Animal Feed Science and Technology 275 (2021) 114868

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Bunkers or round bales: Losses and silage quality with or without acid treatment of low dry matter grass crops

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ARTICLE INFO

Keywords:
Round bale silage
Acidic additive
Invisible losses
Fermentation
Ethanol
Aerobic stability

ABSTRACT

Grass clover crops were harvested with or without application of 4 L/t of a formic- and propionic acid-based silage additive and ensiled in one bunker silo and 6 round bales per treatment in each of three harvests. The study aimed to compare losses, grass silage quality and aerobic stability obtained either with round bales or precision chopped grass ensiled in bunker silos. Round bales were either sealed immediately or after delay until bunker silos were covered. Unpredicted rain showers during the three harvests gave crop DM as low as 194, 186 and 213 g/kg, respectively.

Due to the lower pressure exerted on the crop by the baler than by packing vehicles in the bunkers, and the longer particle length in bales, densities in baled silage were much lower than in bunker silage, 531 vs 833 kg/m^3 ($P < 0.001$), and 111 vs 164 kg DM/m^3 ($P < 0.001$). Presumably due to early cell rupture and higher release of effluent caused by the applied acid, densities were higher in treated than in untreated silage, in bunkers 170 vs. 159 kg DM/m^3 ($P = 0.08$), and in bales, 114 vs. 109 kg DM/m^3 ($P = 0.02$).

A much lower proportion of ensiled crop DM could be offered to livestock from bunkers than from round bales, 833 vs. 927 g/kg ($P < 0.001$). The amount of moulded, wasted silage DM was significantly higher in bunkers than in bales, 26 vs. 0.6 g/kg, ($P < 0.001$), and the sum of DM lost by crop respiration, effluent runoff, anaerobic fermentation, aerobic deterioration and gaseous losses was significantly higher from bunkers than bales, 141 vs. 72 g/kg ($P < 0.002$). Acid treatment caused only minor decreases in DM losses. It restricted acid fermentation and improved silage intake potential both in bunkers and bales ($P < 0.001$), and caused higher stability in bales ($P < 0.009$). High ethanol concentrations were found in acid treated bunker silage but not in treated bale silage. Also, a reduction in heat induced increases in fiber bound protein obtained by acid treatment in bales, but not in bunkers, suggested that the applied dosage was too low to restrict heating in bunkers, and favored yeast growth. The larger surface area susceptible to heating, and loss of additive in effluent, make higher acid dosages, or a higher proportion of ingredients that inhibit yeast growth, necessary to low DM grass crops ensiled in bunkers.

Abbreviations: A, acid treated; AA, acetic acid; AAT, amino acids absorbed in the intestine; ADF, acid detergent fiber; ADIP, acid detergent insoluble protein; ADL, acid detergent lignin; BSP, True buffer soluble protein; C, control; CP, crude protein; DM, dry matter; DOMD, digestible organic matter in dry matter; FW, fresh weight; FA, formic acid; H, harvest number; IP, buffer-insoluble protein; LA, lactic acid; ME, metabolizable energy; NDF, neutral detergent fiber; NDIP, neutral detergent insoluble protein; NE, net energy; NE_L, net energy lactation; NH_3-N, ammonia-nitrogen; NPN, non protein nitrogen; OM, organic matter; OMD, organic matter digestibility; PA, propionic acid; PBV, protein balance in the rumen; PPO, polyphenol oxidase; r, correlation coefficient; SDMI, silage dry matter intake; SEM, standard error of the mean; TA, total acids; TP, true protein; VOS, digestibility of organic matter in rumen fluid *in vitro*; WSC, water soluble carbohydrates.

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https://doi.org/10.1016/j.anifeedsci.2021.114868
Received 19 October 2020; Received in revised form 30 December 2020; Accepted 3 February 2021
Available online 8 February 2021

1. Introduction

Bunker silos and round bales are two widely used storage systems for conserved forages. Whereas round bales are compacted and sealed automatically a few minutes after the crop is picked up in the field, manual work by several persons is required to cover bunkers. The time period when plants respire and thereby consume water soluble carbohydrates (WSC), and temperature increases, may reach hours in bunker silos. The need for additives adding costs to the production, may therefore differ between baling and ensiling in bunkers.

Further, the flexibility and efficiency at unloading and feeding differ considerably between the two methods. The speed of removal of silage from the face, as well as maintenance of a smooth surface of the face, is crucially important for minimizing losses from bunker silos. Round bales, however, are usually fed the same day as plastic wrap is removed. Vissers et al. (2007) found that small fractions from the top 50 cm of bunker silage, with above 5 log spores/g of butyric acid bacteria, caused by aerobic deterioration in anaerobic niches, was the primary cause of high spore concentrations in milk. During the anaerobic storage phase, however, silage may be more safely stored in bunkers than bales, usually with thicker and more plastic sheeting on top to protect against damage from birds and other animals. Plastic consumption per g crop is calculated to be more than 5 times higher for bales than for bunker silos (Randby et al., 2020), which may imply both higher costs and an environmental problem. The current trend in Norway for turning to preservation in bunkers is partly related to this and to the increased herd sizes allowing higher total silage consumption rates and speed of removal from silo faces. Feeding of silage from bunkers may as well be more efficient than feeding of round bales when herd size is large.

This study aimed to compare losses, fermentation quality, and aerobic stability in bunker and round bale silage, and to explore the effects of applying an efficient formic and propionic acid-based silage additive to wet grass crops in bunkers and bales. The hypotheses were: 1. Losses are lower and fermentation more restricted in bales than in bunkers. 2. Application of a formic- and propionic acid-based additive to grass crops during ensiling reduces losses, restricts fermentation, and increases aerobic stability of silage in both bunkers and bales, with more pronounced effects in bunkers than bales.

2. Material and methods

2.1. Experimental design

The study was conducted at the Animal Production Experimental Centre at the University of Life Sciences, Ås, Norway (59°40′N, 10°47′E; elevation 93 m.a.s.l.). In each of three grass crop harvests, of them two primary growths (H1; June 1–2, H2; June 6), and one second regrowth (H3; September 21–22) in 2017, two identical bunker silos were filled simultaneously. One silo was filled with untreated crop, and one with acid treated crop. At each of three time points within a harvest, on average 1.5, 5.1 and 13.5 h after starting bunker silo filling, four round bales were produced from the same sward. Two of these were acid treated (A) and two were untreated (C). Of the two bales within treatment, one bale was sealed immediately and one after delay until covering of the bunkers. The delays lasted between 3.5 and 25.9 h for single bales, on average 16.7, 8.3 and 18.2 h in H1, H2 and H3, respectively. At the same three time points within a harvest, crop for each of the two silos, A and C, harvested for the bunkers, was filled into two laboratory scale silos, of which one was sealed immediately and one after delay until covering of the bunkers. The delays lasted between 1 and 23.5 h for single silos, on average 14.4, 6.1 and 16.3 h for H1, H2 and H3, respectively. In total, the study comprised 6 bunker silos, 36 round bales, and 36 laboratory scale silos. Results from bunker silos, only, are previously given by Randby and Bakken (2021), where more details on bunker silo harvesting may be found.

2.2. Harvested crops and ensiling in bunkers

Information on grass crops, botanical composition and stage of maturity is given by Randby and Bakken (2021), where also information on mowing, tedding, harvesting, additive application, crop transportation, silo filling, consolidation and plastic coverage of bunkers are available.

2.3. Ensiling in round bales

At three time points during each harvest, four round bales were produced from windrows close to those simultaneously picked up for bunkers. The combined baler and wrapper, Orkel hiQ Smartbaler (Orkel, Fannrem, Norway) with 20 fixed knives, giving 52 mm theoretical chop length was used. Two of the four bales were applied the same silage additive, at the same target dosage as for bunkers, 4 L/t, through nozzles leading the additive directly into the bale chamber using Prodevice PDH 10 pump (Agronic, Haapavesi, Finland), regulated by Orkel steering box. Applied additive in total for the two bales was manually measured at the 200 L drum attached to the tractor. One untreated (C) and one acid treated (A) bale were immediately wrapped with 8 layers of 0.75 m wide and 0.025 mm thick white Triowrap 750 plastic film (Trioplast, Smålandsstenar, Sweden). The other two bales, one C and one A, were applied net only, before all four bales were transported to the experimental site using Silagrip 2 UM-7800 (UM Underhaug, Nærbø, Norway) and weighed. Core samples for DM determination were taken from the two unwrapped bales and pooled, intended to represent all four bales harvested at the same time point. Immediately afterwards, temperature sensors were placed in each unwrapped bale some 30−40 cm from bale surface, to monitor temperature development. When bunker silos were sealed, the six unwrapped round bales (two bales from each of three time points) that had been stored unwrapped on average for 14.4 h, were reweighed and

thereafter wrapped with 8 layers of plastic. Consumption of plastic wrap film was calculated to be 1.69 g/kg crop. Additive application rate was measured to be 5.0, 4.3 and 3.1 L/t for treated bales in H1, H2, and H3, respectively.

2.4. Ensiling in laboratory silos

At the same three time points during each harvest as for round bale production, crop harvested by the precision chopper for bunker silos was withdrawn for ensiling in laboratory scale, using plastic bags. Five kg was withdrawn from a load with untreated crop and 5 kg from a load with acid treated crop. Two portions from each load, each of approximately 2 kg, were filled into plastic bags and weighed. Within treatment group, one silo bag was sealed immediately using Euromatic ECO 80 vakuum machine (Univac group S.r.l. Euromatic division, Fiorenzuola d'Arda, Italy) and one bag was fitted with temperature sensor and stored outdoors on average for 12.2 h, until bunkers were sealed. Then, all six unsealed bags were reweighed and sealed. Laboratory silo bags were stored outdoors in a non-insulated container to obtain the same storage temperature as in bunkers and bales.

2.5. Sampling of fresh crop for bunkers, bales and laboratory silos

Six to ten fresh crop portions were grabbed by hand from every trailer load entering the bunker silos. Within trailer load, these were mixed and used for two samples of 500 and 200 g, respectively. The 500 g portions were stored at 4 °C for 0–2 days, when they were dried at 100 °C to constant weight for DM determination. These 125 single trailer load samples included the 18 loads from which crop for laboratory silos was collected. In addition, 9 core samples from round bales, 3 from each harvest, were dried at 100 °C to constant weight for DM determination. The 200 g portions were stored at −20 °C, and later pooled to 6 or 7 samples per harvest, in total 19 samples, that were freeze dried for chemical analyses.

2.6. Opening and sampling from bunkers, round bales and laboratory silos

At three time points during unloading of a pair of bunker silos, four round bales and four laboratory scale silos were opened. This was done in the opposite order compared to the order of ensiling, to ensure similar storage time for silage from bunkers, bales and laboratory silos. Information on storage and unloading times for bunkers, and temperatures, precipitation, and sampling procedures for bunker silage, are given by Randby and Bakken (2021).

Round bales and laboratory silos were weighed. When storage time was completed, silage bales were weighed with the plastic wrap still on, and subsequently, when plastic was removed for silage sampling, effluent flowed out, and the amount could not be measured. This obvious erroneous measurement of silage bale weights, where an unknown portion of the observed weight was effluent, continued until all bales were opened. Attempting to correct for this mistake, a linear relationship of effluent weights on round bale crop weights from a previous study was used, where effluent was measured in 45 round bales ensiled in tight plastic bags, with crop DM from 193 to 254 g/kg (Randby and Kjus, 1989). When used on data from the present study, the weight of effluent was assumed to decrease from 5.3 to 2.7 % of bale FW with increasing crop DM from 151 to 243 g/kg. This estimated weight of effluent was subtracted from the observed bale silage weights to avoid an underestimate of round bale losses. Four bales successfully wilted to 296 g DM/kg did not contain effluent and was not corrected.

Bale surfaces were inspected for moulded or deteriorated silage that was manually removed and weighed. The term "offered silage" is used for silage given to livestock as feed. Several core samples were taken and mixed to a silage sample of at least 1.8 kg from each bale. Mould was not detected in laboratory silos. Samples from each bale, each laboratory silo, and 6 pooled samples per bunker silo were shared into 4 portions that were later used for (1) analysis of fermentation quality, (2) aerobic stability test, (3) freeze dried for chemical analyses and (4) oven dried at 103 °C and corrected for volatiles for DM determination.

2.7. Spot silage samples from bunker silo faces and round bales for pH and Clostridium tyrobutyricum analyses

At the same three time points during unloading of bunkers, when round bales and laboratory silos were opened, core samples from four spots: side, shoulder, top and mid, of the face of bunker silos and from two spots in bales: surface and mid, were taken. Spots from the bunker silo face were described by Randby and Bakken (2021). Spots from bales were: surface: the 10−15 cm outermost part; mid: 15−45 cm from surface. The corer was washed in Antibac (ethanol, isopropanol, n-propanol, water) between each sample. Samples were stored at −20 °C until analysis.

2.8. Chemical analyses, and analysis of spores of Clostridium tyrobutyricum in spot silage samples, and aerobic stability test

Silage samples oven dried at 103 °C to constant weight were corrected for volatiles according to NorFor (Åkerlind et al., 2011) and used to calculate the portion of crop DM that was recovered as silage or lost. Silage samples kept undried were analysed for pH, NH_3-N, organic acids and ethanol by Eurofins Agro Testing Wageningen, The Netherlands. Methods were given by Randby and Bakken (2021).

Freeze dried fresh crop and silage samples were equilibrated to room humidity and milled to pass a 1.0-mm screen (Retsch SM200 cutting mill (Retsch GmbH, Haan, Germany)) prior to analyses of DM (103 °C for 4 h), ash (550 °C for 4 h), water soluble carbohydrates (WSC), crude protein (CP), true protein (TP), buffer-insoluble protein (IP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP) and digestibility of organic matter in rumen fluid *in vitro* (VOS). Analytical methods for these analyses were the same as described by Randby

Table 1
Chemical composition of fresh grass crops ensiled in bunkers, round bales and laboratory silos during three harvests, as weighted averages of dry matter yields from all fields within harvest.

Harvest		DM[1],	g/kg DM		Protein fractions[2], g N/kg total N					g/kg DM				g/kg		Per kg DM			
	N	g/kg	OM	CP	A	B1	B2	B3	C	WSC	NDF	ADF	ADL	OMD	DOMD	MJ ME	MJ NE_L	g AAT	g PBV
1	5	194	921	177	261	55.5	490	171	22.8	103	526	298	44.2	0.751	691	10.9	6.40	75.3	40.1
2	6	186	930	162	295	30.4	541	111	22.9	118	520	299	9.8	0.756	703	11.1	6.55	76.1	33.3
3	6	213	926	166	323	52.2	444	141	40.2	121	503	291	52.0	0.734	680	10.6	6.25	73.8	39.1

[1] DM and composition weighted according to crop weight filled in bunkers. Separate samples for bales and laboratory silos were only analysed for DM. Average DM concentration, g/kg, in harvest 1, 2 and 3, respectively, for round bales: 214, 180, 220, and for laboratory silos: 228, 180, 223.

[2] Protein fractions: A = Non protein nitrogen (NPN, calculated as CP-TP), B1 = True buffer soluble protein (BSP, calculated as TP-IP), B2 = Neutral detergent soluble protein, calculated as IP-NDIP, B3 = Neutral detergent insoluble protein (calculated as NDIP-ADIP (insoluble in neutral detergent but soluble in acid detergent)), C = Acid detergent insoluble protein (ADIP).

et al. (2020). Measurement of aerobic stability of silages, and analysis of spores of *C. tyrobutyricum,* were as described by Randby and Bakken (2021).

2.9. Calculations

Silage *in vivo* organic matter digestibility (OMD), digestible OM in DM (DOMD), metabolizable energy (ME), net energy lactation (NE_L), metabolizable protein expressed as amino acids absorbed in the intestine (AAT), and protein balance in the rumen (PBV), were calculated as described by Randby et al. (2020). Based on silage concentrations of DM, total fermentation acids, NDF, DOMD, and harvest (primary versus regrowth), silage DM intake (SDMI) index was calculated according to Huhtanen et al. (2007). Analytical results of the feed protein fractions TP, IP, NDIP and ADIP are presented as A, B1, B2, B3 and C, with decreasing solubility and rate of enzyme degradability according to Licitra et al. (1996): Protein fraction A = Non protein nitrogen (NPN, calculated as CP-TP), B1 = True buffer soluble protein (BSP, calculated as TP-IP), B2 = Neutral detergent soluble protein, calculated as IP-NDIP, B3 = Neutral detergent insoluble protein (calculated as NDIP-ADIP (insoluble in neutral detergent but soluble in acid detergent)), C = Acid detergent insoluble protein (ADIP).

2.10. Statistical analyses

All data was analysed using SAS (release 9.4, 2002–2012; SAS Institute inc., Cary, NC, USA). Round bale weights at ensiling and opening, and densities, were analysed using the PROC MIXED procedure by the model: $Y_{ijk} = \mu + S_i + D_j + H_k + S_i \times Dj^{+} e_{ijk}$, where μ = general mean, S_i = effect of additive *i*, D_j = effect of sealing time j, H_k = effect of harvest *k*, $S_i \times D_j$ = interaction, and e_{ijk} is the random residual error. The $S_i \times H_k$ *and* $D_j \times H_k$ interactions were insignificant for all variables and therefore excluded from the model. The RANDOM statement was included for the nine time points, three at each harvest, when round bales and laboratory silos were produced (Table 2). The model $Y_{ik} = \mu + S_i + H_k + S_i \times H_k + e_{ik}$, with effects as described above, and including the RANDOM statement, was used to evaluate temperature increases in bales and laboratory silos during delayed aerobic storage, with results given in the text.

Losses, silage chemical composition and aerobic stability from bunkers, bales and laboratory silos were analysed using the PROC MIXED procedure by the model: $Y_{ik} = \mu + S_i + H_k + S_i \times H_k + e_{ik}$, where μ = general mean, S_i = silo treatment *i*, *i* = 1–10, H_k = effect of harvest *k*, $S_i \times H_k$ = the effect of interaction, and e_{ik} is the random residual error. For silage composition and aerobic stability, the RANDOM statement was included for the nine time points when round bales and laboratory silos were sampled. Of six analysed samples from each bunker silo, two samples were assigned each of the three time points within harvest. Treatment means were separated using the PDIFF statement, and contrasts were estimated using the ESTIMATE statement. Silo treatment i: 1. Bunkers with no additive, 2. Bunkers applied additive, 3. Bales with no additive, sealed immediately, 4. Bales with no additive, sealed after delay, 5. Additive treated bales sealed immediately, 6. Additive treated bales sealed after delay, 7. Laboratory silos with no additive, sealed immediately, 8. Laboratory silos with no additive, sealed after delay, 9. Laboratory silos applied acidic additive and sealed immediately, 10. Laboratory silos applied acidic additive and sealed after delay (Table 3–5). The same model was also used to analyse bales

Table 2
Effect of acidic additive treatment (A) versus untreated control (C) on fresh crop and silage weights, dry matter concentrations, and wet and dry matter densities of round bales.

				Fresh crop					Silage				
Harvest	Additive	Sealing[1]	N	Kg	DM g/kg	Kg DM	Kg per m^3	Kg DM per m^3	Kg[2]	DM g/kg	Kg DM[2]	Kg per m^3 [2]	Kg DM per m^3 [2]
1			12	912	214	194	563	120	822[a]	219	182	508[a]	112
2			12	924	180	167	570	103	808[a]	191	155	499[a]	96
3			12	1018	220	221	629	136	951[b]	215	203	587[b]	125
SEM				43.5		23.0	26.9	14.2	36.7	23.3	23.6	22.7	14.6
P				0.19		0.27	0.19	0.27	0.02	0.66	0.36	0.02	0.36
	C	Imm.	9	936	205	191	578	118	860	206	178	531	110
	C	Del.	9	932	205	190	576	117	853	204	174	527	107
	A	Imm.	9	959	205	195	592	121	859	213	184	531	113
	A	Del.	9	977	205	199	603	123	870	210	184	537	114
	SEM	Additive and Sealing		25.6		13.3	15.8	8.2	21.6	13.5	13.7	13.4	8.5
	SEM	Additive × Sealing		26.6		13.4	16.4	8.3	22.5	13.7	13.9	13.9	8.6
	P	Additive		0.002		0.003	0.002	0.003	0.38	0.03	0.02	0.38	0.02
	P	Sealing		0.50		0.64	0.50	0.64	0.80	0.44	0.65	0.80	0.65
	P	Additive × Sealing		0.27		0.23	0.27	0.23	0.35	0.96	0.50	0.35	0.49

Means with different letters differ at $P < 0.05$.

[1] Imm = immediate sealing Del = delayed sealing.

[2] An unknown portion of effluent was embedded in silage bales when weighed, that flowed out when plastic wrap was removed. In the table, weights of individual silage bales are subtracted an expected amount of effluent according to crop DM. Uncorrected values for silage bales in harvest 1–3, respectively: Kg: 851, 851, 986, kg DM: 187, 163, 210, kg per m^3: 526, 525, 609, kg DM per m^3: 116, 101, 130. Uncorrected values for the four bale treatments: no additive and sealed immediately, no additive and sealed after delay, additive treated and sealed immediately, additive treated and sealed after delay, respectively: Kg: 895, 889, 895, 906, kg DM: 184, 181, 191, 192, kg per m^3: 553, 549, 553, 560, kg DM per m^3: 114, 112, 118, 118.

alone, $i = 3$–6, with results given in the text, where appropriate.

The frequency of spot samples with detected growth of *C. tyrobutyricum* from the three harvests, and from bunkers and round bales, was analysed with the Chi-square test using the PROC FREQ procedure. Additionally, pH, and the number of detected *C. tyrobutyricum* colonies per g sample in the three harvests and the six silage treatments were analysed using the PROC MIXED procedure by the model $Y_{ik} = \mu + S_i + H_k + S_i \times H_k + e_{ik}$, where μ = general mean, S_i = the effect of silo treatment *i*, $i = 1$-6, H_k = effect of harvest *k*, $S_i \times H_k$ = the effect of interaction, and e_{ik} is the random residual error. The RANDOM statement was included for the nine time points, three at each harvest, when round bales were produced. Silo treatment *i* was as described for analyses of chemical composition. Values from bunkers were means over 4 points in the silo face, and values from bales were means over 2 points: surface and mid (Table 6).

Counts of *C. tyrobutyricum* were $\log_{10}$ transformed. Negative results (below detection limit) were defined as half of the detection limit, i.e. 5 cfu/g = 0.70 log cfu/g (Vissers et al., 2007). Results were considered statistically significant at $P < 0.05$, and *P*-values between 0.05 and 0.1 were considered to indicate trends.

3. Results

3.1. Round bale weights, and densities of fresh crop and silage. Crop DM, temperatures and occurrence of mould in bales and laboratory silos

Chemical composition of fresh grass crops for bunkers, round bales and laboratory silos, as weighted averages, is given in Table 1, and crop DM in bales, that had a total variation from 151 to 296 g DM/kg, in Table 2. During aerobic storage until delayed sealing, on

Table 3
Effect of harvest, silo type (bunkers, roundbales or laboratory silos), and ensiling practices (additive treatment and sealing time) on harvested crop recovered as offered silage or wasted silage, and invisible losses through respiration, effluent, fermentation, and aerobic deterioration.

					g/kg crop			g/kg crop DM		
Harvest	Silo type	Additive	Sealing[1]	N	Offered silage	Wasted Silage[2]	Invisible losses	Offered silage	Wasted Silage[2]	Invisible losses
1				26	919^{a}	13.0^{a}	72.9^{a}	906	13.0^{a}	86.0
2				26	900^{a}	8.6^{ab}	94.9^{a}	902	8.7^{ab}	92.4
3				26	956^{b}	5.5^{b}	40.6^{b}	921	5.4^{b}	75.5
SEM					11.1	0.86	11.2	10.2	0.82	10.2
P					0.003	<0.001	0.005	0.39	<0.001	0.50
	Bunkers	C		3	852^{ab}	25.8^{a}	122^{ab}	829^{a}	25.0^{a}	146
	Bunkers	A		3	814^{a}	26.0^{a}	160^{a}	837^{a}	26.9^{a}	136
	Bales[3]	C	Imm.	9	918^{b}	0.2^{b}	82.0^{b}	931^{b}	0.2^{b}	68.6
	Bales[3]	C	Del.	9	914^{b}	2.0^{b}	84.4^{b}	916^{b}	2.0^{b}	82.0
	Bales[3]	A	Imm.	9	898^{b}	0.2^{b}	102^{ab}	939^{b}	0.3^{b}	61.1
	Bales[3]	A	Del.	9	892^{b}	0.0^{b}	108^{ab}	923^{b}	0.0^{b}	76.9
	Labsilos	C	Imm.	9	992^{c}		8.2^{c}	934^{b}		65.9
	Labsilos	C	Del.	9	988^{c}		12.0^{c}	913^{b}		87.3
	Labsilos	A	Imm.	9	994^{c}		6.4^{c}	937^{b}		62.8
	Labsilos	A	Del.	9	991^{c}		9.5^{c}	941^{b}		59.5
SEM	Bunkers				29.6	1.63	29.8	27.3	1.56	27.3
SEM	Bales and Labsilos				17.1	0.94	17.2	15.8	0.90	15.8
P	Treatment[4]				<0.001	<0.001	<0.001	0.008	<0.001	0.11
P	Treatment × Harvest				0.94	0.002	0.97	0.56	<0.001	0.66
P	Contrasts									
	Bunkers vs. Bales				0.003	<0.001	0.04	<0.001	<0.001	0.002
	Bunkers vs. Labsilos				<0.001		<0.001	<0.001		0.001
	Bales vs. Labsilos				<0.001		<0.001	0.73		0.77

Means with different letters differ at $P < 0.05$.

[1] Imm = immediate sealing Del = delayed sealing.

[2] No silage was wasted from the laboratory scale silos because the sealing was perfect and prohibited aerobic deterioration. Therefore, laboratory silos were not included in statistical evaluation of wasted silage, so mean values from each harvest are from 14 observations, of which 2 are from bunkers.

[3] For treatment 3–6 (see below), an unknown portion of effluent was embedded in silage bales when weighed, that flowed out when plastic wrap was removed. Estimated losses in the table are based on silage weights of individual bales subtracted an expected amount of effluent according to crop DM. Losses based on observed, uncorrected weights were for silage bales in harvest 1–3, respectively, given in g/kg crop: Offered silage: 932, 918, 970, invisible losses: 60.3, 76.5, 26.9, and given in g/kg crop DM: Offered silage: 920, 922, 935, invisible losses: 72.4, 72.7, 62.0. Losses based on observed, uncorrected bale weights were for treatment 3–6, respectively, given in g/kg crop: Offered silage: 955, 951, 935, 929, invisible losses: 44.8, 47.2, 64.9, 70.5, and given in g/kg crop DM: Offered silage: 970, 954, 978, 962, invisible losses: 30.1, 43.9, 21.3, 37.6.

[4] Treatments: Ten treatments are the combinations of silo types, additive, and sealing: 1. Bunkers with no additive (C), 2. Bunkers applied acidic additive (A), 3. Bales with no additive sealed immediately, 4. Bales with no additive sealed after delay, 5. Additive treated bales sealed immediately, 6. Additive treated bales sealed after delay, 7. Laboratory silos with no additive sealed immediately, 8. Laboratory silos with no additive sealed after delay, 9. Laboratory silos applied acidic additive and sealed immediately, 10. Laboratory silos applied acidic additive and sealed after delay.

Table 4
Effect of harvest, silo type (bunkers, bales or laboratory silos), and ensiling practices (additive treatment and sealing time) on chemical composition, protein fractions, digestibility, and calculated energy and protein values of silages.

Harvest	Silo type	Additive	Sealing[1]		g/kg DM		Protein fractions[2], g N/kg total N					g/kg DM			g/kg		Per kg DM			
				N	OM	CP	A	B1	B2	B3	C	NDF	ADF	ADL	OMD	DOMD	MJ ME	MJ NE_L	g AAT	g PBV
1				36	918	169	600^{a}	23.2^{a}	283^{a}	63.1^{a}	31.1^{a}	500^{b}	322	31.4	0.738	676	10.6	6.21	70.0	47.7
2				36	934	158	626^{a}	43.3^{b}	250^{a}	49.2^{b}	31.8^{a}	532^{c}	339	29.5	0.721	671	10.5	6.13	69.7	36.7
3				36	927	163	518^{b}	36.8^{b}	334^{b}	69.2^{a}	43.0^{b}	477^{a}	317	27.7	0.729	675	10.6	6.18	69.9	41.8
SEM					5.24	3.92	16.1	2.95	13.5	2.84	2.92	12.2	7.22	2.32	0.011	7.13	0.13	0.095	0.36	37.3
P					0.12	0.12	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.09	0.53	0.54	0.86	0.81	0.81	0.87	0.12
	Bunker	C		18	928^{ab}	160^{ab}	561^{c}	36.8	297^{b}	64.7^{c}	40.3^{a}	524^{ab}	339^{a}	32.9^{a}	0.722^{b}	668^{b}	10.4^{b}	6.10^{b}	69.6^{b}	39.1^{ab}
	Bunker	A		18	931^{a}	157^{a}	524^{b}	34.8	315^{ab}	83.6^{b}	42.7^{a}	532^{a}	344^{a}	32.4^{a}	0.722^{b}	670^{bc}	10.5^{bc}	6.12^{b}	69.7^{b}	36.6^{a}
	Bales	C	Imm.	9	931^{a}	158^{a}	660^{e}	32.5	245^{f}	29.4^{d}	33.4^{b}	512^{bcd}	344^{a}	34.8^{a}	0.720^{a}	668^{bc}	10.4^{b}	6.10^{b}	69.6^{b}	37.3^{a}
	Bales	C	Del.	9	930^{a}	166^{bc}	630^{de}	31.7	263^{ef}	39.5^{d}	35.8^{b}	517^{abc}	340^{a}	34.2^{a}	0.717^{a}	665^{b}	10.4^{b}	6.06^{b}	69.4^{b}	45.9^{bcd}
	Bales	A	Imm.	9	928^{abc}	157^{a}	619^{d}	38.7	271^{de}	38.8^{d}	33.2^{b}	499^{cdef}	320^{bc}	29.0^{bc}	0.735^{cd}	680^{cd}	10.7^{cd}	6.26^{cd}	70.2^{c}	35.5^{a}
	Bales	A	Del.	9	928^{abc}	163^{abc}	565^{c}	35.6	303^{bc}	62.4^{c}	33.7^{b}	496^{def}	317^{bc}	29.4^{b}	0.740^{cde}	685^{d}	10.7^{de}	6.31^{de}	70.4^{c}	40.9^{abc}
	Labsilo	C	Imm.	9	921^{d}	168^{c}	617^{d}	26.3	283^{cde}	39.9^{d}	33.9^{b}	482^{fg}	314^{bc}	26.1^{bcd}	0.729^{bc}	670^{bc}	10.5^{bc}	6.13^{bc}	69.7^{b}	47.0^{cd}
	Labsilo	C	Del.	9	919^{d}	169^{c}	578^{c}	34.6	289^{cd}	63.7^{c}	34.9^{b}	506^{cde}	325^{b}	26.1^{bcd}	0.709^{a}	649^{a}	10.1^{a}	5.88^{a}	68.6^{a}	50.2^{d}
	Labsilo	A	Imm.	9	924^{bcd}	168^{c}	576^{c}	42.4	290^{cd}	59.0^{c}	32.4^{b}	473^{g}	308^{c}	24.6^{d}	0.748^{de}	689^{d}	10.8^{de}	6.38^{de}	70.6^{c}	45.5^{bcd}
	Labsilo	A	Del.	9	923^{cd}	165^{abc}	479^{a}	30.9	333^{a}	123.9^{a}	32.8^{b}	492^{ef}	311^{c}	25.7^{cd}	0.753^{e}	693^{d}	10.9^{e}	6.42^{e}	70.8^{c}	42.4^{abcd}
SEM	Bunkers				3.28	2.94	12.1	3.73	9.66	3.86	1.68	8.14	5.25	1.55	0.007	5.04	0.092	0.066	0.25	2.82
SEM	Bales and Labsilos				3.56	3.60	14.8	5.23	11.6	5.46	2.04	9.33	6.31	1.78	0.008	5.98	0.108	0.077	0.30	3.46
P	Treatment[3]				<0.001	0.002	<0.001	0.65	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
P	Treatment × Harvest				0.85	<0.001	0.03	0.60	0.02	0.22	0.04	0.67	0.13	<0.001	0.84	0.63	0.65	0.64	0.60	<0.001
P	Contrasts																			
	Bunkers vs. Bales				0.58	0.22	<0.001	0.75	<0.001	<0.001	<0.001	<0.001	0.002	0.35	0.08	0.09	0.08	0.08	0.09	0.31
	Bunkers vs. Labsilos				<0.001	<0.001	0.02	0.54	0.27	0.51	<0.001	<0.001	<0.001	<0.001	<0.001	0.048	0.03	0.02	0.06	<0.001
	Bales vs. Labsilos				<0.001	0.002	<0.001	0.77	<0.001	<0.001	0.64	<0.001	<0.001	<0.001	0.05	0.79	0.64	0.60	0.83	0.002
	A vs. C in Bunkers				0.18	0.43	0.003	0.70	0.0496	<0.001	0.15	0.22	0.29	0.68	0.96	0.71	0.75	0.75	0.70	0.39
	A vs. C in Bales				0.15	0.49	<0.001	0.33	<0.001	0.004	0.49	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.23
	A vs. C in Labsilos				0.10	0.49	<0.001	0.23	0.005	<0.001	0.28	0.08	0.04	0.45	<0.001	<0.001	<0.001	<0.001	<0.001	0.11
	Sealing time in Bales				0.87	0.02	0.001	0.70	0.007	0.003	0.36	0.89	0.48	0.96	0.85	0.93	0.91	0.91	0.92	0.02
	Sealing time in Labsilos				0.41	0.82	<0.001	0.77	0.009	<0.001	0.68	0.001	0.19	0.66	0.14	0.07	0.08	0.08	0.07	0.998

Means with different letters differ at $P < 0.05$.

[1] Imm = immediate sealing Del = delayed sealing.

[2] Protein fractions: A = Non protein nitrogen (NPN, calculated as CP-TP), B1 = True buffer soluble protein (BSP, calculated as TP-IP), B2 = Neutral detergent soluble protein, calculated as IP-NDIP, B3 = Neutral detergent insoluble protein (calculated as NDIP-ADIP (insoluble in neutral detergent but soluble in acid detergent)), C = Acid detergent insoluble protein (ADIP).

[3] Treatments: Ten treatments are the combinations of silo types, additive, and sealing: 1. Bunkers with no additive (C), 2. Bunkers applied acidic additive (A), 3. Bales with no additive sealed immediately, 4. Bales with no additive sealed after delay, 5. Additive treated bales sealed immediately, 6. Additive treated bales sealed after delay, 7. Laboratory silos with no additive sealed immediately, 8. Laboratory silos with no additive sealed after delay, 9. Laboratory silos applied acidic additive and sealed immediately, 10. Laboratory silos applied acidic additive and sealed after delay.

average 8 kg weight loss was observed, due to respiration, effluent runoff, and evaporation. While stored unwrapped during a shower, two bales in H2 with 196 g crop DM/kg, increased their weight with 1 and 6 kg, respectively, apparently due to absorption of rainwater.

Fresh crop weights of H1 and H2 bales were numerically lower than of H3 bales, and they lost more weight until opening (Table 2). Silage weight and FW density of H3 bales were therefore significantly higher than of H1 and H2 bales. On DM basis, however, silage bale weights and densities did not differ significantly among harvests.

Additive treatment produced on average 34 kg heavier bales than no treatment (of which 5 kg was the applied additive), which gave 20 kg ($P = 0.002$), and 4 kg DM ($P = 0.003$) more crop per m^3. At bale opening, this difference was smaller and insignificant on FW basis, however, due to higher DM concentration in A than C silage ($P = 0.03$), A bales contained 8 kg more DM than C bales ($P = 0.02$), and 5 kg more DM/m^3 than C bales ($P = 0.02$). No effect of delayed sealing was found on crop or silage weights or densities.

Initial temperatures measured in round bales stored unwrapped with sensors were 14.9, 18.7, and 13.5 °C for H1, H2 and H3, respectively, and 15.9 and 15.5 °C in C and A bales, respectively. Following 3.5–25.9 h delayed sealing for individual bales, on average 14.4 h, only small temperature increases were measured until wrapping, when temperatures had reached 17.5 and 16.3 °C in C and A bales, respectively (NS).

By unknown reason 14.5 kg moulded silage was found in one C bale with 296 g crop DM/kg and delayed sealing. Otherwise, only 2, 1.5, 1 or 0.1 kg moulded silage was found in 4 other bales. Apart from the bale with 0.1 kg mould, these bales were from H1.

Crop withdrawn from trailer loads for ensiling in laboratory silos contained on average 228, 180 and 223 g DM/kg in H1, H2 and H3, respectively, with total variation from 158 to 296 g DM/kg, and a total mean of 210 g DM/kg (not presented in Table). Initial temperatures in crop for laboratory silos were 18.4, 19.2 and 14.8 °C in H1, H2 and H3, respectively, which were, already at that point, significantly higher in C than in A crop, 18.0 vs. 16.9 °C, ($P = 0.01$). Further, during aerobic storage, C silos increased their temperatures faster than A silos, and at sealing, on average 12.2 h later, temperatures were 22.8 and 17.9 °C in C and A silos, respectively ($P = 0.004$). When stored aerobically over a night in H3, the two A silos decreased their temperatures by 1.7 and 2.6 °C, while temperatures had increased by 2.4 and 1.1 °C in the respective C silos.

3.2. Harvested crop recovered as offered silage or wasted silage, and invisible losses in bunkers, round bales and laboratory silos

On average for bunkers, bales and laboratory silos, the proportion of offered silage was higher, and invisible losses smaller, in H3 compared with H1 and H2 ($P \leq 0.005$) on FW basis (Table 3). On DM basis, these differences were smaller and not significant. The proportion of wasted silage was significantly higher in H1 than in H3, with H2 being intermediate, both on FW and DM basis ($P < 0.001$).

Contrasts showed that the proportion of offered silage on FW basis was lowest from bunkers, intermediate from round bales, and highest from laboratory silos ($P \leq 0.003$). There was, however, no significant difference for this variable between C bunkers and bales. On DM basis, the proportion of offered silage was similar for the two bunkers, but was lower in bunkers, on average 833 g/kg crop DM, than in bales and laboratory silos, with averages of 927 and 931 g/kg crop DM, respectively ($P < 0.008$). Contrasts showed that invisible FW losses were highest from bunkers, intermediate from bales, and lowest from laboratory silos ($P \leq 0.04$). Losses from C bunkers did, however, not differ significantly from losses from bales, and A bunkers differed significantly only from C bales. On DM basis, contrasts showed that invisible losses were higher from bunkers than from bales and laboratory silos ($P \leq 0.002$), that did not differ from each other. Across harvests, the proportion of wasted silage, on FW and DM basis, was higher from bunkers than from bales ($P < 0.001$), and there was a significant treatment × harvest interaction ($P \leq 0.002$) resulting from waste from bales in H1, only, and waste from bunkers in all harvests.

3.3. Chemical composition, digestibility, and calculated energy and protein values of silages

Silage composition was similar in the three harvests, apart from different proportions of protein fractions, and of NDF concentrations (Table 4). On N basis, H3 had lower proportion of protein A fraction than H1 and H2, and higher proportions of protein B2 and C fractions ($P < 0.001$). Also, protein B3 fraction was higher in H3 than in H2 ($P < 0.001$), and numerically higher in H3 than in H1. Protein B1 fraction was significantly higher in H2 and H3 than in H1 ($P < 0.001$). In H3, NDF concentration was significantly lower than in H1 and H2, with the highest value in H2 ($P < 0.001$). Also, ADF tended to be lower in H3 than in H2.

Laboratory silages had lower OM and higher CP concentrations than bunkers and bales ($P \leq 0.002$). In bales, however, CP concentrations were low and similar to bunkers when immediately sealed, and higher and similar to laboratory silos when sealed after delay. A significant treatment × harvest interaction showed that bunker silages were low in CP in H1 and H2, however, in H3, bunker silage had similar CP concentrations to laboratory C silos and delayed sealed C bales.

On N basis, proportions of protein A fraction in silages were highest in round bales, significantly lower in laboratory silos ($P < 0.001$), and even lower in bunkers ($P = 0.02$). Acid treatment reduced protein A fraction in all silo types ($P < 0.004$), and delayed sealing reduced A fraction in bales and laboratory silos ($P = 0.001$). The differences observed in B2 and B3 fractions were largely the same as those observed in protein A fraction, with signs reversed, because proportions of protein B1 and C fractions were low. Proportions of protein fractions B2 and B3 were significantly lower in bales than in laboratory and bunker silos ($P < 0.001$). Acid treatment increased B2 and B3 fractions in all silo types ($P \leq 0.05$), and delayed sealing increased B2 and B3 fractions in bales and laboratory silages ($P \leq 0.009$). Protein C fraction was higher in bunkers than in bales and laboratory silos ($P < 0.001$).

Within all harvests, the lowest proportion of protein A fraction appeared in delayed sealed laboratory A silage and the highest proportion in immediately sealed C bale silage, with extreme values of 427 in H3 and 709 in H1, respectively. The difference between

Table 5
Effect of harvest, silo type (bunkers, bales or laboratory silos), and ensiling practices (additive treatment and sealing time) on fermentation quality, intake potential and aerobic stability of silages.

Harvest	Silo type	Additive	Sealing[1]		g/kg		g/kg N	g/kg DM									Aerobic
				N	DM	pH	NH_3-N	WSC	LA	FA	AA	PA	BA	TA	Ethanol	SDMI	stab.,h[2]
1				36	212	4.32^{b}	61.9^{a}	16.6^{a}	70.3^{a}	5.77	19.6^{b}	2.17^{a}	1.20	99.1^{a}	8.9^{a}	99	145
2				36	182	4.11^{a}	63.8^{a}	4.7^{a}	75.7^{a}	6.00	26.2^{c}	2.66^{a}	0.04	111^{a}	18.4^{b}	93	165
3				36	212	4.34^{b}	50.5^{b}	58.7^{b}	57.1^{b}	5.45	13.7^{a}	1.57^{b}	0.00	77.8^{b}	7.5^{a}	95	162
SEM					15.6	0.048	3.65	5.09	4.01	0.44	1.79	0.21	0.62	4.78	1.03	2.07	10.6
P					0.31	0.002	0.03	<0.001	0.005	0.68	<0.001	0.001	0.30	<0.001	<0.001	0.28	0.39
	Bunkers	C		18	193	4.18^{a}	58.5^{d}	4.4^{a}	90.2^{e}	0.63^{a}	35.4^{a}	2.04^{cd}	0.26	129^{d}	6.3^{a}	92^{a}	196^{ab}
	Bunkers	A		18	203	4.21^{a}	51.0^{bc}	10.6^{ab}	65.6^{bc}	8.68^{b}	26.8^{b}	2.97^{e}	0.12	104^{c}	16.4^{e}	97^{b}	224^{a}
	Bales	C	Imm	9	206	4.13^{a}	67.6^{e}	20.5^{b}	83.0^{de}	0.61^{a}	13.9^{c}	0.06^{a}	0.00	97^{bc}	11.1^{bcd}	95^{b}	106^{d}
	Bales	C	Del	9	204	4.29^{a}	70.6^{e}	11.4^{ab}	71.2^{cd}	0.74^{a}	22.8^{b}	1.75^{bc}	0.00	97^{bc}	12.7^{cd}	95^{ab}	126^{cd}
	Bales	A	Imm	9	213	4.21^{a}	57.2^{cd}	51.6^{c}	47.7^{a}	12.2^{c}	11.6^{c}	3.27^{e}	0.00	75^{a}	10.1^{bc}	103^{c}	166^{bc}
	Bales	A	Del	9	210	4.23^{a}	52.4^{bcd}	47.3^{c}	51.8^{ab}	9.74^{b}	13.6^{c}	2.75^{de}	0.00	78^{a}	14.1^{cde}	103^{c}	170^{bc}
	Labsilos	C	Imm	9	199	4.25^{a}	68.1^{e}	8.3^{a}	86.6^{de}	0.57^{a}	22.3^{b}	0.90^{ab}	0.00	110^{c}	8.3^{ab}	94^{ab}	119^{cd}
	Labsilos	C	Del	9	196	4.56^{b}	75.7^{e}	6.5^{a}	65.2^{bc}	0.86^{a}	25.6^{b}	1.35^{bc}	3.76	97^{bc}	14.7^{de}	91^{a}	116^{cd}
	Labsilos	A	Imm	9	196	4.26^{a}	44.9^{ab}	57.3^{c}	56.2^{abc}	11.8^{c}	11.5^{c}	2.95^{e}	0.00	82^{ab}	10.5^{bcd}	102^{c}	180^{ab}
	Labsilos	A	Del	9	198	4.24^{a}	41.4^{a}	48.7^{c}	59.5^{abc}	11.6^{c}	14.8^{c}	3.32^{e}	0.00	89^{ab}	12.1^{bcd}	102^{c}	169^{bc}
SEM	Bunkers				10.0	0.049	2.82	3.93	4.52	0.47	1.67	0.25	0.75	4.50	1.12	2.07	13.8
SEM	Bales and Labsilos				11.0	0.067	3.49	4.86	6.23	0.64	2.21	0.35	1.05	5.97	1.53	2.27	19.4
P	Treatment[3]				0.33	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.24	<0.001	<0.001	<0.001	<0.001
P	Treatment × Harvest				0.56	<0.001	0.67	<0.001	<0.001	0.01	0.20	0.01	0.20	<0.001	<0.001	<0.001	0.18
P	Contrasts																
	Bunkers vs. Bales				0.03	0.62	<0.001	<0.001	0.001	0.009	<0.001	0.03	0.80	<0.001	0.53	<0.001	<0.001
	Bunkers vs. Labsilos				0.91	0.004	0.19	<0.001	0.01	<0.001	<0.001	0.12	0.31	<0.001	0.96	0.002	<0.001
	Bales vs. Labsilos				0.02	0.01	0.03	0.39	0.42	0.39	0.04	0.48	0.20	0.04	0.56	0.09	0.77
	A vs. C in Bunkers				0.13	0.68	0.01	0.13	<0.001	<0.001	<0.001	0.008	0.89	<0.001	<0.001	<0.001	0.15
	A vs. C in Bales				0.34	0.83	<0.001	<0.001	<0.001	<0.001	0.006	<0.001	1.00	<0.001	0.89	<0.001	0.009
	A vs. C in Labsilos				0.88	0.02	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	0.07	0.002	0.88	<0.001	0.004
	Sealing time in Bales				0.74	0.14	0.75	0.10	0.53	0.06	0.009	0.09	1.00	0.85	0.07	0.75	0.54
	Sealing time in Labsilos				0.90	0.03	0.47	0.20	0.14	0.98	0.11	0.23	0.07	0.54	0.01	0.23	0.71

Means with different letters differ at $P < 0.05$.

[1] Imm = immediate sealing Del = delayed sealing.

[2] Aerobic stability, hours.

[3] Treatments: Ten treatments are the combinations of silo types, additive, and sealing: 1. Bunkers with no additive (C), 2. Bunkers applied acidic additive (A), 3. Bales with no additive sealed immediately, 4. Bales with no additive sealed after delay, 5. Additive treated bales sealed immediately, 6. Additive treated bales sealed after delay, 7. Laboratory silos with no additive sealed immediately, 8. Laboratory silos with no additive sealed after delay, 9. Laboratory silos applied acidic additive and sealed immediately, 10. Laboratory silos applied acidic additive and sealed after delay.

treatments was larger within H1 than within H2 and H3, that might explain the treatment × harvest interaction in protein A fraction. Similar conditions, with signs reversed, may be the cause for interaction in protein fraction B2. Bunkers had the highest protein fraction C, however, in H3, fraction C was even higher in delayed sealed C silages in bales and laboratory silos, which might have caused the treatment × harvest interaction.

Silage NDF concentrations were highest in bunkers, lower in round bales, and lowest in laboratory silos ($P < 0.001$). Acid treatment reduced silage NDF concentrations in bales ($P = 0.01$), with the same tendency in laboratory silos ($P = 0.08$). Delayed sealing increased NDF concentrations in laboratory silage ($P = 0.001$). Silage ADF concentrations were highest in bunkers, lower in round bales ($P = 0.002$), and lowest in laboratory silos ($P < 0.001$). Acid treatment reduced silage ADF concentrations in bales ($P = 0.01$) and laboratory silos ($P = 0.04$). Silage ADL concentrations were lower in laboratory silos than in round bales and bunkers ($P < 0.001$). Acid treatment reduced ADL concentrations in bale silage ($P < 0.001$). However, these effects on ADL were only apparent in H2 and H3, which may have caused the treatment × harvest interaction.

All measures of digestibility and energy values, OMD, DOMD, ME and NE_L, tended to be lower in bunker silage than in round bale silage, and were significantly lower in bunker silage than in laboratory silage ($P < 0.05$). Acid treatment increased all these measures significantly in bale and laboratory silages ($P < 0.001$), but gave only a small numerical increase in bunker silage. Delayed sealed laboratory C silage had significantly lower DOMD, ME and NE_L values than all other silages, and, also lower AAT value. Otherwise, AAT values tended to be lower in bunker silage than in bale and laboratory silage, and were significantly higher in A than C silage in bales and laboratory silos. Silage PBV values were higher in laboratory silages than in bunker and bale silages ($P < 0.01$), and delayed sealing increased PBV in bale silage ($P = 0.02$).

3.4. Fermentation quality, silage intake potential, and aerobic stability of silages

In line with slightly lower silage DM concentrations in H2 than in H1 and H3, silage pH was lower and concentrations of acetic acid (AA) and ethanol were higher in H2 than in H1 and H3 (Table 5). Despite equal DM concentrations in H1 and H3 silage, NH_3-N, LA, AA, PA and TA were significantly higher, and WSC lower, in H1 than in H3. Although average silage DM concentration was only slightly higher in bales (208 g/kg) than in bunkers and laboratory silos (197 g/kg), and no significant differences between single treatments were apparent, contrasts revealed that this difference in DM concentration was significant ($P \leq 0.03$). Laboratory silos that were untreated and sealed after delay had significantly higher pH than the corresponding immediately sealed silos and all other silages. This was partly due to heavy butyric acid (BA) fermentation in one of the 9 laboratory silos with delayed sealing. However, round bales that were untreated and sealed after delay tended as well to have higher pH than the corresponding immediately sealed bales ($P = 0.07$).

Acid treatment reduced proteolysis to NH_3-N significantly in all silo types ($P \leq 0.01$), with no effect of sealing time. Greatest effect was found within laboratory silos, where A silages had the lowest values, and C silages significantly higher values.

Concentrations of WSC varied tremendously, from virtually nil (0.3 g/kg DM) in untreated bunker silage in H1, to 134 g/kg DM in acid-treated, immediately sealed laboratory silos in H3. On average across harvests, untreated bunker silage had the lowest WSC concentration, however, it did not differ significantly from several other low values. Contrasts showed a highly significant effect of acid treatment on WSC concentration in round bale and laboratory silage, but not in bunker silage, possibly because in H2, WSC concentration in A silage was even lower than in C silage, that gave a significant treatment × harvest interaction.

Lactic acid concentrations were significantly higher in C than in A silage in all silo types ($P \leq 0.004$), whereas sealing time had no effect. On average over harvests and acid treatment, LA concentrations were higher in bunker silage (77.9 g/kg DM) than in bale (63.4 g/kg DM) and laboratory silages (66.9 g/kg DM; $P = 0.01$), however, in H2, LA concentrations were lower in bunker silage (59.9 g/kg DM) than in bale (74.5 g/kg DM) and laboratory silages (84.9 g/kg DM). In H1 and H2, the highest LA concentrations were found in immediately sealed C silage from laboratory silos (94 and 101 g/kg DM) and bales (82 and 91 g/kg DM), whereas in H3, LA concentrations in those silages were more restricted (77 and 65 g LA/kg DM in laboratory and bale silage, respectively), with the highest observed LA concentration (108 g/kg DM) in bunker C. These factors may have produced the significant treatment × harvest interaction.

Bunker silages had higher average AA concentrations than laboratory silages, which again had higher concentrations than round bales ($P \leq 0.04$). Acid treatment reduced AA concentrations in all silage types ($P \leq 0.006$). Delayed sealing increased AA concentrations in bales ($P < 0.009$).

As constituents of the applied additive, FA and PA were found in higher concentrations in A than C silages from all silo types ($P \leq 0.008$). However, their presence also in C silages demonstrated that they were fermentation products, as well. Butyric acid was detected in low concentrations (< 2 g/kg DM) in 2 samples from A bunkers and in 5 samples from C bunkers, all from H1 or H2. Butyric acid was also detected in high concentration, 33.8 g/kg DM, in one sample from laboratory silage (delayed sealed C silage from H1). That silage had 163 g DM/kg, pH = 5.53, and an awful smell. Butyric acid was neither detected in any bale silage, nor in any H3 silage. Total acid concentrations were significantly higher in C than in A silage in all silage types ($P \leq 0.002$), whereas sealing time had no effect. On average over harvests, TA concentrations were higher in bunker silage than in laboratory silage ($P < 0.001$), that again were higher than in bale silage ($P < 0.04$).

Of all the ten silage types, across harvests, A bunkers had highest and C bunkers lowest ethanol concentration ($P < 0.001$). Whereas acid treatment significantly increased ethanol concentrations in bunker silages, it did not influence ethanol concentrations in round bales and laboratory silages. Delayed sealing, however, significantly increased ethanol concentrations in laboratory silos ($P < 0.001$) and tended to increase it in bales ($P = 0.07$). Whereas ethanol concentrations differed significantly between harvests, with by far the highest values in H2, bunker C silage had low and similar concentrations (5.9–6.9 g/kg DM) in all harvests. In H2, also immediately sealed laboratory C silage had a moderate ethanol concentration (9.8 g/kg DM), whereas all other silage treatments contained in the

range 15.8–30.7 g ethanol/kg DM. In H1, all silages had a moderate ethanol concentration in the range 6.2–11.7 g/kg DM, with the lowest value in immediately sealed A bales and the highest value in bunker A silage. In H3, where average ethanol concentration was lowest, there was a large difference between treatments, from 1.6 g/kg DM in immediately sealed laboratory A silos to 18.9 g/kg DM in delayed sealed laboratory C silos.

The relative SDMI-index presents the expected quantitative intake of silage DM by dairy cows, where one index unit corresponds to the default value of 0.10 kg in SDMI. Calculated SDMI indexes varied from 85 in delayed sealed laboratory C silage in H2 to 110 in immediately sealed laboratory A silage in H3. For all silo types, SDMI indexes were significantly higher in A than C silage ($P < 0.001$), with no effect of sealing time. Average SDMI indexes were highest in round bale silage, whereas bunker silages had significantly lower SDMI indexes than bale and laboratory silages ($P \leq 0.002$). However, mainly due to high SDMI index in bunker A silage in H2 (99), average indexes were numerically higher in bunker silages (96) than in bale and laboratory silages (94) in H2, that may explain the significant treatment × harvest interaction.

On average, aerobic stability was significantly higher in bunker silages than in bale and laboratory silages ($P < 0.001$). Acid treatment improved aerobic stability significantly in bale and laboratory silages ($P \leq 0.004$). No effect was found of sealing time.

3.5. *Clostridium tyrobutyricum* spores in spot silage samples from bunker silo faces and round bales

Spores of *C. tyrobutyricum* were detected in 14 of 48 spot silage samples from H3, which was a lower frequency than from H1 and H2, where *C. tyrobutyricum* was detected in 23 and 26 of 48 samples, respectively ($P = 0.04$; Table 6). Also, the number of *C. tyrobutyricum* colonies found per g sample from H3 tended to be lower than from H1 and H2 ($P = 0.09$).

Spores of *C. tyrobutyricum* were detected in higher frequencies in samples from bunkers than from round bales ($P = 0.04$), and the number of colonies found per g sample was significantly higher in silage from bunkers than from bales ($P < 0.001$), with no effect of additive treatment in bunkers or bales, or of sealing time in bales. Average pH tended to be higher in spot silage samples from bunkers than from bales ($P = 0.08$). Spot silage samples from surface or mid in round bales did not differ in spore frequency, number of colonies, or pH.

4. Discussion

4.1. Round bale weights, and densities of fresh crop and silage

The reason why H3 bales were heavier than H1 and H2 bales, although crop DM was similar, might be related to crop yield and physical properties of the crop (Table 2). Rinne and Nykänen (2000) found that regrowth grasses contain a higher leaf proportion than primary growths, so the regrowth may have been easier to compact than the primary growths. Additionally, regrowth stands are often

Table 6
Effect of harvest, silo type (bunkers or round bales), and ensiling practices (acid treatment and sealing time) on pH in grass silage and the frequencies and concentrations of *C. tyrobutyricum* spores in grass silage. Means of four sampling points from the face of bunkers: mid, side, top, shoulder, and of two sampling points in bales: mid and surface.

Harvest	Silo type	Additive	Sealing	Tot	*C. tyrobutyricum*		
				N	N[1]	Log cfu/g[2]	pH
1				48	23	1.07	4.37
2				48	26	1.24	4.36
3				48	14	0.89	4.36
X[2] or SEM					6.60	0.115	0.095
P					0.04	0.09	1.00
	Bunkers	C		36	22	1.45[a]	4.55
	Bunkers	A		36	19	1.50[a]	4.60
	Bales	C	Imm	18	7	0.90[b]	4.17
	Bales	C	Del	18	4	0.85[b]	4.27
	Bales	A	Imm	18	6	0.87[b]	4.35
	Bales	A	Del	18	5	0.83[b]	4.24
SEM	Bunkers					0.13	0.104
SEM	Bales					0.18	0.148
X[2]					11.8		
P	Treatment[3]				0.04	<0.001	0.08
P	Treatment × Harvest					0.38	0.08

Means with different letters differ at $P < 0.05$.

[1] Number of samples above detection limit.

[2] Detection limit = 1.00 log cfu/g (10 cfu/g) for *C. tyrobutyricum*. Concentrations in samples below detection limit are set to half of detection limit i.e. 0.70 log cfu/g (5 cfu/g).

[3] Treatments: Six treatments are the combinations of silo types, additive treatment, and sealing: 1. Bunkers with no additive (C), 2. Bunkers applied acidic additive (A), 3. Bales with no additive sealed immediately, 4. Bales with no additive sealed after delay, 5. Additive treated bales sealed immediately, 6. Additive treated bales sealed after delay.

shorter than primary growths, and therefore a larger area is needed to produce a bale, that gets highly compacted due to longer driving distance, and therefore a longer time when pressure is exerted on the crop by the baler. This is consistent with measured average driving times of 86, 72 and 139 s per bale in H1, H2 and H3, respectively. Like in bunker silos (Randby and Bakken, 2021), the higher density in treated than untreated bale silage was probably caused by an immediate cell rupture in fresh crops caused by the applied acid that increased mass compaction. In previous work where every second of 255 round bales were applied acid, 2 % higher FW was observed in treated bales (Randby, 2001).

4.2. Harvested crop recovered as offered silage or wasted silage, and invisible losses in bunkers, round bales and laboratory silos

The higher proportion of offered silage, and lower proportions of wasted silage and invisible losses in H3 compared with H1 and H2 on FW basis (Table 3), were apparently due to lower effluent runoff from bunkers and bales caused by higher crop DM in H3. Because DM concentration in effluent is low, often in the range 60–80 g/kg (Bastiman, 1976; McDonald et al., 1991; Randby, 1997), differences between harvests in offered silage and invisible losses were smaller, and insignificant, on DM basis.

In bunkers and bales, offered silage on FW basis was numerically lower in A silages than in C silages. Due to differences in silage DM concentrations, however, where C silages were lower (bunkers) or equal (roundbales), and A silages higher than in the ensiled crop, the proportion of offered silage on DM basis changed to be slightly higher in A than C silages in both bunkers and bales. In laboratory silages, where no effluent ran off, offered silage on FW basis was indeed high. On DM basis, offered silage as well as invisible losses were similar for round bales and laboratory silos, and within those two silo types, offered silage was numerically higher in A than C silage, and higher in immediately than in delayed sealed silage, as should be expected. McEniry et al. (2007) and Seppälä et al. (2016) obtained similar FW losses in laboratory silos as in the present study, however, they did not present DM losses. In immediately sealed laboratory silos, only approximately 0.3 % DM loss due to initial respiration of oxygen trapped in the crop during filling was expected (McDonald et al., 1991). Otherwise, no other losses than those arising from fermentation, between 2 and 4 % of DM, with energy losses very much lower, was expected, with an indirect inverse relationship between DM content of the ensiled crop and fermentation losses (McDonald et al., 1991). Due to the low DM concentration in laboratory silages, the observed average invisible DM loss of 64 g/kg for immediately sealed silos was within the expected range.

Considerably less of ensiled crop DM could be offered to animals following storage in bunkers (833 g/kg) compared with round bales (927 g/kg) and laboratory silos (932 g/kg). These results resembled results from a study performed with higher crop DM concentrations, on average 294 g DM/kg, at the same site the previous year (Randby et al., 2020), where offered silage DM averaged 870, 929 and 963 g/kg with the same three storage systems, respectively.

In the present study, wasted silage DM from bunker silos were only a half (26 g/kg) of that found with drier silages the previous year (55 g/kg; Randby et al., 2020). On the other hand, invisible DM losses were nearly doubled (141 vs 75 g/kg), resulting in 167 vs 130 g/kg total bunker DM losses with wet and drier crop, respectively, i.e. 37 g/kg higher total bunker DM losses with the wetter crop in the present study. Wasted silage DM from round bales was virtually nil (0.6 g/kg) in the present study, and low (13 g/kg) also with the drier crop the previous year. Invisible DM losses from round bales were estimated (see *2.6.*) to be 72 g/kg in the present study, and measured to be 58 g/kg with the drier crop the previous year, resulting in very similar (73 vs 71 g/kg) total round bale DM losses with wet and drier crop, respectively.

Although successful round bale wrapping prevents air infusion, it is not completely watertight. Some effluent leakage from wet bales during storage is often observed, as also in the present study. Even if some effluent had already escaped from some bales at weighing prior to opening, round bale weights were corrected for the total expected amount of effluent according to crop DM concentration. Therefore, the performed correction has more likely over- than under-estimated silage losses from round bales.

Postharvest respiration that increases crop temperature during silo filling is considered to be the main challenge in silage production (Van Soest, 1994) and was expected to be severe in bunker silos due to the long time until complete anaerobiosis occur. The speed of filling will determine how large the temperature increase will be prior to silo sealing (Muck et al., 2003). Maximum plant respiration will occur at approximately 35 °C, and the effect of temperature on respiration loss is higher in wetter than in drier crops (Muck et al., 2003). Of practical reasons, temperatures could not be measured in bunkers in the current study. Maximum crop temperatures measured at sealing was 21.5 °C in bales and 30.5 °C in laboratory silos. Temperatures increased faster in untreated than in acid treated crop and this was probably the case in bunkers, as well. Van Soest (1994) stated that larger masses are more prone to heating because there is less surface for radiant losses, which suggests that increased crop temperature attained in bunkers during filling is retained for a longer time than in bales, and especially compared with laboratory silos. In all silo structures, total DM loss was numerically higher in C than A silage despite higher DM loss through effluent in A silage of bunkers and bales. This suggested that low respiration losses in A silages had more than outweighed the increased DM losses caused by higher effluent runoff.

Randby et al. (2020) recommended that packing vehicle weight should be tuned to crop wetness and morphology aiming to restrict DM loss through effluent from immature, low DM crops, and to restrict DM loss through respiration and aerobic deterioration during storage and unloading from dry and stiff crops. Unfortunately, both a heavy wheel loader and a tractor were used for consolidation of every load in the present study, which may have contributed to more effluent than necessary being squeezed out from the very low-DM crops. According to Wilkinson and Rinne (2018) current recommendations are to chop wilted grass crops (280–350 g DM/kg) to 25–50 mm theoretical chop length (TCL) to facilitate good consolidation in the silo, but to chop wetter grass crops (200–280 g DM/kg) to longer average particle length (80–100 mm TCL) to reduce effluent production. The much lower pressure exerted on the crop by the baler has apparently contributed to lower DM loss through effluent from round bales. This lower pressure from the baler, in addition to the higher particle length of grass crops obtained with stationary knives in the round baler than with the precision chopper, has contributed to much lower densities in bales than in bunkers: on FW basis, 531 vs 833 kg/m^3 ($P < 0.001$), and on DM basis, 111 vs 164

kg/m^3, ($P < 0.001$), where bunker silo densities were given by Randby and Bakken (2021). Although high silage density is a prerequisite in order to restrict respiration loss during filling, storage, and unloading of bunker silos, these sources of losses use to be higher in bunkers than in bales. This is simply because round bales are normally wrapped within a few minutes following harvesting, and are normally offered to animals the same day as plastic wrap is removed. Also, during storage, wrapped bales seem to be more airtight than bunkers, albeit less dense, shown by the lower amount of wasted silage from bales than bunkers. Huhnke et al. (1997, cited by Muck et al., 2003) also experienced low DM losses in wrapped bale silage.

4.3. Chemical composition, digestibility, and calculated energy and protein values of silages

Crude protein in fresh forages is composed of 20–30 % NPN (fraction A), 60–70 % true available protein (fraction B) and 4–15 % unavailable nitrogen (fraction C; Van Soest, 1994). Fresh grass crop in the present study was within the higher ranges of these normal values for A and B fractions, and within the lower range for the C fraction (Table 1). Compared with fresh crop, the A fraction was doubled in silage, whereas the B fractions, especially B2 that is soluble in neutral detergent, and B3 that is soluble in acid detergent, were considerably reduced, and the indigestible C fraction was slightly increased (Table 4). Good-quality silages are low in ammonia, and amino acids dominate the NPN fraction (Van Soest, 1994). Numerous factors affect the proteolysis of TP to NPN, where prolonged wilting during unfavorable drying conditions increases it and rapid wilting retards it. In general, heat reduces proteolysis, however, heating and moulding in high DM haylage increase the C fraction (Van Soest, 1994). The reason why proteolysis was lower in H3, with lower A fraction and higher B2 fraction than in H1 and H2, is not found, but might be related to a higher red clover proportion in H3. This clover species contains more polyphenol oxidase (PPO) and its substrate o-diphenol than most grasses do (Parveen et al., 2010). When PPO converts phenol to quinones, which bind with proteins, proteolysis is restricted. Wilting time was longest in H3, and air temperature was similar in H1 and H3. In both fresh crop and silage, the C fraction was higher in H3 than in H1 and H2. Also, the previous year, protein C fraction was higher in the second regrowth than in the primary growth (Randby et al., 2020), that might be related to seasonal factors, e.g. light intensity and day length. Cell wall components decrease with increasing light (Van Soest, 1994).

The significantly lower concentrations of CP and ash (higher OM) in bunker and bale silages than in laboratory silage (Table 4) were probably due to loss of effluent from bunkers and bales, because effluent contains much higher CP and ash concentrations than crop and silage (Randby, 1997).

Silage protein fractions were significantly influenced by silo type, acid treatment and sealing time, where protein A proportion varied from 479 to 660 g N/kg N. The consistent reduction in protein A fraction in delayed sealed silages compared with the corresponding immediately sealed silages was probably a heating effect (Van Soest, 1994). Nicholson et al. (1991) found significantly higher NPN proportion in baled than in precision chopped, bagged, alfalfa, possibly due to approximately 6 °C lower temperature in bales than in the bag, caused by the greater mass of silage in the bag and more rapid heat loss from the smaller bales.

Increasing rates of FA application result in decreasing rates of proteolysis because it predominantly is the result of plant enzyme activity, that may be restricted by applied acid (McDonald et al., 1991). Further degradation of amino acids to NH_3-N is brought about by microbial activity (McDonald et al., 1991), and about a third of the higher protein A fraction in C than in A silages could be ascribed to higher microbial degradation of protein to NH_3-N (Table 5). Proteolytic degradation also involves deamination of amino acids with resultant formation of amines, that are significant components of NPN fractions of silage (Van Soest, 1994). In both round bales and laboratory silos, delayed sealing reduced proteolysis in C silages as well as in A silages, but the effect was much higher in A than C silages. Compared with immediately sealed C silages, the reduced proteolysis (decrease in protein fraction A) in delayed sealed A silages amounted to 117 g N/kg N on average for bales and laboratory silos, giving the sum effect of acid treatment and heating caused by delayed sealing.

Acid treatment in bunker silos reduced proteolysis similarly to in immediately sealed bales and laboratory silos, by 37 g N/kg N, i.e. less than in delayed sealed bales and laboratory silos, that suggested that bunkers were not heated. On the other hand, bunker silages had significantly higher protein C fractions than bale and laboratory silages, that suggested a slight heat damage. Maillard reactions are important above 50 °C but may be detectable at temperatures as low as 30 °C if sustained for long periods (Van Soest, 1994). The highest measured temperatures before sealing in the present study were 21.5 °C in a round bale and 31 °C in a laboratory silo. It is probable that temperatures might have exceeded 30 °C in the bunkers, and that this sustained for some time, however, the level of the protein C fractions in bunker silage was only slightly above that of the initial crop, so a possible heat damage must have been small.

Differences within NDF and ADF fractions, with the highest values in bunker silages and the lowest in laboratory silages were consistent with some degree of protein bound to fiber. Acid treatment in bales and laboratory silos reduced, or tended to reduce silage NDF and ADF concentrations, and even reduced silage ADL concentrations in bales, that suggested a slight Maillard reaction in untreated round bales. Clearly higher NDF concentrations in delayed than in immediately sealed laboratory silage indicated that protein was loosely bound in NDF, that was supported by high levels of protein fractions B2 and B3 in delayed sealed laboratory silage, especially when acid treated.

Digestibility and energy values in both C and A bunkers were similar to C bales and C laboratory silos, whereas A bales and A laboratory silos had significantly higher values. Also, NDF, ADF and ADL were similar in C and A bunkers and C bales, whereas A bales were significantly lower. This suggested that acid treatment in bunkers did not restrict the binding of protein to fiber, although it did so in bales and laboratory silos. This further suggests that acid treatment in bunkers could not prohibit the small, but significant reduction in digestibility caused by fiber bound protein, that was prevented by acid treatment in bales and laboratory silos, probably due to reduced initial crop temperature or reduced initial pH. Poorer effect of acid treatment in bunkers than in bales and laboratory silos may be related to two factors: (1) The much larger surface area susceptible to heating in bunkers required higher acid dosages, and (2) Some of the applied acid was lost through effluent. Formic acid is highly water soluble, and in a three year study with low DM crops in roofed

tower silos, Randby (1997) found four times higher FA concentrations in effluent DM than in silage DM, that suggested that about a third of applied acid was lost through effluent. A similar calculation based on applied FA, analysed FA in silage, and the proportion of offered silage in the present study, suggests that about 59 %, 68 % and 86 % of applied FA was recovered in bunker, round bale and laboratory silages, respectively, and that effluent was the main source of lost FA.

4.4. Fermentation quality and intake potential

The more restricted fermentation in H3 compared with H1 despite equal DM concentration, similar additive application rate and similar air temperature was most pronounced in A bales and A laboratory silos (Table 5). According to Huhnke et al., (1997, cited by Muck et al., 2003), the long particles and low densities in bale silage compared with precision chopped silage may contribute to reduced fermentation due to reduced availability of sugar to the bacteria. Crop for laboratory silage was precision chopped like crop for bunkers, however, pressure and density were low.

Results regarding additive treatment in bunker silos were discussed by Randby and Bakken (2021), with the main conclusion that the more restricted acid fermentation in A than C silage, gave a significantly higher potential for feed intake of A than C silage. Ethanol concentration, however, that does not influence silage intake (Huhtanen et al., 2007), was higher than wanted in bunker A silage (Table 5).

The totally 108 silages evaluated in the present study comprised a large variation of fermentation qualities, that highly depended on the experimental factors: silo types, acid treatment, and sealing time. Only one single sample of laboratory silage, that was assigned to all the poorest treatment levels, was butyric acid fermented, otherwise, all other silages were mainly well preserved, but varied from restrictedly to extensively fermented.

On average, bale silages were more restrictedly fermented than bunker silages, with higher concentrations of WSC, and lower concentrations of NH_3-N, LA, AA, PA and TA. With alfalfa at a much higher DM level, 390 g/kg, also Nicholson et al. (1991) found more restricted fermentation in long crop for round bales than in precision chopped crop for bag silage. McEniry et al. (2008) found overall lower concentrations of fermentation acids in baled silage than in precision chopped crop ensiled in laboratory silos. Only for AA, levels were lower in bales than in laboratory silos in the present study, otherwise, fermentation pattern was similar. Coblentz and Akins (2018) stated that the slower and less extensive fermentation pattern in baled than in precision chopped silages are linked to restricted availability of sugars to lactic acid producing bacteria, and to the long-stemmed nature of baled silage, that requires diffusion of plant sugars from inside to reach lactic acid producing bacteria that are adherent to the outside surface of forage plants.

Whereas ethanol concentrations significantly increased by acid treatment in bunker silos, in bales and laboratory silos ethanol concentrations were not influenced by acid treatment, but tended to increase, or increased significantly, by delayed sealing. Fermentative yeasts that are unable to utilize lactate, e.g. Saccharomyces spp., are the dominant ethanol producer in anaerobic silage (Jonson and Pahlow, 1984). They highly rely on WSC as a carbon source, for which they compete with lactic acid bacteria. High yeast counts have been found in grass silages with high residual sugar levels resulting from treatments such as formic acid, as well as in wilted silages and silages in which the initial aerobic phase is prolonged (McDonald et al., 1991). Jonson and Pahlow (1984) found that aeration increased yeasts numbers, and McEniry et al. (2007) observed increased ethanol fermentation with slight air infiltration of low DM grass silage. By contrast, in alfalfa wilted to on average 410 g DM/kg, with silage ethanol concentrations below 3.5 g/kg DM, Coblentz et al. (2016) found that ethanol concentrations declined with increasing time delay for bale wrapping, and, also declined with increasing internal bale temperature from 32 to 68 °C at wrapping. Regressions of ethanol concentration on silage constituents in the present study showed that ethanol increased with decreasing silage concentrations of both WSC and LA ($R^2 = 0.39$, $P < 0.001$). Depending on the microbial competition, WSC from ensiled crop can either largely remain in the silage, as for A bales and A laboratory silos, or be fermented to LA, as for bunker silo C, immediately sealed C bales, and laboratory C silos, or be extensively fermented to ethanol, as for bunker silo A, and delayed sealed bales and laboratory silos. Ethanol fermentation in silage is often unpredictable, however, during conditions where formic acid-based additives in low or recommended doses (2–5 L/t) increase ethanol concentration compared with negative control, an increase in application rate (6–7 L/t) has restricted concentrations to below untreated silage (Chamberlain and Quig, 1987; Kennedy, 1990; Jaakkola et al., 2006).

Prediction of feed intake is important because performance of ruminants is more closely related to feed intake than to diet digestibility or efficiency of converting digestible energy to net energy (Mertens, 1994). The higher expected feed intake of round bale than of bunker silages in the present study, especially when acid treated, could mainly be ascribed to lower concentrations of fermentation acids, but also to higher DOMD, higher DM and lower NDF. The SDMI indexes suggest that silage intake was expected to be 1.1 kg DM higher of round bale silage A than of bunker silage C because bunker C would depress intake with 8×0.1 kg DM = 0.8 kg DM, compared with a SDMI of 100, whereas bale silage A would increase intake with 0.3 kg DM, where 0.1 kg DM is the default value per unit of SDMI index (Huhtanen et al., 2007). Further, each kg DM of bale silage A contained 0.3 MJ of ME more than bunker silage C. In a forage-based feeding system where the use of concentrates is restricted, this would have a pronounced influence on daily gain and milk yield in ruminants. If daily dairy cow intake in a grass silage only system was 14 kg DM, that equals 146 MJ ME, of bunker silage C, the intake of bale silage A would have been 15.1 kg DM that equals 162 MJ ME. Huhtanen and Nousiainen (2012) determined dairy cow responses to increased supply of ME to be approximately 0.1 kg energy corrected milk (ECM) yield per MJ of ME intake. Estimated daily energy intake response to a change from bunker silage C to bale silage A would be 16 MJ ME, equal to a milk yield response of 1.6 kg ECM. Partly due to the negative relationship between the level of concentrate supplementation and silage intake potential, and partly due to reduced digestion of high-concentrate diets, the milk yield response to the best silage would be smaller with increasing concentrate allowance.

4.5. Aerobic stability of silages

Yeasts, particularly lactate-assimilating yeasts, are the primary initiators of aerobic spoilage in silage (Pahlow et al., 2003). Silages produced with mixtures of acetic, propionic and formic acid have proved to be more stable than untreated silage when exposed to air (Lindgren et al., 1985). Propionic acid, that seems to act by inhibition of sugar uptake to yeast cells under aerobic conditions (Mann and McDonald, 1976) were particularly effective. The minimum inhibitory concentrations against yeasts and moulds at pH 4, of 63, 94 and >250 mM, for PA, AA, and LA, respectively (Woolford, 1975), is consistent with the lower p*K*a value, 3.08, of LA compared with the more effective AA and PA that have p*K*a values of 4.76 and 4.86, respectively, making them less dissociated and therefore more effective (Wilkinson and Davis, 2012).

In the present study, neither WSC, nor LA or ethanol concentrations were related to aerobic stability. However, increasing silage concentrations of PA and FA correlated positively with measured aerobic stability, with a similar tendency for AA, with correlation coefficients (r) of 0.37, 0.33 and 0.17, respectively. Increasing levels of NH_3-N, g/kg TN, and increasing pH correlated negatively with aerobic stability, with r of −0.35 and −0.20, respectively. The best model of aerobic stability was: Aerobic stability, hours = 212 + 15.2 × PA, g/kg DM − 1.37 × NH_3-N, g/kg TN, $R^2 = 0.23$, $P < 0.001$. However, almost equally good models were also found by the combinations of AA and NH_3-N, or FA and AA, both with $R^2 = 0.22$, $P < 0.001$, possibly because FA was strongly positively correlated with PA, r = 0.65, and negatively correlated with NH_3-N, g/kg TN, r = −0.51 and AA, r = −0.40. Propionic acid was significantly higher in bunkers than bales, and NH_3-N lower in bunkers than bales, in line with the significantly higher aerobic stability of bunker than bale silage. Concentrations of NH_3-N, g/kg TN were significantly reduced by acid treatment in all silo types, in line with the significant, or the tendency for, improved aerobic stability of treated silages.

4.6. Clostridium tyrobutyricum spores in spot silage samples from bunker silo faces and round bales

Clostridium tyrobutyricum may lead to off flavors and excessive gas formation in cheese because it is able to convert LA into BA, H_2 and CO_2 at relatively low pH. The goal is to obtain < 1 spore/mL of milk, which can easily be obtained if the offered silage does not contain deteriorated spots with > 3 log spores/g (Vissers et al., 2006). All silages in the present study were well below this level, however, compared with bales, bunkers had significantly higher frequencies of samples where spores of C. *tyrobutyricum* were detected, as well as higher average spore concentrations (Table 6). Vissers et al. (2007) found that elevated spore concentrations were associated with signs of aerobic deterioration. Contrary to this, higher average spore frequencies and concentrations were found in bunker than in bale silage, despite higher aerobic stability in bunker silage. In the present study, bunker silage samples for aerobic stability test were withdrawn from silage unloaded with block cutter 3–4 days per week for feeding of livestock, and similarly, from bales as fed. Samples for analysis of C. *tyrobutyricum* were, on the other hand, averages from four spots from the silo face, where mid samples contained 0.83 log cfu/g of spores, similar to bales, and significantly less than side and shoulder samples, 1.98 and 1.92 log cfu/g (Randby and Bakken, 2021). If samples for aerobic stability had been withdrawn from bunker silo faces that had been exposed to air, results could have been different. In the present study, aerobic stability was merely a consequence of chemical and microbial composition of fully anaerobically stored silages, and not a result of ongoing aerobic deterioration that is associated with elevated spore concentrations (Vissers et al., 2007).

5. Conclusions

A considerably lower proportion of ensiled crop DM could be offered to livestock from bunkers than from round bales. The sum of losses amounted to 17 % and 7 % of ensiled crop DM, for bunkers and bales, respectively, and was not significantly affected by application of an acidic additive. In both bunkers and bales, acid treatment improved silage intake potential due to restricted acid fermentation. Additive application rate seemed to be too low to prevent temperature increases in bunkers. The longer time until the surface is plastic covered in bunkers than in bales may allow temperature increases, and therefore higher acid dosages are required. The high ethanol concentration in acid treated bunker silage also suggested that application rate was suboptimal in bunkers, or that the additive should have contained a higher proportion of propionic acid or other ingredients that inhibit yeast growth.

Hypothesis 1. that losses are lower and fermentation more restricted in bales than in bunkers was confirmed. The part of hypothesis 2, that additive application restricted fermentation in both bunkers and bales was also confirmed, however, the expectation of a more pronounced effect in bunkers than bales was rejected. The part of hypothesis 2, that additive application reduces losses in both bunkers and bales could not be confirmed with significant results. The part of hypothesis 2, that additive application increases aerobic stability of silage in bunkers and bales was clearly confirmed in bales but was not fulfilled in bunkers. These conclusions may be valid for low-DM grass crops, only.

Funding

The work has been financed by the Norwegian Research Funding for Agriculture and the Food Industry, The County Governor of Rogaland, and the industry partners Addcon Nordic AS, Agromiljø AS, Animalia, Fiskå Mølle, FK Agri, FK Rogaland Agder, Felleskjøpet fôrutvikling, Norske FK, Nortura, Strand Unikorn, TINE Rådgiving og medlem and Yara Norge.

CRediT authorship contribution statement

Å.T. Randby: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing - original draft, Writing - review & editing. **A.K. Bakken:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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