The Potential Use of Tree Leaf Silage For Livestock Nutrition, Including Willow, Drumstick, Mulberry, and Acadia Species

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THE POTENTIAL USE OF TREE LEAF SILAGE FOR LIVESTOCK NUTRITION, INCLUDING WILLOW, DRUMSTICK, MULBERRY, AND ACACIA SPECIES.

by

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Leaf silage has been historically used as ruminant feed, with multiple positive attributes such as being a secure, preserved feed source that is relatively accessible. However, the digestibility, nutritive value, and potential anti-nutritive factors are not well researched or known. The goal of this review is to examine recent literature on leaf silage and its potential advantages and practical limits of being utilized as livestock feed. The scope of this study was limited to willow (*Salix* spp.), acacia (*Acacia* spp.), mulberry (*Morus alba* and *Broussonetia papyrifera*), and drumstick leaf silage (*Moringa oleifera*), due to the relatively scarce amount of research available on the use of tree leaf silage in livestock. Each leaf species offers silage of different nutritive value, and the addition of inoculants can significantly change the quality of a leaf silage. More research is needed to fully understand the use of leaf silage in livestock nutrition, especially when comparing different leaf species and their value as silages.
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INTRODUCTION

Silage background and overview

Silage is a commonly used preserved feed made from fermented plant material, which provides livestock with additional nutrition, especially when access to other fresh pasture and forage is limited or not available. The ensiling process involves taking freshly harvested forages, most commonly grasses, cereals and corn, or grains, and fermenting them anaerobically (Jones et al., 2017). The fermentation process is controlled by fibrolytic microbes which can break down complex plant carbohydrates and results in an acidic, low pH environment with significant volatile fatty acids, such as acetate, propionate, butyrate, and others that provide ruminants with key nutrition that can improve livestock production (Jones et al., 2017). Importantly, lactic acid bacteria which anaerobically ferment the silage, convert water soluble carbohydrates in the silage to lactic acid (Jones et al., 2017, Oregon State University 2021). The strong activity and high level of lactic acid and lactic acid-producing bacteria are vital for the ensiling process; the acidity of the silage prevents further microbial activity and spoilage over time-- thus preserving it (Jones et al., 2017).

The characteristics of the forage that is being ensiled is hugely important, as well (Jones et al., 2017). Qualities such as sugar content and water-soluble carbohydrate content, high moisture, and the specific bacterial community present are all significant and influence the final silage product and the ensiling process. Prospective silage forages must have sufficient sugar/water-soluble carbohydrates, moisture, and protein. A dry matter content between 30-50%, with moisture content ideally around 65-70%, has been
cited as the desirable level for ensiling (Jones et al., 2017, Oregon State University 2021).

While tree leaves are not commonly used for silage, studies have been performed exploring the ensilability of such tree leaves and the effects tree leaf silage may have on livestock nutrition. Specifically, multiple studies have been done of the use of drumstick leaves, willow leaves, mulberry leaves, and acacia leaves in silage and livestock nutrition. Commonly, these trees are investigated due to their high levels of crude protein and their ability to grow in harsh or typically unsuitable conditions, making them more appealing when other forages and crops may be scarce. Additionally, these trees are cited for the use and function that the rest of the tree may have for farmers, such as providing wood and timber, live fencing, or preventing soil erosion. Many of the forages discussed in this review have high levels of crude protein which, as explained previously, is one of their attractive qualities as a forage, though ensiling can promote protein degradation, noted by the lower protein content found in ensiled forages versus that of their fresh counterparts (Jayanegara et al., 2018). Ensiling can lead to the proteolysis of protein, resulting in non-protein nitrogen, which cannot be effectively utilized by the livestock (Jayanegara et al., 2018, Wang et al., 2020).
Leaf harvest

One potential downside to the use of leaf silage would be the difficulty and labor involved in harvesting tree leaves. Willow often must be grown on a two-to-three-year rotation basis, and this prolonged wait time to first harvest is a disadvantage of using tree leaf silage (Smith et al., 2014, Ghalley 2009). Another downside of willow harvest is the implication in several articles and studies on the use of manual labor and hand pruning and cutting for harvest (Smith et al., 2014, Barry et al., 2007). However, studies on the use of drumstick leaves for silage harvested after a four-month growth period, and harvested every 45-50 days, and other sources cited the ability to harvest up to 9 times per year (Zeng et al., 2017). Mulberry harvest similarly seems to be relatively fast, though slightly slower and later than drumstick, with the ability to harvest the first crop six months after initial planting, followed by two more harvests within the first year, and then following the first year, harvest can be done roughly 70 days apart (Datta 2000). Harvest appears to be by hand, according to a source provided through a conference on mulberry leaf harvest and cultivation, through its recommendation for the use of hand tools to harvest the leaves (Datta 2000). Such harvest by hand is a disadvantage to leaf silage, given how tedious the harvest of the leaves would be, especially for a large-scale livestock production. Many of the studies on these four tree species specifically used for silage did not note their methods of harvest. Overall, though the information on the actual harvest of the leaves of these four tree species is relatively scarce, it seems that the harvest is tedious, with multiple studies recommending the harvesting by hand. These factors are two potential disadvantages to the use of leaf silage for livestock.
Phenolic compounds and toxins

A stark potential benefit of using tree leaves for silage is because of their level of phenolic compounds such as tannins. Tannins are polyphenolic compounds found at high concentrations in many tree leaves, especially those discussed in this review. Tannins, at moderate levels, have been found to be beneficial to livestock, though they can be harmful at high levels by both reducing feed intake by the livestock and reducing digestibility of the forage (Jayanegara et al., 2018, Aerts et al, 1999). Furthermore, tannins can reduce the bioavailability of protein in both silage and in the rumen by binding to them, which in turn can lead to increase of bypass protein absorption in the intestine by the ruminant and help prevent the associated pH increase that comes with rapid protein degradation in the rumen (Jayanegara et al., 2018, Aerts et al, 1999). This relationship has been reflected in the increase in productivity noted by livestock when consuming forages with moderate levels of tannins (Jayanegara et al., 2018, Aerts et al, 1999). Feeds containing between 2-4\% dry matter of proanthocyanidins (condensed tannins) can lead to increased absorption of amino acids by the ruminant which can lead to increased production as indicated by increased body weight, increased ovulation rate, increased milk yield, and increased wool growth (Aerts et al., 1999). Moderate levels of proanthocyanidins decrease the rate of degradation of protein within the rumen, which allows for more protein and amino acids to enter the small intestine for absorption by the ruminant (Aerts et al., 1999).

Additionally, tannins and phenolic compounds have been found to protect some livestock against parasites and can decrease methane emissions (Jayanegara et al., 2018, Aerts et al, 1999). This added benefit of proanthocyanidins in sheep has been noted; they
have been shown to lead to a reduction of intestinal parasites in sheep, and a reduction in bloat in cattle (Aerts et al., 1999). Sheep that consumed proanthocyanidins through their forages had reduced parasite-induced diarrhea, as opposed to sheep that did not consume forages with significant proanthocyanidin levels (Aerts et al., 1999). Finally, proanthocyanidins have been found to disrupt protein foam in the rumen that causes bloat in cattle, which is harmful to the animal (Aerts et al., 1999). Hence, the other beneficial effects of moderate levels of dietary condensed tannins. Aerts et al., (1999) continues to describe the potential benefits of genetically engineering commonly used forage plants such as white clover or lucerne to elevate their levels of condensed tannins and to reap the benefits of moderate levels of condensed tannins in ruminant feed.

Conversely, high levels of proanthocyanidins (between 6-12% dry matter) can decrease productivity and feed efficiency (Aerts et al., 1999). Relevant to this review, the harmful effects of condensed tannins fed from acacia leaves (Acacia aneura) have been noted, which contains 12% proanthocyanidins and led to reduced wool growth, reduced dry matter intake, and decreased digestion of sulfur and nitrogen (Aerts et al., 1999).

Interestingly, only slight differences in silage quality correlated with increasing tannins (Jayanegara et al., 2018). Measured levels of lactate, acetate, propionate, ethanol, and pH in the silage were unrelated to the presence of tannins (Jayanegara et al., 2018). However, increasing concentration of tannins was found to be related to decreased butyric acid concentration, which is a desired trait and indicates the inhibition of Clostridia species by tannins (Jayanegara et al., 2018). Increasing tannin concentration was correlated with decreasing rumen degradable protein, which allows for more use of protein by the ruminant (Aerts et al., 1999, Jayanegara et al., 2018).
The palatability of tannins in forages for sheep has also been studied. One experiment explored on the palatability of both ensiled and fresh forages with high tannin levels, although it is important to note that the study focused forages other than those highlighted in this review—sainfoin, trefoil, and chicory (Häring et al., 2008). The ensiled version of such forages had higher levels of tannins than the unensiled, dried samples (Häring et al., 2008). During the palatability trials, the tanniferous forage samples were offered along with clover and ryegrass as the control to groups of sheep. Despite the concerns mentioned in other studies regarding the potential of high levels of tannins to reduce palatability, it was found that the ensiled tanniferous forages had similar palatability as the control mixture of ryegrass and clover (Häring et al., 2008). Once again, it is key to note that this study features forages that were not focused on in this review, since research regarding the palatability of the leaf species in this review were not apparent. Though this study provides potentially significant findings on the palatability of ensiled forages with high levels of tannins, it cannot be assumed that the tree leaf species focused on in this review (willow, acacia, drumstick, and mulberry) would have the same palatability results as indicated by the study (Häring et al., 2008). Still, none of the reviewed studies on acacia, willow, drumstick, and mulberry indicated that the livestock found such silages completely unpalatable.

Toxins within tree and shrub leaves are also of concern, broadly speaking. Notably, several species of Acacia were listed in an analysis of tree and shrub forage toxins and anti-nutritional factors (Kamar 1992). Some Acacia species contain cyanogens, oxalate, and alkaloids, and tannins’ potential as an anti-nutritive factor in all potential livestock forages was yet again reiterated (Kamar 1992). More so, as noted
above in previous discussion of the literature on tannin content and livestock nutrition, multiple *Acacia* spp. were noted for their harmful levels of condensed and hydrolysable tannins, resulting in reduced growth, production, and digestibility in livestock (Kamar 1992). Cyanogens, when consumed in sufficient quantity and within sufficient time, lead to death as ATP production is halted, while oxalates can interfere with digestibility and use of calcium (Kamar 1992). These anti-nutritive factors and the potential toxicity they may cause is important to consider when examining the benefits and costs of using leaves over other forage choices-- especially *Acacia* spp., as they were especially noted to have high levels of anti-nutritive factors (Kamar 1992).

**Scope of study**

This study examines current and recent literature on the use of different tree leaves for the purpose of feeding to livestock as silage. Cited literature was limited to studies on willow (*Salix* species), acacia (*Acacia* species), white and paper mulberry (*Morus alba* and *Broussonetia papyrifera*), and drumstick (*Moringa oleifera*) leaf silage; despite historical and present use of leaf silage around the globe, published research on the effects of tree leaf silage on the ruminal microbial communities and the effects on the ruminant remain relatively scarce. The purpose of this review was to explore the potential benefits and advantages of tree leaf silage as well as the limits associated with leaf silage, as demonstrated by experiments and studies on feeding leaf silage to livestock.
WILLOW LEAF SILAGE

Most of the literature on willow silage explores it as a solution to problems such as weather and season related fodder scarcity and fodder storage limitations, as well as because of its availability in some locations; this same idea holds true for other tree species and their leaves’ potential use for ensiling. There are multiple studies published on the use of willow silage to supplement the feeding of zoo ruminants, and one study detailing the potential benefits of farmers in Bhutan growing willow trees and ensiling the leaves themselves to sustain their livestock throughout the winter, discussed below.

“Willow Silage – An Alternative to Winter Fodder” is a short study published by the South Asia Pro Poor Livestock Policy Programme and details the benefits of willow leaf silage for farmers in Bhutan, as well as details the ensiling process (Ghalley 2009). This publication highlights the ease of use of willow silage, due to its hardy nature, the simple ensiling process, and the benefit of using willow silage to conserve other winter fodders for later in the winter season (Ghalley 2009). Willow (Salix babylonica) is a hardy tree, with tolerance to wet and dry soil conditions and high altitudes. In addition to its tolerance for more unfavorable conditions, willow trees are used as fencing by farmers in Bhutan (Ghalley 2009). This study compares the crude protein and fiber values of willow to other winter fodder options, which demonstrate that the willow samples do have comparable crude protein and crude fiber values to other winter fodder options such as clover, straws, and hays, promoting willow as a good source of silage and nutrition for livestock (Ghalley 2009).
According to a different study on the use of willow leaves for livestock nutrition, willow leaves when harvested at peak nutritional level (late fall) have higher nutritional value for livestock than silage and hay do (Wangchuk et al., 2008). Specifically noted in one study, willow should be ensiled in late October to maintain optimal nutritive value that can be fed during the winter season (Ghalley 2009). The ensiling process is simple and the same process that would be used for other, more typical pastures: the willow leaf samples are anaerobically fermented for roughly a month (Ghalley 2009). No cutting of the leaves is necessary, and steps to ensure protection from moisture and air should be taken to fully allow the silage to anaerobically ferment (Ghalley 2009). Thus, ensiling willow is quite feasible.

![Silage making](image)

*Figure 2. "Silage making" (Ghalley 2009).*

A few studies on the use of willow silage have been published due to the potential benefit leaf silage can have in zoos and the herbivores kept in zoos. Zoos must provide forage to their ruminant animals but may struggle to provide year-round forage in some geographic locations. Akin to the farmers in Bhutan as detailed above, ensiling forage can be used as a solution to the limitations posed by the weather and seasons (Nijboer et al., 2006). More so, the use of browse silage can be cost-effective for zoos. The literature on use of tree leaf silage for ruminants, both in zoos and in livestock, is scarce, however
the Zurich Zoo and Rotterdam Zoo both have utilized leaf silage for some of their animals (Nijboer et al., 2006). The Zurich Zoo ensiled willow, hazel, and maple leaves and fed it to the black rhinoceros. Nutritional analyses of their three-leaf silage indicate that the ensiling process does not diminish the leaves’ nutritional quality (Nijboer et al., 2006). Similarly, the Rotterdam Zoo ensiled willow leaves and provided it to their browsers during the winter season (Nijboer et al., 2006). The browsers at the Rotterdam Zoo found the willow silage palatable and preferred the ensiled samples to frozen samples (Nijboer et al., 2006).

Furthermore, one study was done on the preference of foliage feeds by nyala antelope (*Tragelaphus angasii*) and results of feeding trials indicated that the antelope found both ensiled and fresh maple (*Acer platanoides*) leaves palatable (Przybylo 2020). Though literature on maple leaf silage is extremely limited (only this single literature on the feeding trials of maple leaf silage to nyala antelope was apparent to the author, in addition to the mention of maple silage by the journal on the Zurich Zoo), it provides interesting insight for the sake of this literature review. Their conclusions were that tree leaf silage could be valuable to assist in zoos providing adequate nutrition to their animals, and that leaf silage was palatable to the antelope, although palatability of silage would depend on how the silage is prepared and from what source leaf (Przybylo 2020).

The above reviewed journals on the possibility of using ensiled tree leaves for browsers living in zoos, especially during the winter months, all underline the need for more research on leaf silage, especially for more unconventional leaf silages, especially those such as maple.
One study on willow silage (Salix viminalis) for livestock—specifically, dairy cattle—in the United Kingdom provided a wealth of knowledge in comparison to the niche journals reviewed above. They ensiled both willow leaf and willow leaf plus stem samples, then analyzed the resulting willow silage samples and concluded that the willow silage samples were not suitable for the nutritional needs of lactating dairy cows, due to its low organic matter digestibility values (0.421 g/kg for leaves and stems and 0.511 g/kg for leaves only, as opposed to the ideal value range of 0.65-0.70 g/kg for lactating dairy cattle) (Smith et al., 2014). Additionally, this focused study found that their silage samples had a low concentration of water-soluble carbohydrates and a consequent low fermentation acid profile and contained more acetic acid than lactic acid while generally, a higher lactic acid to acetic acid ratio is desirable (Smith et al., 2014). Despite the unsuitability of willow silage for lactating dairy cows, the study determined that there is merit to be held in potentially using willow silage for other groups of livestock with lower energy demands. (Smith et al., 2014). Once again, the researchers cited the availability of willow tree forage over other forage in the winter season as one of the major benefits of exploring willow silage as a feed option, as well as its ability to improve pasture quality and the welfare of the livestock (Smith et al., 2014). In other discussions of studies on other leaf silages, studies have been done on the influence of lactic acid bacteria and carbohydrate additives, which have demonstrated to greatly improve silage quality; perhaps future experiments on adding carbohydrate or bacterial inoculants to willow silage should be done to examine if willow silage quality can be improved and thus be more useful for livestock. Of course, the question of whether the
nutritional and other benefits of using willow silage make it more appealing than more conventional silage forages must be examined when considering using any leaf silage.

Like those previously discussed, this study emphasizes the need to reaffirm its findings with more research and larger scale studies. Interestingly, this study claims that the nutritive value and digestibility of tree fodder decreases from spring to autumn, which opposes the claim made previously by a study on willow that the leaves have peak nutritive value when harvested and ensiled in late autumn (Ghalley 2009, Smith et al., 2014). Out of all the found literature on willow silage, this UK based study provides the most data and information regarding the nutritive value of willow silage (Smith et al., 2014). The ensiling of the willow leaves and leaves and stems led to decreased water-soluble carbohydrates and decreased fiber fractions (Smith et al., 2014). This is typical of the ensiling process, in which water-soluble carbohydrates are converted to fermentation acids, and acid hydrolysis can lead to decreased fiber fractions, however it was found that the willow silage had an unusually high pH (average of 5.79), which indicates less fermentation activity (Smith et al., 2014). Still, the researchers of this study asserted that the willow silage has the potential to be ensiled well and be beneficial for some livestock (Smith et al., 2014). Additionally, the willow silage contained mostly acetic acid, rather than lactic acid (Smith et al., 2014). This is consistent with its unusually and undesirably high pH; once again indicating low lactic acid bacteria fermentation activity.

Like the other leaf species explored in this study, willow is known for being generally high in condensed tannins. Condensed tannin concentrations vary with species of willow leaves, as *Salix kinuyanagi* had 4x as much condensed tannins as *Salix matsudana x alba* (Smith et al., 2014). Furthermore, this study determined that
environmental factors influence the amount of condensed tannins found within the willow silage; harsher, poorer growth conditions for the willow trees led to increased tannin concentrations (Smith et al., 2014). This information would be useful when choosing a willow species to utilize for silage, because, as explained in the previous discussion on tannins in forages, a moderate concentration of tannins is preferable to a high concentration and the options provided by different species and the level of control provided by controlling growth conditions is significant.

Overall, the current literature on the use of willow silage for both livestock and browsing ruminants in zoos is limited, however there is promising data and literature on the subject. Willow is a feasible silage, although more research should be done into production and use. The consensus is that willow can be a potentially beneficial and useful silage option due to its availability, its comparable nutritive value to other fodders (although it may not be suitable for all livestock of all stages), and finally its palatability.

*Figure 3. "Willow leaf silage" (M. Rinne 2014)*
ACACIA LEAF SILAGE

Acacias are another group of trees and shrubs that have been examined as potential feed sources for livestock. Consistent with some of the other discussed tree species, such as willow or drumstick (detailed below), acacia is noted for its hardiness in terms of climate and soil quality (Ali et al., 2017, Dynes & Schlink 2002). Two journals looked to acacia species as forage alternatives during periods of drought in Egypt and Australia, as acacia species are more drought-tolerant than other forages (Dynes & Schlink 2002, El Shaer 2000). Though the Australian-based study seemed to focus solely on fresh acacia leaves, the Egyptian study discussed the potential of acacia leaf silage of the species *Acacia saligna*. Like the discussions on the benefits of using willow for livestock forage, acacia’s use as timber and fuel (from its wood), windbreak, and in mitigating soil erosion was highlighted (El Shaer 2000).

Though acacia is noted for its high protein, its nutritive value is limited by its high levels of lignin and fibers as these decrease digestibility and intake (El-Waziry 2007, Dynes & Schlink 2002, El Shaer 2000). However, ensiling improved digestibility by the livestock, indicating that ensiling acacia leaves may counter some of its less desirable nutritive qualities (El Shaer 2000). These findings are emphasized by the second, Australian-based study, who asserted that the digestibility of acacia is increased through ensiling and the addition of supplements to promote ensiling (Dynes & Schlink 2002, El Shaer 2000).

Multiple species of acacia have been studied and most Australian acacia species have been found to contain adequate crude protein for livestock consumption (Dynes &
Schlink 2002). Interestingly, some species of acacia were reported to contain inadequate amounts of other nutrients for livestock, whether that be toxic, high levels of a certain nutrient such as copper, or whether they had too little of a nutrient, such as phosphorus (Dynes & Schlink 2002). Acacia contains high levels of secondary compounds such as nitrite, oxalates, and tannins; such compounds can be hugely harmful to livestock in high amounts, although the benefits of low levels of tannins have been discussed previously (Dynes & Schlink 2002, Aerts et al., 1999). These secondary compounds are also often to blame for decreased intake of acacia (Dynes & Schlink 2002). However, there are several methods to combat the adverse aspects of acacia. Addition of polyethylene glycol to the feed decreases the effects of tannins and consequently buffers the potentially harmful effects of the high levels of tannins found in acacia; similarly, the addition of alkalis and oxidative substances decrease amounts of condensed tannins within acacia feed (El-Waziry 2007, Dynes & Schlink 2002). Arguments in support of selecting acacia for lower levels of secondary compounds, as well as controlling growth environment (as some studies sampled their data from wild acacia) would be a straightforward way to combat the negative nutritive qualities of acacias (Dynes & Schlink 2002, El Shaer 2000).

Furthermore, supplementation with molasses, phosphorus, and protein meal has been shown to increase the intake of acacia and the productivity in the livestock consuming it (Dynes & Schlink 2002). Other studies have utilized the addition of other forages, such as saltbush species, as a method of increasing the crude protein as well (El-Waziry 2007, Dynes & Schlink 2002).

Another study had findings like those discussed above; this study tested the nutritive effects of three different processing techniques of acacia (*Acacia hockii*)
leaves—ensiling, drying, and fresh (Aruwayo et al., 2020). They concluded that ensiling was the most beneficial method of processing acacia leaves, as it resulted in the best degradation of protein and fibers that allowed for best nutrition for the livestock (Aruwayo et al., 2020). As said above, ensiling also promoted more intake and digestibility, counteracting the antinutritive qualities caused by the secondary compounds within acacia (Aruwayo et al., 2020).
The leaves of the drumstick tree, *Moringa oleifera*, have also been used for silage with reported positive effects on the milk and meat quality of the animals consuming it. One study on the use of *Moringa oleifera* silage in dairy cattle compared ensiled drumstick leaves to the control group of wheat and hay silage (Cohen-Zinder et al., 2016). This study emphasized the necessary step of wilting drumstick leaves prior to ensiling to prevent mold and they used the same process of ensiling through the mixing of drumstick leaves with wheat hay and molasses to achieve sufficiently low pH (Cohen-Zinder et al., 2016). Leaves and soft twigs and branches of the drumstick plant were harvested and used for ensiling in this study (Cohen-Zinder et al., 2016). The *Moringa oleifera* silage had higher crude protein, but similar acidity (pH of 4) and similar dry matter content to the control silages (Cohen-Zinder et al., 2016). They also found that the cows fed the drumstick leaf silage had 20% more antioxidative activity than the cows fed wheat and hay silage (Cohen-Zinder et al., 2016). The most significant finding of this study is that the cows that consumed the drumstick leaf silage had higher milk yields (Cohen-Zinder et al., 2016).

Moderate levels of phenols and tannins in ruminant feed led to increased production (Cohen-Zinder et al., 2016). This has been noted in other studies, as discussed above, with ruminants that consumed higher phenolic foods showed increased fat yield and milk yield (Cohen-Zinder et al., 2016). However, the research brought forth by these studies suggest that the use of leaf silages may be another method of incorporating condensed tannins into ruminant feeds, given the higher levels of phenolic compounds...
found within *Moringa oleifera* leaves (Cohen-Zinder et al., 2016, Cohen-Zinder et al., 2017).

The use of *Moringa oleifera* leaf silage in place of alfalfa hay on dairy cattle’s milk yield and nutrient apparent digestibility was explored by a later study as well (Zeng et al., 2017). Over a 35-day feeding trial, a herd of sixty Holstein cattle was divided into three groups, with one control group (fed alfalfa hay and no drumstick leaf silage) and two groups fed both alfalfa hay and drumstick leaf silage, one consuming high ratio of drumstick leaf silage (50% of alfalfa and 100% of maize silage replaced by drumstick leaf silage) and one consuming low ratio of drumstick leaf silage (25% of alfalfa and 50% of maize silage replaced by drumstick leaf silage) (Zeng et al., 2017). Like the proposed benefits of using willow and acacia silage over typical grass, corn, or grain-based silage, drumstick leaf silage is explored as a potential silage due to the tree’s wide availability, ability to grow in harsher conditions, and nutrition—including high crude protein, high levels of vitamins A, D, E, and sufficient amino acids within the leaves of the plant (Zeng et al., 2017). Furthermore, other studies have found that fresh and dried drumstick leaves can positively affect milk yield and nutrient digestibility in comparison to other forage types (Zeng et al., 2017).

Milk composition was unaffected by the substitution of drumstick leaf silage in the diet of the dairy cattle (Zeng et al., 2017). Milk yield decreased a small amount with increasing drumstick leaf silage ratio, which differed from other studies on drumstick leaf effects on dairy performance (Zeng et al., 2017). Additionally, drumstick leaf silage was found to lead to decreased nutrient digestibility, relative to other forages such as easily digestible alfalfa, maize, and wheat (Zeng et al., 2017). Finally, they found that *Moringa*
Moringa oleifera silage supplementation only led to increased urea concentration and decreased cholesterol concentrations found through serum index analysis (Zeng et al., 2017). In summary, this study found that silage made from drumstick plants mixed with oat hay was a viable feed source for dairy cattle relative to alfalfa hay and other forages. The resulting decrease in milk yield with increasing drumstick leaf silage ratio was not significant enough to conclude that drumstick leaf silage was correlated with decreased milk yield (Zeng et al., 2017).

Similarly, another study ensiled Moringa oleifera leaves with or without molasses and inoculants and tested whether the feeding of drumstick leaf silage in place of maize silage would affect milk production (Cohen-Zinder et al., 2017). The high levels of crude protein found in Moringa oleifera led to it being of interest for researchers, given that protein is necessary in high levels for dairy production, (Cohen-Zinder et al., 2017). Additionally, the antioxidants found in Moringa oleifera leaves and the ability of the leaves to hold their nutritive value over long periods of time also make it a potentially quality plant to use for silage (Cohen-Zinder et al., 2017). The focus of their experiment was on the potential antioxidative properties of ensiled Moringa oleifera, which they suspected were due to the high levels of polyphenols, anthocyanins, and tannins found within the leaves (Cohen-Zinder et al., 2017).

Drumstick leaves were ensiled under three different treatments: control (plain Moringa oleifera leaves), with molasses added, with molasses and Lactobacillus inoculants (Cohen-Zinder et al., 2017). They also fed their samples to Holstein dairy cattle, though unlike previous studies they solely used drumstick leaf and twigs, rather than including branches and trunks which lowered the crude protein content in the silage.
produced by other researchers (Cohen-Zinder et al., 2017, Zeng et al., 2017). This *Moringa oleifera* silage had a higher crude protein content than the maize silage they compared it to, with 180g/kg DM versus 90g/kg DM (Cohen-Zinder et al., 2017).

Without the addition of molasses into the ensiling process of drumstick leaves, drumstick leaf silage would not be viable; the pH after ensiling was too high (5.2) and the concentration of lactic acid to acetic acid was too low (Cohen-Zinder et al., 2017). Addition of molasses, and the further addition of *Lactobacillus* inoculants, led to lower, more viable pH levels of 4.2 as well as higher levels of lactic acid to acetic acid, and finally, stabilized the drumstick leaf silage by reducing levels of mold and yeasts found within the silage (Cohen-Zinder et al., 2017). They also found that the antioxidative capacity of *Moringa oleifera* increased with ensiling, while wheat and sorghum silages (used in this study as a control against drumstick leaf silage) had lower antioxidative capacities, even compared to drumstick leaf ensiled without molasses or inoculant additives. The researchers expected to find polyphenols correlated with the antioxidative qualities of drumstick leaf silage, however they found that polyphenols decreased with ensiling of the drumstick leaves and that the two silage qualities were not related (Cohen-Zinder et al., 2017). Furthermore, high levels of free amino acids were found in the *Moringa oleifera* silage, indicating high protein degradation (Cohen-Zinder et al., 2017).

Unlike the findings of Zeng et al., (2017), Cohen-Zinder et al., (2017) found that feeding of *Moringa oleifera* silage led to increased milk yield, though this effect was not considered long term as the increase in milk yield diminished over time. They also found that drumstick leaf silage did not affect milk composition, which is consistent with other studies (Zeng et al., 2017). Most importantly, drumstick leaf silage was found to decrease
somatic cell counts (SCC) in the milk of cows that consumed it, which is a hugely notable potential benefit of using drumstick leaves for silage given that SCC is considered a huge indicator for health of dairy cattle and of their udder, along with milk quality (Cohen-Zinder et al., 2017).

The relationship between antioxidant supplementation and decreased SCC in milk is well-noted (Weiss 2019). Supplementation of vitamins E, selenium, zinc, and beta-carotene plus vitamin A (all antioxidants) have been reported to decrease SCC (Weiss 2019). Thus, the potentially high antioxidative capacity of drumstick leaf silage and its subsequent ability to lower SCC count in dairy cattle is significant, and further strengthens the support for the potential use of drumstick leaf silage in agriculture.

The ensiling process for *Moringa oleifera* leaves is further studied and detailed (Wang et al., 2019). As noted in the previously examined studies, this study found that the addition of lactic acid bacterial inoculants and the additional step of wilting the drumstick leaves prior to ensiling largely improved the fermentation qualities of the final silage product (Wang et al., 2019). This study brought up another potential benefit of using drumstick leaves in livestock feed, which would be the noted effect of decreased methane emissions produced by livestock that were fed drumstick leaves in place of soybean meal (Wang et al., 2019).

Drumstick leaves were ensiled under four different treatments: wilted or unwilted and inoculated or uninoculated (Wang et al., 2019). They found that both the wilted and unwilted *Moringa oleifera* silage had high levels of water-soluble carbohydrates, which are vital for the lactic acid producing bacteria to convert into lactic acid during the fermentation process (Wang et al., 2019). Additionally, this study notes that both wilted
and unwilted samples achieved sufficiently low pH (less than 4.2) when inoculated, while the unwilted and wilted samples that did not have inoculants added had pH values of 4.70 and 4.28 (Wang et al., 2019). The significance of this study is that the addition of inoculants for *Lactobacillus farcininis* and *Lactococcus lactis* resulted in lower pH values, higher levels of lactic acid, and higher ratios of lactic acid to acetic acid, and that wilting the drumstick leaves prior to ensiling resulted in higher ratios of lactic acid to acetic acid (Wang et al., 2019). Inoculation decreased the abundance of other bacteria such as *Enterobacter* spp. which would compete with lactic acid producing bacteria and decrease the silage quality (Wang et al., 2019). The presence of propionic or butyric acid was not noted in any of the ensiled samples (Wang et al., 2019). Understanding how best to ensile the leaves of *Moringa oleifera* is essential to fully study and potentially reap the benefits of using drumstick leaf silage in livestock.
MULBERRY LEAF SILAGE

Mulberry leaves have also been studied and noted for their potential use for ensiling, particularly in Asian countries and particularly as a supplement when other feed is scarce (Hao et al., 2020, He et al., 2019). Like the other leaves noted in this study, mulberry leaves are noted for their high protein content and high tannin and phenolic compound content (Hao et al., 2020). Also, like other trees noted in this review, mulberry trees have potential uses outside of feed as improving soil quality by preventing erosion (Hao et al., 2020). Mulberry leaves even have reported comparable digestibility to alfalfa hay (Trabi et al., 2017).

The use of paper mulberry tree leaves (*Broussonetia papyrifera*) was explored in Holstein dairy cattle (Hao et al., 2020). A group of 45 cattle were divided into three treatment groups, one not consuming paper mulberry silage, one being fed 4.5% then 9% paper mulberry silage, and one fed 13.5% then 18% paper mulberry silage (Hao et al., 2020). While they did not find any resulting increase in milk yield because of feeding paper mulberry silage, a higher antioxidant capacity was found in the cattle fed paper mulberry silage (Hao et al., 2020) This is consistent with other findings that explored the relationship between drumstick leaf silage containing high levels of tannins and other phenolic compounds and the antioxidative ability it had on the livestock consuming it (Cohen-Zinder et al., 2017). Additionally, the consumption of paper mulberry silage did not affect the bacteria found in the cattle’s feces, nor did paper mulberry silage have significantly different digestibility from the control fed cattle (Hao et al., 2020). Furthermore, dry matter intake was unaffected by the addition of paper mulberry silage,
which is very important especially when considering the potential harmful effects that
tannins have caused on intake in livestock (Hao et al., 2020).

Tannic acid was found to have beneficial effects during the ensiling process
(Wang et al., 2020). A low level of tannic acid (2%) within mulberry leaf silage led to
decreased butyric acid, increased lactate and acetate, and decreased pH—all indicators of
good silage quality (Wang et al., 2020). Additionally, tannic acid inhibited some levels of
Clostridium species, which have been shown to decrease fermentation quality and ability
during the ensiling process (Wang et al., 2020). Production of butyric acid by Clostridium
species is highly undesired in silage as it can raise pH and decrease lactic acid, and many
species produce serious toxins; thus, this potential of tannic acid to inhibit Clostridium
growth is very beneficial (Jones et al., 2017). This study also found results that are
consistent with previous discussion on the effects of tannins and polyphenols during
ensiling; that is, tannic acid and other polyphenolic compounds prevent protein
degradation in the rumen and allow for more bypass protein to enter the small intestine
for absorption by the ruminant (Wang et al., 2020, Aerts et al., 2020).

The measured pH of white mulberry leaf silage in this study was high, especially
by silage standards, ranging between 6.51-6.89 (Wang et al., 2020). Interestingly, the
lactic acid bacteria count also decreased with addition of tannic acid (Wang et al., 2020).
Still, mulberry leaves had sufficient levels of high water-soluble carbohydrates, crude
protein, and low levels of fiber that made it valuable as a potential high-protein, high
quality silage (Wang et al., 2020). Silage additives, such as lactic acid bacteria inoculants
or molasses, as other studies have explored in their studies on leaf silage, may help lower
the pH (as shown in other studies) and increase the levels of the vital lactic acid bacteria
that produce a silage of good quality, especially given the exceptionally high pH that was found in the mulberry leaf silage (Wang et al., 2020).

Some other studies have indeed explored the effects of adding sugars or bacterial additives to mulberry leaf silage during ensiling (He et al., 2019, Wang et al., 2019, Trabi et al., 2017). As expected, the addition of lactic acid bacteria (*Lactobacillus casei*) and the addition of cellulase led to an increase in levels of lactate, decreased pH, decreased protein degradation, and increased antioxidant activity (He et al., 2019). Once again, these qualities are desirable in silage and provide further support for argument to supplement mulberry leaf silage with lactic acid bacteria inoculants and other additives such as cellulase or sugars (He et al., 2019). This study also noted the poor microbial populations that are originally found in mulberry leaves, also emphasizing the importance of supporting lactic acid bacteria dominance during the ensiling process (He et al., 2019). This may explain the results of studies which found high pH levels and low lactic acid bacteria counts in their silage (Wang et al., 2020).

Another study performed followed a similar premise as previous studies, by studying the effects of adding *Lactobacillus casei* and sucrose to mulberry leaf silage (Wang et al., 2019, He et al., 2019). An additional study did the same, only added glucose rather than sucrose in addition to adding three different species of *Lactobacillus* (Trabi et al., 2019). The findings of both studies were consistent with previously discussed results of previous studies: addition of lactic acid bacteria and sugar or cellulase led to improved silage quality which was indicated by decreased pH, increased lactic and acetic acid content, and lactic acid bacteria dominating the silage bacterial community more (He et al., 2019, Trabi et al., 2019, Wang et al., 2019). This study
reasserted the viability of mulberry leaf silage due to its high crude protein and low fiber, though the addition of sucrose or glucose and lactic acid bacteria is vital as indicated by the superior silage quality produced because of this supplementation (Trabi et al., 2019). Glucose added at a 3% dry matter basis was necessary to produce significant effects (Trabi et al., 2019). Propionic acid was found at increased levels with a treatment of 3% glucose, and significant effects on neutral detergent fiber and acid detergent fiber were not noted (Trabi et al., 2019). At the highest treatment of glucose (3%), measured pH of the mulberry leaf silage was found to be 5.30 (Trabi et al., 2019). This was lower than the control silage (with glucose nor lactic acid bacteria added), however this is still higher than desirable for silage (less than 4.2). This elevated pH level means that the mulberry leaf silage is not sufficiently preserved (Trabi et al., 2017)

Overall, while mulberry leaf has great potential to be a high-quality silage due to its low fiber, high protein, and high moisture (thus it ensiles more readily), additives such as sugars (sucrose or glucose), lactic acid bacteria inoculants, or cellulase is necessary in to lower the pH and increase the levels of lactic and acetic acid—desirable qualities of silage.
## COMPARISON BETWEEN LEAF SILAGES

*Table 1. Nutritive comparison between leaf silages.*

<table>
<thead>
<tr>
<th>Leaf Silage Species</th>
<th>DM (g/kg)</th>
<th>Crude Protein (g/kg)</th>
<th>Neutral detergent fiber (g/kg)</th>
<th>Acid detergent fiber (g/kg)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow (<em>Salix viminalis)</em></td>
<td>282</td>
<td>219</td>
<td>287</td>
<td>199</td>
<td>5.78</td>
</tr>
<tr>
<td><em>Moringa oleifera</em></td>
<td>305.3</td>
<td>93.5</td>
<td>550.2</td>
<td>350.3</td>
<td>3.68</td>
</tr>
<tr>
<td><em>Acacia saligna</em></td>
<td>371</td>
<td>102</td>
<td>540</td>
<td>396</td>
<td>-</td>
</tr>
<tr>
<td><em>Morus alba</em></td>
<td>433.6</td>
<td>-</td>
<td>372.7</td>
<td>163.6</td>
<td>5.77</td>
</tr>
</tbody>
</table>

1: Data for willow leaf only silage (Smith et al., 2014). 2: Data mixed silage, 42% *Moringa oleifera* and 57.5% oat hay (Zeng et al., 2017). 3: Data for *Acacia saligna* silage (El Shaer 2000). 4: Data for *Morus alba* silage (Trabi et al., 2017).
Table 2. Fermentation acid comparison between leaf silages.

<table>
<thead>
<tr>
<th>Leaf Silage Species</th>
<th>Lactic acid (g/kg)</th>
<th>Acetic acid (g/kg)</th>
<th>Propionic acid (g/kg)</th>
<th>Butyric acid (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Salix viminalis</em>(^1)</td>
<td>2.5</td>
<td>4.7</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td><em>Moringa oleifera</em>(^2)</td>
<td>60.20</td>
<td>18.29</td>
<td>&lt;0.06</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td><em>Morus alba</em>(^3)</td>
<td>5.21</td>
<td>2.91</td>
<td>1.78</td>
<td>2.34</td>
</tr>
</tbody>
</table>

\(^1\): Data for willow leaf only silage (Smith et al., 2014). \(^2\): Data mixed silage, 42% *Moringa oleifera* and 57.5% oat hay (Zeng et al., 2017). \(^3\): Data for *Morus alba* silage (Trabi et al., 2017).

The data used to compare the four types of leaf silage was limited in that many studies did not list their nutritive analysis of their studied leaf silage. More so, many studies altered other factors within a single species of leaf silage, such as addition of lactic acid bacterial inoculants, glucose or molasses, wilting or not wilting, and the aim of this comparison was to focus on pure leaf silage. However, the only available data for *Moringa oleifera* was a sample of mixed drumstick and oat hay silage, hence its use in this comparison (Zeng et al., 2017). Additionally, many studies did not analyze the same factors and thus the data was limited to studies that provided analysis of the same feed qualities in order to have a consistent and more thorough comparison. Still, some studies did not list important factors such as pH or crude protein, which was noted (Table 1). Fermentation acid analysis of acacia silage could not be found, hence its absence from the second comparison (Table 2).
Out of the four tree species, the measured pH for *Moringa oleifera* silage was most favorable, as the pH for *Salix viminalis* and *Morus alba* were quite high for silage (Table 1). It is important to note that the *Moringa oleifera* samples used for this comparison was a mixed silage, containing more than half by weight oat hay. *Moringa oleifera* was also found to have the highest levels of lactic acid and acetic acid, indicating high fermentation activity, consistent with its low pH. *Moringa oleifera* also produced the most favorable levels of butyric and propionic acid, with *Morus alba* silage having the most undesirable butyric and propionic acid levels; lower butyric and propionic acid levels are more desirable as it is indicative of lower activity by *Clostridia* spp. and allows for more lactic acid bacteria activity (Table 2). Interestingly, *Moringa oleifera* had the lowest levels of crude protein and higher levels of acid detergent fiber (ADF) and neutral detergent fiber (NDF) (Table 1). Willow silage would be most desirable based on its high crude protein and low NDF and ADF levels, which indicate higher intake and digestibility of the feed by the livestock. Acacia silage is least desirable in regard to NDF and ADF levels, as it contains the highest levels of ADF and NDF, followed by drumstick silage.

Overall, a comparison between the four tree silage types shows that each leaf species type has different benefits and disadvantages. Analysis of pure *Moringa oleifera* silage is necessary to have a more thorough and consistent comparison between the four tree types, and more data is needed on both acacia silage and mulberry silage. While drumstick leaf silage had the most favorable fermentation acid profile and pH, willow silage had the most favorable protein, ADF, and NDF levels.
CONCLUSIONS

The use of tree leaves for silage, especially drumstick, willow, acacia, and mulberry leaves, poses great potential benefits. Such leaf species may contain high levels of crude protein and the moderate levels of proanthocyanidins needed to reap maximum benefit of better protein availability, reduction in harm from parasites, and reduction in bloat risk. Furthermore, such tree species may be favorable—especially during seasons or times when other forages are not as feasible—due to their accessibility, multi-purpose function, and hardier nature. Further research on the potential anti-nutritive factors and toxicity is necessary for better understanding of the advantages and disadvantages of using tree leaves as candidates for ensiling. Additionally, more focused studies on the palatability of these tree leaf species are needed as well, although current literature has little indication that these ensiled tree leaf species are found to be completely unpalatable by livestock. Still, more research on these matters would lead to an overall better understanding of the use of tree leaves for silage.

The comparison between all four types of examined leaf silages did not provide a clearly superior leaf silage. As explained throughout this review, each species of leaf provides different advantages or disadvantages to livestock and likewise, their nutritive analyses and fermentation acid profiles have significant differences between them. More research is needed to provide more consistent and clear analysis on the nutrition and fermentation profiles of different types of leaf silages, as some data is missing or influenced by additives to the leaf silage, such as other forages like oat hay, sugars like glucose or molasses, or bacterial inoculants.
REFERENCES


AUTHOR’S BIOGRAPHY

Jade Chin was born January 25th, 2000 and is originally from Madison, Connecticut. She is currently majoring in Animal Science and Veterinary Sciences, with a pre-veterinary concentration. Additionally, she is a Biology major with minors in Neuroscience and Psychology. Jade plans to attend the University of Glasgow in her upcoming senior year through the Facilitated Early Entry Program for Animal Science Students (FEEPASS) and plans to attend veterinary school after undergraduate graduation in 2022. She enjoys spending time with her cat, cooking and baking, spending time with friends (when safe), reading, going for walks, among other hobbies, when she has the time.