Baled silage management

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1. Introduction

Bale silage has proved to be a good alternative to haymaking for silage on small-to-medium farms in lowlands and highlands to produce higher quality forage than hay (Hancock and Collins, 2006; Borreani et al., 2007a). Over the last 25 years, baled silage has become an economical alternative to other harvesting systems in Europe (Tabacco et al., 2011), and this has led to a remarkable increase in the amount of herbage stored as silage (from 30% to 80% of the total harvested dry matter, depending on the country considered) (Wilkinson and Toivonen, 2003) and has been gaining popularity in the US over the last decade (Arriola et al., 2015; Coblentz and Akins, 2018).

Big bale silage is by now a well-established conservation system for storing excellent quality forage, and provides an opportunity to maintain the high feeding value of young herbage (Hancock and Collins, 2006; Borreani et al., 2007a; Coblentz and Akins, 2018). Forage for baled silage is often wilted extensively and therefore presents more limited fermentation than conventional silage stored in horizontal silos (Borreani and Tabacco, 2018). Moisture is known to influence silage fermentation and the production of fermentation acids (Coblentz and Akins, 2018). A greater dry matter (DM) content than 35% (moisture < 65%) is commonly adopted by farmers to avoid effluents, to minimize bale deformation and to reduce the number of bales per hectare and the plastic consumption per tonne of stored DM (Han et al., 2006; McEniry et al., 2007; Tabacco et al., 2013). This results in a restricted fermentation and consequently in a higher pH than precision-chopped silages with the same DM content, as reported in Figure 1 (Borreani and Tabacco, 2018). Figure 2 reports the relationships between lactic acid and silage pH for corn silage and for baled alfalfa and grass silages. It appears that the buffering capacity of grassland forages reduces the acidification effect due to lactic acid, compared to well conserved corn silages. The high DM content of baled silages and the reduced release of solubles from plant tissues in a few cases has resulted in a final pH of less than 4.2 being achieved, which is considered sufficient to reduce the risks of clostridial fermentation in all forages. Moreover, the reduced moisture content at harvest, due to the wilting process, reduces the water activity (a_w) of the forage and this results in a synergistic inhibitory effect with pH on clostridial development, as can clearly be seen in Table 1 (Pahlow et al., 2003).

Another factor that could influence clostridial growth in baled silages is a delay in wrapping after baling, which leads to a reduction in the carbohydrates that are available for fermentation, due to plant tissue and microbial respiration, and results in a higher final pH (Ciotti et al., 1989; Niyigena et al., 2019).

Table 1. Indicative critical pH values for anaerobically stable silages, as influenced by water activity in the absence of free nitrates in the forage at ensiling (from Pahlow et al., 2003).

	DM content (%)						
	20	25	30	35	40	45	50
Moisture (%)	80	75	70	65	60	55	50
Water activity (a_w)	0.999	0.995	0.990	0.966	0.960	0.956	0.950
Maximum pH for stable silage	4.20	4.35	4.45	4.60	4.75	4.85	5.00

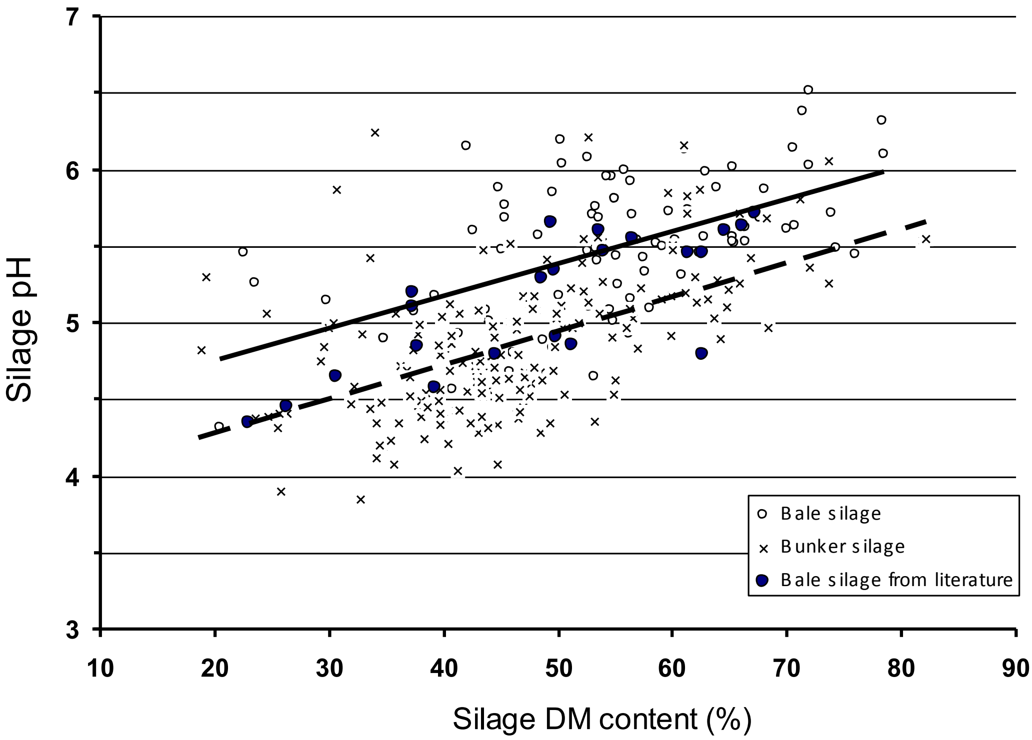


Figure 1. Relationship between silage pH and DM content of grass and legume silages conserved in bunker silos (dotted regression line; pH = 0.0223 DM content + 3.839; R^2 = 0.309**) or in wrapped bales (continuous regression line; pH = 0.0212 DM content + 4.327; R^2 = 0.292*) on dairy farms in northern Italy (n = 277) (adapted from Borreani and Tabacco, 2018). The black circles refer to data from Coblentz and Akins (2018).

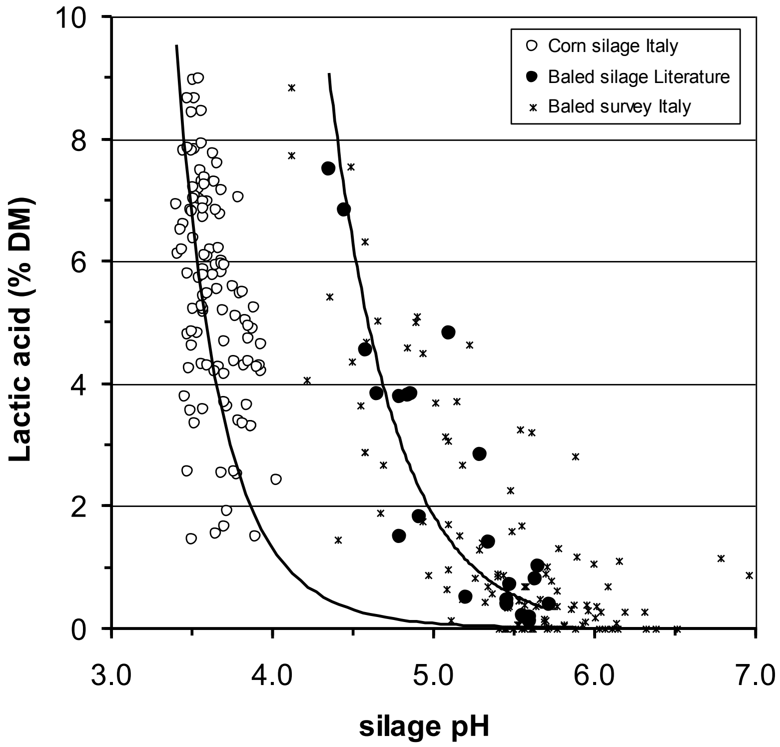
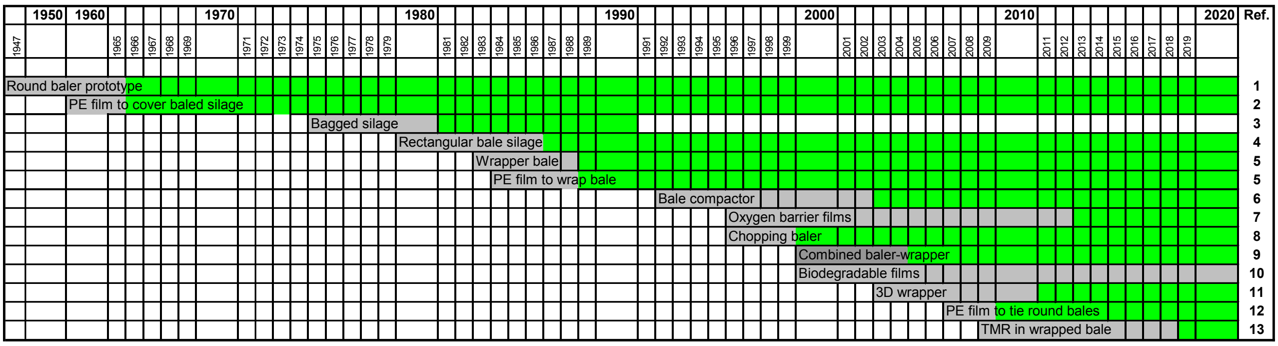


Figure 2. Relationship between lactic acid and silage pH in corn silage (the open circles refer to data from Borreani and Tabacco, 2010); in baled silage from literature (black circles, alfalfa and grass baled silages from Coblentz and Akins, 2018), and in baled silages from an Italian survey on farm (asterisks, alfalfa and grass bales from Nucera et al., 2016).

The main innovation milestones concerning bale silage technology are reported in Figure 3. The concept of conserving grass as silage in big round bales originated in the early ‘70s and it involved ensiling individual or two bales together in polyethylene plastic bags or rectangular bales covered with plastic films (Marshall and Howe, 1989). Defective sealing, especially at the neck of the bag, allowed air to penetrate the bale and, as a result, bagged silages often showed mold development and extensive aerobic deterioration (Wilkinson et al., 2003). For these reasons, bagged bales were quickly replaced by a new wrapper developed by Silawrap in 1982 and they had completely disappeared by the beginning of 1990s. In 1985, Tom Golden, marketing director of Silawrap (Kverneland group, Norway), said, about a newly developed bale wrapping machine: “*It'll revolutionize round bale silage making”* as it was a fast, low-cost way of wrapping bales in spoilage-proof plastic (Anonymous, 1985). In the 90s, improvements were made to baler machines with the introduction of chopping devices and improved forage compaction in the bale chamber, which led to high density and well-shaped bales being obtained (Tremblay et al., 1997). New machines that integrate both a baler and a wrapper are now available on the market, and they are able to increase productivity and reduce operation costs, compared to the use of two separate machines (Münster, 2001).

In 2017, the Kverneland Group introduced the non-stop bale production process onto the market with the introduction of a film-on-film applicator option and two bale chambers arranged in series – a full sized main chamber and a pre-chamber, located directly above the intake rotor, which is about two thirds the size of the main chamber. This design results in an extremely compact machine with a non-stop capability. Earlier this year (2019), this system was combined with a wrapping machine. The newly proposed system, named "*FastBale"*, is a non-stop round baler wrapper that integrates a pre-chamber with a main chamber and a wrapper (https://ien.kverneland.com/Kverneland-brand-Corporate-site/Bale-Equipment/Round-Balers/Kverneland-FastBale).

Another innovation aspect regards the improvement of the quality of film applications during wrapping (Borreani et al., 2007b; Bisaglia et al., 2011) and the development of stretch films with a high barrier to oxygen (Borreani and Tabacco, 2008).



References: 1 = https://en.wikipedia.org/wiki/Baler; 2 = Wilkinson et al., 2003; 3 = Marshall and Howe, 1989; 4 = Shinners et al., 1996; 5 = Anonymous, 1996; 6 = Anonymous, 1990, 1992; 7 = Borreani and Tabacco, 2017; 8 = Tremblay et al., 1997; 9 = Münster, 2001; 10 = Keller et al., 2000; 11 = Borreani et al., 2007b; 12 = Bisaglia et al., 2011; 13 = Wang et al., 2010.

Figure 3. Main innovations in baled silage from the '50s onwards. In gray = prototypes and setting of the technology; in green = commercial development and diffusion.

2. Factors that affect bale silage quality

In addition to the crop type and morfological stage at cutting, the moisture content, pH drop, density, porosity and air-tightness are the main factors that influence the quality of silage, and they have been found to be influenced by the wilting process before baling (moisture and sugar contents), the type of baler (density and porosity), the wrapping delay (respiration of fermentable carbohydrates), the characteristics of the stretch film and number of layers applied (to achieve the best anaerobic environment), the length of storage and by mechanical damage to the plastic cover (lost air-tightness) (Borreani and Tabacco, 2018; Coblentz and Akins, 2018).

The higher DM content and the increased porosity of forages conserved in wrapped bales increase the risk of fungal growth (O'Brien et al., 2008; Tabacco et al., 2013), and consequently increase the risk of mycotoxicosis (O'Brien et al., 2007; McElhinney et al., 2016) and *Listeria* contamination (Fenlon et al., 1989; Nucera et al., 2016). Even though the baled silage system is based on a well-established procedure, the fact that the incidence of mold spoilage can be relatively high (O’Brien et al., 2008; Borreani and Tabacco, 2010) suggests that the current bale ensiling practices may be considered only partially satisfactory (McEniry et al., 2011). Air-tightness has to be maintained for extended conservation periods to keep the molded surface as low as possible, because more than 40% of the stored DM in baled silage is within a space of 120 mm from the film cover, and the reduced total thickness of the combined layers of stretch-film on the bale side (from 80 µm for 4 layers to 120 µm for 6 layers) makes wrapped bales more susceptible to oxygen ingress than horizontal silos (Tabacco et al., 2013).

Furthermore, the stretch polyethylene wrapping system has shown some limits, with regards to sealing efficiency (Jacobsson et al., 2002), concerning the high permeability to oxygen of stretch films (Borreani and Tabacco, 2008; 2010) and the non-uniform distribution of plastic films between the ends and the curved surface of the bale (Borreani et al., 2007b). These problems lead to undesirable air exchanges over the conservation period, and it has been suggested that an increasing number of plastic film layers is required. A significant reduction in mold growth and an improvement in silage conservation quality are obtained when six or more layers of plastic film are applied instead of four, especially for high DM content baled forages (Keller et al., 1998; Borreani and Tabacco, 2008). Increasing the layers of plastic film contributes to increasing the hygienic quality of the overall silage, as the bale surface covered by mold is reduced, especially when the baled silage is conserved for long conservation periods (Figure 4). Several layers of stretch film ensure a better airtight cover, but also lead to prohibitive increases in costs, in plastic usage and in environmental concerns, due to the necessity of disposing of the additional plastic (Lingvall, 1995; Borreani and Tabacco, 2017).

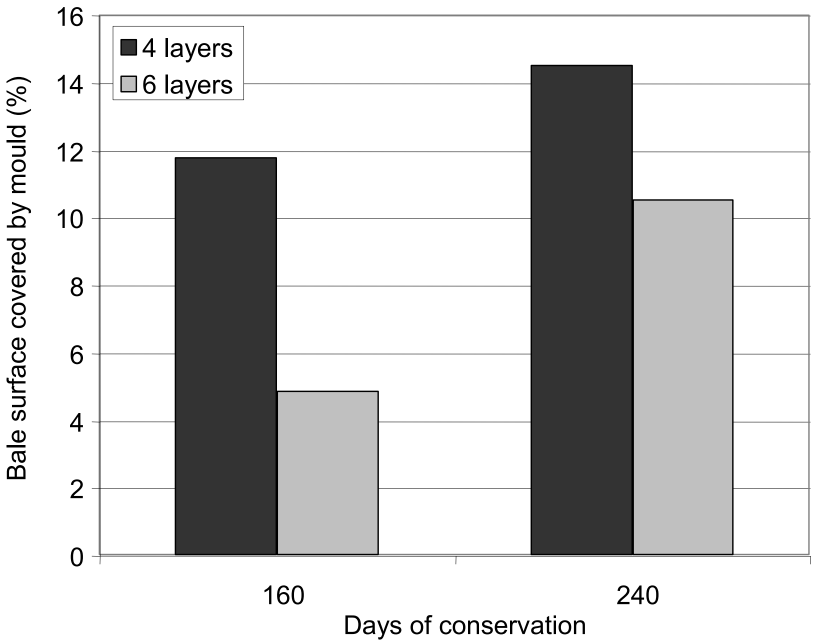


Figure 4. Bale surface covered by mold in relation to the days of conservation and number of layers of PE films for grass and legume silages from a farm survey in Northern Italy (G. Borreani and E. Tabacco, University of Turin, unpublished data).

The technical solutions that have been introduced on the market to improve bale silage quality in the last few decades have involved the following aspects: speeding up the wilting process to reduce the field period and mechanical losses during harvesting and to improve bale densities, especially for high DM content silages; increasing the uniformity of the plastic distribution over the bale surface; and reducing plastic permeability to oxygen (Borreani and Tabacco, 2018). The rapid development of the wrapping bale technology has led to a great improvement in the ensiling process, and this has been achieved by increasing bale densities using round balers equipped with chopping-devices (Tremblay at al., 1997; Borreani and Tabacco, 2006), reducing the working times, thanks to the use of combined baler-wrapper machines (Münster, 2001), improving the uniformity of the plastic distribution on the bale surface using a new-concept 3D wrapping system (Borreani et al., 2007b) or round balers equipped with film-tying attachments to replace the standard net-tying system with a film tying system, in order to improve the airtightness of the coverage on the curved bale surfaces (Bisaglia et al., 2007), and the use of oxygen barrier films (Borreani and Tabacco, 2009).

2.1. Bale density

Improving the bale density, in order to reduce forage porosity and plastic use, has been one of the main goals of baled silages since the '90s (Shinners, 2003). Herbage is rolled during baling, but this does not give the bale a high density and it makes oxygen exclusion more difficult. Silage compaction has been improved as a result of the introduction of variable chamber balers and the addition of chopping devices to balers (Tremblay et al., 1997). Round balers with a cutting system behind the pickup are available on the market and could provide the following advantages: density increases of up to 15% (Figure 5), with subsequent improvements in baler productivity and silage quality (Borreani and Tabacco, 2006), and bales that are more readily processed by TMR mixer-feeders (Shinners, 2003). The technique of cutting herbage into shorter lengths on entry to the bale chamber could facilitate the release of plant sugars and provide an aid to obtaining a better bale density (Shinners, 2003). It has been found, from a literature review covering research works from 1984 to 2019, that the bale DM density is related to the moisture content of the forage at baling, with densities increasing as the moisture content decreases till 50% (silage), plateauing for moisture contents ranging between 50% and 20% (haylage) and then decreasing again for a moisture content lower than 20% (hays) (Figure 6). Within each moisture range, the use of variable chamber balers and of a cutting system before the baler chamber could increase the DM density of the bales.

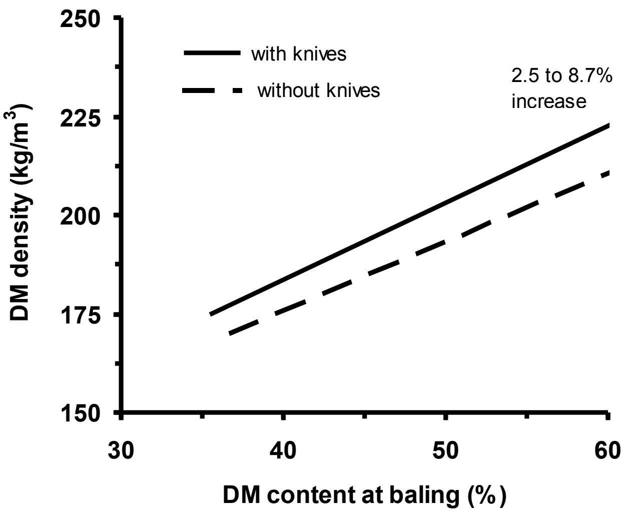


Figure 5. Bale DM density in relation to the DM content at baling of alfalfa and Italian ryegrass with and without a baler cutting device (adapted from Borreani and Tabacco, 2006).

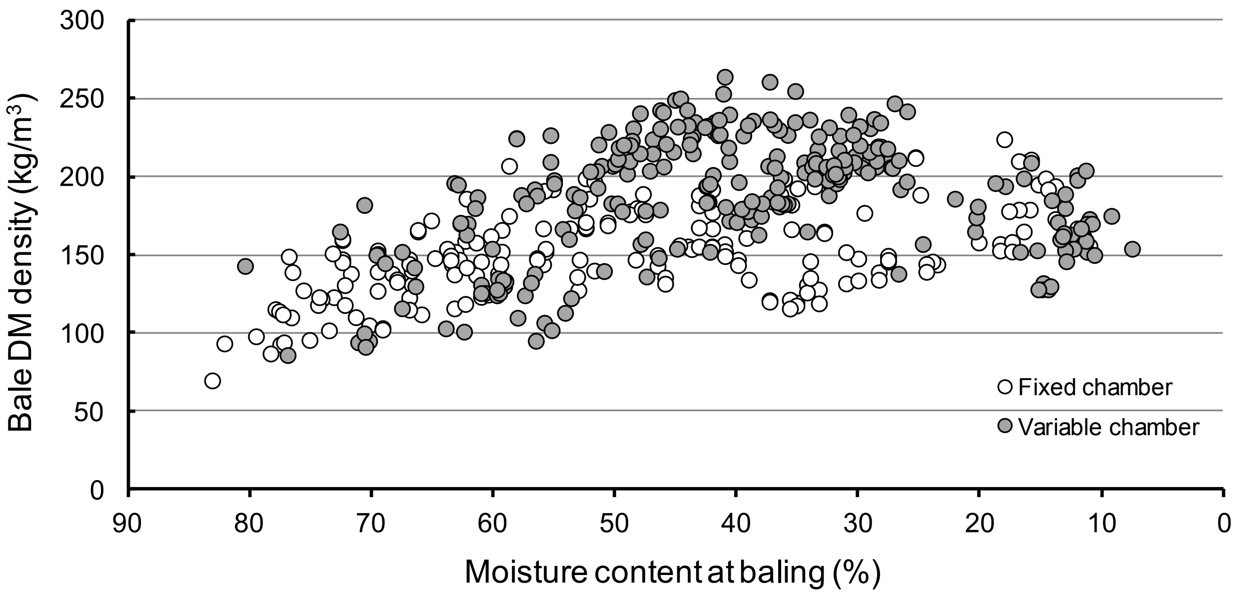


Figure 6. Scatter plot of the moisture at baling and bale DM density with variable and fixed chamber balers. The data were obtained from a review of the literature on bale silage, haylage and hay from 1984 to 2019.

2.2. Improving the uniformity of the plastic distribution

Traditionally, four layers of polythene are applied in two subsequent and complete rotations of a bale, with an overlap of 50% between layers. A significant reduction in mold growth and an improvement in silage conservation quality is obtained by increasing the number of layers, but this causes a waste of plastic film in conventional wrapping systems, due to the higher proportion of plastic distributed on the flat ends (Figure 7 - Conventional wrapper).

In order to increase the uniformity of the plastic distribution, two different solutions have recently appeared on the market: a selective 3D wrapper and round-balers equipped with a tying system to secure large round bales with polyethylene tying-film in the baler chamber. The improvement in efficiency that may be obtained with the new selective wrapper concept (3D), based on a biaxial rotation of film applicators, is reported in Figure 6. This concept is of great interest because it reduces the amount of plastic used per bale, while improving the uniformity of the plastic distribution on the surface and increasing the number of layers in the areas that are most at risk to damage (Borreani et al., 2007b). In a conventional wrapper bale, which is nominally wrapped with four layers of plastic film, the flat ends have as many as 16-20 layers in the center, a number which gradually decreases to four layers at the outer edge and on the curved surface.

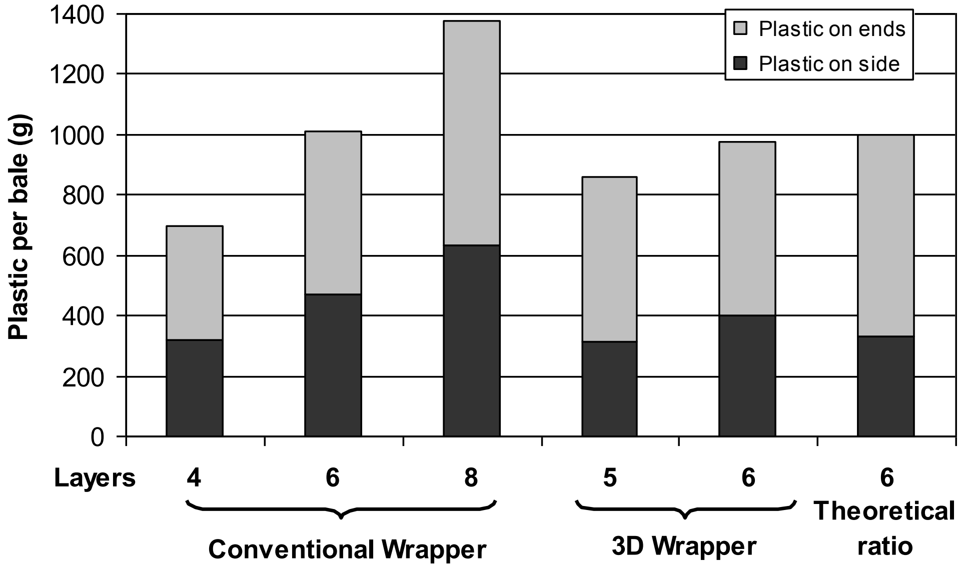


Figure 7. Plastic distribution on the bale surface (bale diameter 1.2 m). Theoretical ratio means the uniform distribution of 120 m of plastic film (6 layers) over the whole bale surface (adapted from Borreani et al., 2007b).

Some new-generation balers have recently been equipped with tying systems that allow a bale to be secured in the press chamber using twine, net or polyethylene film. Replacing the standard net used to secure bales with a polyethylene film represents an innovative alternative to net-tying when preparing round bales for silage, and it has been shown to improve the airtightness of the coverage on the curved surface of the bale and to reduce the bale surface covered by mold (Bisaglia et al., 2011). Tabacco et al. (2013) studied the possibility of reducing mold growth on the surface of low-moisture baled silage of grass-legume mixtures for a long conservation period (8 months), without increasing plastic costs, by replacing polyethylene net with polyethylene tying-film to secure large round bales in the baler chamber. The high DM content of the silages restricted fermentation and resulted in low concentrations of acids, with pH values in the inner part of the bale ranging from 5.41 to 5.70. The use of tying film, compared to net, led to a reduction in the number of holes and an improvement in the anaerobic status of the baled silage, even with just four layers of stretch-film, and resulted in a decrease in mold counts and visible mold growth over the bale surface (Table 2). The Authors of this study concluded that, with similar costs for plastic and the same amount of plastic used to secure the bale with net and wrapping it in four layers of stretch-film, it is possible, using a tying film of 16 μm in the baler chamber, to obtain more than six effective layers of plastic on the curved side and on the edges of the bale, and therefore to reduce the risk of cover puncturing and the incidence of mold growth over the bale surface to a similar level to that of baled silage wrapped in six layers of polyethylene and secured with net.

Table 2. Bale weight, bale density, plastic consumption, plastic thickness on the curved side of the bale, plastic damage, surface covered by mold, DM losses, and costs of plastic in relation to the tying method and the number of plastic layers applied (from Tabacco et al., 2013).

Items	Tying Method			
	Net-tying		Film-tying	
	4 Layers	6 Layers	4 Layers	6 Layers
Surface covered by mold (%)	25.3	2.6	3.3	0.8
DM losses (g/kg DM)	56	30	29	28
Net/film per bale for tying (g)	216	209	260	271
Stretch-film wrap per bale (g)	901	1275	901	1256
Total plastic per bale (g)	1117	1484	1161	1527
Thickness of stretch-film wrap (µm)	79	121	81	119
Thickness of tying film (µm)	-	-	43	46
Micro-holes in the plastic cover (n)	14	5	7	3
Cost of the tying film/net (€/bale)	0.81	0.78	0.71	0.75
Cost of the stretch-film wrap (€/bale)	2.92	4.12	2.91	4.06
Plastic cost per bale (€)	3.72	4.91	3.63	4.81
Plastic cost per tonne of harvested DM (€)	10.97	14.00	9.58	13.30

2.3. Oxygen barrier films to wrap bale silages

Improving the oxygen impermeability of stretch film has been identified as one of the most effective ways of obtaining significant improvements in the conservation quality of baled silage (Borreani and Tabacco, 2008; 2017). New plastic manufacturing technologies, coupled with new low oxygen permeability polymers that can be coextruded with PE, offer the possibility of producing multilayer stretch films for the wrapping of bale silages at costs that are competitive with those of the conventionally used PE on farms (Borreani and Tabacco, 2017). Most plastic films for stretch-wrap silage production are made of coextruded, linear, low-density polyethylene, and are 25 µm thick before being stretched 50% or more during application. The high O_2 permeability of PE films seems to be one of the main drawbacks of wrapped silage, especially for long conservation periods (Borreani and Tabacco, 2008; 2017). The new generation of high oxygen barrier (HOB) films improve oxygen impermeability 374-fold compared to standard PE films, and maintain similar mechanical properties to those of the best performing PE stretch films (Borreani and Tabacco, 2017). When tested at a farm scale, the HOB stretch films were effective in reducing the DM losses during conservation to values of around 2% for alfalfa baled silage with a DM content ranging from 55 to 65% (Figure 8). Other authors have reported DM losses of 6% (Hancock and Collins, 2006), or of 7% of the total harvested DM (Shinners et al., 2009b; Borreani and Tabacco, 2008) for alfalfa silage baled at similar DM contents and wrapped with standard PE stretch films.

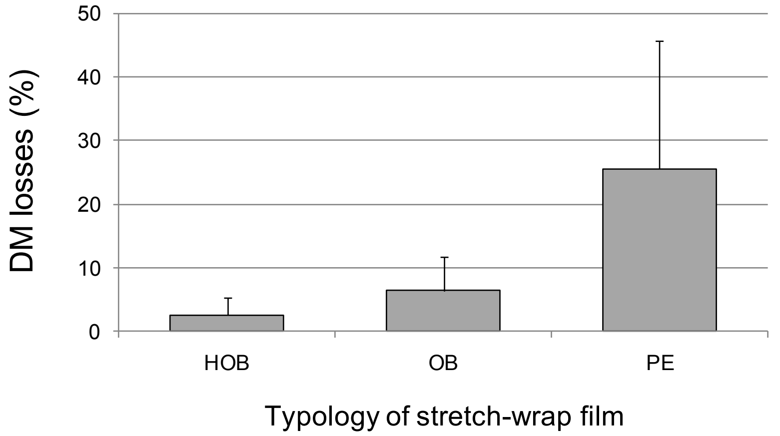


Figure 8. DM losses in relation to the oxygen impermeability of stretch films on alfalfa baled silages after 420 d of conservation (average of three trials in Northern Italy). HOB, high barrier film (4 layers); OB, medium barrier film (4 layers); PE, standard polyethylene film (6 layers) (adapted from Borreani and Tabacco, 2010).

Oxygen barrier films also have a remarkable influence on the evolution of the surface covered by mold: the higher the barrier properties of the plastic film utilized to wrap the bales are, the greater the reduction in mold growth on the bale surface over the conservation period (Figure 9).

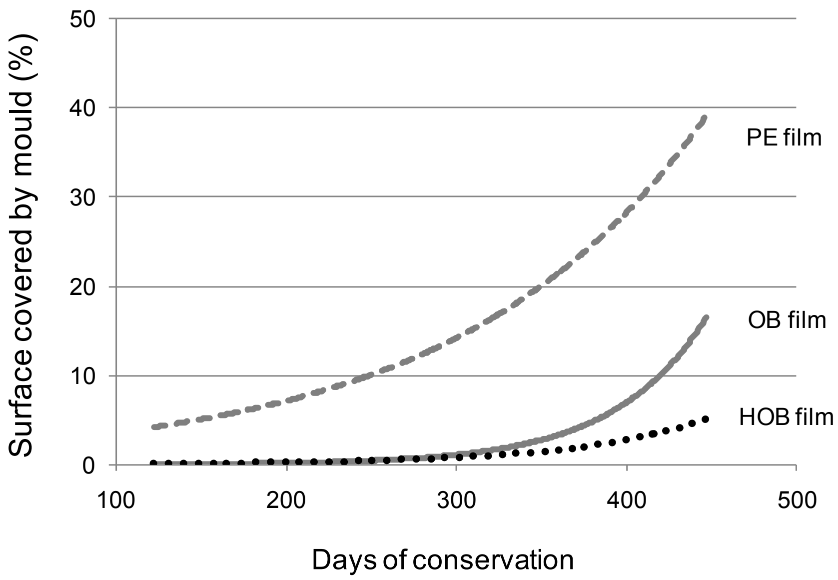


Figure 9. Surface covered by mold in relation to the days of conservation in baled alfalfa silage wrapped with stretch film with different oxygen impermeability. HOB, high barrier film; OB, medium barrier film; PE, standard polyethylene film (adapted from Borreani and Tabacco, 2010).

2.4. Storage management and plastic bale damage

Bales are usually wrapped in the field immediately after baling and before being transported to the storage site and are invariably stored outdoors (McNamara et al., 2001). If the integrity of the stretch film is damaged during storage, the subsequent ingress of oxygen will permit the growth of filamentous fungi and other microorganisms, thus resulting in extensive quantitative and qualitative losses (McNamara et al., 2001; Kawamoto et al., 2012). The plastic stretch-film surrounding baled silage is prone to damage during storage, prior to being fed to livestock, by many vertebrates. Damage by birds (McNamara et al., 2002) and by rats (Kawamoto et al., 2012) has been reported to be the most frequent on farms, while that caused by cats, dogs and other farm livestock is comparatively limited (McNamara et al., 2002). Direct physical barriers to bird access, as opposed to scaring devices, such as the use of nets securely positioned 1 m above and beside the bales, appear to be the most reliable way of preventing damage (McNamara et al., 2002). Whole cereal baled silages result to be particularly attractive to rats, which could easily damage bales stored under a masking situation (Kawamoto et al., 2012). It has been suggested that creating open spaces between the bales and not covering bales with plastic sheets reduce the number of hiding places that are available for rats, thereby decreasing their potential damage.

The storing position of in-line bales on the ground plays an important role in preventing mold development on the bale surface (Figure 10). The storing position has been shown to influence the amount of surface covered by mold to a great extent, for both Italian ryegrass and alfalfa forages, by reducing the area of visible mold on the curved surface of bales that were stored on their flat ends (Table 3) (Bisaglia et al., 2011). These data are in agreement with McCormick et al. (2002) who reported that the appearance of mold was virtually absent on end-stored bales, whereas mold damage was more prevalent on bales stored on their curved surface.

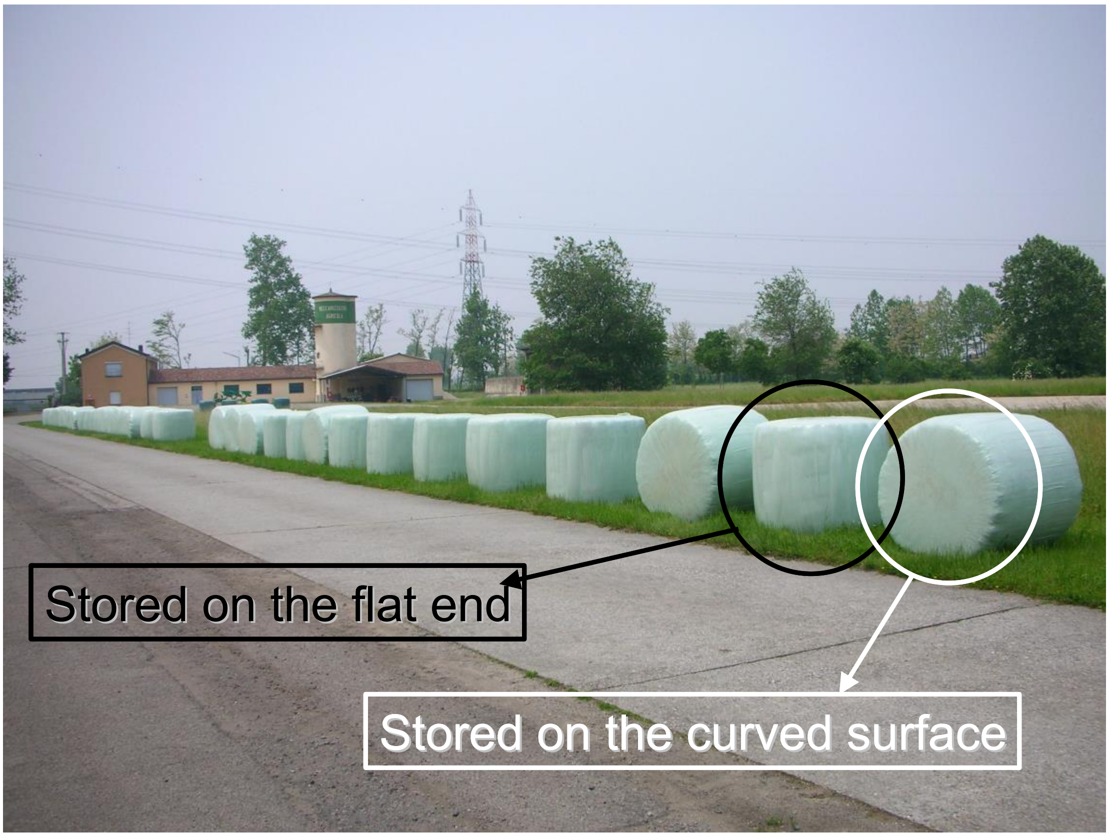


Figure 10. Bale storing position.

Table 3. The storing position and of number of layers were found to affect the bale surface covered by mold in alfalfa and Italian ryegrass baled silages after 180 d of conservation outdoors (from net-tying treatment, Bisaglia et al., 2011). END = stored on the end; SITE = stored on the curved surface.

Crop		Bale surface covered by mold (%)		DM losses (%)	
	PE film layers	END	SITE	END	SITE
Italian ryegrass (45% DM content)	4	11.1	23.1	6.5	5.8
	6	5.8	11.8	5.8	6.4
Alfalfa (56% DM content)	4	22.3	24.5	2.6	2.8
	6	9.4	13.7	2.8	2.7

3. Ensiling fine chopped material in wrapped bales

The need to ensile fine chopped forages or milled grains has become important to reduce the production costs of milk and meat, even for small to medium farms. The agricultural compactors that have recently appeared on the market are able to transform bulk material, such as biomass and fine particle materials, into easy-to-handle, high-density round bales. These baler-wrapper combined machines are able to bale more than 30 different materials, such as corn silage, high moisture grain silage, grass and legume chopped forages, sugar pulp, total mixed rations (TMR), cotton, grape marc, etc, by tying the bale with plastic film and then wrapping the bale with stretch plastic film. To the best of the authors' knowledge, the compactors available on the market for fine-chopped material are made by Orkel, Goweil and Hisarlar. Many of these new machines have adopted some or all of the technical solutions described above, such as film tying in the compression chamber and two film dispensers to speed up the wrapping operation. The first machine that was able to bale fine-chopped material was developed in Norway (Anonymous, 1990), and it was designed to be top-filled by a forage chopper.

Weinberg et al. (2011) showed the possibility of ensiling TMR in square bales and presented the results of an established commercial process that is based on the production of dense bales of silage under high pressure, followed by packing and wrapping with 8 to 9 layers of polyethylene stretch film. Weinberg et al. (2011), Miron et al. (2012) and Shaani et al. (2015), utilizing the same machine, indicated that the DM density of a bale was above 400 kg/m^3, which is more than twice the average DM density of silage in a bunker silo (Savoie and Jofriet, 2003), that the fermentation process takes place during storage even for already ensiled material, and that the forage quality can be maintained outdoors for a long period of time, even under hot summer conditions. Furthermore, the preserved TMR showed an increase in aerobic stability, compared to that of the fresh TMR.

This technology has been successfully used for the preservation of high-moisture by-products stored with dry feeds (Miron et al., 2012; Shaani et al., 2015), or as completely finished TMR for lactating dairy cows (Wang et al., 2010; Weinberg et al., 2011). Ensiling TMR is becoming a wide-spread practice, and the advantages attributed to it include: the supply of homogeneous feed over time to the animals, labor savings during preparation and the opportunity of including otherwise perishable moist by-products (Weinberg et al., 2011; Shaani et al., 2015). Forage crops conserved as silage in round bales undergo a slight reduction in particle size during harvest (Muck, 2006), are baled at a higher DM concentration, are stored at a lower bulk density, and are less fermented than silages stored in bunker silos (Weinberg et al., 2011). In the last few years, stationary compactor machines have been developed to suitably conserve, apart from finished TMR, fine chopped forage or ground grain that were previously only conserved in stack silos, thus allowing them to be stored until needed and to be transported like any other commodity. Many chopped forages, such as whole corn silage, whole ear corn silage and whole crop soybean silage, could be profitably preserved in wrapped bales as feeds for lactating cows on small-medium sized farms, as well fine chopped corn stover, rice straw and other lignocellulosic wastes, as ensiled biomass that could be used to produce bioenergy and biofuels (Borreani G. and Tabacco E., University of Turin, pers. com., 2017; Anonymous, 2017).

Our group (Forage Team, University of Turin, Italy) carried out a trial on a farm in Northern Italy in 2018 to compare bunker silage and a bale compactor on the first cut of Italian ryegrass. The forage was wilted for 2 days till a DM content of around 45% was reached, and it was harvested and chopped using a conventional forage harvester to a 30-mm theoretical length of cut and then ensiled in both a bunker silo and with an agricultural compactor (Dens-X, Orkel, Fannrem, Norvay). The silages were opened after two conservation periods (64 and 142 d) and the fermentative and microbial parameters were analyzed (Table 4). The fermentative silage quality was comparable for the two ensiling methods, with the bales having a lower pH and higher lactic acid content than the bunker silages. Moreover, the microbial reduction of yeast and the mold count were very similar for both conservation methods and after both conservation times. An agricultural compactor that produces wrapped bales could hence be an alternative solution to ensiling fine-chopped forages or other fine particle materials mixed together, such as TMR, thus overcoming the problem of the lower DM densities and lower level of fermentation that characterize conventional baled silages. These machines are, at the moment, managed by contractors and are able to produce from 40 to 60 bales per hour at a cost per bale of around €18-20 (Italian contractor costs for baling, wrapping, hauling and storing in 2019) for a 900 to 1200 kg 120 mm diameter bale.

Table 4. Chopped Italian ryegrass silage ensiled in both a bunker silo and in bales produced by a compactor (Orkel, Norvay) opened after 64 and 142 days of conservation (Tabacco et al., unpublished data).

Items [1]	Conservation period							
	64 d				142 d			
	Bunker	Compactor bale	SE	*P*-value	Bunker	Compactor bale	SE	*P*-value
DM content (%)	48.0	49.1	0.91	NS	42.8	44.7	0.67	*
pH	4.41	4.27	0.031	***	4.40	4.33	0.021	**
Lactic acid (g/kg DM)	45.9	54.5	2.14	*	66.6	71.4	1.45	*
Acetic acid (g/kg DM)	16.7	16.9	0.37	NS	23.1	25.8	0.81	NS
1,2 propanediol (g/kg DM)	3.05	4.14	0.49	NS	5.17	6.86	0.52	NS
Ethanol (g/kg DM)	2.79	3.69	0.25	NS	7.89	13.24	1.60	*
Butyric acid (g/kg DM)	<0.01	<0.01	-	-	<0.01	<0.01	-	-
Yeasts (log cfu/g/ silage)	<1.00	0.93	-	-	<1.00	1.67	-	-
Mold (log cfu/g/ silage)	1.68	1.58	0.15	NS	0.98	0.90	0.26	NS
LAB (log cfu/g/ silage)	8.57	7.17	0.41	**	3.00	5.84	1.42	***

[1] cfu = colony forming units; LAB = Lactic acid bacteria.

Over 2019, the Forage Team (University of Turin, Italy) have conducted several extension trials on farms with agricultural compactors that produced bale silages of whole crop cereals (corn, sorghum, winter cereals), wilted chopped forages (alfalfa, Italian ryegrass, and grass-legume mixtures), high moisture ear corn and TMR. Each forage was sampled during ensiling, the bales were weighed immediately after baling, the bale dimensions were measured, and the FM (fresh matter) and DM density were calculated. The relationship between the DM density of the bales obtained using the compactors and those reported in Figure 5 from conventional balers is reported in Figure 11. It can be observed that, for any moisture content, the bales made with the compactor were denser than those obtained with conventional balers, with higher values than 450 kg DM/m^3 for high moisture ear corn (highest value 591 kg DM/m^3) and ranging from 324 to 499 kg DM/m^3 for TMR. These DM densities are comparable with the highest values obtained in bunker silos (Savoie and Jofriet, 2003; Borreani et al., 2018). However, further research is needed to evaluate the fermentative profiles, aerobic stabilities, DM recoveries, nutritional qualities and economic feasibility that may be obtained from ensiling with compactors, compared to conventional balers.

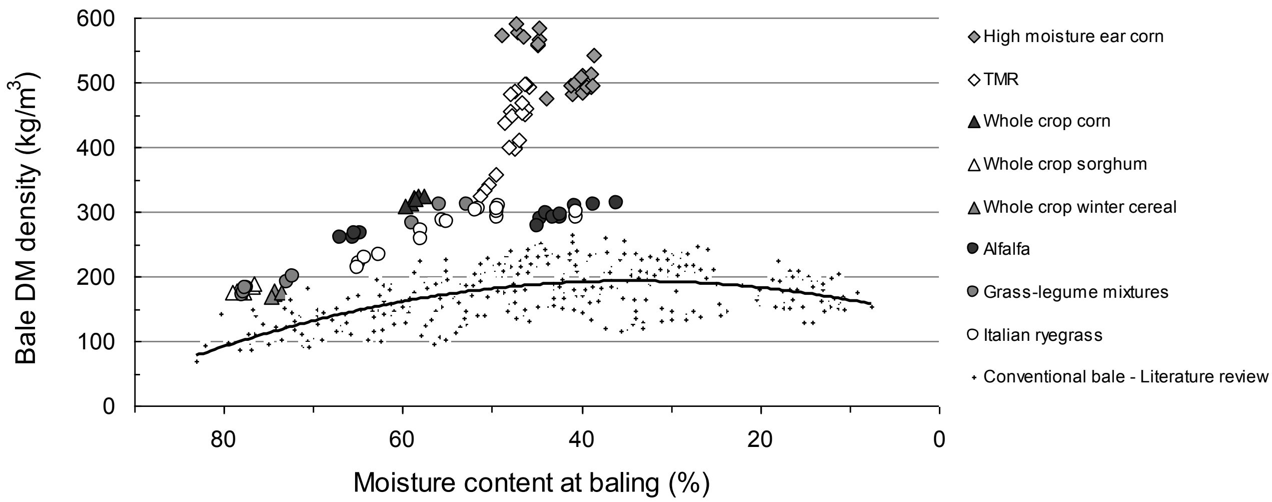


Figure 11. Bale densities of baled silages produced on commercial farms in Northern Italy with bale compactors plotted against the moisture content at ensiling and compared with the DM density of conventional round bales obtained from the literature review (black line regression equation - reported in Figure 5).

4. Conclusions

The technical and research innovations that have been developed over the last few decades in the field of wrapped bales provide an opportunity to successfully plan farm silage making, while maximizing silage quality and minimizing losses. The reported new technical solutions will improve the feasibility of producing high DM content baleage and of maintaining the nutritional and microbial quality of the forage, while reducing the cost per tonne of stored DM. The improvement in the uniformity of baled silage, in terms of nutritional and hygienic quality, is a priority to make this technique successful in terms of the economic sustainability of dairy production systems.

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