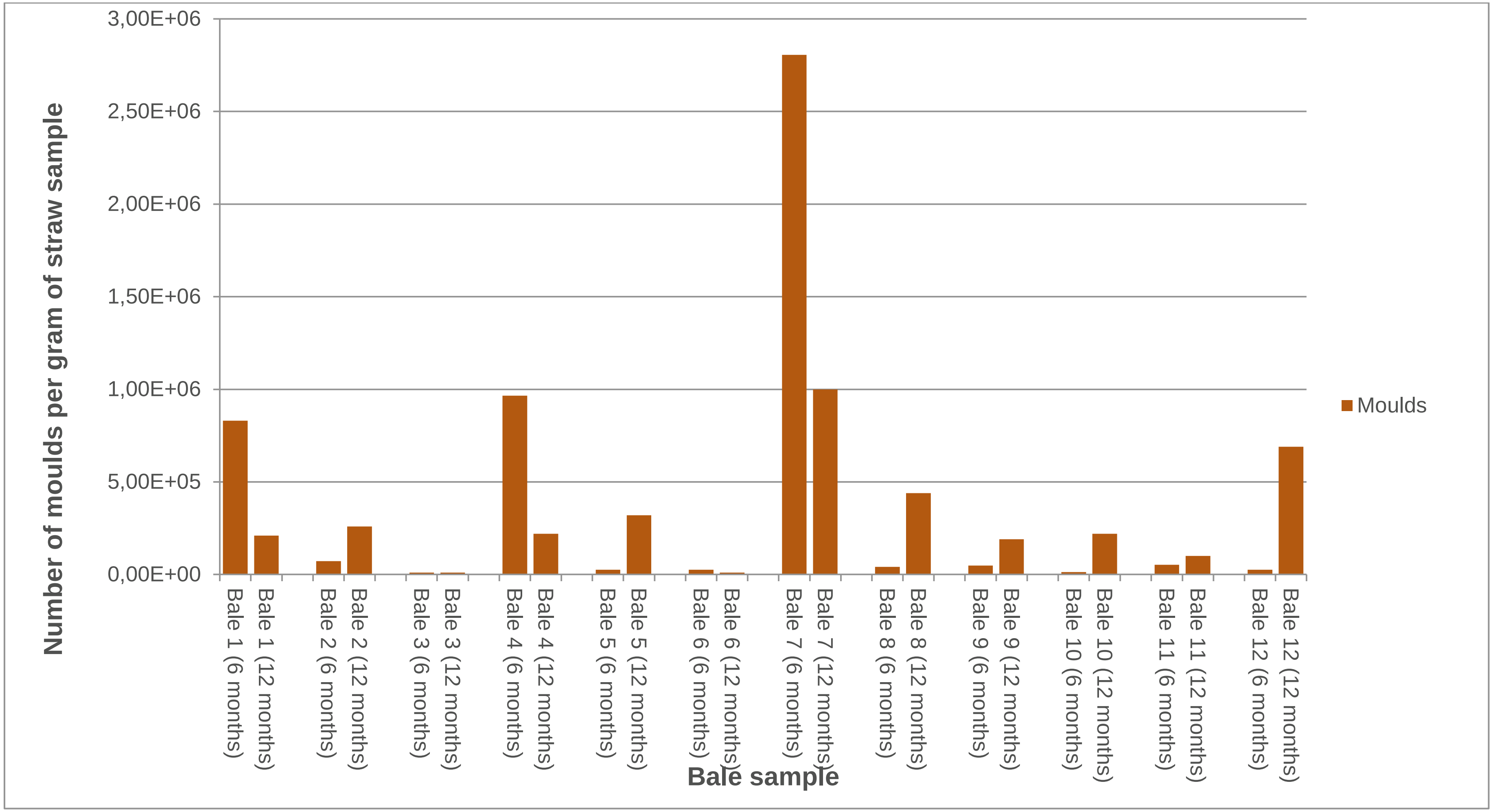


Figure 11. Determination of the number of moulds (per gram of straw sample) in the experimental bales. Information on the bales is presented in Table 1.

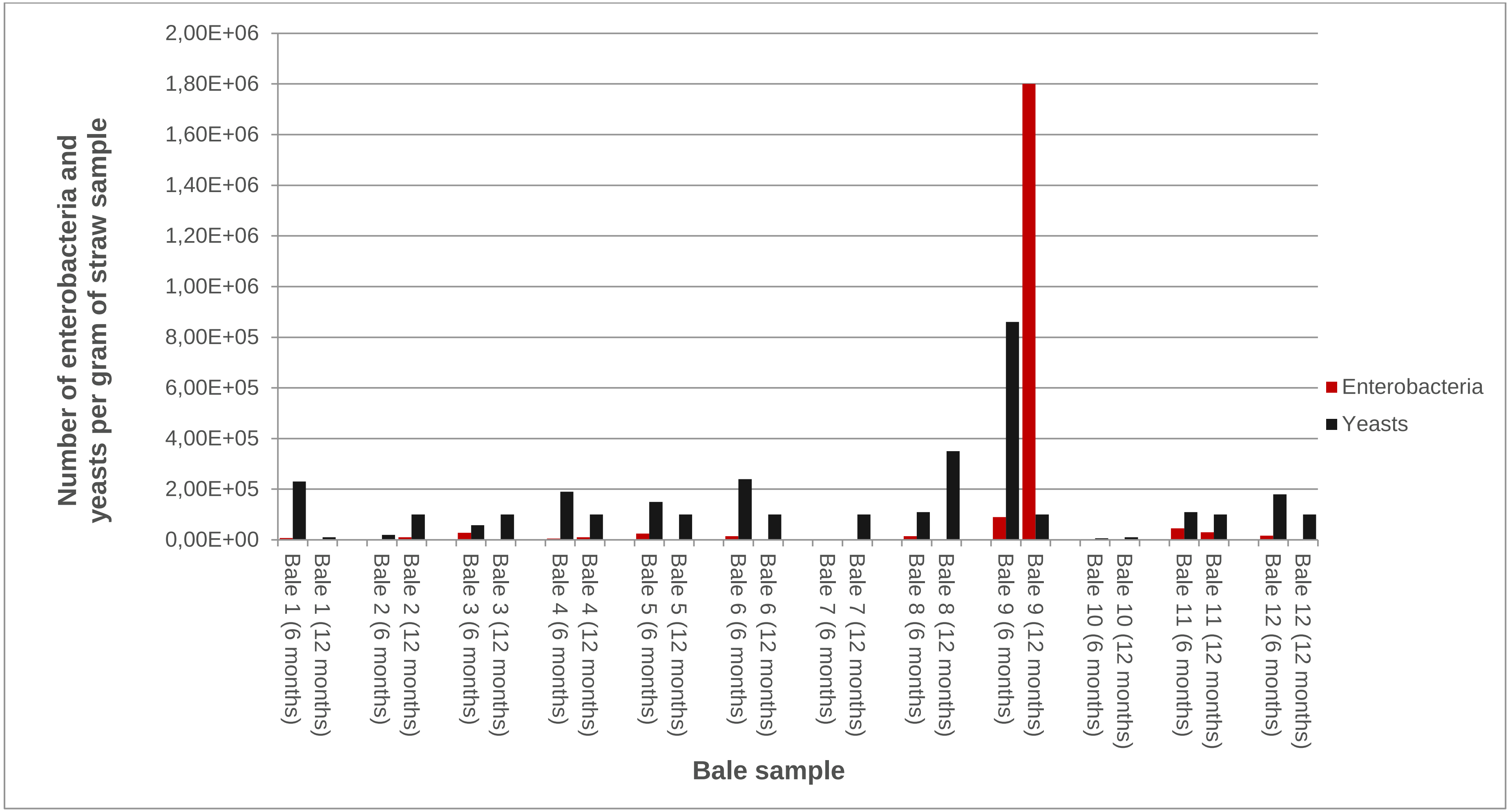


Figure 12. Determination of the number of enterobacteria and yeasts (per gram of straw sample) in the experimental bales. Information on the bales is presented in Table 1.

4 Materials and methods (2015 – 2016 experiment)

The target of the second experiment was to obtain more exact information of the storage of moist cereal straw. For this reason four replicated bales of every treatment were made. The number of treatments was decreased so that total amount of the bales was 24, like in the first experiment. Bacteria-preservative was replaced by propionic acid preparation. The experiment consisted of the following 6 treatments: three wrapping levels (0 layers, 3 layers, 6 layers)*2 preservative levels (with or without). The target moisture content of bales was about 20 % (wet basis).

The bales were made at Ruukki Research Station 30.9.2015. Barley had been harvested 29.9. (replicates 1-2) and 30.9. (replicates 3-4). Raking was not used; the bales were made directly after combine harvester. The bales were made with an integrated round baler wrapper (McHale Fusion 3) with full bale density setting. Propionic acid (Propcorn Plus) was spread directly to baler's pick up by applicator according to manufacturer's instructions (8 l/fresh ton).

Wrapped bales were stored outside and bales without wrapping were stored stacked inside cold storage hall until the beginning of April 2016. The bales were weighed before and after storage on scales, with an accuracy of ± 5 kg. The moisture samples were taken from the unwrapped bales immediately after baling with hollow drill (630 x 20 mm). Inside temperature of unwrapped bales was measured from the middle of the bales three times by using these holes during autumn 2015. Between the measurements the holes were closed by plastic. The same hollow drill was used to take moisture and microbiological samples from all bales in the end of the experiment in April 2016 (4 samples per bale).

After storage the bales were splitted in half and an organoleptic analyses were performed immediately. Every bale was scored on a scale of one to ten by two persons, who didn't know about the bale treatments. The things which affected to scores were: visible mould or dust surface or inside of the bale, colour of straw and smell of straw.

Moisture determination and microbiological analyses were performed similarly like in the experiment 2013 – 2014. Because moisture content of the bales varied a lot between replicates 1-2 and 3-4, the results are presented separately for every bale.

5 Results & discussion (2015 – 2016 experiment)

5.1 Organoleptic analyses

Organoleptic analyses after removing the wrapping plastics and splitting the bales showed that the bales without plastics were mouldy. This was the biggest reason to low scores (fig. 13). 3 or 6 layers plastic wrapping film enhanced the score in organoleptic analysis clearly. Also use of propionic acid enchanged the scores. Big variation in moisture content between replicates 1-2 and 3-4 can be seen also here.

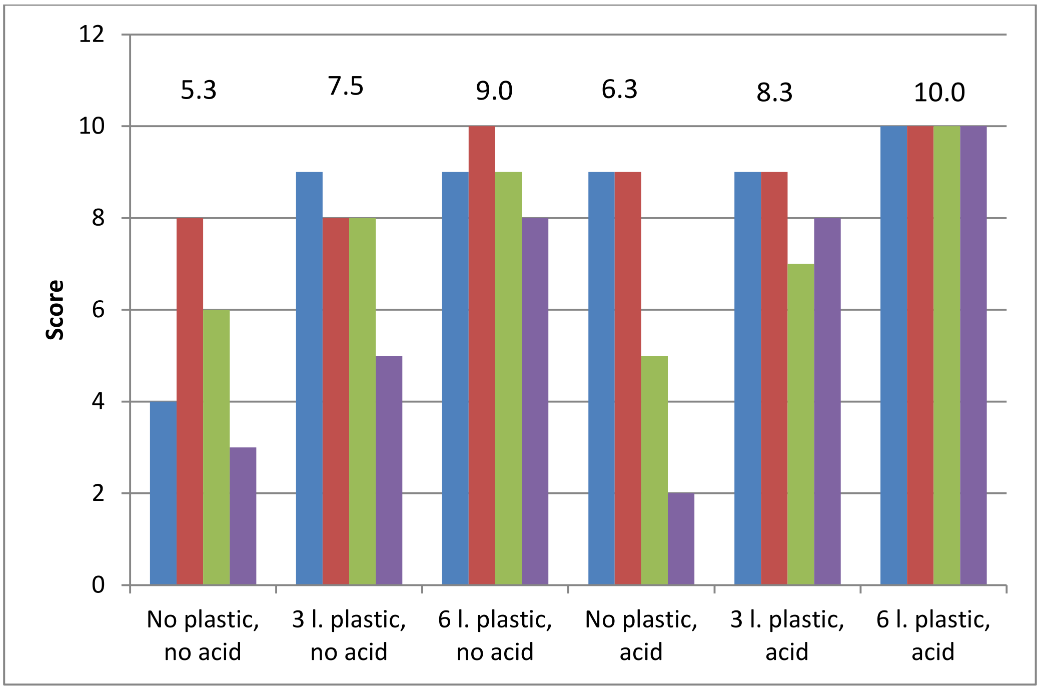


Figure 13. Scores given for the straw bales in the organoleptic analyses in the beginning of April 2016. The scale was 1 to 10 and the average of the treatment is shown above the bars. 3 l. plastic = 3 layers of wrapping plastics.

5.2 Physical characteristics of the bales

As seen in Fig. 14, moisture content in replicates 1 – 2 were near to target (20 %), but bales in replicates 3 - 4 were much moister than desired. The initial moisture content could be measured only in bales without wrapping (Fig. 15). It seems that bales without wrapping had lost some moisture during storage (compare Figs. 14 and 15). This can be also noted, when looking at bale weight losses during storage (Fig. 16 and 17). Moist bales without wrapping had lost 50 – 95 kg of their weight during storage. If the bales were wrapped with plastics, maximum weight loss was 12 kg/bale. If the bales were dry enough (replicates 1 – 2), maximum weight loss was under 10 kg/bale with or without wrapping.

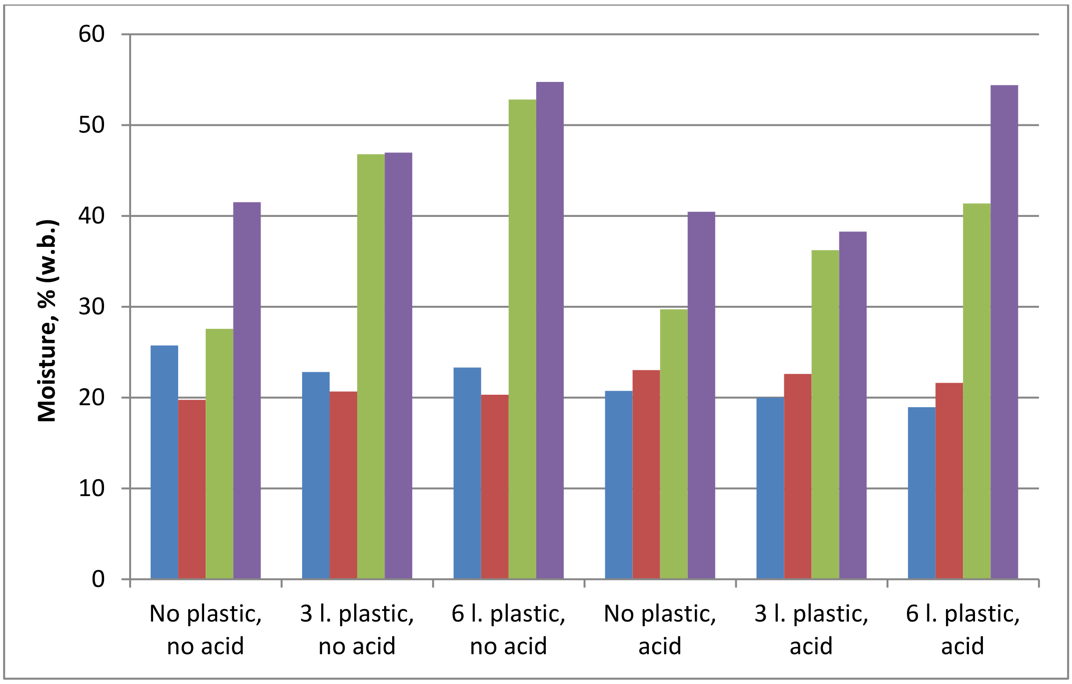


Figure 14. Moisture content (w.b.) of straw bales after 6 months storage (1.4.2016). 3 l. plastic = 3 layers of wrapping plastics.

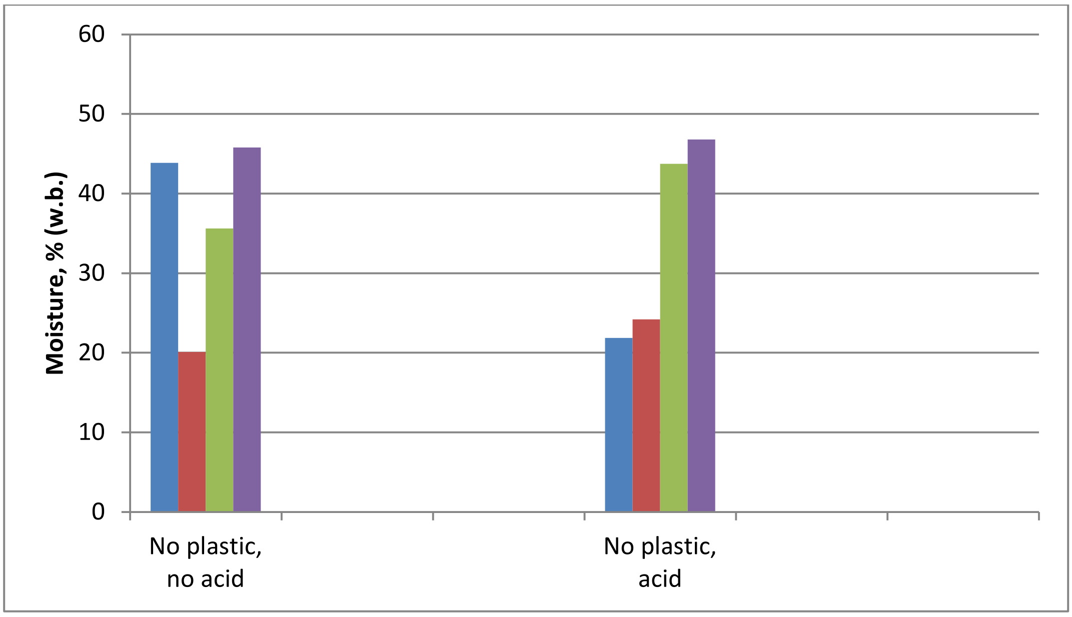


Figure 15. Moisture content (w.b.) of straw bales before storage (2.10.2015). Only bales without plastic wrappping could be sampled and measured before storage.

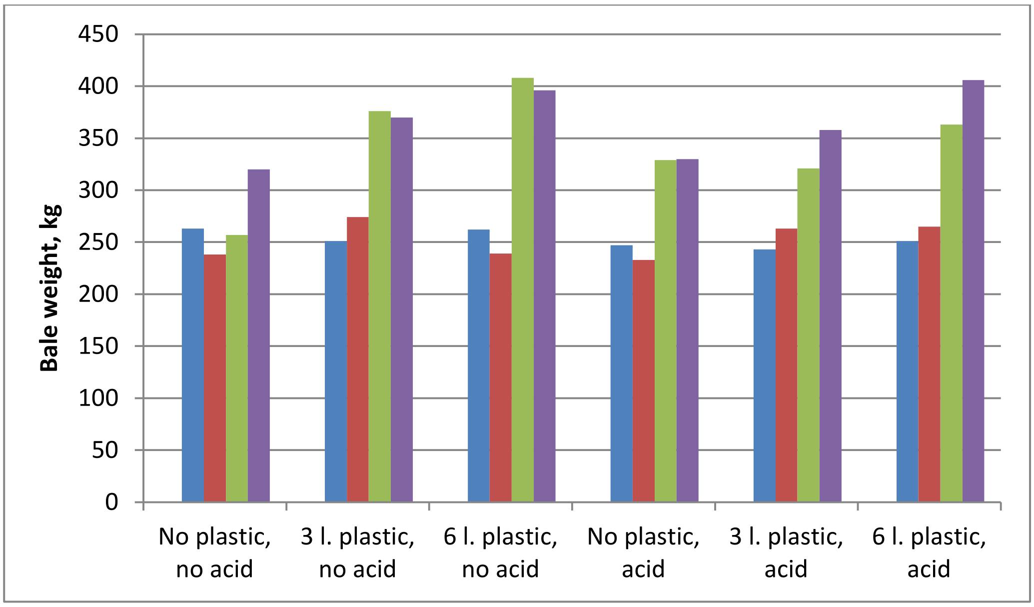


Figure 16. Bale weights before storage (2.10.2015).

Moist bales without wrapping lost 8 – 16 % of their dry matter. This was about 20 – 40 % of total weight loss. The remaining part of loss consisted evaporation of the moisture. Total weight losses are approximately the same than in the experiment 2013 - 14. Proportion of dry matter could now be estimated more exactly.

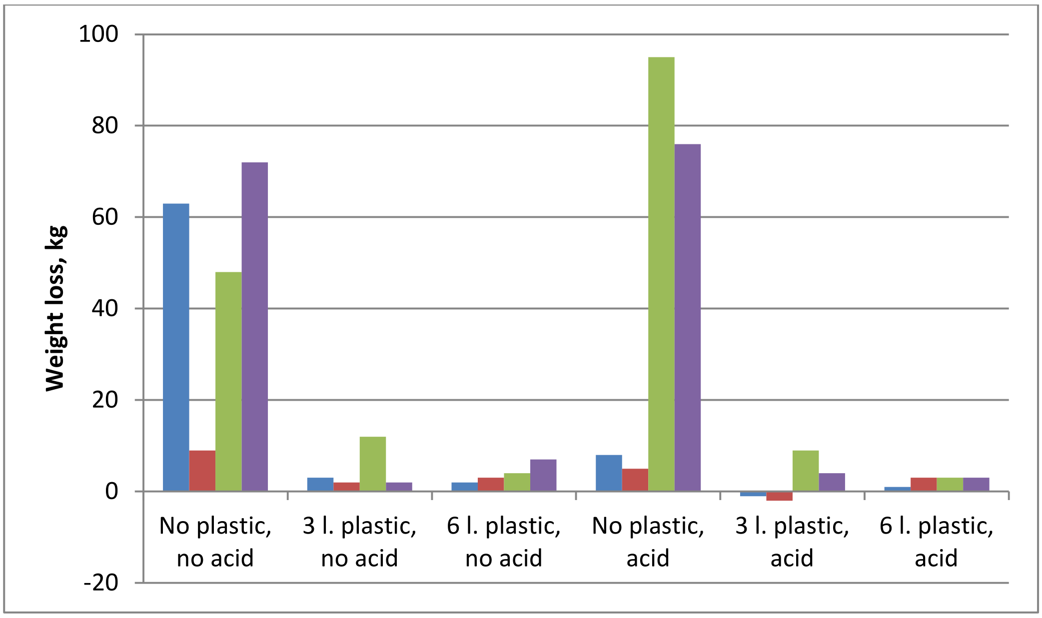


Figure 17. Weight loss of bales during six months storage.

Weight losses were of consequence of heating up of straw. Moist bales without wrapping got warm quite soon after baling (Fig. 18). Not even propionic acid couldn't prevent that. Maximum observed temperature was 57 °C. Dry bales didn't start to get warm.

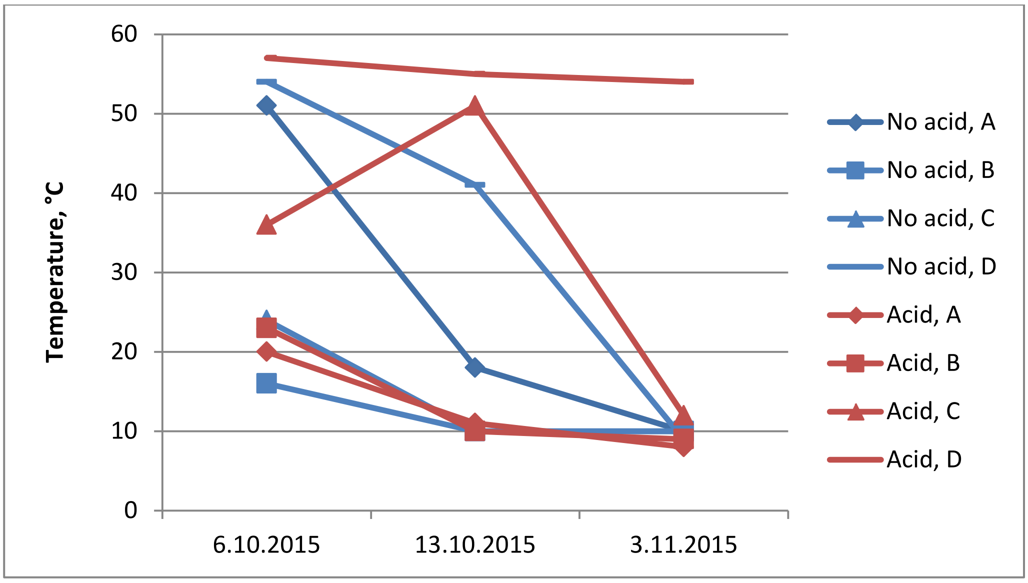


Figure 18. Temperature inside of the bales during autumn 2015. Measurement was done for the bales without plastic wrapping. Treatments: "No plastic, no acid" and "No plastic, acid". Bales A – D = bales involved in the treatment.

5.3 Microbiological analyses

Microbiological analyses show that – as expected - acid treatment combined with plastic wrapping gives the best protection against microbial growth (Figs. 19-20). Eukaryotic microbes, i.e. yeasts and moulds, thrived in conditions with no acid addition and plastic wrapping (Fig. 21). Also, moisture seems to be a growth enhancer, as the bale with the lowest moisture (bale B) had the lowest count of yeasts and moulds.

Enterobacteria are known to favour microaerophilic conditions with pH close to neutral. In the current study, a bale with the highest moisture (bale D) preserved in six layers of plastic wrapping and no acid treatment seemed to create a favourable environment for the growth of enterobacteria (Fig. 20 a).

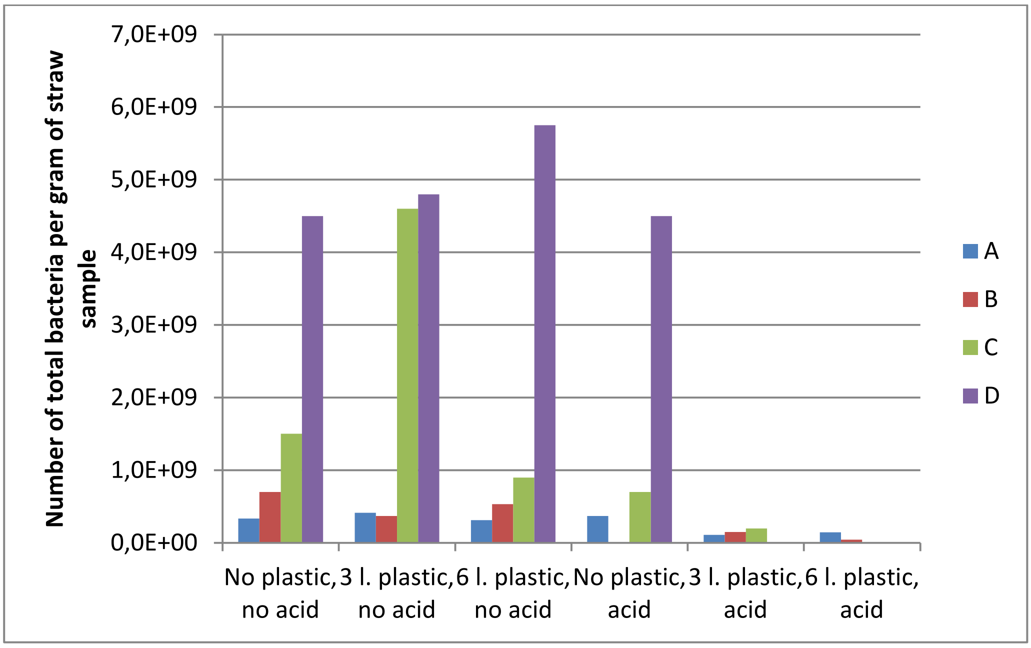
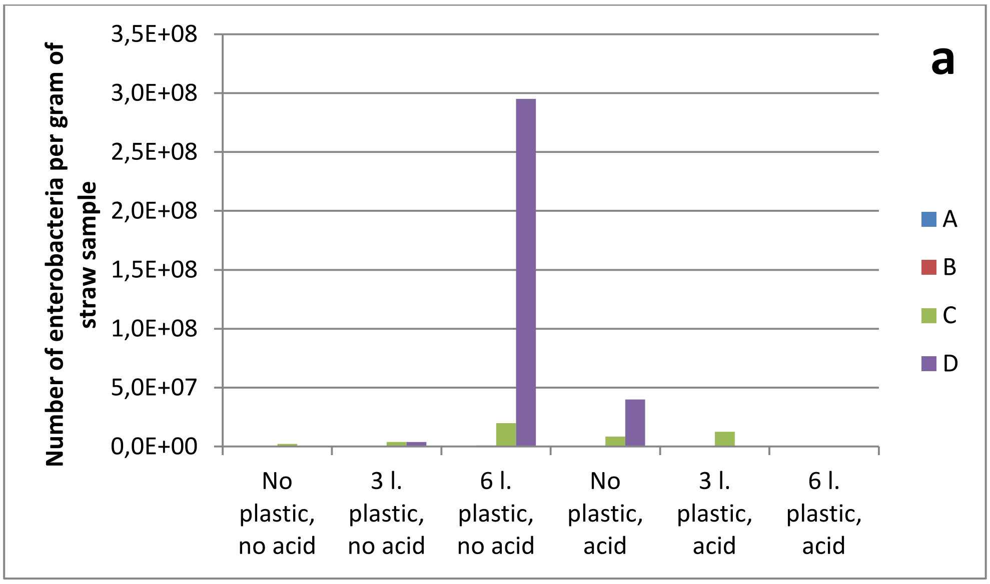


Figure 19. Determination of the number of total bacteria (per gram of straw sample) in the experimental bales (A, B, C and D).



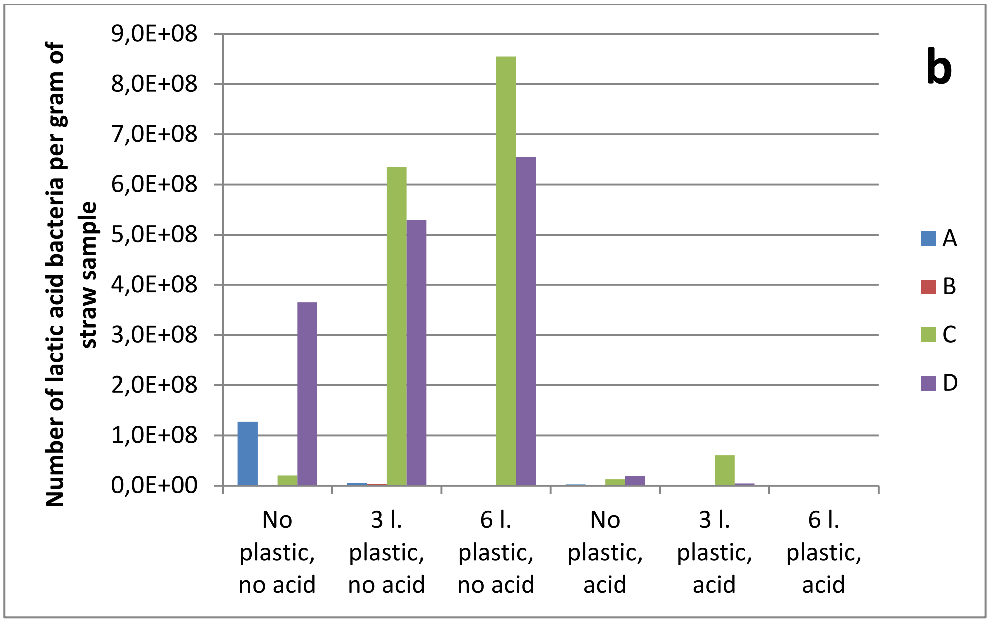
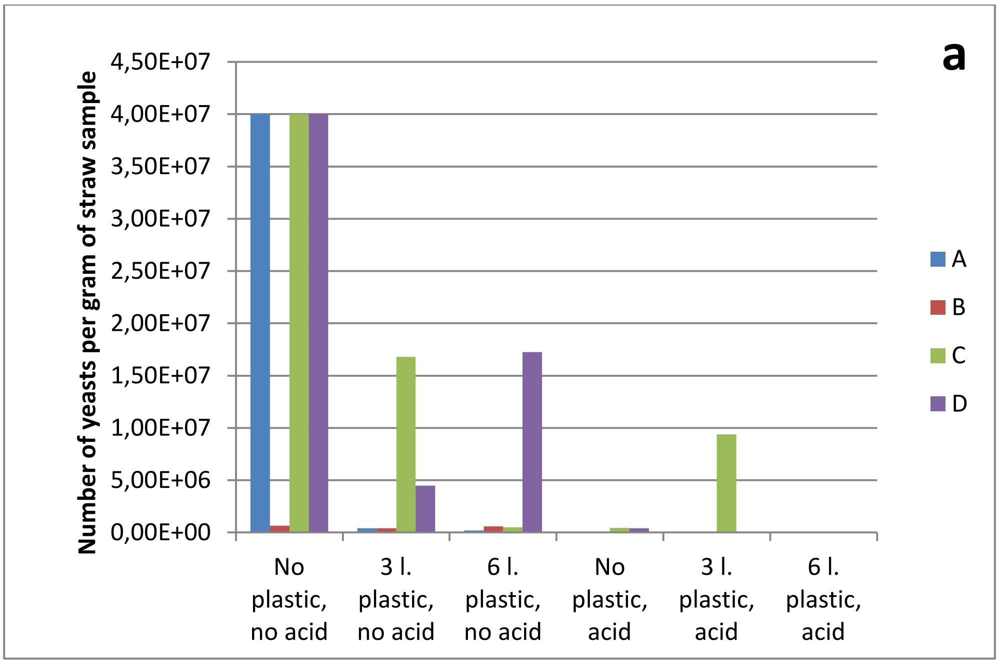


Figure 20. Determination of the number of a) enterobacteria and b) lactic acid bacteria (per gram of straw sample) in the experimental bales (A, B, C and D).



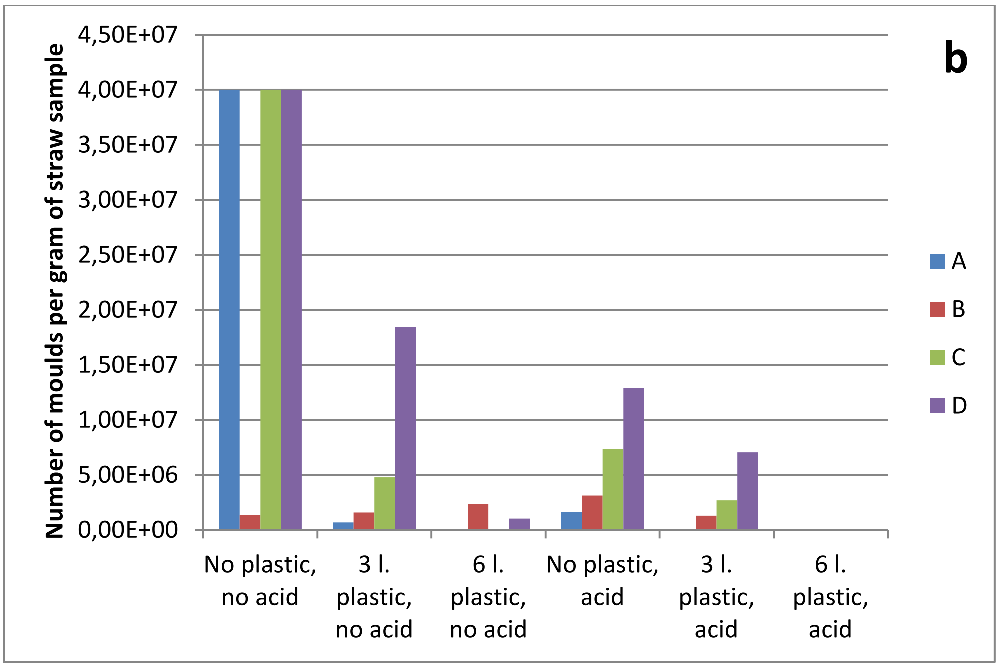


Figure 21. Determination of the number of a) yeasts and b) molds (per gram of straw sample) in the experimental bales (A, B, C and D).

5.4 Costs of wrapping and preservatives

Costs of plastic wrapping of round bales consists of plastic film and more expensive machinery in baling. We calculated that plastic film would cost 8 – 16 eur/ton DM straw, for 3 or 6 layers respectively. The use of more complicated machinery in baling would cost about 3.5 eur/ton DM more compared to round baler which cannot wrap (depreciation time: 12 years, interest: 5%). On the other hand, when plastic wrapping is not used the bale heaps have to be covered by plastic film or tarpaulin, which would cost about 6 eur/ton DM (Paappanen et al. 2008). Therefore, the costs of wrapping can be estimated to be 5.5 – 13.5 eur/ton DM more compared to system, where the bales are not wrapped but they are stored under plastic film or tarpaulin.

The extra cost of microbial preservative used in the experiment would be 4 – 5 eur/ton DM. Cost of propionic acid would be 14 – 16 eur/ton DM (dosage: 8 l/fresh ton).

The most expensive is to build storage hall for straw bales, which could cost 20 – 40 eur/ton DM (Bernesson & Nilsson 2005, Rinne 2011). However, storage hall is a sustainable solution, because plastic waste is not generated like when the bales are stored outdoor under plastic film or wrapped. On the other hand, wrapping film can be utilized effectively for heat production at power plants. The moist straw cannot be stored in storage hall without wrapping.

6 Conclusions

Round baled straw, which moisture content was over 25 % did not preserve well without plastic wrapping. Quite low amount of plastic film (3 layers) maintained straw quality advisable over winter (6 months). When straw was stored for 12 months (first experiment), 6 layers of wrapping seemed to maintain moist straw quality slightly better than 3 layers, but the quality had already decreased, being poorer than after 6 months of storage. If the straw bales are stored without wrapping, moisture content should be under 20 % and the bales should be stored under the roof.

The biological preservative didn’t seem to help clearly to maintain quality of straw with or without wrapping, but our straw was moister than manufacturer of preservative recommends. Yet, a high number of lactic acid bacteria – originating either from preservative or natural environment – seem to contribute to the declined number of moulds. This is most probably due to the organic acids produced by lactic acid bacteria.

Propionic acid together with plastic wrapping maintained straw quality quite well regardless of straw moisture (second experiment). The acid helped a little also when straw was stored unwrapped, but in this case straw moisture content should be under 25 %.

The moist bales without plastic wrapping but stored under the roof, lost their dry matter 8 – 16 % already during 6 months storage. This can have economical importance, because harvest and storage costs of straw are relatively high. Besides, decay is caused by microbes, which generates health risks to workers dealing with straw (Kotimaa et al. 1991).

Moisture content of unwrapped bales was under 20 % after 12 months' storage and microbical activity seemed to cease. The unwrapped bales had dried during storage.The same phenomenon was also observed by Ahokas et al. (1983). According to their study, straw has low equilibrium moisture content, and straw in small square bales dried spontaneously under the roof due to microbial warming. In our study, spontaneous drying of straw may have occurred more than in real-life storage, because the bales were separated from each others by wooden pallets. On farms it is common for 3-5 round bales to be stacked unseparated, and in these conditions the bales are more likely to decay than dry out.

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