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Advances in the Evaluation and Application of Nutritionally Valuable Woody Feeding Plants

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Abstract

This review presents the current status of woody feed resources in China. *Morus alba*, Moringa, and *Broussonetia papyrifera* were evaluated with respect to their nutritional value, and their impact on the performance and product quality of herbivores, monogastric and aquatic animals. Feed resources are becoming increasingly scarce in China, and therefore woody forage, as an alternative feed resource, is attracting increasing attention. Woody forage is abundant in nutrients and natural active substances as well as being of high nutritional and feeding value, thereby enhancing the health of livestock and poultry, while improving the quality and flavor of the resulting product. In short, the development of woody plants has many advantages, increasing the feeding and economic value, but also helping solve the problem of feed shortages. The development and utilization of woody plants as a feed resource is therefore of great significance in promoting the stable development of animal husbandry.

Keywords: Woody forage; *Morus alba*; Moringa; *Broussonetia papyrifera*; Nutritional value; Feeding effect

Introduction

Woody feed, also known as 'woodgrass' or 'woody forage', refers to young shoots and leaves, flowers, fruit, seeds and their by-products of woody plants with feeding value that can be used not only for direct grazing, but also for collecting, cutting, and processing [1]. In China, economic development is causing an increase in living standards, thereby increasing the demand for eggs, milk and meat, which is leading to a sharp increase in the development of animal husbandry. Not only is this having a direct effect on grassland areas, which are continuingly shrinking, but it is also leading to a reduction in the area of grassland occupied by livestock, creating imbalance between livestock and available land. As a result, herb and grain feed resources are no longer able to meet the demands of livestock production.

At present, China is facing a shortage of total feed resources, with a lack of grain-based energy feeds, a severe shortage of protein feeds. Moreover, the supply and demand relationship is currently characterized by a lack of concentrated, protein and green feed, and insufficient overall amounts of feed in general [2,3]. Meanwhile, woody feed resources are particularly rich in nutrients, especially the branches and leaves, which have a high crude protein, amino acid and mineral content [4]. They are therefore an important feeding supplement for ruminant livestock. According to recent reports, China's existing forest area covers approximately 147.2 million hectares [5]. Meanwhile, the annual average fodder and leaf feed requirements of animal are approximately 500 million tons, while only about 300 million tons are available [6]. The development of woody feed resources is therefore important in helping alleviate feed shortages in the livestock industry, thereby ensuring the stable development of animal husbandry in China.

In this review, we report the current status of woody feed resources in China. To do so, *Morus alba*, Moringa, and *Broussonetia papyrifera*, all of which are important woody crops, were evaluated with respect to their nutritional value, and their impact on the performance and product quality of herbivores, monogastric and aquatic animals.

The application status of woody plant feed in China and overseas

Because woody plants are rich in nutrients, they are widely used as a nitrogen source for ruminants. As a result, large amounts of woody plant species are cultivated in parts of Africa, America, Asia and Australia, most of which are used as a protein resource in cow and goat feed. In Africa, the most abundant and widely used species is *Calliandra calothyrus*. The earliest research on *C. calothyrus* was conducted in 2003, revealing high palatability as well as increases in milk quality and an average yield increase of 1.5 L per day when added to cattle feed [7]. In addition, supplementation with *C. calothyrus* was also found to improve nitrogen retention in cattle fed a low-protein diet [8]. *Albizia lebbeck* is another important woody feed in western Africa, and although abundantly available is poorly valorized [9]. Recent research suggests that *A. lebbeck* could be used as a protein concentrate in dietary supplements to combat widespread malnutrition [10]. Moreover, it also possesses hepatoprotective and antioxidant activity [11] and the platelet anti-aggregation activity *in vitro* [12]. Similar plants include *Bauhinia purpurea* linn and *Cratylia argentea* Benth, both of which are planted widely across North America Studies have also shown that they can improve the quality and absorption rate of feed as well as the digestibility of crude protein [13,14]. In Asia, 13 species of woody plants are widely used in ruminant feeding systems; namely, *Areca catechu, Acacia nilotica, A. sieberiana, Manihot esculenta, Erythrina variegata, Ficus exasperata, F. bengalnensis, F. religiosa, Gliricidia sepium, Artocarpus heterophyllus, Albizia lebbeck, Prosopis. juliflora, P. glandulosa, Cajanus cajan* and *Tamarindus indica* [15]. A large number of woody feed plants are cutlivated in Austrailia such as *Chamaecytisus proliferus, Leucaena leucocephala* and *Atriplex* spp., all of which are used mainly to feed cattle, providing sustainable high productivity [16]. Thus, overall, the development and application of woody plants is relatively widespread around the world.

In China, woody feed cultivation is among the most abundant and the most widely used. Because China has a long standing tradition of woody feed application [17], it is in an excellent situation for the development of new woody feed resources. Due to the complex diversity of woody forage plants, they can be roughly divided into six types according to their appearance: conifer arbor, broadleaf arbor, shrub, semi-shrub, woody canebrake and bamboo [1]. Of the numerous woody feed resources, research in China tends to have focused on the nutritional and feeding value of *M. alba*, Moringa and *B. papyrifera*. The following provides a summary of these studies.

Nutritional Value

Nutritional value of *Morus alba*

The chemical composition of mulberry leaves is extremely complex, and is affected by a number of factors, such as genetic and physiological characteristics as well as the climate, soil and cultivation conditions [18]. In order to meet the demand for specialized edible mulberry varieties, factor analysis was applied to comprehensively evaluate the nutritional quality of leaves from different mulberry germplasms and varieties [19], and the nutritional composition of mulberry is listed in Table 1 [19]. In addition to the basic nutrients, mulberry also possesses indispensable trace elements, while the leaves are rich in protein and contain at least 17 kinds of amino acid, the most abundant of which are glutamic and aspartic acid (13.7 and 12.3%, respectively). Research also illustrates, in addition, that essential amino acids in mulberry leaves account for 32.61% of the requirements of animals [20]. The amino acid contents of mulberry leaves are listed in Table 2 [20].

Table 1: The nutritional composition of mulberry (*Morus alba*) leaves (air-dry basis) [19]

Nutritional component	Content (% / mg/g)
Moisture	61.74-79.30%
Crude protein	13.61-24.97%
Carbohydrate	3.99-17.44%
Ash	0.09-0.23%
Ca	1.05-4.33%
P	0.16-0.62%
S	0.12-0.32%
Mg	0.11-0.45%
Fe	135.29-314.66 mg /g
Mn	18.65-124.75 mg /g
Zn	17.95-45.86 mg /g
Cu	6.85-25.81 mg /g

Table 2: Amino acid contents of mulberry (*Morus alba*) leaves (dry matter basis) (Wang et al., 2015)

Item	Content (mg/g)
Ile	10.0
Leu	27.0
Lys	25.1
Met	9.8
Phe	22.3
Thr	16.6
Val	13.1
Asp	43.8
Ser	19.0
Gly	23.0
Ala	26.1
Glu	48.9
Cys	3.4
Tyr	15.4
His	9.2
Arg	25.9
Pro	18.8

Mulberry leaves are therefore an exceptional source of protein and worth developing as a woody feed resource. Research also suggests that mulberry leaves contain a wide variety of fatty acids, mainly palmitic, linolenic, linoleic, stearic, oleic, arachidic, palmitoleic, behenic and cerotic acid, which account for 26.87, 22.99, 13.40, 6.99, 3.17, 3.43, 3.05, 2.93 and 1.63% of the total, respectively [21]. Mulberry leaves were also found to contain abundant secondary metabolites such as flavonoids, alkaloids and polyphenols [22,23,24], all of which possess numerous bioactivities. The most abundant are flavonoids such as astragalin and quercetin, both of which possess antioxidant activity [25]. The effect of total flavonoids from mulberry leaves on sugar metabolism, antioxidative enzyme and albumin glycosylation activity in diabetic rats was also examined, revealing a decrease in blood glucose and lipid peroxide and an increase in plasma superoxide dismutase activity (SOD) as well as inhibition of albumin glycosylation [26]. With the increasing number of diabetic patients, human studies are focusing on the effects of 1-deoxynojirimycin [27,28], fagomine, and other alkaloids from mulberry leaves [29]. For example, research suggests that 1-deoxynojirimycin, a natural α-glycosidase inhibitor, can reduce increases in postprandial blood glucose and maintain stable blood-sugar levels [30]. Mulberry leaf is therefore of high pharmaceutical value with potential as a natural health care product. However, studies on the effect of bioavailable substances in mulberry leaves on the health of livestock and poultry have yet to be carried out. In animal husbandry, the prospect of mulberry application should therefore be considerable.

Nutritional value of Moringa

The nutritional characteristics of Moringa are also rich, not only the leaves but also the stems, pods and seeds. The most notable features are its high protein and low fiber content. In was previously revealed that Moringa leaf powder had a crude protein content close to 28% and a true protein content of up to 81.3% [31]. Moreover, Moringa leaves were found to contain 14 to 17 fatty acids, of which linolenic acid accounts for 57% [32]. The nutritional composition of Moringa is shown in Table 3 [31,32]. As shown, it contains at least 17 kinds of amino acid, representing a total content of 20.49%. Of these, glutamic and aspartic acid are most abundant, accounting for 14.52% of the total. In addition, Moringa contains five essential amino acids including lysine and threonine, both of which are lacking in animal staple diet [33]. The amino acid content of *Moringa oleifera* is given in Table 4 [33]. Moringa is therefore a potentially good source of protein. Moringa leaves also contain large amounts of vitamins and minerals (Table 5; 34], which were previously shown to overcome the negative effects of iron deficiency in rats [35].

Table 3: Nutritional composition of *Moringa oleifera* leaves (dry matter basis) (Liu and Guo-Hua, 2004; Sánchez-Machado et al., 2010) [31,32]

Nutritional component	Content (%)
Crude protein	27.6
Crude fat	8.65
Crude fiber	7.12
Total starch	5.65
Total sugar	15.12
Total flavonoids	1.09
Linolenic acid	56.87
Palmitic acid	23.28
Linoleic acid	6.11
Oleic acid	5.12
Arachidonate	0.21

Table 4: Amino acid contents of *Moringa oleifera* leaves (dry matter basis) (Rao, 2007) [33]

Item	Content (%)
Glu	3.05
Asp	3.05
Phe	2.00
Leu	1.47
Val	1.34
Lys	1.23
Arg	1.07
Ala	1.06
Ile	1.04
Thr	0.95
Ser	0.90
Gly	0.82
Pro	0.82
Tyr	0.54
Met	0.45
His	0.36
Cys	0.34

Table 5: Vitamin and mineral contents of *Moringa oleifera* leaves (dry matter basis) (Ding, 2014) [34]

Item	Content (mg/kg)
VE	1130.0
Pantothenic acid	891.0
β-carotene	603.0
VC	368.0
VB_2	19.0
K	15505
Ca	16920
P	5651
Mg	3243
Fe	164.8
Al	133.
Cu	77.6
Mn	62.5
Zn	47.6
Se	0.6

Moringa also contains a number of active substances such as flavonoids, polysaccharides and polyphenols. According to Tumer et al. (2015), isothiocyanate from Moringa leaves is not only rich in content, but also has a very strong antioxidant capacity. Moringa leaves also contain quercetin, kaempferol, chlorogenic acid and zeatin, all of which have anti-oxidant [36,37], anti-tumor [38] and anti-bacterial effects [39]. Moringa is therefore of potential use as a natural multi-functional health supplement. Saponins, meanwhile, are an inert substance and non-toxic to animals. According to a report, the contents of tannins, trypsin inhibitor, nitrate and oxalic acid in Moringa are very low at 20.7mg/g, 1.45 TIU/g, 17 mg/g and 10.5 mg/g, respectively [40]. Based on these findings, the potential wide-spread use of Moringa as a feed resource should therefore be considered.

Nutritional value of *Broussonetia papyrifera*

B. papyrifera leaves are rich in protein, vitamins, carbohydrates, trace elements, and various amino acids, notably the leaves. The crude protein content is twice that of wheat and three times that of corn and rice, while the crude fat content is twice that of rice and wheat. The only plant with a higher content is soybean; however, the content of nitrogen-free extract is higher in *B. papyrifera* [41]. Table 6 compares the nutritional value of *B. papyrifera* leaves with alfalfa and soybean meal [41]. Zhou [42] previously analyzed the amino acid composition of *B. papyrifera* leaves and found approximately 16 kinds of amino acid, the content of which varied depending on the plant part (Table 7). As shown, seven essential amino acids were found.

Table 6: Nutritional composition of *Broussonetia papyrifera* leaves, alfalfa and soybean meal (air-dry basis) (Tu et al., 2009)

	Content (% / mg/kg)		
Item	*B. papyrifera* leaves	Alfalfa	Soybean meal
Moisture	9.1%	13.0%	11.0%
Crude protein	26.1%	19.1%	44.2%
Crude fat	5.2%	2.3%	1.9%
NDF	15.9%	36.7%	13.6%
ADF	13.0%	25.0%	9.6%
Ash	15.4%	7.6%	6.1%
Ca	3.4%	1.4%	0.3%
Total P	0.2%	0.5%	0.6%
Cu	8.3 mg/kg	9.7 mg/kg	23.5 mg/kg
Fe	247.1 mg/kg	3.6 mg/kg	181.0 mg/kg

Content (% / mg/kg)			
Item	*B. papyrifera* leaves	Alfalfa	Soybean meal
Mn	50.3 mg/kg	30.7 mg/kg	27.4 mg/kg
Zn	62.9 mg/kg	16.0 mg/kg	45.4 mg/kg
Mg	62.3 mg/kg	3600.0 mg/kg	2700.0 mg/kg

Table 7: Total amino acid content and composition of different parts of the *Broussonetia papyrifera* plant (dry matter basis) (Zhou, 2005)

Content (g /100g)				
Item	Leaves	Aggregate fruit	Male inflorescence	Fruit
Asp	2.55	2.84	2.08	1.50
Thr	1.07	0.39	0.29	0.36
Ser	0.80	0.38	0.46	0.40
Glu	3.13	1.37	3.41	2.18
Gly	1.55	0.73	0.98	1.05
Ala	1.65	0.51	0.43	0.54
Val	1.63	0.57	1.08	0.68
Met	0.41	0.06	0.15	0.09
Ile	1.42	0.47	0.72	0.54
Leu	2.50	0.70	1.06	0.91
Tyr	0.87	0.47	0.33	0.40
Phe	1.43	0.50	0.41	0.58
Lys	1.49	0.58	1.14	0.76
His	0.57	0.29	0.34	0.34
Arg	1.50	1.30	2.65	1.74
Pro	1.57	0.65	0.31	0.30
Cys	0.08	0.04	0.04	0.07

As shown in Tables 6 and 7, *B. papyrifera* leaves also have a high protein content, making them a potentially high-quality plant protein feed. However, they also contain anti-nutritional factors such as tannins. Tannins affect the digestion and absorption of nutrients mainly in combination with other substances in the diet (enzymes, sugars, proteins and metal ions), which can result in precipitation, thereby reducing the overall nutritional value. Processing of *B. papyrifera* leaves is therefore needed prior to potential use as a feed resource.

Feeding Effect

Feeding effect of *Morus alba*

At present, Mulberry leaves are widely used in poultry breeding. Different studies have shown that the addition of mulberry leaf powder to chicken feed has differing effects on laying performance, but a significant effect on overall egg quality [43]. A previous study examined the effect of adding 2.5, 5, 7.5 and 10% mulberry feed to the basic diet of China Agricultural University dwarf layers, revealing significant improvements in yolk color, the Haugh unit and egg shell thickness as well as indexes of egg shape and egg shell strength at amounts of 7.5 and 10.0% [44]. Study also examined the effect of adding 3, 6, 9 and 12% mulberry leaf powder to the diet of roman layers,and revealed significant increases in yolk color and reductions in damage to the shell [45]. At lower levels, the more powder that was added, the more significant the effect; however, at over 9%, a negative impact on egg production, average egg weight and feed efficiency was observed. Similarly, Wu et al. (2014) added 2, 4, 6 and 8% mulberry powder to the basal diet of Luoman brown layers and revealed a significant ameliorating effect on yolk color; however, at 8%, a significant decrease in total protein, globulin and albumin was observed ($P<0.05$) along with a significant decrease in food consumption and egg production ($P<0.01$). They therefore concluded that mulberry, as a protein feed resource, should not exceed 4% of the basal diet of laying hens. Mulberry leaf powder was also found to be beneficial in terms of muscle quality in broiler hens [46]. Addition of 5% mulberry leaves significantly improved the quality of breast muscle by increasing the content of polyunsaturated fatty acids and decreasing the content of saturated fatty acids and the omega 6 to omega 3 ratio. Moreover, Lan et al. (2012) reported that addition of 5% mulberry leaves to the broiler diet reduced the abdominal fat rate. Adding mulberry leaf powder to fowl diet was also found to reduce the phenomenon of feather pecking and decrease the ammonia content in fowl feces, thereby reducing environmental pollution [47].

In swine, addition of mulberry leaf powder to the diet of pigs was found to have a significant effect on pork quality and flavor [48]. Adding 10-15% forage mulberry to the basal diet of finisher pigs did not affect growth performance, and moreover, improved pork quality by slowing down the decrease in muscle pH after slaughter, increasing the fat, polyunsaturated fatty acid, total amino acid and linoleic acid content in the muscle, and decreasing the back fat thickness and content of saturated fatty acids. Meanwhile, another study revealed that basal diet containing 10% mulberry leaves had no effect on the growth rate of finisher pigs, but decreased the leaf lard percentage and back fat thickness, and increased the contents of inosinic acid and fat in the muscle, [49]. Moreover, the mechanism behind these effects was found to be the regulation of fat metabolism and deposition via regulation of sucrose, lipase and glucose-metabolizing enzyme activity in the liver. In addition, mulberry leaf powder was also found to have an important effect on growth performance, meat quality and serum biochemical indexes in finisher pigs [50]. For example, a significant decrease in the average daily gain and significant increase in the ratio of feed to gain was observed in 'Duroc × Yorkshire × Landrace' finisher pigs fed diet containing 15%

mulberry leaf powder in [51]. Moreover, at levels of 5, 10 and 15%, SOD activity and the urea nitrogen content increased significantly along with a significant decrease in the malondialdehyde content in the serum, thereby improving the overall antioxidant performance of the muscle. Furthermore, adding mulberry leaf powder to the diet of breeding sow was also found to have a significant impact on reproductive performance [51].

In herbivores, mulberry leaves can improve rumen fermentation efficiency and digestibility. For example, according to Huyen et al. [52], increasing levels of mulberry leaf pellets (MUP) at a rate of 600g mulberry leaf pellets/head/day, which can improve the apparent digestibility of dry matter, organic matter, crude protein, neutral detergent fiber and acid detergent fiber, and increase in total volatile fatty acid, acetate and butyrate concentrations and the acetate to propionate ratio with a linear. Studies also suggest that the addition of mulberry leaves after silage to the diet of beef cattle can significantly increase the fatty acid content of the meat, including that of arachidate and behenate [53]. Furthermore, addition of mulberry leaf flavonoids to the diet of calves had important effects on energy and nitrogen metabolism, rumen microbial protein synthesis and rumen fermentation [54]. An increase in the metabolizable energy rate and nitrogen biological value of pre-weaning calves, decrease in fecal energy and total excrete nitrogen, increase in the metabolizability of gross energy and utilization of nitrogen in post-weaning calves as well as improvements in rumen fermentation were also observed. Moreover, addition of mulberry leaf powder to the diet of Xiangdong black goats had similar effects, such as an increase in total volatile fatty acids and acetic acid contents, and a significant increase in the ratio of acetic to propionic acid [55]. Dietary supplementation with mulberry leaf powder therefore has significant beneficial effects on rumen fermentation. Mulberry leaves can also promote growth of herbivores to a certain extent, reducing the cost of feeding, and thereby improving economic efficiency. In general, mulberry leaf powder has the potential to reduce the feed gain ratio, while increasing dry matter intake, daily gain, and milk production and performance.

Moreover, in aquatic animals, with the shortage of fishmeal resources and increasing prices, the search is on for an alternative plant feed source. Mulberry leaf powder could therefore be added to aquatic feed as a protein source; however, its crude fiber content is high, and there are a number of anti-nutritional that could have negative effects on aquatic animals when added to excess. Chen et al. (2015) revealed no effects on growth when 40% fish meal was replaced with fermented mulberry leaf protein in a low fish meal diet (fish meal content: 5%), while 80% inhibited growth, but effectively reduced blood glucose and lipid contents. Moreover, Shen et al. (2016) confirmed these results, revealing that a low level of fermented mulberry leaf powder had no effect on growth of Tilapia, while high levels inhibited growth, but decreased serum lipid and blood glucose levels, and enhanced the antioxidant ability in hyperlipidemic Tilapia with in a dose-dependent manner. Overall, therefore, mulberry leaf powder could be added to aquatic animal feed, but not at excessive quantities.

Meanwhile, according to Hou [56], rex rabbit fed a diet supplemented with 10% mulberry leaf powder had a lower ratio of feed to weight gain, with an increase in amino acids in the muscles, improving overall flavor and meat quality. Since mulberry leaves have a high protein content, Jiao et al. (2016) also investigated its potential use as rabbit protein fodder, revealing no effect on the daily gain, feed intake or feed weight ratio. Mulberry leaf powder could therefore completely replace alfalfa as protein fodder for growing rabbits.

Feeding effect of Moringa

As mentioned above, Moringa is rich in nutrients and can therefore be used as feed for broiler and laying hens. Research on the application of Moringa in animal husbandry is therefore increasing. A study has shown that up to 15% Moringa leaf powder could be incorporated into the broiler diet without adverse effects on haematological and serum biochemical indices; however, up to 20% caused a significant increase in the uric acid concentration [57]. Moreover, Kumar et al. (2017) examined the effect of *M. oleifera* leaf meal on growth performance as well as the lipid profile and meat fatty acid composition of Vanaraja chicken, revealing a significant decrease in total cholesterol and triglyceride levels, and significant improvements in the fatty acid composition. Furthermore, addition of *M. oieifera* leaves also enhanced the ability of broiler hens to resist heat stress [58] and improved the meat quality and antioxidant capacity [59]. Moreover, *M. oleifera* leaf was also found to have a vital effect on performance, egg quality, plasma parameters and organ histopathological indices in laying hens [60]. Dietary supplementation with 5% *M. oleifera* leaf also improved yolk color and protein absorption without adverse effects on laying performance or egg quality [60]. Moreover, dietary supplementation with 8% was found to significantly decrease the concentration of low density lipoprotein and total cholesterol [61]. Thus, Moringa leaf powder has no negative effects on production performance, egg quality, the nutritional composition of the yolk or serum biochemical indexes in laying hens, while improving yolk color and decreasing blood fat. These findings are therefore highly significant in terms of the development of new feed resources.

In swine, research on Moringa is currently focused on finisher pigs. Cross-bred (Duroc × Landrace × Yorkshire) finisher pigs fed a basal diet supplemented with 3, 6 and 9% Moringa leaf showed a significant increase in final body weight, carcass straight length, serum SOD activity and average daily gain, with a significant decrease in the ratio of feed to gain, back fat thickness and serum malondialdehyde [62]. In addition, 5% Moringa oleifera leaf meal to finisher pig feed had no negative effect on feed conversion efficiency, carcass or meat quality traits, and even improved shelf life [63]. However, Moringa leaf powder was also found to have a negative effect on the growth performance of finisher pigs when the concentration was too high [64]. Meanwhile, in Mong Cai pigs, addition of Moringa leaf powder not only had no negative effect on growth, but also has maintained nitrogen balance, thereby improving the digestion and utilization of nitrogen [65]. According to these findings, Moringa-based meal could constitute an important protein source in the diet of growing pigs.

In herbivores, Moringa can also be used as high-quality roughage in dairy cow farming, mainly as green fodder and silage. *Moringa oleifera*, both fresh and ensiled, was previously compared with Elephant grass as the main feedstuff of dairy cows [66]. Accordingly, fresh Moringa treatment was found to increase the grassy flavor and aroma of the milk, while ensiled Moringa increased the digestibility of both protein and fiber. Meanwhile, the partial replacement of alfalfa hay and maize silage with *M. oleifera* silage had no negative effects on milk yield, in vivo nutrient apparent digestibility or serum biochemical indexes in lactating cows, thereby reducing feeding costs and increasing economic efficiency [67]. Due to its high protein content, it was also found that Moringa leaf meal could replace soybean meal in the dairy cow diet with no significant effect on milk composition or the organoleptic characteristics of the milk [68]. A study also revealed that milk yield, 4% fat corrected milk and energy corrected milk increased significantly in dairy cows fed *M. oleifera* [69]. More importantly, replacement of 50% alfalfa with *M. oleifera* leaves and peduncles was found to have an important impact on production performance, and plasma biochemical, antioxidant and immune indexes in lactating dairy cows [70]. It has also been shown that 15% Moringa leaf powder to the diet can increase milk yield and energy corrected milk and feed intake, while enhancing nutrient digestibility and ruminal fermentation in goats [71]. An increase in growth performance in goats was also observed, with improvements in carcass quality and flavor [72]. These studies all confirm that Moringa leaf powder can be used as a high-quality protein feed resource for ruminants.

However, in aquatic animals, Moringa application is very rare because of its anti-nutritional factors such as polyphenols, tannins, saponins and phytic acid, all of which have a negative effect on the growth and health of fish. However, studies also suggest that dietary supplementation with *M. oleifera* leaves significantly improves growth performance and increases the muscle protein profile, potentially improving the quality of fish and increasing aquaculture yield [73]. Thus, the use of Moringa as aquatic animal feed requires further attention.

Feeding effect of *Broussonetia papyrifera*

As mentioned above, *B. papyrifera* leaves are rich in protein, amino acids, vitamins and various trace elements, making them a good source of unconventional feed. A number of studies have reported that mulberry leaves could replace the basic diet of broiler hens, with no significant effect on yield. For example, adding fermented *B. papyrifera* leaves not only had no adverse effects on growth of AA broilers, but also increased the pH of the muscles and the content of IMP + HxR, thereby improving meat quality [74]. *B. papyrifera* leaves have also been shown to be suitable for laying hens. For example, Li [75] examined the effects on production performance, egg quality, serum biochemical parameters and immunity, revealing significant increases in yolk color, and the relative weight and thickness of the shell. Moreover, expression of IL-2 mRNA in the spleen was also significantly improved; that is, the Th1 immune response was promoted.

In swine, *B. papyrifera* leaves have mainly been used in growing and finisher pigs, with few reports on sows and weaned piglets. The leaves are rich in nutrients, but the fiber content is high and the protein structure is complicated, hindering digestion and resulting in nutrient loss if fed directly to monogastric animals. As a result, *B. papyrifera* leaves need to be processed prior to use. For example, studies have shown that adding fermented leaves to the diet can significantly reduce the thickness of the backfat and significantly increase the average daily gain of growing pigs as well as the content of free amino acids and sodium glutamate in the muscles, deepening the color of the meat [76]. It is well known that pork taste has a direct positive correlation with intramuscular fat content and meat flavor. Addition of *B. papyrifera* leaf powder could therefore have a positive effect on fat deposition in growing pigs, and therefore, taste of the final product. *B. papyrifera* leaves were also fed to growing pigs by fermentation, with improvements in both the quality and feed efficiency , as well as a positive weight gain effect [77].

In contrast, few reports have documented the application of *B. papyrifera* leaves in cattle and sheep diets. However, one study revealed that cow feed containing the leaves of *B. papyrifera* had no effect on milk production, milk fat or milk protein, but reduced economic costs [74]. In addition, positive effects on growth performance and the blood profile of West African Dwarf sheep were revealed [78]. Thus, while application of *B. papyrifera* leaves in herbivore diets remains limited, it could potentially replace expensive feeds, thereby reducing farming costs.

Conclusions

The findings of this review suggest that alternative resources such as *Morus alba*, Moringa and *Broussonetia papyrifera* could be used in animal feed, while maintaining productivity and the quality of meat, eggs and milk. Although research on the feeding value of woody plants in China has achieved fruitful results, and has since been applied to animal husbandry, resulting in economic, ecological and social gains, China's livestock and poultry feed conversion efficiency rates remain low because of continuing problems with the development, production and utilization of woody feed. To maximize the economic benefits, it is therefore necessary to fully understand the feed values, while developing further technologies aimed at actively realizing the production and application of woody feed. Comprehensive evaluation is therefore important to fully exploit the feeding value of woody plants. Moreover, the utilization value of woody plants is also significantly higher than that of herbaceous feed plants, and therefore, combined with existing feed resources in agriculture production, forestry, animal husbandry and other sideline industries, could aid further economic and ecological benefits.

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