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Effects of compaction pressure on silage fermentation in bunker silo

F. Tan[1,*], I.S. Dalmıs[2] and F. Koc[3]

[1]University of Namık Kemal, Faculty of Agriculture, Department of Biosystem Engineering, Campus street, Number:1, TR59030 Tekırdag, Turkey
[2]University of Namık Kemal, Faculty of Corlu Engineering, Department of Mechanical Engineering, University 1, Sokak No:13, TR59860 Corlu/Tekirdag, Turkey
[3]University of Namık Kemal, Faculty of Agriculture, Department of Animal Science, Campus street, Number:1, 59030 Tekirdag, Turkey.
[*]Correspondence: ftan@nku.edu.tr

Abstract. The aim of this research was to determine the effects of compaction pressure on maize silage fermentation under field conditions. The CAT 955 L type work machine was used for the compaction of the material. In this research, a pressure measurement system was developed to measure the compaction pressure in bunker silos. In bunker silos, 24 points for pressure and temperature measurement were identified. Chemical and microbiological analyzes were made by taking samples from each measurement point. The lowest temperature is measured in the back wall of the silo. There is a significant relationship between pressure and temperature. Pressure had a significant effect ($P < 0.05$) on silage fermentation. There was a significant correlation between regions in bunker silo and pressure ($R^2 = 0.914$, $P < 0.01$).

Key words: Silage, pressure, compaction, bunker silo, pressure measure method.

INTRODUCTION

Ensiling is a common preservation method for moist forage crops. It is based on lactic acid bacteria (LAB), convert water-soluble carbohydrates (WSCs) into organic acids, mainly lactic acid (LA), under anaerobic conditions. As a result, pH decreases and the forage is preserved from spoilage microorganisms (McDonald et al., 1991; Filya, 2004).

Chopped whole crop maize is the major crop ensiled in Turkey. Silage making in bunker silos and stack type silos are generally more common than other types of silo. For this reason, the compaction process is an important process for silage. High losses and low quality can occur if the compaction is too low. Toruk et al. (2010) reported that fermentation characteristics of the silage were affected positively by increasing compaction. Darby & Jofriet (1993) found that the density of silage in bunker silos increased by increasing compaction equipment mass. For this reason, work machine or heavy tractors of 20 t and more are often used in large bunker silos. Roy et al. (2001) indicated that more compacting time will be needed to achieve an enough density. Compaction equipment mass, compaction time, packing time and layer thickness were important factors on the silage density and silage quality (Ruppel et al., 1995; Muck & Holmes, 2000; Roy et al., 2001). In previous studies, the pressure on the bunker silo material was generally measured under laboratory conditions. In a laboratory study, Savoie et al. (2004) found that the average dry matter (DM) density of maize silage was significantly affected by layer thickness, crop processing, and pressure but not by time of compaction or moisture content.

The effect of pressure on the ensiling properties of maize was studied under field conditions. The pressure measurement system (PMS) was developed and used in this study. This system is based on the compaction pressure determination. The pressure sensing rubber globes were used to detect the pressure coming from each direction. Turner & Raper (2001) used similar a method for determination of soil compaction. Pressure sensing rubber globes and temperature sensors retrieved after opening the silo.

The aim of this study was to determine the effect of pressure on the fermentation of maize silage under field conditions.

MATERIALS AND METHODS

Whole crop maize (*Zea mays* L.) was harvested at early dent maturity stage (25% DM) on 18 October 2014. The effect of pressure on the ensiling properties of maize was studied under field conditions. The pressure measurement system (PMS), which was developed by the researchers, was used to measure the pressure applied on the silage.

Compaction equipment

The work machine was used as the compaction equipment (Fig. 1). The technical specifications of the machine are given in Table 1.

Figure 1. Compaction equipment.

Table 1. The technical specifications of compaction equipment

Specification		
Power	130/96.9	HP per kW
Weight	13,700	kg
Track shoe width	432	mm
Length of track on ground	2,355	mm
Ground contact area	2.03	m^2

Bunker silo and measurement points

The size of the bunker silo was 7,500 mm wide by 27,000 mm long by 2,250 mm high (Fig. 2). The location of pressure and temperature sensors in bunker silos are given in Table 2.

To characterize the silage profile, three location factors were chosen (D'Amours & Savoie, 2005).

The silo was divided into three regions (A, B, C) (Fig. 2).

Three locations were defined in each region (right, center and left).

Three layers of thickness from the floor were taken (0.5 m, 1 m and 1.5 m). The distance between sensors was equal.

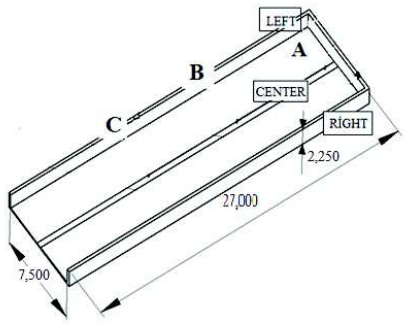

Figure 2. Bunker silo and trials.

Table 2. The location of pressure and temperature sensors in bunker silo

Region		A			B			C		
		Locations								
Heights	Sensor	Left	Center	Right	Left	Center	Right	Left	Center	Right
1.5	P*	AL15	AC15	AR15	BL15	BC15	BR15			
1	P	AL1	AC1	AR1	BL1	BC1	BR1	CL1	CC1	CR1
1	T**	AL1	AC1	AR1	BL1	BC1	BR1	CL1	CC1	CR1
0.5	P	AL05	AC05	AR05	BL05	BC05	BR05	CL05	CC05	CR05

*P: Pressure sensor; **T: Temperature sensor.

The temperature sensors (9 units) are only located in the middle layer (layer thickness 1 m). Pressure sensors (24 units) are located in all layers. For the temperature measurement, the E-348-UA-002-08 model temperature sensors were used.

Measurement system

A pressure measurement system (PMS) was used to determine the compaction pressure. PMS has mainly five units (Fig. 3). These are:

- Pressure sensing rubber globes;
- Hydraulic hose connections;
- Pressure sensors;
- Data collection, recording and storage and
- Portable computer.

Pressure sensing rubber globes were connected to pressure sensors via the hydraulic hoses. The pressure sensing rubber globes can detect the pressure coming from each direction. The sensor outputs were connected to NI DAQ measurement and storage system.

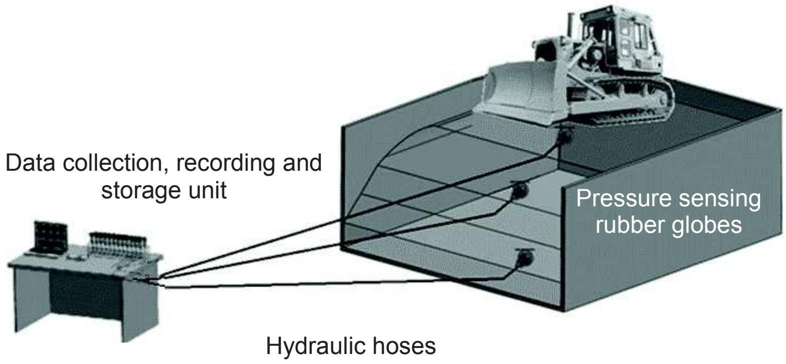

Figure 3. Pressure measurement system (PMS).

Mesens 500 series 4–20 mA of the 4 bar capacity pressure sensors were used. Sensor capacity was determined according to the work machine's weight. Pressure and temperature measurement sensors were installed at these measuring points (Fig. 3). In hydraulically operated system, water was used for pressure transmission (Turner & Raper, 2001). The portable computer and data collection, recording and storage unit of the PMS was placed at the outer surface of the silo. The data acquisition system is based on a graphical programming language NI LabVIEW software and NI CompactDAQ hardware modules. The data is stored in an MS Excel.

Analytical procedures

Chemical and microbial analyses were in triplicate. The DM content of the silages was determined by oven drying for 48 h at 60 °C (Akyıldız, 1984). The pH in fresh material and silage samples was measured according to the British Standard method (Anonymous, 1986). The ammonia nitrogen (NH_3-N) content of silages was determined according to Anonymous (1986). The water soluble carbohydrates (WSC) content of silages was determined by spectrophotometer (Shimadzu UV-1201, Kyoto, Japan) after reaction with antron reagent (Thomas, 1977). LA was determined by the spectrophotometric method (Koc & Coskuntuna, 2003).

Microbiological evaluation included enumeration of lactobacilli on pour-plate Rogosa agar (Oxoid CM627, Oxoid, Basingstoke, UK). Yeast and moulds were determined by pour plating in malt extract agar (Oxoid CM59) that had been acidified, after autoclaving, by the addition of 85% lactic acid at a concentration of 0.5% vol/vol. Plates were incubated aerobically at 32 °C for 48 to 72 h (Seale et. al., 1990).

Statistical analysis

To evaluate statistical significance between the pressure and temperature in bunker silo, the data was analyzed using the ANOVA procedure, and significant differences among means were determined by Tukey test and correlation test was performed between all parameters (SPSS v.15.0).

RESULTS AND DISCUSSION

The fresh maize contained 228 and 150 g kg^{-1} DM, WSC, respectively, and the pH value was 4.48. The log numbers of colony forming unit (cfu g^{-1}) of yeasts and moulds in the fresh material were 1.81 and 1.51 respectively.

The effects of pressure on the chemical composition of the silages according to regions (A, B, C) in bunker silo are given in Table 3. The effects of pressure on the chemical composition of the silages according to locations (right, center, left) in bunker silo are given in Table 4.

The effects of compaction pressure on DM content was found statistically significant in regions and insignificant in locations. DM content increased by the increasing pressure. Roy et al. (2001) also reported significant relationship between DM of chopped corn and pressure in experimental range of 120 and 480 kpa. DM content and pH values of the silages were similar to trends found by Yıldız et al. (2010). The lowest DM content was measured in the A region (22.15%), the highest DM content was measured in the C region (26.03%). There was a significant correlation between DM content and pressure (R^2 = -0.624, $P < 0.05$).

The maize silage was well-preserved, as would be expected with carbohydrate rich crops. The pH value of maize silage was lower than the fresh maize. In the experiment, the WSCs in silage decreased by the decrease in pH. The effects of compaction pressure on pH values were found statistically significant in regions and insignificant in locations. pH values were decreased by the increasing pressure.

The lowest pH value was measured in the C region (3.23), which is a result of the fact that the LA content was the highest in the C region, and the highest pH value was measured in the A region (3.73). Peterson (1988) stated that for a good quality silage, pH should be under 4.3. The pH values determined in all regions were found in the appropriate range for fermentation. There was a significant correlation between pH values and pressure (R^2 = 0.910, $P < 0.01$). The pH values of the silage in bunker silo were affected positively by the increasing compaction pressure. One of the main factors affecting silage quality is the rate of decline in ambient pH at the early stage of fermentation. It is desirable that the pH value should be reduced to below 4.2, 4.0 rapidly. The rate of decrease in pH is related to LA production. The changes that can be observed in the silage in terms of these properties depend on the WSC content and composition of the material, the concentration of the epiphytic microorganism and the density of the applied bacteria. In many circumstances, materials with high WSC content have the advantage that suitable fermentation development can be achieved (Davies et al., 1998).

The effects of compaction pressure on NH_3-N was found statistically significant in regions and insignificant in locations. The pressure is generally high at the right side, and low at the left side. The operator was able to compact in regions C and B; however, couldn't compact enough in region A, which is closest to the back wall of the silo. Region A caused the overall average to be lower than expected. NH_3-N value increased by the increasing pressure. The lowest NH_3-N was measured in the C region (0.18%), the highest NH_3-N was measured in the A region (0.45%).

Table 3. Results of chemical and microbiological analysis values according to regions

Region	Pressure (Bar)	Temperature (°C)	DM (%)	pH	NH_3-N (g kg^{-1})	LA (%)	WSC (g kg^{-1})	Yeast (cfu g^{-1})	Mould (cfu g^{-1})
A	0.25 ± 0.09 **a***	18.30 ± 1.47 **a**	22.74 ± 1.56 **a**	3.80 ± 0.12 **b**	0.45 ± 0.2 **b**	11.36 ± 2.8 **a**	93.92 ± 31.7	1.81 ± 0.1 **b**	0.0 ± 0.0
B	0.35 ± 0.01 **b**	22.46 ± 3.50 **b**	25.34 ± 1.00 **b**	3.76 ± 0.9 **b**	0.22 ± 0.1 **a**	13.36 ± 0.3 **b**	108.8 ± 4.9	1.84 ± 0.1 **a**	0.6 ± 0.9
C	0.38 ± 0.02 **c**	29.2 6 ± 3.51 **c**	26.09 ± 0.50 **b**	3.23 ± 0.5 **a**	0.18 ± 0.2 **a**	14.30 ± 0.3 **b**	111.7 ± 8.1	1.66 ± 0.0 **ab**	0.0 ± 0.0
Mean	0.32 ± 0.05	23.34 ± 5.42	24.72 ± 1.81	3.60 ± 0.2	0.29 ± 0.2	13.1 ± 2.03	104.82 ± 20.8	1.66 ± 0.1	0.2 ± 0.6
Min.	0.21	16.63	20.07	3.16	0.05	7.00	48.80	1.40	0.0
Max.	0.39	33.54	26.93	4.01	0.66	14.80	122.50	4.15	1.81
F	*114.48*	*30.82*	22.52	96.75	6.89	7.43	2.22	0.32	2.28
P	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	*ns*	$P < 0.05$	*ns*

*Mean values on the same column with the same superscript do not differ significantly at $P < 0.05$; *ns*: not significant $P < 0.05$; DM dry matter; NH_3-N concentration of ammonia-nitrogen; LA lactic acid; WSC water soluble carbohydrates.

Table 4. Results of chemical and microbiological analysis values according to locations

Location	Pressure (Bar)	Temperature (°C)	DM (%)	pH	NH_3-N (g kg^{-1})	LA (%)	WSC (g kg^{-1})	Yeast (cfu g^{-1})	Mould (cfu g^{-1})
Right	0.34.± 0.04	25.99 ± 6.61	24.73 ± 1.96	3.62 ± 0.3	0.22 ± 0.2	13.66 ± 0.5 **b**	93.04 ± 31.4 **a**	1.69 ± 0.0	0.0 ± 0.0
Center	0.32 ± 0.06	22.48 ± 5.75	24.53 ± 2.27	3.57 ± 0.3	0.24 ± 0.1	13.66 ± 0.9 **b**	115.4 ± 5.8 **b**	1.96 ± 0.8	0.0 ± 0.0
Left	0.31 ± 0.06	21.56 ± 2.55	24.91 ± 1.24	3.60 ± 0.2	0.40 ± 0.2	11.70 ± 3.1 **a**	105.9 ± 1.4 **ab**	1.66 ± 0.1	0.4 ± 0.79
Mean	0.32 ± 0.06	23.34±5.42	24.72 ± 1.81	3.60 ± 0.2	0.29 ± 0.2	13.1 ± 2.03	104.82 ± 20.8	1.77 ± 0.4	0.2 ± 0.4
Min.	0.21	16.63	20.07	3.16	0.05	7.00	48.80	1.40	0.0
Max.	0.39	33.54	26.93	4.01	0.66	14.80	122.50	4.15	1.81
F	*0.44*	*1.77*	0.09	0.074	2.30	3.28	3.31	1.01	2.28
P	*ns*	*ns*	*ns*	*ns*	*ns*	$P < 0.05$	$P < 0.05$	*ns*	*ns*

*Mean values on the same column with the same superscript do not differ significantly at $P < 0.05$; *ns*: not significant $P < 0.05$; DM dry matter; NH_3-N concentration of ammonia-nitrogen; LA lactic acid; WSC water soluble carbohydrates.

Table 5. Correlations between all parameters

	DM	pH	NH_3-N	LA	WSC	Yeast	Mould	Pressure	Temperature
Regions	0.770**	-.840**	-.562**	0.606*	*ns*	*ns*	*ns*	-.914**	-.840**
A	0.723**	*ns*	*ns*	-.925**	0.738*	*ns*	*ns*	*ns*	0.986**
B	-.810**	*ns*	0.915**	*ns*	*ns*	*ns*	*ns*	*ns*	0.900**
C	*ns*	*ns*	*ns*	*ns*	-.963**	*ns*	*ns*	0.878**	-.668**
Locations	*ns*	*ns*	*ns*	-0.401*	*ns*	*ns*	*ns*	*ns*	*ns*
Right	-.742*	0.836**	0.860**	*ns*	-.893**	0.710*	*ns*	0.940**	0.846**
Center	-.714*	0.873**	*ns*	-.980**	0.933**	*ns*	*ns*	0.916**	0.911**
Left	*ns*	0.874**	0.938**	-.895**	0.783*	*ns*	0.724*	0.927**	0.907**
Pressure	-0.624*	0.910**	0.461*	-.542**	*ns*	*ns*	*ns*	1	0.747**
Temperature	-0.701**	0.640**	0.635**	-.780**	*ns*	0.749*	0.733*	0.747**	1
DM	1	-.458*	-.413*	*ns*	*ns*	*ns*	*ns*	-.624**	-.701**
pH	-.458*	1	0.390*	-.491**	*ns*	*ns*	*ns*	0.910**	0.640**
NH_3-N	-.413*	0.390*	1	-.586**	-.457*	*ns*	*ns*	0.461*	0.635**
LA	*ns*	-.491**	-.586**	1	*ns*	*ns*	*ns*	-.542**	-.780**
WSC	*ns*	*ns*	-.457*	*ns*	1	*ns*	*ns*	*ns*	*ns*
Yeast	*ns*	*ns*	*ns*	*ns*	*ns*	1	0.830**	*ns*	*ns*
Mould	*ns*	*ns*	*ns*	*ns*	*ns*	0.830**	1	*ns*	0.733*

**. Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); *ns*: not significant $P < 0.05$; DM dry matter; NH_3-N concentration of ammonia-nitrogen; LA lactic acid; WSC water soluble carbohydrates; A region closest to the back wall of the silo; B region in the centre of the silo, C region in front of the silo; Right 1.0 m from both the right side wall; Center in the middle of the silo; Left 1.0 m from both the left side wall.

There was a significant correlation between NH_3-N and pressure ($R^2 = 0.461$, $P < 0.05$). The lowest NH_3-N was measured on the right while the highest NH_3-N was measured on the left. The low NH_3-N concentration may be attributed to the sharp decline in pH, which made aerobic microorganism and plant enzymes inhibit rapidly, resulting in protein degradation during fermentation process.

The effects of compaction pressure on LA were found statistically significant both in regions ($R^2 = 0.606$, $P < 0.01$) and in locations ($R^2 = -0.401$, $P < 0.01$). LA content increased by the increasing pressure. The lowest LA content was measured in the A region (11.59%), and the highest LA content was measured in the C region (14.3%). Alcicek & Ozkan (1997) stated that the value of LA should be over 2.0% in high-quality silages. The values of this study about LA were sufficient. Toruk et al. (2010) reported that fermentation characteristics of the silage were affected positively by the increasing compaction. There was a significant correlation between LA content and pressure ($R^2 = -0.542$, $P < 0.01$).

There was no statistically significant correlation between WSC, yeast, mould and pressure in both regions and locations.

Correlations between all parameters and pressure were shown in Table 5. There was a significant correlation between regions in bunker silo and pressure ($R^2 = -0.914$, $P < 0.01$).

CONCLUSION

The data of this study indicated that fermentation characteristics of the maize silage were positively affected by the increasing compaction pressure. The pressure showed positive correlation with pH, NH_3-N and temperature, whereas it was negatively correlated with DM and LA. The effects of compaction pressure was found statistically significant in regions, while insignificant in locations. The pressure was the lowest in the back wall of the silo and the highest in the front side of the silo. This may be due to the application of less compression time in the back wall of the silo than in the front of the silo.

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