INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
24–0091/2024/32–1–27–34
DOI: 10.17957/IJAB/15.2172
http://www.fspublishers.org

Review Article

Chemical Profiling, Antioxidant and Antimicrobial Activities of *Newbouldia laevis* and its Impact on Production Indices, Meat Quality, Blood Characteristics, Rumen Fermentation and Microbiology of Ruminants

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Received 17 February 2024; Accepted 08 March 2024; Published 26 May 2024

Abstract

The scarcity of quality fodder during the dry season poses a threat to sustainable ruminant production in developing nations. Thus, research into the use of the leaves of under-utilised plants as an alternative to conventional browse fodder has been advocated. One such under-utilised plant resource with both nutritional and medicinal properties is *Newbouldia laevis* (P. Beav) Seem. It is a medium-sized plant native to tropical Africa that belongs to the family Bignoniaceae. Nutritional and phytochemical constituents, as well as antioxidant and antimicrobial activities of *N. laevis* were discussed in this review. This paper indicates that leaves of *N. laevis* plants are high in protein, minerals, and fibre, but low in antinutrient factors. The plant is also endowed with important phytochemicals, including polyphenols, and flavonoids; with numerous studies showing their pharmacological properties, including antioxidant and antimicrobial activities. This review indicates that *N. laevis* bark and root extracts reduced methane emissions in ruminants. The result of the review shows the inclusion of *N. laevis* leaves beyond 50% may not be tolerated by ruminants for best performance. Knowledge gaps were identified, and future research directions were highlighted.

Keywords: *Newbouldia laevis;* Nutrient composition; Phytochemicals; Ruminants performance

Introduction

Ruminant production fulfils important economic and social functions in developing countries. Rural farmers in developing countries keep ruminants basically as an investment and source of manure or for meat at home or during festivals (Ikwuegbu *et al*. 1993). The main limitation to ruminant productivity in developing countries during the dry season is poor nutrition, as the primary feed materials (*i.e*., natural pastures and agro-by products) are high in fibre, low in nitrogen, and of poor quality. In view of this, efforts have centred on the use of abundant but unconventional browse plants that remain evergreen year-round as sustainable alternatives.

Newbouldia laevis (Fig. 1) is a medium-sized angiosperm in the Bignoniaceae family. It is native to tropical Africa and grows well in moist and well-drained soil (Arbonnier 2004). The plant is commonly called a boundary tree (Hausa - *Aduruku* or *Bareshi*; Igbo - *Ogirishi*; Yoruba-*Akoko*) that grows to a height of 2–3 m (Okeke 2003). The plant is available year-round, providing succulent greenish leaves for ruminant feeding, especially during the dry season when fodder quality is reduced. The leaves contain 42.24–71.62% dry matter (DM), 5.57–17.17% crude protein (CP), 2.49–12.00% total ash, 11.52–12.38% crude fiber (CF), 3.00–13.59% ether extract (EE), 21.74–55.98% carbohydrates, 50.98–52.00% neutral detergent fiber (NDF), 36.00–39.81% acid detergent fiber (ADF), 15.93% lignin, 23.88% cellulose, and 11.06% hemicellulose (Adelusi *et al*. 2016a; Ikhimioya *et al.* 2017a, b; Okpara 2021). The CP values reported for *N. laevis* leaves ranged from 5.57 to 17.17%, with the upper limit exceeding the 8% CP critical limit required for optimum microbial activities in the rumen (Norton 2003). Several parts of *N. laevis* plants are used in folklore medicine to treat a variety of ailments (Eyong *et al*. 2006; Akinpelu *et*

To cite this paper: Ogbuewu IP, M Mabelebele, CA Mbajiorgu (2024). Chemical profiling, antioxidant and antimicrobial activities of *Newbouldia laevis* and its impact on production indices, meat quality, blood characteristics, rumen fermentation and microbiology of ruminants. *Intl J Agric Biol* 32:27–34

al. 2008). Analytical studies indicate that *N. laevis* contain glycosides, alkaloids, flavonoids, terpenoids, furan naphthoquinones and benzofuran derivatives (Gormann *et al*. 2003; Akerele *et al*. 2011; Iwu *et al*. 2012; Anaduaka *et al*. 2013; Ayoola *et al*. 2016), and this may explain their pharmacological effects, including antioxidant, anti-cancer, anti-antimicrobial, and wound healing properties (Kuete *et al*. 2007; Usman and Osuji 2007). Based on the medicinal and nutritional properties of *N. laevis*, the current paper attempts to discuss current knowledge on the chemical composition, pharmacological (antioxidant, and antimicrobial) properties of *N. laevis*, as well as the effect of its inclusion on ruminant diets on growth performance, nutrient digestibility, blood characteristics, rumen fermentation parameters, and the rumen microbiology of ruminants, to identify knowledge gaps and unveil future research directions.

N. laevis as a source of essential nutrients

The results of proximate analysis are widely used in research and industry for rapid estimation of nutrients in feed resources and finished feed (AOAC 2000). Though such findings may not provide an accurate picture of the nutrient content of the feed, they do provide clues for further studies. Analytical studies indicate that different parts of *N. laevis* contain CP, fibre, ash, carbohydrate and crude fat (Table 1). Ikhimioya *et al*. (2007); Khaled (2021) showed that *N. laevis* leaves contained 42.24% dry matter (DM), 5.68–15.57% CP, 5.61–13.59% EE, 10.54% CF, 2.15–2.49% ash, and 21.02% carbohydrates, which were lower than the 9.63% CP and 5.27% ash found in *N. laevis* roots (Ojeaga *et al.* 2018). The soil type and plant parts used could explain the difference. However, the CP level of 9.63% reported for *N. laevis* roots by Ojeaga *et al*. (2018) were higher than the value of 8.44% reported for *Panicum maximum* by Ikhimioya and Imasuen (2007). In addition, the protein content in *N. laevis* leaf was lower than the 25.85% reported in *Microdesmis puberula*, but higher than the value of 13.65% reported in *Diodia scandens* by Okoli *et al.* (2003). Studies have shown that season, plant part, age, soil type, plant species, location, and stage of maturity affect plant nutrient contents (Norton 1994), and this could explain the observed differences. Table 1 indicates that protein content of *N. laevis* leaves ranged from 5.57 to 17.17%, with the upper limit exceeding the 10–12% minimum crude protein requirements of ruminants as estimated by ARC (1985). According to Norton (2003), protein provides the ammonia needed by rumen microbes for optimal growth.

N. laevis is moderately rich in ether extract (fats), which serve as a source of bioactive compounds (Verma 2006). The moderate concentration of ether extract in *N. laevis* suggests that it can be used as an energy source in livestock feed (Odedire and Babayemi 2008). The ash content reflects the amount of minerals contained in feed samples; therefore, the *N. laevis* contained significant quantities of minerals (Aborisade *et al.* 2017). The protein and ash content reported by Khaled (2021) for *N. laevis* was lower than the 28.11% CP and 4.81% total ash earlier reported for the same plant by Gidado *et al*. (2003). The total ash value of 8.38% obtained for *N. laevis* by Yusuf *et al.* (2013) was lower than the 2.51% reported for the same plant by Ayoola *et al.* (2016). The differences in total ash values between the authors can be explained by the fact that the nutrient content of leaves varies with season, soil type, and analytical methods.

Dietary fibre has attracted a lot of research attention in livestock production due to the benefits it provides to animals. In the ruminants, fibre is used as a source of energy by the rumen microbes, whereas in non-ruminants, it helps in feed digestion and nutrient utilisation when consumed at a moderate level. The fibre levels obtained in cassava leaves (15.6%) and guava leaves (16.1%) by Aduku (1999) were comparable to the values reported for *N. laevis* (Table 1). Available research indicates that *N. laevis* is high in neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, hemicellulose, and lignin (Table 1). Research has revealed that *N. laevis* leaves contain significant amounts of retinol (vitamin A), ascorbic acid (vitamin C), and tocopherol (vitamin E), which have the ability to mop up excess free radicals and prevent oxidative damage in small animal models and humans (Anaduaka *et al*. 2013). Furthermore, Uja *et al*. (2022) found that *N. laevis* contained appreciable amounts of vitamin B_1, B_2, B_6, B_9, C, D, E, K, β-carotene and vitamin A.

N. laevis as a source of phytochemicals, bioactive compounds, antioxidants, and antimicrobials

N. laevis contains a huge array of phytochemicals commonly called secondary metabolites. These compounds are produced by plants in response to environmental stress, diseases, and insect attacks (Khoddami *et al.* 2013). Some of the phytochemicals detected in *N. laevis* (leaf, root, stem, and bark) include alkaloids, saponins, tannins, flavonoids, terpenoids, phenols, phenylpropanoids, and several others (Germann *et al.* 2006; Anaduaka *et al.* 2013; Habu and Ibeh 2015; Adelusi *et al*. 2016a, b; Ayoola *et al*. 2016). *N. laevis* leaves contain 40.78% flavonoids, 21.73% alkaloids, 15.99% saponins, 1.03% cyanides, and 12.13% glycosides/reducing sugars (Bosha *et al.* 2018). Adelusi *et al*. (2016a, b) showed that *N laevis* leaves are richer in tannins than *P. maximum, Spondia mombin* and *Azadirachta indica* plants. In a related study, Habu and Ibeh (2015) and Ayoola *et al.* (2016) revealed that *N laevis* leaves contain an appreciable amount of flavonoids, terpenoids, alkaloids, polyphenols and cyanides. Usman and Osuji (2007) also show that the methanolic leaf extract of *N. laevis* contains tannins, flavonoids, steroids, terpenes, and cardiac glycosides. The pharmacological activities of some of these bioactive compounds, including antimicrobial, antioxidant, and antiviral activities, have been demonstrated (Habu and Ibeh 2015; Ayoola *et al.* 2016). Natural antioxidants such as phenolic compounds, ascorbic acid (vitamin C), tocopherols (vitamin E) and flavonoids have been detected in *N. laevis* (Anaduaka *et al*. 2013; Habu and Ibeh 2015; Bosha *et al*. 2018). A report from a phytochemical study revealed that *N. laevis* stem bark is rich in flavonoids (Table 2), which have been documented to have various pharmacological properties. Ayoola *et al*. (2016) put the flavonoid level of *N. laevis* leaf at 392 mg/100 g, which was greater than the value of 7 mg/100 g reported in *Alium sativum* bulb, indicating that *N. laevis* leaf is higher in flavonoids than *A. sativum* bulb.

The neuroprotective and cardio-protective properties of quercetin, a potent antioxidant flavonoid, have been reported by Costa *et al*. (2016). The flavonoid content of *N laevis* leaves reported by Ayoola *et al.* (2016) was also higher than the values of 187.2, 145.44 and 180.00 mg/100 g reported for *Gongronema latifolium*, *Mucuna pruriens*, and *Garcinia kola* leaf meals, respectively, by Okoli *et al*. (2019). Dermane *et al.* (2020) showed that leaf extracts of *N. laevis* plant contained withasomnine and newbouldine. The use of *N. laevis* for the treatment of malaria in traditional medicine could be ascribed to the presence of withasomnine in the plant, which has been reported to exhibit strong antimalarial activity (Fieser 1927). *N. laevis* root bark contains lapachol derivatives (*i.e*., naturally occurring naphthoquinones compounds), which have been found to possess anticancer, antimicrobial, and antitumor activities (Dermane *et al.* 2020).

Research has suggested that most animal and human degenerative diseases are caused by harmful free radical reactions (Khan *et al*. 2018). Several herbal products have been shown to have free radical scavenging properties, which could be linked to the presence of polyphenolic compounds (Pettersen *et al*. 2004; Kumar *et al*. 2012). Antioxidant compounds have also been shown to boost immunity and protect the structural integrity of immune cells (Carr and Maggini 2017). 2, 2-diphenyl-1-picrylhydrazyl (DPPH) has been routinely employed to assess the antioxidant activity of herbal products (Ogbuewu and Mbajiorgu 2023; Omeje *et al.* 2023). The dose-dependent DPPH radical scavenging potential of *N. laevis* leaf extract has been highlighted (Habu and Ibeh 2015). *N. laevis* has antioxidant activity comparable to ascorbic acid (Habu and Ibeh 2015; Omeje *et al*. 2023). The antioxidant properties of *N. laevis* could be attributed to a high level of flavonoids, such as quercetin, naringin, luteolin, kaempferol, and myricetin, all of which have been shown to have antioxidant ability (Kumar *et al*. 2012). Furthermore, the presence of tannins in *N. laevis* plant (Adelusi *et al.* 2016b) would have contributed to its antioxidant potential. Tannins and alkaloids have previously been shown to have free radical-scavenging properties (Patel *et al.* 2012; Deng *et al.* 2019). Evidence abounds that *N. laevis* stem-bark extract has higher DPPH and OH* scavenging abilities than the *N. laevis* leaf extract (Akomolafe *et al.* 2018; Salemcity *et al.* 2020). Also, *N. laevis* stem-bark extract has a higher FRAP potential than the leaf extract (Habu and Ibeh 2015). These findings indicate that bioactive compounds isolated from *N. laevis* plant could be used to treat varieties of chronic degenerative diseases in which oxidative damage and inflammatory processes play crucial roles in their pathogenesis.

The recognition and use of *N. laevis* as an antimicrobial agent in farm animals and humans has been attributed to their high phytochemical composition. Terpenoids, one of the phytochemicals detected in *N. laevis* have been reported to possess antimicrobial properties, which could be attributed to their ability to disrupt the integrity of microbial cell membranes, resulting in bactericidal effects (Tawheed and Monika 2014). *N. laevis* has antibacterial activity against *Proteus mirabilis*, *Escherichia coli*, *Salmonella* sp., *Klebsiella* sp., *Pseudomonas aeruginosa* and *Staphylococcus aureus* (Usman and Osuji 2007; Khaled 2021), which might be ascribed to the inhibitory effect of its phytochemicals on microbial cell membranes. Antimicrobial screening revealed that *N. laevis* is effective against *Salmonella typhi*, *S. aureus*, *P. aeruginosa*, *Candida albican* and *Aspergillus niger* (Orakwue and Obiogbolu 2021). Similarly, *N. laevis* is active against *S. aureus* and *E. coli* and this antibacterial action can be linked to the action of their phytochemicals, such as tannins, saponins, and alkaloids contained in the plant (Obum-Nnadi *et al.* 2020). The antimicrobial activity of *N. laevis* extract can be linked to the synergistic action of its bioactive compounds. Furthermore, Iwu *et al.* (2018) showed that *N. laevis* leaf extract inhibited the growth of *P. aeruginosa, S. aureus, E. coli, S. typhi, C. albican* and *A. niger*. Research suggests that *N. laevis* has high antibacterial activity against blood pathogens compared to some conventional antibiotics (Akande *et al.* 2020).

Effects of *N. laevis* on ruminant performance

Growth performance and nutrient digestibility: Okpara (2021) found that West African dwarf (WAD) goats fed a concentrate diet supplemented with *P. maximum* leaf meal (*i.e*., the control diet) had better average daily gain (ADG), feed intake, and feed conversion ratio (FCR) than goats fed fresh, air-dried and sun-dried *N. laevis* leaf meals. This effect could be due to the presence of anti-nutritional factors in *N. laevis*, such as saponins, tannins, oxalate, phytic acid, trypsin inhibitors, and haemagglutinnin (Ikhimioya *et al*. 2007), which may negatively affect nutrient utilisation when certain thresholds are exceeded. On the contrary, Yusuf *et al*. (2016a) found improved feed intake, ADG, and FCR in WAD rams that received *N. laevis* leaf extracts at 30 and 60 mg/kg for 3 consecutive days for 14 weeks. In the same study, the authors revealed that administration of *N. laevis* leaf extracts to rams at 30 and 60 mg/kg for 3 consecutive days for 14 weeks had no reduction effect on faecal egg counts. This observation is in agreement with Adelusi *et al*.

Table 1: Nutritional composition of different parts of *N. laevis* plant

	Plant part						
	Leaf*	Leaf **	Leaf+	Root##	Leaf***	Leaf#	Stem++
Dry matter (%)	92.80	-	42.24 - 45.00			84.47	
Crude protein (%)	18.72	9.81	6.68 - 15.57	9.63	16.22	12,26	
Crude fat (%)	24.70	16.50	5.61-13.59		20.87	16.30	
Crude fibre (%)	32.46	33.40	10.54-13.28		30.46	15.60	
Ash (%)	8.38	7.90	2.49 - 2.51	5.27	8.16	4.27	
Carbohydrates (%)	15.74	26.66	21.02-55.98		18.49	36.03	
NDF %		50.87^	20.22-50.98	37.15			
ADF %		39.81^	39.81	31.50			
Lignin		15.93^	15.93				
Cellulose		23.88^	23.88				
Hemicellulose %		11.06^	11.28	15.65			
Calcium %		0.51^					
Phosphorus %		0.26^					
Potassium %		1.02^					
Sodium %		0.17^					
Magnesium %		0.27^					
Copper mg. kg^{-1}		5.26^					
Iron mg. kg^{-1}		77.83^					
Manganese mg. kg^{-1}		102.67^					
Zinc ppm		59.27^					
Vitamin A (mg/100 g)	5.19++						3.01
Vitamin C (mg/100 g)	2.35++						1.05
Vitamin E (mg/100 g)	9.33++						4.08
Magnesium (mg/100 g)	76.12++						54.25
Iron (mg/100 g)	16.84++						1.19
Selenium (mg/100 g)	3.08++						0.29

Source: *Yusuf *et al.* (2013); **Ushie *et al.* (2021); +Ayoola *et al.* (2016); +Ikhimioya *et al.* (2017 a, b); ++Anaduaka *et al.* (2013); ***Orakwue and Obiogbolu (2021); #Isah *et al.* (2013); ##Ojeaga *et al.* (2018); ^Ikhimioya *et al.* (2007); +Khaled (2021)

(2016b) who found numerically higher feed intake and ADG in male WAD rams offered a concentrate diet supplemented with *N. laevis* leaves at 40 g/day at 2% of BW than those fed a diet without *N. laevis* leaves supplementation. Reportedly, WAD goats fed *P. maximum* or *Pennisetum purpureum* supplemented with *N. laevis* leaves at 25 and 50% had improved ADG, and FCR than those fed diet without *N. laevis* leaves, thus enhancing growth performance (Isah *et al*. 2013; Ikhimioya *et al*. 2017b).

Female WAD goats fed a diet containing *N. laevis* leaves at 25 and 50% had improved digestibility values for DM, NDF, ADF, lignin, hemicellulose and cellulose (Ikhimioya *et al*. 2017a). This improvement could be attributed to a high level of CP in *N. laevis* leaves, which can be attributed to their high CP level, which increased the proliferation of the rumen microbes, and hence increased fibre digestion in the rumen. This observation implies that the proteins present in *N. laevis* leaves were easily degraded in the rumen, which may have assisted in fibre degradation. Ikhimioya *et al.* (2017a) also found higher organic matter in WAD goats fed *N. laevis* leaves at 25 and 50%, indicating that large amounts of nutrients may bypass the rumen microbes. Adelusi *et al*. (2016 b) revealed that goats on the control and *N. laevis*-supplemented diets had comparable NDF, ADF, and CP digestibility. The similar CP digestibility can be ascribed to the presence of tannins in *N. laevis* leaves, which at a moderate level promote post-ruminal digestion and absorption of protein (McMahon *et al.* 2000). In the same experiment, the authors discovered that goats fed *N. laevis* leaves had higher nitrogen retention than those fed a concentrate diet, and this can be due to the higher CP and moderate tannin content of the leaves (Yusuf *et al.* 2013; Orakwue and Obiogbolu 2021). A similar pattern was identified in female WAD goats fed *N. laevis* leaves at 25 and 50% (Ikhimioya *et al.* 2017a). The higher nitrogen balance and retention in goats fed *N. laevis* leaves suggest that supplementing basal diet with *N. laevis* leaves at 25 and 50% can provide sufficient proteins for ruminant maintenance and growth, particularly during the dry season when the quality of available grasses and fodders is reduced. The improved nitrogen balance witnessed in goats offered *N. laevis* leaves might be linked to the high CP level of the leaves (Ikhimioya 2008). This observation is consistent with the results of Ikhimioya *et al.* (2007c) in WAD sheep. In a related study, Yusuf *et al.* (2016b) observed similar dry matter intake, ADG, and protein efficiency ratios in goats aged 9 to 12 months fed a basal diet containing dried *N. laevis* leaves at 0, 5, 7.5 and 10% for 56 days. In a similar study, Ngodigha and Oji (2009) noticed a lower rate of degradation of *N. laevis* leaves in cattle rumen when compared with *Palisota hirsuta*. The high content of lignin in *N. laevis* leaves may account for their slow degradation rate (Ikhimioya *et al*. 2007; Ngodigha and Oji 2009; Ayoola *et al.* 2016). This also suggests that *N. laevis* leaves may have undergone significant lignification at the time they were harvested.

Haematology and blood chemistry

Blood is employed in nutritional assessment to determine the quality of feedstuffs and finished feed (Ogbuewu *et al*. 2015; Ogbuewu and Mbajiorgu 2023). Ikhimioya and Imasuen (2007) showed that supplementation of *N. laevis* leaf in ruminant diet at 25–50% supported the production of blood components. The packed cell volume (PCV) of 29.40–34.00% recorded by Ikhimioya and Imasuen (2007) in ruminants fed *N. laevis* leaves at 25–50% fell within the value (21–35%) reported for goats (Daramola *et al*. 2005). However, these values were below the values of 35.50–36.90% reported for WAD goats by Taiwo and Ogunsanmi (2003). However, differences in sex, breed, diet composition and age of goats may explain the effect (Taiwo and Ogunsanmi 2003; Daramola *et al*. 2005). The numerically higher haemoglobin (Hb) counts in goats fed *N. laevis* leaves confirm the earlier report that the plant is rich in crude protein. There are linear relationships between Hb and protein intake and increase with increasing dietary protein intake (Ndlovu *et al*. 2007). This observation is in agreement with Yusuf *et al*. (2016b) who noticed increased Hb and erythrocyte counts in WAD goats fed a concentrate diet having 5 and 10% milled *N. laevis* leaves. Serum proteins are vital in the immune response, osmotic regulation, and transportation of various substances in the animal body (Jain 1986). A body of evidence suggests that *N. laevis* leaves improved serum protein in goats (Esugbohungbe and Oduyemi 2002; Ikhimioya and Imasuen 2007), suggesting their safety as a novel feed resource in goats. In a similar study, Adelusi *et al.* (2016a) found that inclusion of 40 g *N. laevis* leaf meal per day in a concentrate diet at 2 kg BW increased the concentration of blood urea nitrogen in male WAD goats.

Rumen fermentation and microbiology

Ruminants have been identified to produce greenhouse gases, particularly methane (Steinfeld *et al.* 2006), which, when released into the environment, contribute to global warming. According to the UNFCCC (2007), methane has a 21-fold higher global warming ability than carbon dioxide. Available research shows that methane production from ruminants reduces nutrient uptake from the digestive tracts (Woyengo *et al*. 2004). Given the foregoing, animal nutritionists are looking for ways to manipulate the rumen microbiota composition to reduce methane emissions by ruminants and increase their productivity. A study by Ojeaga *et al.* (2018) showed the potential of the barks and roots of *N. laevis* plant to reduce methane emissions in ruminants. The potential of *Carica papaya* seed, *Spondias mombin* seed, *Azadiracta indica* bark/stem, *Alstonia boneei* leaves, *Psidium guajava* leaves and *Sida acuta* root to reduce *in vitro* methane production in ruminants has also been reported in the literature (Ojeaga *et al*. 2018). The ability of bioactive compounds in *N. laevis* roots to inhibit the activity of ammonia-producing bacteria may account for the decrease in methane emission (Wallace *et al.* 2002), resulting in improved nitrogen utilization. In contrast,

Table 2: Flavonoids constituent of the stem bark extract

Constituents	Concentrations (mg/100 g)
(+)-catechin	47.11
Apigenin	15.68
Resveratrol	3.80
Genistein	1.22
Daidzein	6.77
Butein	5.35
Naringenin	8.23
Biochanin	8.41
Luteolin	18.90
Kaempferol	41.54
(−)-epicatechin	5.77
(−)-epigallocatechin	1.63
Gallocatechin	1.45
Quercetin	37.64
(−)-epicatechin-3-gallate	2.83
(−)-epigallocatechin-3-gallate	2.73
Isorhamnetin	11.83
Robinetin	5.94
Myricetin	7.26
Baicalein	5.46
Nobiletin	3.72
Tangeretin	2.73
Artemetin	2.13
Silymarin	1.87
Naringin	15.49
Hesperidin	2.47

Source: Omeje *et al*. (2023)

Fig. 1: *Newbouldia laevis* plant
Source: https://en.wikipedia.org/wiki/Newbouldia

Adelusi *et al.* (2016a) found that the addition of NLL meal to a diet of male WAD goats at 40 g/day increased rumen NH_3N production, total volatile fatty acids (VFAs) and methane production. The increase in ammonia nitrogen (NH_3N) concentration in male WAD goats fed *N. laevis* leaf meal indicates the ability of *N. laevis* leaf meal to supply soluble nitrogen to the rumen microbes, thus increasing rumen microbial activity. This finding supports Ranjah (1980) who demonstrated that the level of NH_3 in the rumen fluid is determined by the quantity and solubility of protein offered to the animals. Furthermore, the reported increase in VFA concentration in goats fed *N. laevis* leaf meal at 40 g/day, suggesting increased microbial activity in the rumen (Woyengo *et al*. 2004). The inability of *N. laevis* leaf meal to suppress methane production in WAD goats, as demonstrated by Adelusi *et al.* (2016a), may be explained by the low level of saponin in the leaves, which has been reported to hinder the activities of methanogens and protozoa, which are the main rumen microorganisms involved in methane production (Sliwinski *et al*. 2002). This observation contradicted the results of Ojeaga *et al*. (2018), who reported that *N. laevis* barks and roots reduced methane production in ruminants. The reported difference could be partly explained by the part of the plant used.

Isah *et al*. (2013) found that supplementing the basal diet of *P. purpureum* with *N. laevis* leaves reduced total coliform and total fungi counts in the rumen of WAD goats by 38% while increasing the total microbial, total yeast, and lactic acid bacteria (LAB) counts by 66, 88 and 83%, respectively. The reduction in coliform and fungi counts could be ascribed to the presence of tannins present in the *N. laevis* leaves (Ikhimioya *et al*. 2007). The decline in the number of bacteria in the rumen of ruminants fed *N. laevis* could be attributed to a decrease in the population of gram-positive bacteria, which are prone to inhibition action by plant compounds than did gram-negative bacteria (Davidson and Naidu 2000). Isah *et al* (2013) also detected the presence of *Saccharomyces cerevisiae, Lactobacillus lactis*, *Micrococcus acidophilus*, *Bacillus subtilis*, *Proteus morganii*, *Streptococcus lacis* and *Aspergillus terreus* in the rumen of WAD goats *N. laevis* leaves as against *B. cereus*, *Pseudomonas aureginosa*, *Protecus vulgaricus*, *Staphylococcus aureus*, *B. macerans*, *S. faecum*, *M. acidophilus*, *L. lactis*, *S. cerevisiae* and *A. niger* found in ruminants fed a basal diet of *P. purpureum.* This finding implies that *N. laevis* leaves supplementation modified the composition of rumen microbes.

Meat quality

The preservative influence of *N. laevis* leaf extracts on the shelf-life of fresh meat in tropical environments has been reported (Popoola *et al.* 2020). The high ambient temperature prevalent in the tropics promotes the activities of reactive oxygen species and spoilage microbes, thereby reducing the shelf life of fresh meat. Popoola *et al*. (2020) found that aqueous extracts of wet and dried leaves of *N. laevis* plants reduced oxidative rancidity and the population of spoilage microbes in fresh meat under tropical conditions. The reduced oxidative rancidity of fresh chicken meat treated with aqueous extracts of *N. laevis* leaves could be attributed to the free radical scavenging ability of flavonoids found in the plant, which, according to Atmani *et al.* (2009) protect biological systems from free radical attack. Leaves of *N. laevis* leaves have been shown to have antimicrobial activity (Kuete *et al.* 2007; Usman and Osuji 2007), which could explain the reduction in the population of deterioration microbes in fresh goat meat treated with an aqueous extracts of *N. laevis* leaves in a tropical environment. Popoola *et al*. (2020) also revealed that fresh goat meat treated with aqueous extract of *N. laevis* leaves improved the colour intensity and shelf life at 48 h post-slaughter.

Research gaps identified

Available reports indicate scanty data on the mineral, vitamin, and amino acid composition of various parts of *N. laevis*. Given the potential of *N. laevis* in improving ruminant productivity, there is knowledge gap on the inclusion level of *N. laevis* that supported the best production and health parameters, as well as the mechanisms of action of its bioactive compounds. Furthermore, there is little or no published evidence on the effect of *N. laevis* on the internal organs of ruminants. Aside from the preservative effect of aqueous *N. laevis* leaf extracts on the shelf life of fresh ruminant meat, it is critical to investigate the effect of dietary *N. laevis* supplementation on milk yield, milk composition, and meat quality of ruminants, as such data is lacking. Moreso, there is a scarcity of reports on the efficacy of *N. laevis* extracts in controlling the intestinal parasites in ruminants. There is also a knowledge gap on the blood and meat antioxidant activities of ruminants on dietary *N. laevis* supplementation.

Conclusion

This review indicates that various parts of *N. laevis* leaves are rich in crude protein and phytochemicals with the potential to improve ruminant productivity. The result of this review indicates that *N. laevis* has antimicrobial and antioxidant properties. This investigation also showed that inclusion of *N. laevis* leaves at 50% in ruminant diets resulted in better nutrient digestibility and body weight gain. The findings of this study showed that the bark and roots of *N. laevis* reduce methanogenesis in ruminants. However, more research should be done to determine the inclusion levels of *N. laevis* that optimised body weight gain, rumen fermentation parameters, nutrient digestibility and blood indices in ruminants, as such reports are lacking. In addition, more studies should be done to better understand the mechanisms of action of *N. laevis* bioactive compounds in reducing methane emission in ruminants.

Acknowledgements

The authors acknowledge the staff of e-Library of Federal University of Technology Owerri for their assistance.

Author Contributions

IPO, MM and CAM conceptualised the study, IPO and MM searched the literature and synthesised the Tables and Figures, MM, IPO and CAM drafted the manuscript and interpreted the results.

Conflicts of Interest

All the authors have no conflict of interest to declare.

Data Availability

Data are available as figures and tables without restriction.

Ethics Approval

Not applicable in this study.

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