Temperature measurements of large scale silo face to asses aerobic deterioration of corn silage on farm

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1. Introduction

Silage is an efficient technique for the conservation of the energy of the harvested forage since microorganism fermentation transforms sugars into organic reduced compounds (lactate, acetate, mannitol and ethanol), transferring to ATP a very small amount of energy compared with that obtained from a system in an atmosphere of oxygen (McDonald et al., 1991). It has long been recognized that the presence of air produce deleterious effect on silage (Beck and Gross, 1964; Woolford, 1990). Oxygen enables various aerobic spoilage microorganisms, which survive in the anaerobic phase of ensiling, to become active and to multiply, causing aerobic deterioration (Woolford, 1990). Aerobic deterioration usually results in high dry matter (DM) loss (Bolsen et al., 1993) and the loss of important nutritional components (Kung et al., 1998) and may lead to potentially toxic substances or undesirable microorganisms which can negatively affect food quality and safety (Wilkinson et al., 1999; Ivanek et al., 2006; Vissers et al., 2007; Tabacco et al., 2009). A large part of the silage stored in horizontal silos is exposed to air penetration, especially in the upper part near the walls which are difficult to seal properly (Ashbell and Lisker, 1988). Much greater losses can occur, however, when the silos is opened for feeding, because air penetrates the silages and promotes the growth of aerobic, acid-tolerant microorganisms and the oxidation of fermentation products present in the silages (Danner et al., 2003). On the farm this deterioration is usually manifested by a rise in temperature and by the appearance of molds in the peripheral areas of the silo (Ashbell and Weinberg, 1992). Silages that spoil and heat in the silo or in the feedbunk may dramatically affect daily DM intakes, because cows are reluctant to consume unstable silages especially during the warm season when DM intake is already compromised (Mahanna and Chase, 2003).
Since the evaluation of microbiological and chemical quality of the working face of a silage during the feed-out phase would require many samples, expensive labor and equipment, qualified personnel, and time-consuming laboratory analyses, a simple method to assess silage quality, with good accuracy and quickness is necessary.
The aim of this paper is to show the correlation between microbial and chemical composition of the silage during the feed-out phase and some easily measurable parameters by technicians and farmers, that are useful to quantify the extent of aerobic deterioration at a farm level.

2. The role of yeast in the aerobic deterioration of silages

Yeasts that metabolize lactic acid are the primary spoilage microorganisms in silage, although acetic acid bacteria can also initiate the aerobic deterioration process in corn silage (Pahlow et al., 2003). It has been suggested that silage with yeast populations in excess of 10^5 g^{-1} DM are regarded as highly susceptible to aerobic deterioration (Beck and Gross, 1964; Daniel et al., 1970).
Immediately after ensiling yeasts compete with other microorganism for fermentable substrates and, during the first week of ensiling, yeast populations can reach 10^7 cfu g^{-1} (Jonsson and Pahlow, 1984). A gradual decrease of yeast counts usually takes place during subsequent storage, depending on factors such as degree of anaerobiosis, pH, and concentrations of undissociated organic acids. The pH levels usually reached in silage are not inhibiting for silage yeast, which usually can grow

within a pH range of 3-8. Under aerobic conditions, yeast tolerate organic acids better than most other microorganisms and consume organic compounds such as lactic, acetic, succinic, malic, citric, propionic acids and ethanol (Moon and Ely, 1979; Middelhowen and Franzen, 1986). These characteristics together with the effect of oxygen and sugars explain why yeasts are notorious spoilers of fermented products and why anaerobic conditions are absolutely necessary to provide an adverse environment for their development (Jonsson, 1989).
Over air exposure, the growth of lactate-utilizing yeasts causes a rise in pH and, as this process proceeds, other aerobic organisms, such as moulds and bacilli, start to proliferate. Lactic acid, acetic acid, and water soluble carbohydrates (WSC) are the main sources of energy for the microorganisms involved in aerobic deterioration. The oxidation of these nutrients results in the production of carbon dioxide and water, with the evolution of heat (McDonald et al., 1991). With the complete oxidation of glucose the temperature rise in the silage mass, assuming a specific heat capacity of 1.89 kJ kg^{-1} $°C^{-1}$ for the silage DM and no loss of heat to the atmosphere is given by the expression:

$$T = (DM * GLUCOSE) / (267.5 – 0.147 * DM)$$

Where DM is DM content in g kg^{-1} and GLUCOSE is the amount of glucose (g kg^{-1} DM) oxidized (McDonald and Whittenbury, 1973). For example, the temperature rise through the complete oxidation of sugars in an insulated silage of DM content 320 g kg^{-1} and sugar content (as glucose) of 50 g kg^{-1} DM, would be 73°C.
When well fermented silages with low values of residual sugars are concerned (as corn silage), the main product oxidized is likely to be lactic acid. The heat produced from the complete oxidation of lactic acid is marginally less (15.16 kJ g^{-1}) than from glucose (15.64 kJ g^{-1}) and therefore the temperature increase from lactic acid oxidation in the above example would be slightly lower, about 70°C. In most practical situations a part of the heat produced through oxidation will be dissipated into the atmosphere, although temperatures as high as 50°C have been recorded in aerobic deteriorated silages (Henderson et al, 1982). Therefore, temperature can be useful as an index of heating associated with aerobic deterioration, since rises in temperature are clearly linked with yeast activity and DM loss and could have application in alerting farmers to the onset of aerobic deterioration (Williams et al., 1994; Tabacco and Borreani, 2002a, b).

3. Temperature measurements at the silo face

Several systems to measure temperature of the working face of a silo could be applied to describe the areas involved in aerobic microbial activity. One method consists in burying temperature loggers inside the silo at the time of silo filling and retrieving them at the feed-out (Kung, 2009), but this option is very expensive and permits to measure only some points of the silage mass. Another options is to use temperature probe or “spike” thermometer (Tabacco and Borreani, 2002a; Schoonmaker, 2009) to monitor the working face of a silo. Tabacco and Borreani (2002a) proposed the use of a probe thermometer to monitor the silage face and to quantify the extent of aerobic deterioration at the farm scale. Briefly, the temperatures are measured by probe thermometer within the stored silages during feed-out at 20-cm depths into the working face. Measurements were taken at 11 locations across the working face (0.25, 0.5, 1.0, 2.0, 3.0 m from both the right and left side walls and in middle of the silo face) and at seven elevations (0.1, 0.2, 0.3, 0.6, 1.0, 2.0 below the top surface and 0.2 m above the base) (Figure 1). Ambient temperature is recorded at the same time. Area of the working face with visible moulds is also determined and measured. The difference between the temperature of the silage sample and the temperature measured in the central zone of the silo (h/2 and x/2, where h = height of the silo; x = width of the silo) were used as an index of heating associated with aerobic deterioration (dT). A silo is considered aerobically deteriorated

when at least 10% of the area of the working face was interested by temperatures 10°C above those recorded in the central zone of the silo and/or visible moulds were present in top layers near side walls.

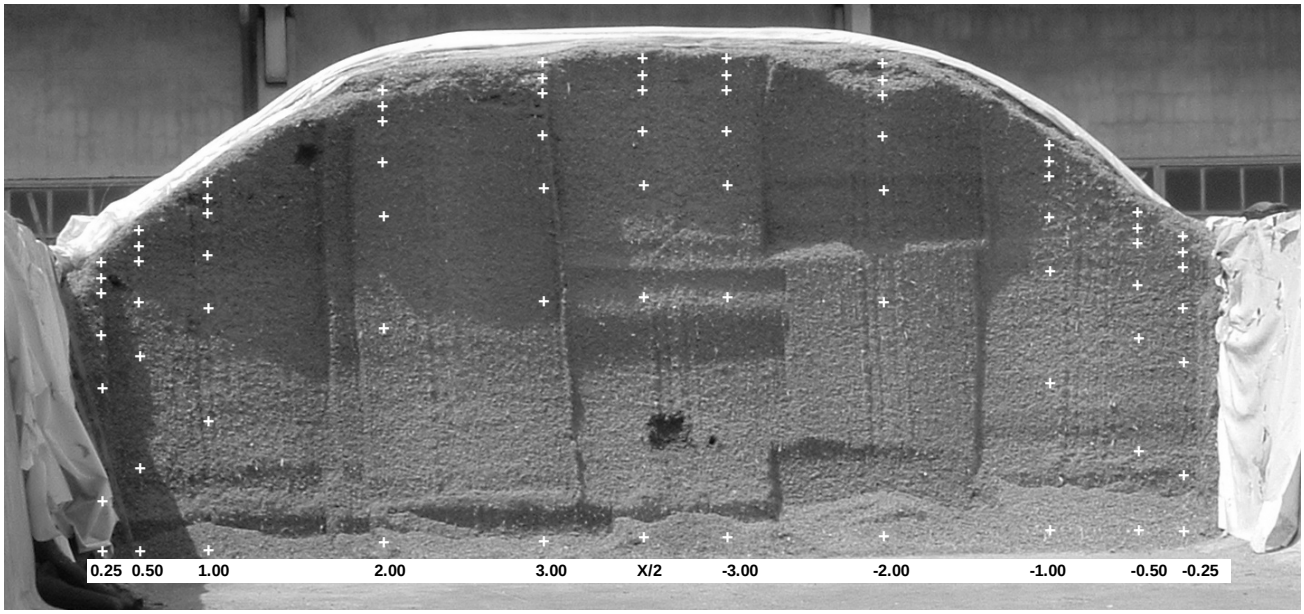

Figure 1. Scheme of temperature measurement on the working face of the silo, with a probe thermometer.

The more recent method proposed to measure temperature at the working face is infrared thermography by heat-sensing digital cameras (Seglar, 2008). Infrared thermography is a noninvasive technique capable of detecting thermal radiation from the surface of any object. Infrared thermography has been widely used in animals to diagnose inflammatory conditions such as sole abscesses and laminitis in horses (Eddy et al., 2001), to predict changes in udder temperature in dairy cows (Berry et al., 2003), and to detect other subclinical inflammation in cattle and dairy cows (Nikkhah et al., 2005). Heat-sensing digital cameras could capture in a single picture the whole temperatures of the working face of a silage. The first attempt to assess the heat production at the silage face was made in 1993 by Cassinis et al., working on bunkers of corn, Italian ryegrass and alfalfa silages. These authors concluded that the temperatures measured on the silo face could be correlated to the "heat status" of the silage, even if the values were always lower than those measured into the silage mass to a dept of 12 cm. The same results were reported by Collombier et al. (2001), who utilized infrared thermography for visualizing deteriorations of corn silage and for testing the efficacy of the *Lactobacillus buchneri* inoculant on silage aerobic stability. These authors found that the surface temperatures were lower than those measured by probe thermometer to a dept of 15 cm in the silage mass, especially in the peripheral areas, where the heat generated by aerobic deterioration is higher than in the silo core. Furthermore it was pointed out that the temperature measurement by infrared thermography is highly influenced by weather (sunny, cloudy, rainy ...), the time of the day, the exposure of the silo face, and the homogeneity of the feed-out face (Cassinis et al., 1993; Collombier et al., 2001).

4. Linking temperature to microbial status of the silage

The heat produced during silo filling is the result of respiratory process that is enabled by the high amount of air trapped in the silage mass, especially when the filling operation are protracted for long time (Woolford, 1990). Under anaerobiosis there is less opportunity for energy to escape from the system in the form of heat. The ATP produced during fermentation is used for microbial

biosynthesis and although it would result in some loss of energy in the form of heat, because of limited ATP production, this loss will be very small. The ATP formed from anaerobic metabolism is only 1 to 2 mol compared with 38 mol obtained for complete oxidation in the respiration process (McDonald et al, 1973a). In temperate environment during the winter season, steam could be released from the core of the silo because of the difference between retained heat (produced by respiration during silo filling and to a lesser extent by fermentation processes) and the ambient temperature. Therefore the presence of steam from the core of the silo does not always mean that silage is spoiling (Borreani et al., 2002; Kung, 2009).

After silo opening under aerobic conditions, the metabolism of lactic and acetic acids by aerobic microorganisms (mainly yeasts) results in an increase in pH, which is well correlated with temperature rise and also with DM loss.

Tabacco and Borreani (2009) presented results from a survey carried out in western Po Plain (Italy) on 54 dairy farms performing well, moderately well and badly to ensure that not only high quality silages were surveyed, encompassing different farm enterprises and representative of a range of ensiling practices. The mean chemical and microbial composition from core, peripheral areas, and molded spots of silages are reported in Table 1. The cores were characterized by a DM content ranging from 26.2 to 41.4% with a mean value of 34.3%, an a_w of 0.981, and a pH of 3.64. The lactic acid ranged from 1.44 to 8.98% of DM, the acetic acid from 0.17 to 5.48% of DM, whereas the butyric acid was always below the detection limit. The microbial characteristics of the core resulted in a mean yeast count of 2.93 log cfu/g, mold count of 1.76 log cfu/g and clostridial spore content of 1.36 log MPN/g. The samples from the peripheral areas with no visible molds presented chemical values that ranged from values similar to those of the core to values that are characteristic of deeply altered silage (pH up to 8.71, absence of lactic and acetic acids and presence of butyric acid with values up to 0.64% of DM). As expected, samples from the molded spots presented a deeply altered chemical and microbial profiles, with mean pH of 6.84, a_w of 0.993, yeast higher than 6 log cfu/g, mold around 8 log cfu/g, and clostridial spore from 1.48 to 7.04 log MPN/g. Furthermore the microbial activity of the deteriorated silage altered the acid contents with absence of lactic and acetic acids and butyric acid content that ranged from <0.001 to 0.24% of DM. The silage temperature in the middle of the silo was in average 18.6°C with values ranging from 12.0 to 22.9°C. Higher values were observed in the peripheral areas and in molded spots of the silo with temperatures up to 54.5°C. As a consequence the calculated dT were on average 9.9 and 13.3°C for the silage from the peripheral areas and from the molded spots, respectively, whereas it was close to 0°C in the silage core. The core samples always showed a pH below 4.0 and a dT below 2°C, whereas silages from the peripheral areas were split into two groups, 53% of them had a pH lower than 4 and a dT lower than 3.5°C and 47% had a pH higher than 4 and a dT higher than 5°C. A positive dT higher than 5°C correspond to pH higher than 4.5 in most of the silages from the peripheral areas (48 out of 51 samples) and in all silage from moldy spots.

Table 1. Mean values of chemical and microbiological characteristic from core, peripheral areas, and molded spots of corn silages observed in the farm survey (Tabacco and Borreani, 2009).

Items		Silage core	Peripheral areas	Molded spots
	n.	108	108	153
DM content (%)	Mean	34.3	34.1	33.4
	SEM	0.27	0.54	0.57
	Range	26.2 – 41.4	16.3 – 47.4	11.5 – 48.4
Water activity (a_w)	Mean	0.981	0.988	0.993
	SEM	0.0010	0.0013	0.0008
	Range	0.960 – 0.990	0.963 – 1.00	0.970 – 1.00
pH	Mean	3.64	4.97	6.84
	SEM	0.013	0.14	0.051
	Range	3.45 – 4.03	3.53 – 8.71	4.70 – 8.33
Yeast (log cfu/g)	Mean	2.93	5.48	6.33
	SEM	0.18	0.22	0.10
	Range	<1.00 – 5.70	<1.00 – 8.57	3.00 – 8.40
Mold (log cfu/g)	Mean	1.76	3.71	8.00
	SEM	0.10	0.18	0.07
	Range	<1.00 – 4.04	<1.00 – 6.65	5.70 – 9.40
Clostridial spore (log MPN/g)	Mean	1.36	2.75	5.08
	SEM	0.057	0.48	0.27
	Range	<1.18 – 2.36	<1.18 – 6.46	1.48 – 7.04
Sample temperature (°C)	Mean	18.6	30.6	35.4
	SEM	0.26	1.10	0.90
	Range	12.0 – 22.9	7.6 – 51.8	12.4 – 54.5
dT (°C)[1]	Mean	-1.5	9.9	13.3
	SEM	0.19	1.06	0.90
	Range	-5.9 – 1.9	-5.7 – 33.5	-6.0 – 33.5
Nitrate (mg/kg fresh matter)	Mean	349	298	48
	SEM	48	79	48
	Range	<100 - 3367	<100 - 4791	<100 – 1523
Lactic acid (% DM)	Mean	5.45	2.91	0.02
	SEM	0.17	0.30	0.0081
	Range	1.44 – 8.98	<0.001 – 7.09	<0.001 – 0.85
Acetic acid (% DM)	Mean	1.67	1.63	0.02
	SEM	0.10	0.20	0.0066
	Range	0.17 – 5.68	<0.001 – 6.16	<0.001 – 0.72
Butyric acid (% DM)	Mean	<0.001	0.03	0.02
	SEM	-	0.020	0.020
	Range	<0.001	<0.001 – 0.64	<0.001 – 0.24

5. Practical examples

In a farm survey carried out over 2 year in western Po Plain (Italy) on 19 dairy farms, Tabacco e Borreani (2002b) identified three groups of farms on the basis of the status of the corn silage during feed-out: A) aerobic deterioration both in winter and in summer; B) aerobic deterioration only in summer; C) no aerobic deterioration both in winter and in summer. Main farm characteristics are listed in Table 2. Farms of group C were characterized by a higher number of lactating cows, higher milk production per cow, and lower area of silo face per cow that result in a higher daily feed-out

rate (Table 3). Over winter top temperatures at the working face exceeded 30°C in farms of group A, while in farms of groups B and C were lower than those recorded in the silage core. During summer the top temperatures were higher than 30°C also in silos of group B. As an example, in Figure 2 are reported the contour map of temperatures of the silo face of two representative farms of group A and C in winter and summer periods. Group A and B had similar feed–out rate both in summer and in winter, but differed for care used to seal and weight down the silo surface (1 *vs*. 2 plastic sheet used; absence *vs.* presence of plastic sheet on side walls; tires only (20-30 kg m^{-2}) vs. tires plus soil (70-100 kg m^{-2}) to weight down the silo surface; absence vs. presence of sandbags to weight down the plastic sheet near side wall). These management practices avoid heating in silages of group B during winter but were not sufficient in summer, if not coupled with feed-out rate higher than 0.25 m, as for farms in group C.
The results underscore the importance of coupling high feed-out rates with careful silo management in order to control aerobic deterioration.

Table 2. Characteristics of the farms involved in the survey (Tabacco and Borreani, 2002).

Group	Farm	Lactating cows	Milk production	Forage crop	Silo	Silo size (m)			Silo face
	(no.)	(no.)	(kg yr^{-1} cow^{-1})	(ha)	(no.)	width	height	length	(m^2 cow^{-1})
A	10	48±9	8352±1536	22±6	1-3	7.4±1.4	2.0±0.5	22±6	0.32±0.10
B	6	50±11	8958±1315	26±5	2-3	7.3±1.1	2.1±0.3	21±3	0.31±0.09
C	3	75±7	11030±150	36±4	3-4	6.4±0.9	2.4±0.4	21±4	0.19±0.01

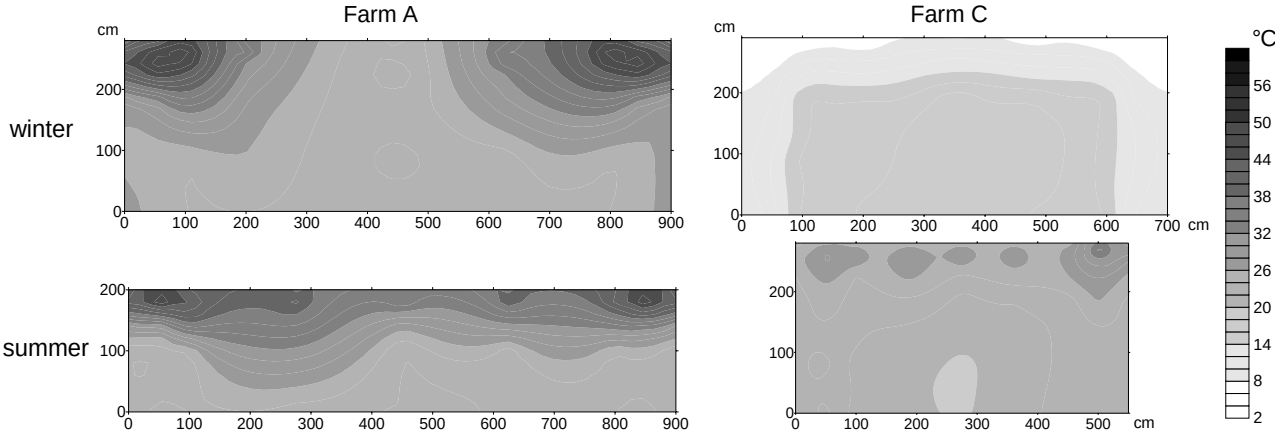

Figure 2. Contour map of temperatures recorded at 20-cm depths of the silo face in two farms of group A and C during winter and summer (Tabacco and Borreani, 2002).

Table 3. Main characteristics of maize silos ‡ involved in the survey (Tabacco and Borreani, 2002).

Group	Daily consumption	Density (kg FM m^{-3})	Winter				Summer			
			Temperature†		pH	Feed-out	Temperature		pH	Feed-out
	kg FM cow^{-1}	top/centre	top	centre	top	(m/d)	top	centre	top	(m/d)
A	21	221/621	35	19	4.9	0.11	36	24	5.1	0.14
B	22	312/634	16	17	3.9	0.13	35	22	4.7	0.16
C	25	321/576	11	16	3.7	0.24	28	23	3.9	0.31

† temperature (°C) was calculated as an average of the 20-cm depth measurements.
‡ Main fermentation characteristics of central zone of maize silages (n = 76) were: DM content 345±27 g kg^{-1}; pH 3.61±0.14; lactic acid 41±12 g kg^{-1} DM; acetic a. 15±9 g kg^{-1} DM; NH_3-N 62±13 g kg^{-1} TN; no butyric acid.

6. Conclusions

Since the prevention of aerobic deterioration at farm level is crucial to animal health, feed and dairy food safety, temperature measurements at the working face during feed-out is a good and simple way to identify the microbial status of the silage and to quantify the extent of spoilage at a farm level.

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