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Review of the nutritional quality of wild sunflower and cassava bran for silage production in dairy cattle

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Abstract

Wild sunflower (*Tithonia diversifolia* (Hemsl.) A. Gray) is a promising forage for dairy cattle because of its relatively high content of protein and non-fibrous carbohydrates. Furthermore, it has secondary metabolites that can modulate rumen fermentation toward more efficient metabolic pathways for the animal and are less harmful to the environment. Also, due to its phonological state nutritional value, it helps establish management strategies that benefit animal performance without affecting forage. On the other hand, cassava bran is a by-product of the extraction of cassava starch (*Manihot esculenta* Crantz) which can be used to feed dairy cattle because of its high starch concentration. The ensiling process favors the use of wild sunflower because it enables its harvest according to its phenological age, maintains stable forage supply, and reduces production costs. Using additives such as sugar, molasses, and fermented juice from epiphytic flora can contribute to the lactic acid fermentation process and reduce nutrient loss during silage production. Using cassava bran when making wild sunflower silage contributes to the conservation of forage because it reduces humidity and provides easily fermentable carbohydrates. Wild sunflower mixed silage and cassava bran with its starch contribution benefit the feeding of dairy cattle because of the protein and secondary metabolites content of wild sunflower., However this hypothesis must be challenged experimentally.

Keywords: Alternative animal feeding; Forage quality; Forage conservation; Tropical forages; Secondary metabolites; Agroindustrial by-products; *Tithonia diversifolia* (Hemls.) A. Gray.

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Study contribution

The use of balanced feed affects production costs in dairy cattle, which is why it is important to find to low-cost feeding alternatives. *Tithonia diversifolia* (Hemls.) A. Gray and *Manihot esculenta* Crantz are resources that can be used to reduce the use of balanced feed. The ensiling process favors the use of tropical forages, but their characteristics limit fermentation during this process. This review presents the nutritional characteristics of wild sunflower and cassava bran which suggest that mixed silage would supply protein and starch at a lower cost, besides the potential beneficial effects of the secondary metabolites of the wild sunflower on milk yield, milk quality, and the environment. It also describes the broad benefit of mixing these resources to improve the fermentation quality of the silage process and the use of additives.

Introduction

Feeding costs represent the main part of production costs referred to dairy cattle.(1) Balanced feed improves milk yield,(2) but it affects the profitability of the system because it represents 30–51(3) or 54 %(4) of production costs in intensive dairies in Antioquia, Colombia. Conventional ingredients used to produce balanced animal feeds are expensive(5) their availability is variable because they are imported resources(6) and prices are unstable because of the U.S. dollar exchange rate. The use of concentrated feeds competes with human nutrition because it involves the use of cereals(7) as a source of starch(8) and soy as a protein source.(9)

On the other hand, the high inclusion of balanced feed increases the risks of ruminal acidosis, decreases milk fat,(1) and may affect feed intake.(10) The aforementioned scenario requires the search for lower cost alternatives easy to produce and to get, which do not compete with human nutrition, support yield, maintain animal health, and are environmentally friendly.(11) For such alternatives it must be taken into account the ability of cattle to produce milk from forage(7) or agro-industrial by-products.(12)

Wild sunflower (*Tithonia diversifolia* (Hemls.) A. Gray) is a promising forage for dairy cattle, especially because of its nutrient content(13) and secondary metabolites.(14, 15) This forage has been evaluated in silvopastoral systems(13, 16) and as silage for dairy cows.(17) The silage process enhances the use of wild sunflower, since it allows its harvest according to the phenological age without depending on the amount of forage consumed by the animals, and makes it easier to keep the forage supply stable and reduce production costs. Cassava bran is a by-product of the starch extraction of cassava (*Manihot esculenta* Crantz) with a high content of non-structural carbohydrates (NSC).(18)It is obtained from the grinding and sieving stage during cassava post-harvest,(19) and contains 60–70 % of starch on a dry basis.(20)

Making mixed silage of wild sunflower and cassava bran to feed dairy cattle and using it as a partial substitute for balanced feed would supply protein and starch at a lower cost, in addition to the beneficial effect of the secondary metabolites of the wild sunflower on milk yield, milk quality, and the environment. Therefore, this review analyzes the nutritional quality of wild sunflower and cassava bran for the production of silage in dairy cattle.

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Wild sunflower

Generalities

(Tithonia diversifolia (Hemls.) A. Gray), commonly called wild sunflower, gold button, wonder tree, false sunflower, bitter quill, mexican litmus, mexican sunflower, margaritona, earth arnica, japanese sunflower or Nitobe chrysanthemum, it is a native to Mexico and Central America.(21) It is important due to its nutritional value, rusticity and high biomass yield.(13) The use of this forage is a promising strategy in cattle because it is a source of protein and secondary metabolites.(14) Wild sunflower is of interest in animal feed due to its high protein content (121.6–245.2 g(kg)$^{-1}$ DM),(22) compared to tropical forages commonly used for grazing.(23) The secondary metabolites of this plant add beneficial properties(24) to the ruminant diet.(25) Furthermore, it has a low fiber concentration, high energy content and high dry matter (DM) degradability.(26)

Wild sunflower was introduced as an ornamental species in many countries, but it has become a rapidly proliferating invasive plant(23) and has extensive adaptation to edaphoclimatic conditions.(25) In Colombia, it grows from sea level (30 °C) up to 2 500 (10 °C)(27) or 2 905 masl,(28) with a rainfall of 800–5 000 mm per year.(27) This species is used for grazing, cutting, and carrying systems or as meal.(29) It also serve as a live fence,(13) to restore soils, as green manure, and in beekeeping.(30) Traditional medicine also administers it for its analgesic, anti-inflammatory,(31) antimalarial, and repellent properties.(32)

Nutritional value

Wild sunflower has been evaluated in the diet of laying hens,(21) broilers,(33) sheep,(34) goats,(35) rabbits,(36) and guinea pigs.(37) However, its potential in high-producing dairy cows is evident.(38) This forage is used in animal feed because of its nutritional value,(13) which depends on the phenological state,(22) soil, forage origin, harvest time, processing method(5) and time of year.(39)

Wild sunflower is very important for its protein(40) and NSC contents; furthermore, it has a low concentration of neutral detergent fiber (NDF) (Table 1). The mean concentration of crude protein (CP) of the wild sunflower reported in previous articles was 193.8 g(kg)$^{-1}$ DM (Table 1). This value is relatively high when compared with tropical grasses such as giant star grass (*Cynodon plectostachyus* (K Schum.) Pilg.; 83 g(kg)$^{-1}$ DM), guinea grass (*Megathyrsus maximus* (Jacq.) BK Simon & SWL Jacobs; 72 g(kg)$^{-1}$ DM), *Urochloa brizantha* (Hochst. ex A. Rich. RD Webster; 90 g(kg)$^{-1}$ DM), gamba grass (*Andropogon gayanus* Kunth; 91 g(kg)$^{-1}$ DM)(41) and elephant grass (*Cenchrus purpureus* (Schumach.) Morrone; 59 g(kg)$^{-1}$ DM).(18)

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Table 1. Chemical composition of wild sunflower (*Tithonia diversifolia*)

Source	DM	Feed fraction (g(kg)$^{-1}$ of DM)[1]						
		CP	NSC	EE	NDF	ADF	Lignin	Ash
Arias et al.(42)	150.0	215.0	221.0[5]	24.0	425.0	368.0	115.0	115.0
Cardona et al.(43)	--	172.0	295.0	11.0	390.0	272.0	--	125.0
Cardona et al.(16)	--	183.0	194.0	30.0	443.0	333.0	--	150.0
Castaño and Cardona(44)	218.1	307.0	161.9	35.9	327.8	235.0	90.9	167.4
Elizondo(45)	94.0	172.0	--	--	378.0	282.0	67.0	170.0
Gallego et al.(29)	--	116.6	360.7[5]	29.6	371.7	324.0	60.2	121.4
Gallego et al.(27) [4]	127.0	133.9	82.2	--	522.7	485.1	--	159.0
Guatusmal et al.(28) [4]	--	240.6	--	--	340.8	161.9	28.9	--
Huertas et al.(14) [2]	300.7	93.6	--	--	491.7	381.7	101.4	105.6
Londoño et al.(22) [3, 4]	181.2	184.7	--	--	519.2	375.0	154.3	143.2
Mahecha et al.(46)	--	223.2	258.2	22.6	358.8	180.8	36.2	137.2
Mahecha et al.(47)	188.1	167.3	--	--	375.7	--	--	--
Mejía et al.(13) [3]	223.0	241.3	140.3[4]	32.5	447.0	364.0	92.0	146.8
Montero et al.(37)	--	244.6	--	60.1	--	--	--	113.2
Navas and Montaña(48)	190.0	200.0	--	--	616.7	426.7	--	--
Roa et al.(33)	--	185.0	--	11.0	--	--	--	129.0
Ramos et al.(49)	170.3	214.4	231.8	29.1	326.9	215.0	--	197.8
Mean	**184.2**	**193.8**	**216.1**	**28.6**	**422.3**	**314.6**	**82.9**	**141.5**
Min	**94.0**	**93.6**	**82.2**	**11.0**	**326.9**	**161.9**	**28.9**	**105.6**
Max	**300.7**	**307.0**	**360.7**	**60.1**	**616.7**	**485.1**	**154.3**	**197.8**

[1]DM: dry matter; CP: crude protein; NSC: non- structural carbohydrates; EE: ether extract; NDF: neutral detergent fiber; ADF: acid detergent fiber.
[2]Wild sunflower silage.
[3]Reviews.
[4]When the authors reported large amounts of data, the mean of the reported data was used.
[5]Estimated according to values reported by the authors (NSC = 1000–CP–EE–NDF–Ash)(50)

Ruminant feed in the high tropics of Colombia (> 2 200 masl) is mainly based on kikuyu (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone).(51) The CP content of wild sunflower is higher than that of *C. clandestinus* reported by some authors (118 g(kg)$^{-1}$ DM)(52) or similar compared to others (239.1 g(kg)$^{-1}$ DM).(16) These differences in the variation of CP (in both species) can be explained by forage origin, soil fertility, time of year,(5) age,(5, 53) fertilization, and environmental conditions.(53)

There is an important variation in the CP of wild sunflower in the literature consulted (minimum concentration of 93.6 and maximum of 307.0 g(kg)$^{-1}$ DM; Table 1). Protein decreases with cutting age,(54) although some authors have observed the opposite behavior(55) such differences could be the result of diverse experimental conditions. Variation in protein concentration depending on the genotype of wild sunflower has been reported.(26) Protein concentration increases with the level of nitrogen fertilization(56, 57) and with the rainy season.(26) Concentrations as high as those reported by some authors (307.0(44) and 343(26) g(kg)$^{-1}$ DM) indicate that wild sunflower has great potential as a source of protein in animal feeding.

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According to the literature, the NDF concentration of corresponding wild sunflower is 422.3 g(kg)$^{-1}$ DM (Table 1), which is smaller than that of *C. clandestinus* (562.1 g(kg)$^{-1}$ DM),(53) *C. plectostachyus* (749 g(kg)$^{-1}$ DM), *M. maximus* (719 g(kg)$^{-1}$ DM), *U. brizantha* (653 g(kg)$^{-1}$ DM), *A. gayanus* (715 g(kg)$^{-1}$ DM) (41) and *C. purpureus* (727 g(kg)$^{-1}$ DM).(18)

Lower fiber content of the forage is associated with a higher DM intake, diet digestibility,(58) and NSC concentration.(50) The NSC concentration of wild sunflower is high,(22) with a mean of 216.1 g(kg)$^{-1}$ DM (Table 1). Tropical forages have a low NSC concentration, which has a negative impact on yield.(42) The major product from NSC fermentation is propionic acid,(59) which is converted into glucose in the liver and thus stimulates milk synthesis.(60) Therefore, the use of wild sunflower in the diet of dairy cows contributes to milk yield(17) because of its NSC content.

The NSC concentration in wild sunflower may contribute to rumen development. Calves experience morphological and metabolic adaptations that allow the transition from a liquid (milk) to a solid diet (forage and concentrate).(61) During the first days of life, the pre-gastric compartments of calves are not prepared for the digestion of a solid diet(62) later on, ruminal fermentation produces volatile fatty acids (VFA) that supply 80 % of the energy.(61) The main anatomical and physiological changes in the transition period (pre-ruminant to ruminant) are found in the pre-gastric compartments.(63) These changes are characterized by rapid growth in size, the establishment of a microbial population,(64) and the ability to absorb VFA.(65)

Ruminal papillae develop for the absorption of nutrients, especially VFA.(64) The chemical and structural composition of the diet influences the height, width, and density of the papillae.(66) Diets high in NSC stimulate rumen microbial proliferation and VFA production(63) such as butyric acid, which stimulates the development of the tissue responsible for absorbing VFA.(50)

Secondary metabolites

Plants produce secondary metabolites with antimicrobial activity that modulate ruminal fermentation and improve nutrient absorption.(67, 68) These natural substances do not cause microbial resistance and can positively affect the animal and the final product.(64) Secondary metabolites are organic compounds that are not directly involved in the regulation of primary growth and developmental events of the plant. Under inadequate environmental conditions, changes occur at cellular level that lead to the accumulation of secondary metabolites that protect the plant. These metabolites are classified as terpenes, phenols, and nitrogen-containing compounds.(69)

Wild sunflower has an antimicrobial effect:(70) antibacterial and antifungal(71) due to the content of alkaloids, flavonoids, tannins, saponins, and steroids(15) if added in the diet of cattle, it reduces methane emissions.(72)

The production of methane deprives the ruminant of carbon sources and represents a loss of energy, by maximizing the flow of hydrogen towards VFA production and not towards methane, it increases yield efficiency and decreases the impact on the environment.(64)

The effect of wild sunflower on methane production is contradictory; some authors found a reduction in cow methane emission,(72) but others did not.(73) There are even those who report a decrease in methane from *in vitro* studies,(14) while

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others report an increase.(74) Such differences can be explained because of the different experimental conditions. Furthermore, secondary wild sunflower metabolite composition depends on the environment, the geographical distribution,(75) phenological state, and genetics.(76)

Terpenes

Wild sunflower contains triterpenes, saponins, and steroids.(24) Saponins have an amphipathic structure consisting of high molecular weight glycosides linked to a steroid or a triterpene.(77) These compounds protect plants from bacteria and fungi,(64) and they are of potential interest in ruminant diet because they reduce rumen protozoa.(78) Saponins affect the integrity of the protozoa membrane(79) because of their surfactant properties;(77) this antiprotozoal effect is associated with the interaction of the sterol in the protozoa membrane with saponin.(64)

A reduction in rumen protozoa decreases methane production,(80) which is important for the energetic efficiency of the cow and for the environment.(78) Defaunation decreases methanogenesis because protozoa supply large amounts of H_2 to methanogenic archaea;(79) approximately 25 % of ruminal methanogens live in association with protozoa.(78) Saponins cause an increase in the ruminal production of propionate in the rumen and decrease that of acetate or butyrate; these changes in VFA are associated with a lower methane emission.(79)

Saponins modify VFA production(79) and decrease the acetate:propionate ratio;(78) an increase in ruminal propionate production is related to greater milk yield.(60) These substances can affect diet digestibility (78) and reduce ammonium production.(80) Protozoa depend mainly on preformed amino acids from bacteria and to a lesser extent on degradable protein in the rumen. Defaunation is associated with a decrease in ruminal ammonium due to decreased proteolysis and deamination.(81) The lethal effect of saponins on protozoa decreases protein degradation and increases the flow of amino acids to the small intestine.(64) The effect of saponins may vary(78) depending on the type of saponin,(77) and *in vitro* assays are not always consistent with *in vivo* results.(78)

Phenolic compounds

Wild sunflower has tannins (free and condensed), phenols, flavonoids, and lignin.(24) The flavonoids in this plant have antibacterial and antioxidant effects.(82) Although tannins are considered antinutritional factors, when used in small concentrations in the diet, they are efficient bactericides, fungicides, antioxidants, mineral chelates, and astringents.(83) Tannins can modify the rumen microbiome, reduce protein degradation, decrease methanogenesis, and inhibit fatty acid biohydrogenation.(64)

Tannins are polyphenols found in plants, and are classified as hydrolysable or condensed.(68) The hydrolysable are polyphenols esterified to a carbohydrate nucleus, while the condensates (proanthocyanins) are covalently linked flavonoid polymers.(84) Tannins bind protein forming a tannin-protein complex,(68) due to the multiple phenolic hydroxyl groups that form hydrogen bonds with the protein.(84) Tannin-protein complex formation affects feed intake,(68) protein degradation(35) and microbial activity.(84) Tannins reduce DM intake(68) because they form com-

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plexes with saliva proteins[85] conferring astringency; however, this effect depends on its concentration in the diet.[68]

Tannins reduce protein degradation in the rumen.[35] Tannin–protein complex is stable at rumen pH (5–7), but dissociate in the acidic environment of the abomasum.[84] When tannins are combined with high-quality protein, they increase the flow of amino acids to the small intestine, improve nitrogen efficiency, and increase milk yield.[68] Less protein degradation decreases nitrogen excretion into the environment.[84] A high tannin consumption may affect protein digestibility of other fractions.[68] They also inactivate extracellular enzymes and the activity of microorganisms These effects depend on the type of the tannin and the dose.[84]

Tannins reduce methane production[86] in two ways: hydrolysable tannins inhibit the growth or activity of methanogenic archaea and protozoa, whereas condensed tannins affect fiber digestion,[87] which limits the availability of H_2 for methane production.[64] The inhibition of microorganisms is possibly caused by the interaction between tannins and specific substrates of the microorganism.[64] Tannins reduce biohydrogenation in the rumen,[86] and increase milk concentration of polyunsaturated fatty acids $C18{:}1_{t\text{-}11}$ and $C18{:}2_{c\text{-}9,t\text{-}11}$[88] This change in lipid profile has a beneficial effect on human health.[89]

Nitrogen-containing metabolites

This group comprises alkaloids, cyanogenic carbohydrates, and glucosinates.[69] Alkaloids are cyclic compounds derived from amino acids and contain nitrogen in a negative oxidation state. They also include similar substances that are not derived from amino acids (pseudoalkaloids) and that do not contain nitrogen within any ring structure (alkaloid-like).[90] Alkaloids are attributed therapeutic effects as antioxidant, cancer prevention, antidiabetic, anti-inflammatory, and vasodilator; but it more research is needed to know how cattle could benefit from these.[90] Wild sunflower contains alkaloids[24] that could have a beneficial effect on the mucosa of the digestive tract.

Including alkaloids in ruminant diets reduces methane production and improves energy and protein utilization.[91] Alkaloids intercalate into the cell wall and DNA of microorganisms blocking calcium channels which favors the formation of propionic acid instead of acetic acid.[92] Alkaloids can be toxic if consumed in high quantities, causing damage to the central nervous system, liver damage, muscle cramps, and death; additionally, they reduce forage intake.[90]

Phenological development of *T. diversifolia* and Its relationship with nutritional value

Phenology studies yearly recurring patterns of growth and development of plants.[93] Production and nutritional quality of forages depend on the phenological state and morphology of the plant.[94] The nutritional value of forage based on its phenological state helps to establish management strategies to achieve higher animal performance without damage to vegetation;[95] particularly, it allows to choose the right time for grazing or harvesting.[96] Maturity index is the main factor that affects the nutritional value of perennial forages, which enables the prediction

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of their nutritive value.[97] As forage maturity increases, protein[97–99] digestibility[97, 99, 100] and energy decrease[95, 99] while there is an increase of fiber and DM production.[95, 98, 99] Forage lipid profile changes and fatty acids of the ω-3 and ω-6 series increase in accordance with forage age[101]

There are several reports on wild sunflower phenology. In one of them, phenological development without considering chemical composition is described[102–106] but others did it.[28, 98, 107] Height of the plant increases linearly with age,[103, 104] but this behavior changes depending on the time of the year[106] and the ecotype.[105] The weight of forages has a quadratic change consistent with age,[104] but it can be linear[103] or not vary,[106] depending on the time of the year. In addition, the growth of wild sunflower in an intensive silvopastoral system is linear.[46] The DM and fiber increase with the age of the forages, but CP and digestibility decrease.[28, 97, 107] Secondary metabolites vary according to phenological age; however, this variation depends on environmental factors[76, 107] and genetic.[76]

Cassava bran in ruminant feeding

About 23 % of the starch produced in the world comes from cassava.[108] Cassava is an important source of starch in tropical countries;[109] it is highly competitive because the root contains more starch (dry basis) than almost any other food crop, and the starch is easy to extract using simple technologies.[108] Cassava bran is the main by-product of cassava starch and is used in animal feed due to its high energy concentration.[110] For every ton of cassava processed, 231–234 of starch and 101–105 kg of cassava bran are produced (880 and 900 $g(kg)^{-1}$ MS, respectively).[19]

Cassava starch is obtained through wet extraction,[108] separating the starch from the crushed cassava by contact with water.[109] The process phases are as follows: washing–peeling, selection–trimming, grating, straining–sieving, sedimentation, fermentation, drying, and grinding.[19] In sum the peel is removed (washing-peeling), the ends are removed (selection-trimming), the starch is released by separating the granules from the fibers (grating) it is extracted with water (straining-sieved), then it is precipitated in channels (sedimentation), and dried to obtain the native starch. When precipitated starch is fermented before dehydrating, sour starch is produced.[111]

Water and fermentation remove endogenous compounds from cassava, and the content of cyanogen glycosides (linamarin and lotaustralin) is almost completely reduced after fermentation.[112] Cassava bran is a fibrous material with a high moisture content ($>$ 800 $g(kg)^{-1}$) resulting from straining and sieving. This by-product constitutes an environmental problem due to the high moisture content,[113] and requires dehydration before use;[19] it is naturally dried to be sold as animal feed.[113] The composition of cassava bran varies depending on the processing plant,[114] but its high NSC concentration and low protein content are consistent (Table 2). Cassava bran is similar to cassava flour, although bran has a slightly higher protein and fiber content.[20] The use of cassava bran in the diet of broilers,[5] quails,[115] ducks,[116], sheep[18, 110], and pigs[20, 117] has been evaluated. This bran is an alternative to corn and reduces production costs because of its high starch content (600–700[20] or 540–700[114] $g(kg)^{-1}$ DM).[117]

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Table 2. Chemical composition of cassava (*Manihot esculenta Crantz*) bran

Source	DM	Feed fraction (g(kg)$^{-1}$ of DM)[1]						
		CP	NSC	EE	NDF	ADF	Lignin	Ash
Carvalho et al.[18]	888.0	24.0	840.0	8.0	113.0	66.0	10.0	15.0
Romero et al.[20]	980.0	30.2	–	5.9	–	–	–	32.6
Diarra y Devi[114] [2]	–	16–20	54–70[3]	1.0	367.0	98.0	39.0	17–28
Abouelezz et al.[116]	893.6	23.7	–	4.5	236.0	–	–	59.4

[1] DM: dry matter; CP: crude protein; NSC: non-structural carbohydrates; EE: ether extract; NDF: neutral detergent fiber; ADF: acid detergent fiber.
[2] Review.
[3] Starch.

Potential use of mixed wild sunflower and cassava bran silage in dairy cattle

Forages represent the most abundant and economical source of nutrients for animals in the intertropical zone[118] and provide between 40 % and 90 % of the nutritional requirements of ruminants in most production systems.[119] climate variability in the intertropical zone prevent a constant forage production and generate the need to have forage reserves to use during drought seasons.[118] Forage conservation methods pretend to preserve digestible nutrients in the most efficient way. Hay making and ensiling are the only options available to farmers wanting to conserve forage on a large scale.[119] Hay making is based on sun-air drying[120] and silage on anaerobic fermentation.[40]

Silage offers advantages over haymaking: large quantities of forage can be conserved in a short time. Forage conservation is less weather dependent while silage is well suited to mechanization it;[119] it is easier to handle, and it reduces substantially rain damage and field losses.[118] The major disadvantage associated with silage making is the loss of forage nutritional value[119] when it is prepared or handled improperly. An insufficient decrease in pH or the presence of oxygen promotes the growth of undesirable microorganisms that are harmful to the nutritional quality of silage.[121]

Silage research up to present time has focused on closing the gap between the feeding value of the original crop and that of the resulting silage.[119] Lactic acid is a product of fermentation[122] that quickly decreases the pH of ensiled forages.[123] The art of silage promotes lactic acid fermentation at the expense of other more energetically expensive fermentations[120] because homolactic fermentation allows greater DM recovery.[123] Fermentation depends on forage composition, lactic acid production, oxigen availability, and adequate sugar supply to allow an acid fermentation sufficiently high to counteract the buffer capacity of the forage.[120] Lactic acid bacteria improve silage quality.[124] Good forage preservation depends on a high production of lactic acid and a pH below 4.2 after the fermentation; these criteria usually produce silages that are stable under anaerobic conditions.[125]

The use of ensiling techniques in tropical areas has been limited because tropical forages often produce acetic fermentation.[126] The limitations for ensiling tropical forages are a low lactic acid bacteria, water-soluble carbohydrates, and DM,[127] added to the morphology and their buffering capacity.[128] Most tropical forages do not produce good silages because they cannot be compressed well,[120] and they have low soluble carbohydrates content that lead to heterolactic fermentation,

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with the dominant metabolic pathway towards acetate production.(129) A pH value above 5.0 is representative of an unstable fermentation and characteristic of ensiled forages with high contents of structural carbohydrates and low water-soluble carbohydrates content; these conditions make it difficult for the establishment of lactic acid bacteria and allow proliferation and dominance of coliforms, yeasts, and molds.(118)

The pH of wild sunflower silage is greater than 4.2(130) and higher than 5, in accordance with its variation during the silage process. which shows the difficulty in ensiling this forage.(131) Moisture content directly affects fermentation, and tropical forages usually have a high moisture content (>80 %), which leads to butyric fermentation.(127) Therefore, it is evident that the low DM concentration (Table 1) of wild sunflower is a limitation for its conservation by ensiling. Although wilting is a feasible strategy to decrease moisture content in short- and thin-stemmed crops, several tropical species are tall, have thick stems, and are difficult to wilt.(132) Furthermore, this strategy becomes difficult due to the rainfall regime in countries such as Colombia.

The use of agro-industrial waste increases the DM content when the forages have a high humidity, and provide non-fibrous carbohydrates.(133) Ensiling forages in mixture with dry feedstuffs reduces leachate, increases intake potential, and improves DM digestibility.(132) Cassava bran has a high DM concentration (Table 2), and therefore, if it is mixed with wild sunflower, it increases the DM of silages. On the other hand, upon exposure to air, silage quality may be reduced because of the introduction of oxygen, which promotes the growth of yeasts, molds, and aerobic bacteria. During exposure to air, silage increases in temperature and pH, and may lose water-soluble carbohydrates, which reduce silage quality. The time during wich the temperature of the silage rises (aerobic stability) affects nutrient losses in the silo, the likelihood of toxic effects of fungal growth, and the management required to minimize exposure to air.(125)

Poor fermentation makes forages more susceptible to aerobic deterioration.(118) Poor aerobic silage stability may cause lower recovery of nutrients, and poor quality silage, which results in reduced DM intake and poor animal performance.(125) It has been reported that wild sunflower has a good aerobic stability.(131) The use of additives in silage production improves its fermentation quality and forage conservation.(134) Cassava bran is used to make silages and it improves the fermentation process.(18) Cane sugar,(135) cane molasses(134) and fermented juice of epiphytic lactic acid bacteria improve fermentation of forages with a low DM and sugar content.(136, 137) The use of additives to make silages of wild sunflower mixed with other scrubs have been evaluated,(138) but no reports were found related to the use of additives in mixed silage of wild sunflower and cassava bran.

Limited information is available on wild sunflower silage in dairy cattle.(40) The *in vitro* fermentation of wild sunflower silage mixed with sugar cane or rice bran,(34) as well as with *C. clandestinus* and polyunsaturated fatty acids has been evaluated.(43) No reports have been found of mixed silage of wild sunflower and cassava bran. The use of mixed silage of wild sunflower and cassava bran has great potential as a partial substitute for concentrate in dairy cattle. Using wild sunflower in the diet of dairy cows at levels of up to 15 % does not affect milk yield or DM intake in Holstein cows grazing on *C. clandestinus*;(29) besides, a level of 15.4 %

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increases the concentration of fatty acids C18:1$_{t\text{-}11}$ and C18:2$_{c\text{-}9,\ t\text{-}11}$[73] which are recognized for their nutraceutical effect.[89]

In lactating calves, feeding a mixture of calf starter and corn silage resulted in longer and wider rumen papillae and DM intake than that of calves fed only starter or corn silage.[139] Although the use of mixed silage of wild sunflower and cassava bran in calves diet was not found, this silage is promising due to the contribution of CP and NSC.

Harvesting machinery and associated labor are big contributors to forage production costs.[140] Mechanization also reduces costs associated with labor. There are some problems in the silage machinery market in mountainous areas, relative to the excessive use of machinery, poor adaptability, single function, and relatively fixed use places.[141] Due to the difficulty of using machinery in mountainous areas, the production and harvesting of wild sunflower silage is carried out manually, as well as transportation to the chopping and silage processing place.

Final considerations

Mixed wild sunflower and cassava bran maybe beneficial for dairy cattle because of its nutritional, economic, and environmental benefits. In addition, it can promote the yield of milk with compounds that have a favorable effect on human health and facilitate the sustainability of dairy production systems. However, this hypothesis must be challenged experimentally in animal models. The quality of the silage can be optimized by harvesting wild sunflower through phenological age, and by improving the ensiling process by combining wild sunflower with cassava bran, as well as using additives.

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Data availability

All relevant data are within the manuscript and its supporting information files.

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Conflicts of interest

This work is part of the doctoral thesis in "Animal Sciences" of the first author. The authors have no conflict of interest to declare in regard to this publication.

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