Effect of short-term storage on quality of wheat stored in large polyethylene bags

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Abstract: The aim of this study was to compare the short-term storage of food grains in large polyethylene bag silos with the conventional bulk storage of grain regarding quality parameters. This storage option provides the chance to get along fluctuations in prices without investment in building operations.

75 t newly harvested wheat with a dry matter content of 89.1% was stored during a period of six months in two polyethylene bags and as control in a granary on the same farm. After two weeks, one month, three and six months samples were collected off the first bag below the polyethylene film and in 1.20 m depth and at the same time samples were taken in the granary. The second bag was kept closed over the six month. Results demonstrated that there are no differences between the measuring points within a bag, between the two bags and no differences between the storage systems regarding the parameters dry matter, pH, starch, crude protein, content of mesophilic microorganisms (bacteria, yeast, mould) and germination. The temperature in the polyethylene bag silos resembled rapidly to the ambient temperature. There was no local overheating due to microbiological activity. The results demonstrate that the temporary grain storage in polyethylene bags does not lead to any grain quality loss compared to the conventional storage. Because of the very low cost, the flexible bagging system represents an alternative to high investment in permanent storage structures for grain.

Key words: wheat, storage, polyethylene bags, quality, costs

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1 Introduction

In most grain production systems, grains must be held in storage for periods varying from one month up to more than a year. To preserve grain from deterioration, water, heat or oxygen has to be withdrawn. Conventional storage systems use drying or aeration systems. The storage of grain in large polyethylene bags under anaerobic conditions provides the chance to get along fluctuations in prices without investment in building operations. The objective of this study was to compare the storage of grain with low moisture content less than 14% in polyethylene bags with the conventional storage of grain in a granary regarding various quality parameters. In particular, this study was to determine, if the evolved carbon dioxide in the bags affects the viability of the grain during storage. It was also to investigate how changes in ambient temperatures affect the conditions in the bags.

Preservation and storage of biomass in large polyethylene bags is practiced in many different countries. Lower costs, lower risk and high quality in an airtight system are the reasons

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for a growing trend. Farmers refuse construction measures because of the costs and choose a flexible storage system, they are thus able to adapt to external conditions.

Although the advantages of the storage in polyethylene bags are discussed only few investigations are published. Busato et al. (2007) investigated the bin location to optimize the wheat harvesting and transport operations. Gaston et al. (2009) developed a mathematical model to describe the heat and moisture transfer of wheat in polyethylene bags. Both papers do not contain information about the quality of the stored wheat.

Reports about the storage of corn have shown that the corn quality remains (Harrel et al., 2007; N.N., 2010; Tipples, 1992). Harrel et al. (2007) found out that the moisture content of the stored corn decreased nearly 2% during the storage period. No live insects had been detected after one resp. two months storage.

The carbon dioxide atmosphere inside the bags brings advantages from the point of view of insect and mould avoidance, but Muenzig (1988) published that a high carbon dioxide level in a storage unit leads to a reduced germination of wheat kernels, a loss of sensory quality and a lower baking volume. These results were found out by grain with moisture content higher than 14%.

Under anaerobic conditions, some activity may continue and is more obvious with grain at higher moisture content. Such an activity can lead to sour off-flavours and odour (Tipples, 1992).

The range of products that can be stored in polyethylene bags is wide: renewable raw materials (grass, corn, whole crop silage, wet and dry cereals, sugar beet), substrates of the processing agro-industries (pressed pulp, brewer's grains, pomace) as well as organic residues. According to the different substrate characteristics and harvesting methods appropriate bagging systems are recommended. The bags sizes range between 6.5’ (1.98 m) up to 12’ (3.66 m) diameter. They are offered up to 150 m length. In a polyethylene bag with 12’ (3.66 m) diameter and 150 m length amounts of 1 000 t can be stored, with a capacity of 2 000 t a day. The so-called “compost bagger” enables the farmers to preserve even the whole sugar beet in a large polyethylene bag all over the year – interesting for biogas production. The compost bagger can be filled with a front loader. Diameters of 6.5’ (1.98 m) or 8’ (2.44 m) are offered for this technique. Results of new trials concentrating on effluent and losses support the future use of bagging technology in the preservation of sugar beets (Wagner, 2009).

A bagging technique with roller mills for crimping and preservation of high moisture grain is an alternative for drying grain. Experiences showed that there is a slight fermentation starting at 25% moisture content with losses of only 1% (Matthiesen et al., 2006; Matthiesen, 2008). Due to the rapid anaerobic conditions during the process the low losses in a bag are a common advantage of the system (approximately 5% for grass and maize, 4 - 5% for beet pulp and brewer’s grains) (Weber, 2006; Weber, 2009).

With the conventional storage of grain in storage boxes a preservation of grain bulks by an air flow is necessary to prevent deterioration (Bala, 1997; Mühlbauer, 2009). The primary aim is the reduction of the moisture content to a safe level, but also dry grain bulks have to be ventilated periodically by an air flow to remove heat energy caused by the respiration of the grain.

The aim of the project was to evaluate the storage of dry grain in polyethylene bags regarding (1) the quality of the grain kernels and (2) the process costs.

2 Materials and methods

2.1 Materials

Wheat variety *Tarso* was harvested on the land of the Budissa Agrarprodukte Preititz / Kleinbautzen GmbH, Germany (51°22’ N, 14°53’ E, http://www.geoco.org/deutschland-de.html) (Table 1).

Table 1 Characteristics of the wheat at harvest

Parameter	Wheat variety *Tarso*
Previous crop	winter rape
Previous crop harvest	06.07.2007
Yield previous crop	3.7 t/ha
Animal slurry to the previous crop	25 m^3/ha cattle slurry, about 8% DM
Tillage	Disc harrow for previous crop, no plow
Sowing	26.09.2007 rotary harrow with seeder
Fertilization	three times potassium ammonium nitrate 20.3.2008: 50 kg/ha N 29.4.2008: 60 kg/ha N 26.5.2008: 50 kg/ha N
Harvest	01.08.2008
Yield	87 deciton/ ha
Moisture content	12.9%
Hectolitre weight	79.6
Crude protein	13.5% DM
Falling number	407
Sedimentaion	43%

DM dry matter

2.2 Methods

2.2.1 Grain Storage

The experiments were undertaken in 2008/09. 75 t newly harvested wheat (parameters see Table 1) was stored into two polyethylene bags (2.70 m diameter, 10 m length, 215 µm film thickness, AG BAG Profi Farmbagger, capacity > 300 t/h) and at the same time in a nonventilated granary on the same farm. After the polyethylene bags had been filled, temperature loggers (Comp. Gemini, Tinytalk, Germany) were inserted into the centre of the silo at eight measuring points lengthwise on the right and left side of the bag (distance of 2 m each).

The Farmbagger used is filled through a hopper, an auger or a conveyor belt. Depending on the substrate and filling system a capacity of > 250 t/h can be achieved (Table 2).

2.2.2 Sampling

After two weeks, one month, three and six months samples each with 0.25 kg were collected on the bag at the same measuring point below the polyethylene film (n = 4) and in 1.20 m depth (n = 4) (Fig. 1). On the granary the samples were collected also at the same measuring points below the surface (n = 4) and in 0.60 m depth (n = 4). The second bag was kept closed for the whole period to analyze the influence of the sampling in the first bag.

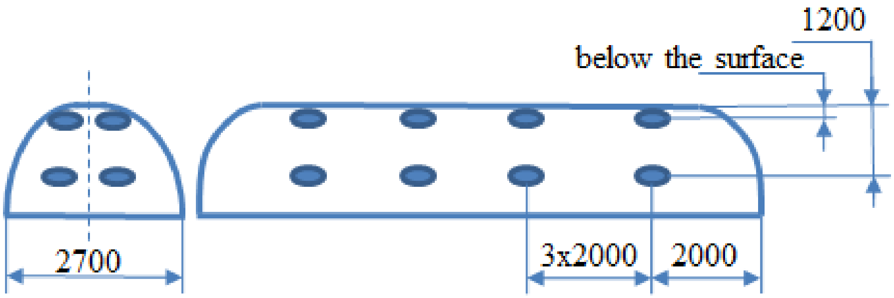

Figure 1 Schematic illustration of the polyethylene bag with the measurement points

Table 2 Technical data sheet Farmbagger Standard, Corn Maize (Bellus et al., 2008)

Parameters	Unit	Data
tractor J.D. 6520	kW	90
motor	rotations /min	2050
power takeoff	rotations /min	540
moisture	%	23.1
broken corn harvest	%	8.1
broken corn in bag	%	8.6
broken corn by bagging	%	0.55
polyethylene bag diameter	m	2.70
technical capacity	t/h	366
technological capacity	t/h	259
performance by using loader	t/h	122
fuel consumption (technical)	l/t	0.03
fuel consumption (technological)	l/t	0.04
safety and guarantee of work	%	100

2.2.3 Analysis

The fresh samples were analyzed according the German standard methods (VDLUFA, 2007) for dry matter (DM) (chap. 3.1), starch (chap. 7.21.1), crude protein (chap. 4.1.1 and 4.1.2), pH-value (chap. 18.1), germination (ISTA, 2003) and the microbiological groups' bacteria, yeast and mould according the German guideline (DGHM, 2007).

Determination of mesophilic bacteria

For the detection of the bacterial content 10 g of wheat grains, suspended in 90 ml of Ringer's solution, were paddled (Stomacher 400, Comp. Laboratory Blender, GB). From the suspension were set serial dilution series in distilled water and aliquots were plating on Plate Count Agar (PCA, Merck, Germany). The petri dishes are incubated for two to four days at 30° C. All grown colonies were counted and taking into account as Colony Forming Units/g Fresh Weight (CFU/g FW) calculated.

Determination of mesophilic yeasts and moulds

The preparation of the samples for the determination of mesophilic yeasts and moulds were the same as for mesophilic bacteria. However the cultivation was on Bengalred- Chloramphenicol Agar (Merck, Germany). The petri dishes were incubated at 25 C for three to seven days. All grown colonies were counted and taking into account as CFU/g FW calculated.

Germination

After the last sampling the germination of wheat samples were tested by two different methods. First, the germination capacity using germination bed test and on the other hand germination potential was calculated with the TTC-test.

Germination bed test

Germination was determined after 6 months of storage. From each variant approach (control, bag 1, bag 2) seeds were designed 4 x 100 in petri dishes (∅ 15 cm) and stored for three days at 4° C, in order to break a possible dormancy, and then five days at 20° C. Daily germinated seeds were removed (visible radicle) and after five days the total number of germinated seeds was given in percentage.

TTC-Test

To investigate the germination potential by the TTC test after six months storage (control, bag 1, bag 2) 2 x 50 seeds were analysed. These grains are soaked approximately 30 minutes in 40° C warm water and afterwards cut with a scalpel lengthwise into two pieces. The seeds are divided so that the embryo is clearly visible. Only one half is used in the experiment. The halved grains are completely covered with 0.5% TTC solution (2-, 3-, 5-Triphenylterazolium-chlorid, MERCK). After one hour incubation at 35° C, the red-colored seedlings are counted under a microscope. The red-coloured part of the seedling was also determined. All at least 1/3 coloured seedlings indicate the presence of active enzymes for germination. The number of coloured grains is multiplied by two and expressed as a percentage.

2.2.4 Statistical Evaluation

All values were measured with 4 repetitions. For each value group arithmetic mean and standard deviation were calculated.

The numbers of bacteria, yeast and mould were evaluated on the basis of differences in their mean values. The evaluation was carried out for the comparisons of (1) bag 1 below the surface vs. bag 1 low, (2) bag 1 vs. bag 2 and (3) bag 1 vs. granary. The evaluation was focused of 6 month storage time.

The statistical evaluation was done with the SAS® 9.1 (SAS, 2004). The measured values within the groups were tested regarding normality (Proc UNIVARIATE) and variance homogeneity (Proc TTEST). Afterwards the t-test (Proc TTEST) was used to find out significant differences of the mean values between the groups.

3 Results and Discussion

Temperature profile during the storage

Information on the conditions of storage is given by the temperature gradients. In the two polyethylene bags approximately the same patterns are visible. Only minor differences were revealed by investigations concerning the temperature development in the silos. There was a gradually decrease in temperature over the six months approximately from 30°C to 0°C; it converges to the ambient temperature (Figure 2).

Chemical analysis

The wheat was stored in with a moisture content of 10.9%.That corresponds to a storable dry matter content of 89.1% (Table 3). The levels of the studied components starch and crude protein correspond to the literature (Jeroch et al., 1993). Within the control samples on the granary the dry matter content of wheat decreases on an average of 89% to 85% during the six-month storage period, but remains still in the storable content.

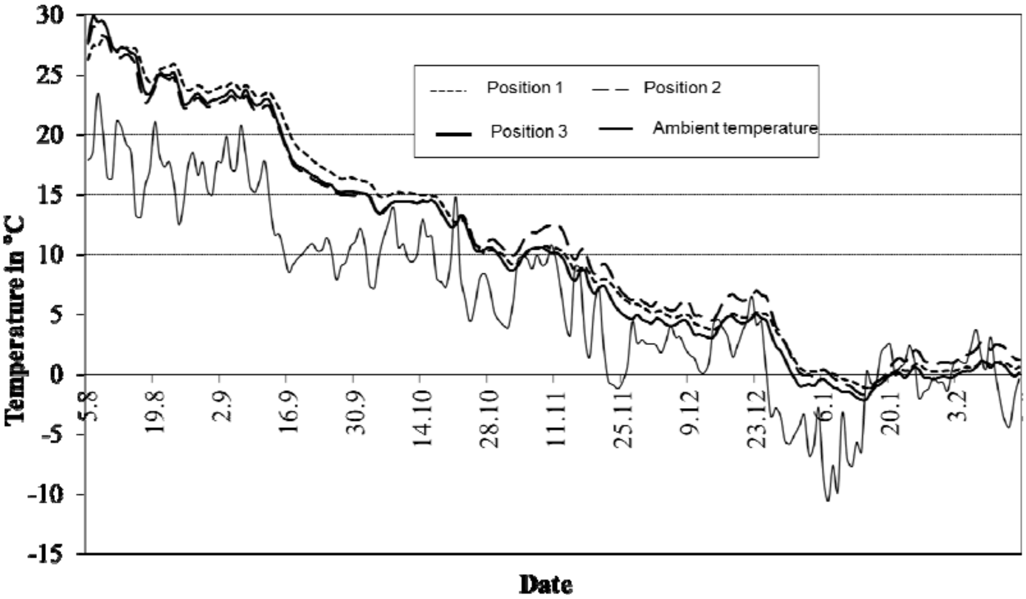

Figure 2 Temperature data in the polyethylene bag no. 2 during the storage in comparison with the ambient temperature

Table 3 Chemical analysis at storage (mean ± standard deviation)

Storage time month	Dry matter %	pH-Value -	Starch % DM	Crude protein % DM
Storing in				
0	89.1 ± 0.10	6.9 ± 0.04	67.2 ± 0.5	14.8 ± 0.2
Storing out				
Granary; below the surface				
0.5	87.7 ± 1.1	6.8 ± 0.10	65.7 ± 0.93	14.6 ± 0.30
1	87.4 ± 0.63	6.8 ± 0.02	65.2 ± 0.12	14.5 ± 0.09
3	88.0 ± 1.0	6.4 ± 0.09	67.3 ± 0.50	14.2 ± 0.69
6	85.4 ± 0.15	6.4 ± 0.03	65.6 ± 0.58	14.4 ± 0.37
Granary; 0.60 m depth				
0.5	88.8 ± 0.37	6.8 ± 0.07	65.2 ± 0.95	16.2 ± 0.09
1	88.3 ± 1.02	6.9 ± 0.05	65.6 ± 1.44	14.2 ± 0.09
3	86.8 ± 0.2	6.5 ± 0.05	67.5 ± 0.29	13.8 ± 0.65
6	86.4 ± 0.38	6.4 ± 0.04	64.6 ± 2.28	13.7 ± 0.39
Bag 1; below the polyethylene film				
0.5	89.0 ± 0.1	7.0 ± 0.14	66.4 ± 0.77	14.6 ± 0.40
1	88.8 ± 0.37	6.9 ± 0.04	64.6 ± 0.77	14.7 ± 0.26
3	87.6 ± 1.52	6.6 ± 0.18	68.0 ± 0.86	13.1 ± 1.41
6	87.7 ± 1.07	6.6 ± 0.10	65.4 ± 0.67	14.0 ± 0.16
Bag 1; 1.20 m depth				
0.5	88.8 ± 0.12	7.0 ± 0.09	66.6 ± 0.60	14.7 ± 0.17
1	89.2 ± 0.19	7.0 ± 0.03	64.6 ± 0.73	14.6 ± 0.26
3	88.8 ± 0.04	6.6 ± 0.05	67.8 ±0.32	12.8 ± 0.52
6	89.3 ± 0.05	6.7 ± 0.20	66.1 ± 0.22	14.0 ± 0.34
Bag 2; below the polyethylene film				
6	89.2 ± 0.20	6.4 ± 0.05	66.2 ± 0.52	14.0 ± 0.34

The moisture content of samples collected below the polyethylene films taken more variable than those taken from 0.60 m depth sections. Causes are certainly the rearrangements of the grain (Table 3).

The moisture content of the bag 1 samples taken in the middle of all samples varies only slightly. The immediately drawn to the surface samples showed a slight increase of 1.4 percentage points, from 1.20 m depth samples, however a slight decrease of 0.2 percentage points. It seems to be obviously that the developed condensations water under the surface of the polyethylene bag was absorbed by the dry grain.

The pH value at storing in was in all variants of 6.9 (Table 3). In the control samples, it decreases during the storage period in all sections in the slightly acidic range up to 6.4. In contrast, the pH value from the bags samples was changing on average by only 0.2 pH units. These changes are negligible. In all storage variants the differences on the pH value in the various sections are not higher than 0.1 pH units.

At the storing in, the starch content of the grain was in a typical range from 67.2% DM (Jeroch et al., 1993) (Table 3). In all storage variants these content shows variations between different sampling dates up to three percentage points DM. On average, the starch values decrease in both on granary and on bags by around two percentage points DM. The variations of the values within storage variants are irrelevant in the various sample sections.

The changes in crude protein are the means of both storage variants with a decrease of 14.8% to 14.0% DM the same direction (Table 3). The variability is more in granary samples than in the lots stored in bags, even within the different sampling sections. The differences are marginal and not significant.

Consideration was given to each test sample by wiping with tissue pieces, whether it had been formed under the film surface, a film of moisture. This was at no time being the case.

Microbiological analysis

At storing in the concentrations of mesophilic bacteria are with values by 10^7 CFU/g FW quite high (Table 4). The guideline value is 10^6 CFU/g FW (DGHM, 2007). However, most of them are part of the normal "cereal flora". Under this generic term are all grouped together in the harvest-fresh seeds occurring product type, mainly yellow pigmented bacteria. Primarily these include representatives of *Flavobacteria* and *Erwinia. ssp.*

At the harvest the concentrations of mesophilic fungi and mesophilic yeasts are somewhat higher than the guideline value for cereals products with 10^4 CFU/g FW respectively 10^3 CFU/g FW (DGHM, 2007).

During storage, the numbers of mesophilic bacteria are changing only very slightly. After 6 months storage in both variants the content reduce on an average from 7.35 log CFU/g FW to 7.17 log CFU/g FW. This is agreeing with the temperature changes. Like the chemical parameters in the granary samples the variations in the various sections are greater than during storage in bags (Table 4).

The content of mesophilic yeasts during storage is subject to greater variation in both storage variants than the content of the bacteria. During the storage the number of yeast in the middle of both storage variants is reduced, however, the reduction for the samples, stored in bags is greater than in the samples on the granary.

The concentration of mesophilic fungi fluctuates during storage about the initial values. After 6 months of storage in all samples the levels were below the initial values independent from the storage variant.

Also, the changes in the mesophilic fungi take place during the storage within in a power of ten. In all storage variants there is a slightly reduction of the content of fungi: in the samples from the bag from 4.62 to 4.31 log CFU/g FW and in the samples from the granary to 4.45 log CFU/g FW. In the samples from the granary higher numbers of fungi were detected in the upper layers and lower number in the lower depths. In the samples from the bag it is reversed.

Table 4 Microbiological analysis (mean ± standard deviation)

Storage time month	Bacteria log CFU/g FW	Yeast log CFU/g FW	Fungi log CFU /g FW
Storing in			
0	7.35 ± 6.4	4.80 ± 4.2	4.62 ± 3.9
Storing out			
Granary; below the surface			
0.5	7.20 ± 6.84	4.47 ± 3.89	4.92 ± 4.65
1	7.27 ± 6.76	5.08 ± 5.70	4.93 ± 4.70
3	7.02 ± 6.10	4.74 ± 4.45	4.94 ± 3.94
6	7.24 ± 6.77	4.93 ± 4.11	4.54 ± 4.05
Granary; 0.60 m depth			
0.5	7.10 ± 6.05	4.87 ± 4.76	4.79 ± 3.81
1	7.26 ± 6.76	5.01 ± 5.07	4.94 ± 4.00
3	7.03 ± 6.44	4.69 ± 4.14	4.64 ± 4.19
6	7.13 ± 6.70	4.53 ± 4.01	4.36 ± 3.98
Bag 1; below the polyethylene film			
0.5	7.31 ± 6.85	5.01 ± 4.39	4.54 ± 4.27
1	7.30 ± 6.91	4.78 ± 4.65	4.33 ± 3.92
3	7.24 ± 6.65	4.89 ± 4.67	4.43 ± 4.50
6	7.21 ± 6.83	4.66 ± 3.97	4.30 ± 3.72
Bag 1; 1.20 m depth			
0.5	7.29 ± 6.73	4.51 ± 4.17	4.59 ± 4.20
1	7.31 ± 6.81	4.77 ± 4.62	4.53 ± 4.36
3	7.18 ± 6.31	4.63 ± 4.08	4.62 ± 4.43
6	7.11 ± 6.51	4.68 ± 4.49	4.52 ± 4.21
Bag 2; below the polyethylene film			
6	7.09 ± 6.75	4.73 ± 4.75	4.21 ± 4.22

No significant differences of numbers of bacteria, yeast and mould after 6 month are found between samples from bag 1 that are taken from the bag part below the surface and from 1.20 m under the surface (middle of the silo bag). This result indicates homogeneous storage condition. In comparison of both locations the samples from the part below the surface are more interesting because of the increased spoilage potential caused by condensation effects.

After 6 months, these samples from bag 1 below the surface and as well from bag 2 show no significant differences in the contamination of bacteria, yeast and mould. Bag 1 was opened four times in order to observe the time-dependent contamination. The repeated sampling does not lead to quality losses in comparison to the bag which keept closed all the time. This result shows that the contamination development can be observe despite repeated opening of the bag.

The comparison of bag 1 and granary shows no differences in the case of bacteria (6 month, below the surface). In contrast differences are visible for yeast and mould. The grain from the granary has got higher contents of yeast and of mould, too.

Germination

After 6 months of storage, the germination tested on the bed test of the control samples with 99% is slightly higher than that of samples stored in bags with 98%. Tested on the TTC-test the germination is with 97% also slightly higher than that of samples stored in bags with 96% (Table 5). The differences are not significant.

The results demonstrate that the short-term grain storage in polyethylene bags does not lead to a loss of germination compared to conventional storage.

Table 5 Germination after storage (mean ± standard deviation)

Storage variant	Germination Bed test %	TTC-Test %
granary	99 ± 1.1	97 ± 1.0
bag 1	98 ± 1.2	100 ± 0
bag 2	98 ± 1.2	93 ± 3.0

Storage in polyethylene bags vs. storage in a granary

A comparison of storage variants for all samples averages shows both in the chemical, as well as for microbiological parameters an almost identical trend (Figure 3).

After six months storage mesophilic bacteria, yeast and moulds are nearly in the same range as at the beginning of storage. It comes during storage at no rise in temperature in the bags. Also, the increasing drop of temperature during storage at autumn and winter had no negative impact on the state of the grain. Moreover, could not absorb moisture under the film surface are found to have symptoms may lead to spoilage.

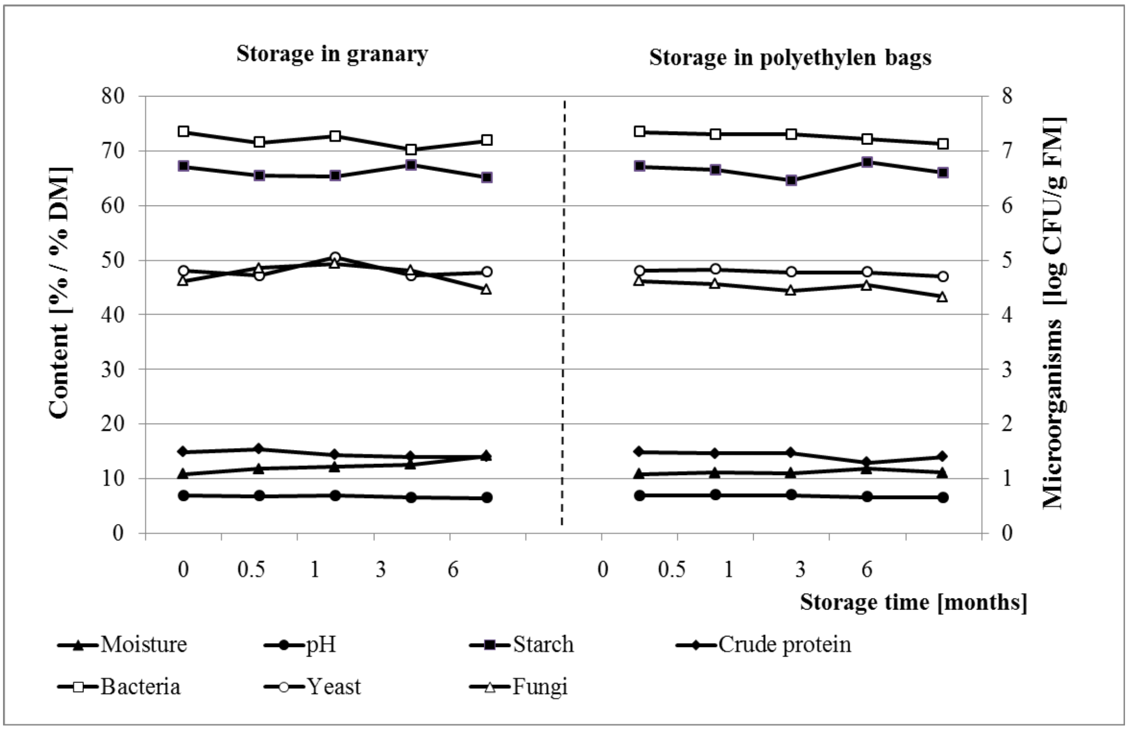

Figure 3 Effect of different storage systems of wheat on chemical and microbiological parameters

Similarly, results demonstrated that there are no differences between the positions "upper part" and "centre" of the bag in parameters as pH value, starch, crude protein, content of bacteria, yeast, mould and germination: no differences between the positions and no differences between the storage systems.

Process costs of the storage in polyethylene bags

The process costs for using the Farmbagger are made up of costs for machines, labor and polyethylene bags (Table 6). The investment costs depending on the equipment is at an average of 30 000 EUR. With an increasing efficiency machine costs will decrease, here comparing 5 000 t and 20 000 t. A silage bag with a diameter of 2.70 m and a length of 75 m can store about 250 t. Maximum of capacity is at 360 t/h. Table 6 shows that costs differ from 2.29 EUR/t (20 000 t/year) to 3.02 EUR/t (5 000 t/year).

Table 6 Process costs for different assumptions

Parameter	Unit	Example 1	Example 2
tonnage	t/year	5 000	20 000
investment costs	EUR	30 000	30 000
capacity	t/h	360	360
diameter of the bags	m	2.7	2.7
length of the bags	m	75	75
storage mass per bag	t	250	250
usage	years	6	6
residual value	EUR	10 000	5 000
number of bags	-	20	80
price/bag with allowance	EUR	445	425
depreciation	EUR/year	3 333	4 167
interest (1/2 invest. 6 % per year)	EUR/year	1 200	1 050
repair costs (0.10 EUR/t)	EUR/year	500	2 000
tractor [1)]	EUR/year	700	2 800
salary (1.5 per bag, 15 EUR/h)	EUR/year	450	1 800
total per year	EUR/year	5 983	10 267
machinery costs	EUR/t	1.20	0.50
bag costs	EUR/t	1.78	1.70
total per year	EUR/t	3.02	2.29

[1)] 0.7 operation hours per bag (filling system: loader wagon), 50 EUR/h (incl. fuel)

4 Conclusions

The storage of grain in large polyethylene bags is not a new method for grain storage and preservation (Harrel et al., 2007; Gaston et al, 2009; N.N. 2010).

The initial question if whether the grain could be damaged by storage in polyethylene bags can be clearly negated. Despite decreasing ambient temperatures no condensation was obtained, which could influence the vitality of the grains. Condensation water was absorbed by the dry grain, thereby the moisture content below the surface of the bag increases slightly without to be come in a critical range over 14% moisture content.

The storage of grain with 12.9% moisture content in polyethylene bags is possible for 6 month. This shows the results based on the investigated chemical and microbiological quality parameters.

The germination of the wheat kernels is maintained over the storage period. The carbon dioxide, produced by respiration of the grain, had no influence on the viability. It can be concluded from the very low differences, that the storage in a polyethylene bag has no influence on the baking characteristics of bread. Further investigations are concentrating on this parameter.

Because of the very low costs of the flexible bagging system the storage in polyethylene bags can be recommended as an alternative to high investment in permanent storage structures for grain. The storage in polyethylene bags is recommended particularly if storage locations can be chosen flexibly to optimise the transport distances. Also advantageously is that different cereal qualities can be stored separately. The variable bag length allows the farmer to adapt the storage capacity to the grain mass which must be stored. Because of the flexible storage capacity all harvested grain can be stored over 6 months up to a time with a high market price.

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