Tropical Grasslands-Forrajes Tropicales (2023) Vol. 11(3):183–197
doi: 10.17138/TGFT(11)183-197

Review Article

The potential role of *Indigofera zollingeriana* as a high-quality forage for cattle in Indonesia

El papel potencial de Indigofera zollingeriana *como forraje de alta calidad para el ganado en Indonesia*

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Abstract

Ownership of cattle in Indonesia is dominated by smallholder farmers, who rely heavily on low-quality mature grasses and crop residues as animal feed. Forage tree legumes (FTLs) provide a practical and profitable option for supplying nutrients limiting cattle growth and reproduction, especially during the dry months. *Indigofera zollingeriana* is a tall, high-yielding plant under investigation as feed, which can produce edible plant material exceeding 4 t dry matter (DM)/ha/harvest, when cut every 68 days. *I. zollingeriana* is adapted to a relatively wide range of climatic conditions and soil-types, with notable high tolerance of acidic soils. Forage quality is high, with high crude protein (265 g/kg DM average) and low fiber (367 g neutral detergent fiber/kg DM) concentrations and high in vitro DM digestibility (72.6%). It contains no identified anti-nutritional compounds but concentration of indospicine, a recognized toxic contaminant in some species of *Indigofera*, is currently unknown. Information on animal responses to feeding *I. zollingeriana* is limited, especially for cattle, but research suggests growth responses in goats are comparable with those for other available FTLs. Research to date suggests *I. zollingeriana* could be a valuable addition to FTLs currently available in Indonesia, especially for acidic soils, but further information is required on performance on saline soils, persistence under regular harvesting, indospicine status, acceptance by cattle and effects on their productivity.

Keywords: Animal production, anti-herbivory, forage-tree legume, growth, nutritive value, preference.

Resumen

En Indonesia, la ganadería está dominada por los pequeños agricultores, que dependen en gran medida de pastos maduros y residuos de cultivos de baja calidad para alimentar a sus animales. Las leguminosas forrajeras arbóreas (FTL en inglés) ofrecen una opción práctica y rentable para suministrar los nutrientes que limitan el crecimiento y la reproducción del ganado, especialmente durante los meses secos. *Indigofera zollingeriana* es una planta de porte alto y de alto rendimiento que se está investigando como forraje, y que puede producir material vegetal comestible superior a 4 t de materia seca (MS)/ha/cosecha, cuando se corta cada 68 días. *I. zollingeriana* se adapta a una gama relativamente amplia de condiciones climáticas y tipos de suelo, con una notable tolerancia a los suelos ácidos. La calidad del forraje es alta, con altas concentraciones de proteína cruda (265 g/kg MS promedio) y baja de fibra (367 g de fibra detergente neutra/kg MS) y alta digestibilidad in vitro de la MS (72.6%). No contiene compuestos antinutricionales identificados, pero actualmente se desconoce la concentración de indospicina, un contaminante tóxico reconocido en algunas especies de *Indigofera*. La información sobre la respuesta de los animales a la alimentación con *I. zollingeriana* es limitada,

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especialmente en el caso del ganado vacuno, pero las investigaciones sugieren que las respuestas de crecimiento en cabras son comparables a las de otros FTL disponibles. Las investigaciones realizadas hasta la fecha sugieren que *I. zollingeriana* podría ser una valiosa adición a los FTL actualmente disponibles en Indonesia, especialmente para suelos ácidos, pero se requiere más información sobre el rendimiento en suelos salinos, la persistencia bajo cosecha regular, el estado de indospicina, la aceptación por el ganado y los efectos sobre su productividad.

Palabras clave: Antiherbivoría, crecimiento, leguminosa arbórea forrajera, preferencia, producción animal, valor nutritivo.

Introduction

Consistent with other developing countries, the demand for red meat, especially beef, in Indonesia is growing with increasing population growth, urbanization, economic strength and per-capita income of the consumer class (Delgado et al. 1999). Currently, the demand for beef markedly outstrips domestic supply with only about half the beef consumed being produced locally (Agus and Widi 2018), despite a long-standing target of self-sufficiency in beef set by successive Indonesian Governments since 1999 (Beef Self-sufficiency Programs, Program Swasembada Daging Sapi PSDS-2005, PSDS-2010 and PSDS-2014) (Chang Hui-Shung et al. 2020). However, an increase in the national cattle herd is restricted by increased urbanization, competition for land for cropping and additional labor inputs required to manage higher cattle numbers (Delgado et al. 1999; Panjaitan et al. 2008). Thus, meaningful increases in beef production in Indonesia in future will be heavily reliant on increasing production per animal, which must be achieved largely within the smallholder farming sector with responsibility for more than 80% of total beef production (Hadi et al. 2002; Agus and Widi 2018).

Beef production systems vary considerably across regions of Indonesia, closely aligned with other demands on the land. In more populated regions of eastern Java, where land availability for cattle production is limited by demands for cropping, feeding systems rely heavily on utilization of crop residues, by-products and available concentrates (Priyanti et al. 2012). In other regions, traditional village systems are based on utilization of native and introduced forages, either grazed or cut-and-carried. Animal productivity is inherently low in these village systems in terms of low growth, calving rates and sale weights of cattle (Dahlanuddin et al. 2019). This is demonstrated in studies carried out with Bali cattle (*Bos javanicus*), a small breed (males 335–363 kg, females 211–242 kg, average body weight) which predominates in the eastern regions of Indonesia. Growth rates of Bali cattle did not exceed 0.3 kg liveweight gain/day where their main feed source was native grass (Damry et al. 2008; Panjaitan et al. 2008; Panjaitan 2012; Quigley et al. 2009; Dahlanuddin et al. 2012; Marsetyo et al. 2012), improved tropical grasses, including elephant grass (*Cenchrus purpureus*) (Quigley et al. 2009; Marsetyo et al. 2012) or corn stover (Marsetyo et al. 2012; 2021). These growth rates are well below the value of 0.85 kg liveweight gain/day reported by Mastika (2003) for Bali cattle fed concentrates, which probably approaches their genetic potential. These findings confirm that locally harvested grasses and crop residues provide insufficient nutrients, especially protein (Quigley et al. 2009), for anything more than modest growth and reproduction. Apart from the low quality of the diet, production is often limited by the inadequate quantity of forage provided, especially during the dry season when availability of forage is limited (Bamualim and Wirdahayati 2003; Pengelly and Lisson 2003; Dahlanuddin et al. 2009; Panjaitan 2012). Furthermore, poor sanitation in crowded pens has led to a high incidence of disease and calf mortality (Dahlanuddin et al. 2009). The modelling of Lisson et al. (2010) showed that it is the integration of the various component feeding options into a smallholder farming system that provides the best chance of adoption and productivity increases. There is ample scope to increase productivity on a per animal basis by the smallholder farming sector (Hadi et al. 2002; Priyanti et al. 2010).

Feeding options for increasing beef production

Nutrient intake of cattle can be increased by feeding concentrates, either produced locally as by-products of agroindustries, including rice bran, copra meal, cassava meals and palm kernel meal, or imported from outside the region, leading to growth rates well in excess of those reported above with low-quality forage or crop residues (Moran 1985; Mastika 2003). However, uptake of concentrate feeding by smallholder farmers is relatively low due to skepticism by farmers about the benefits of feeding and their lack of technical knowledge, unreliable continuity of access to concentrates, variable composition of concentrates, high cost and the need to outlay scarce funds for feeding well in advance of the additional income realized on sale of the animals.

An alternative to feeding concentrates is to provide additional nutrients in the form of nutrient-rich forage. Forage tree legumes (FTLs) have an important role to play in improving nutrition of livestock in Indonesia, although their usefulness goes beyond providing high-quality forage to ruminants and monogastric animals. Additional benefits suggested by Gutteridge and Shelton (1994) included: stabilizing sloping lands against erosion; supplying N-rich mulch for crops; rehabilitation of adverse environments such as saline or arid landscapes; providing a source of firewood; acting as living fences; and providing shade for plantation crops. The extent to which they perform these roles defines their usefulness in a multi-purpose farming situation.

The most widely used FTLs in Indonesia are *Leucaena leucocephala* (Lam.) de Wit, *Sesbania grandiflora* (L.) Poiret and *Gliricidia sepium* (Jacq.) Steud. These tree legumes produce nutrient-rich foliage with crude protein (CP) concentration usually exceeding 200 g/kg dry matter (DM) and dry matter digestibility (DMD) ranging from 55 to 68% (Norton 1994a). However, other factors such as presence of secondary compounds, including mimosine (in *L. leucocephala*), tannins, alkaloids and saponins, can interfere with utilizing nutrients in forage, either directly or through their effects of reducing voluntary intake (Norton 1994a). In an economic analysis of a wide range of feeding strategies investigated in research studies aimed at increasing post-weaning growth of Bali calves, Priyanti et al. (2010) identified that highest profit could be achieved by providing cattle with feeds with high CP concentration, notably *L. leucocephala* in east Java and east Nusa Tenggara and *S. grandiflora* in west Nusa Tenggara and concluded that FTLs had the greatest potential to increase incomes of smallholder farmers in Bali cattle operations. This was confirmed in an economic analysis (Waldron et al. 2019), which showed that a leucaena-based cattle fattening system was profitable for smallholder cattle producers in West Timor, although more so in the wet than the dry season due to higher proportions of FTL in diets and higher growth rates achieved during the wet season.

Indigofera zollingeriana – a viable alternative feed source for cattle?

Indigofera zollingeriana Miq. (synonym *Indigofera teysmannii* Miq.), which belongs to family *Fabaceae*, subfamily *Faboideae* and tribe *Indigofereae*, is one of about 750 *Indigofera* species recognized world-wide (Schrire et al. 2009) that had previously been used in forestry and soil conservation applications (Choudhury et al. 2006) but recently recognized as a possible alternative FTL for feeding to both ruminants and non-ruminants in Indonesia. *I. zollingeriana* is an erect perennial shrub or small tree, growing up to 12 m in height, native to temperate and tropical regions of Asia (Cook et al. 2020), and is well colonized across the major islands of Indonesia (de Kort and Thijsse 1984; GRIN 2023). Other *Indigofera* species, notably *I. tinctoria*, known to have existed in Indonesia for many centuries, have been used to produce indigo dye for the weaving and batik crafts and for export during the Dutch colonial period. While *I. zollingeriana* does not produce the dye (Muzzazinah et al. 2016), it can be used as a green manure, for firewood and as a shade plant for young coffee, tea, cocoa and coconut plants. Several features indicate *I. zollingeriana* could be a valuable plant for commercialized cultivation in Indonesia, particularly its adaptation to a wide range of soil textures ranging from sandy to clay, its tolerance of low soil fertility and moderately dry conditions, despite being better suited to a high rainfall environment, and in particular its ability to grow well on acidic soils (Cook et al. 2020).

I. zollingeriana has been scientifically investigated in Indonesia as a forage for feeding ruminants and monogastrics only since 2009, initiated by the Department of Animal Science and Technology, Bogor Agricultural University (Abdullah et al. 2012). Concurrently, there has been a concerted effort to distribute *I. zollingeriana* more widely through the islands of Indonesia, including Sumatra, Java, Kalimantan, Sulawesi, Maluku and Papua islands, led by the Indonesian Goat Research Station (S. Ginting, unpublished data). In evaluating its potential as an alternative high-quality forage for ruminants in Indonesia, a key question is: does *I. zollingeriana* offer any advantages as a feed source that are not provided by other FTLs already in use?

There is limited literature relating to the growth and nutritive value of *I. zollingeriana*. This situation is exacerbated by the fact that several papers from research in Indonesia refer to a tree legume which was unidentified at time of publication and is generically referred to as *Indigofera* sp. but has since been identified as *I. zollingeriana*. Results from these studies are included in this review only where the plant has been verified as *I. zollingeriana* in follow-up enquiries with the papers' senior authors.

Forage production. The high yield potential of *I. zollingeriana* in a range of environments has been recorded with plants spaced at 1 × 1.5 m in soil of near-neutral pH (6.2), fertilized and irrigated to represent optimal growing conditions giving a yield of edible plant material (leaves, petioles, succulent branches and shoot tips) of 4,096 kg DM/ha/harvest when cut every 68 days (Abdullah and Suharlina 2010). Although total yield was increased by delaying cutting interval to 88 days, the leaf:stem ratio declined at the longer cutting interval. At similar plant spacing and cutting interval of 60 days but on more acidic soil (pH 4.8–5.2), yields of edible forage (leaves, petioles and edible twigs) of up to 7.9 t DM/ha/harvest were measured for *I. zollingeriana* receiving foliar applications of N:P:K fertilizer with trace amounts of magnesium, calcium, copper, iron, zinc, molybdenum and boron (Abdullah 2010). Overall yield of forage can be further increased by reducing plant spacing compared with above plant density, thus increasing number of plants per unit area, despite proportionate reductions in numbers of branches and leaves per plant (Kumalasari et al. 2017). Sirait et al. (2012) harvested *I. zollingeriana* 8 months after planting and recorded total yields of fresh plant material of ca. 52 t/ha (11.4 t DM/ha), demonstrating its high growth potential. Tarigan et al. (2010) subsequently explored effects of cutting height (0.5, 1.0 and 1.5 m above ground) and cutting interval (30, 60 and 90 days) and demonstrated the highest yield of 33.3 t DM/ha/year when *I. zollingeriana* was cut at 1.5 m and 90 days interval.

Tolerance of acidic soils. The ability of *I. zollingeriana* to grow under unfavorable climatic conditions and in marginal areas not suited to cropping, including on saline, infertile and/or acidic soils with the latter being a predominant feature of the Indonesian landscape, defines its potential use. Notohadiprawiro (1989) estimated that acid-mineral soils represented about 38% of Indonesia's land area, located predominantly in Sumatra, Kalimantan, Sulawesi and Irian Jaya, whereas a more recent estimate of Berek (2019) was that acidic soils, including dryland (mainly) and peaty soils, occupied about 55% of the total land area. Acidic soils are often heavily-leached and low in fertility and characterized by aluminum (Al) and manganese (Mn) toxicity with associated deficiencies of essential minerals such as calcium, magnesium, potassium and phosphorus (Foy et al. 1978). Aluminum toxicity, in particular, is a major constraint on these soils for susceptible plants, interfering with plant growth and physiology, especially in the root zone (Foy et al. 1978), leading to reduced capacity for uptake and use of water and key elements and inducing nutrient deficiencies.

In screening a collection of 18 agroforestry species grown on highly acidic (ca. pH 4), Al-toxic soils in southern Cameroon, Kanmegne et al. (2000) reported *I. zollingeriana* to be one of the best for fast growth and high biomass production, outperforming other leguminous species commonly used in Indonesia, *L. leucocephala* and *G. sepium*. *I. zollingeriana* had higher biomass production than either *Calliandra calothyrsus* Meisn. or *G. sepium* when grown in a greenhouse in acidic soil (Ultisol soil type, pH 4.6) with high Al-saturation (Herdiawan and Sutedi 2015). This higher performance of *I. zollingeriana* was associated with no apparent impairment of root growth or root nodulation and lower concentrations of Al in tissues of leaves, stems and roots, indicating greater tolerance of toxic soil conditions. By contrast, root growth was apparently reduced in *G. sepium* and neither it nor *C. calothyrus* displayed any root nodulation. Herdiawan (2016) also found no effect of soil acidity, as modified using dolomite application, on fresh biomass production of *I. zollingeriana* grown under varying light intensities imposed by palm tree shading.

On the slightly acidic peat soils typical of Kalimantan, leaf yields of *I. zollingeriana* over 3 successive harvests at 120-day intervals across a year of 2.6, 8.2 and 6.6 t DM/ha were greater than the 0.2, 0.7 and 0.3 t/ha for *L. leucocephala*, the most widely-grown and successful FTL in Indonesia (Ali et al. 2014). Similarly, on acidic, sandy soils of poor nutrient status in a study in Vietnam, *I. teysmannii* (syn. *I. zollingeriana*) was more productive than 6 other leguminous trees and shrubs, including *L. leucocephala* (a purportedly acid-tolerant cultivar from the Philippines) and *G. sepium* (Ngo et al. 1995). Production of edible leaf and stem over 16 months (cumulative for 3 harvests) was 8.7, 6.4 and 3.7 t DM/ha for *I. zollingeriana*, *G. sepium* and *L. leucocephala*, respectively. Given its demonstrated higher tolerance of acidic soils, *I. zollingeriana* may be one logical option for planting in this environment, providing it also meets the requirement of improving animal production.

Tolerance of drought. There is considerable variation between and within *Indigofera* species in response to stress caused by moisture deficit (Hassen et al. 2007; 2008). *I. zollingeriana* is widely-distributed throughout Southeast Asia, including the major islands of Indonesia, and has been described as 'apparently indifferent to climate', being able to survive over a range from dry to monsoonal areas (de Kort and Thijsse 1984). The

Tropical Forages database factsheet (Cook et al. 2020) refers to *I. zollingeriana* as 'moderately tolerant of dry conditions', being adapted to areas with rainfall as low as 600 mm/annum but recommended for regions of high rainfall. In an investigation into the effects of water deficit on the growth of *I. zollingeriana*, by comparing soil moisture levels of 100, 50 and 25% of field capacity, Herdiawan (2013) found a trend for plant height, number of branches, stem diameter and root weight to decline as moisture level declined, while root length increased and canopy (above-ground plant material):root ratio was not affected, although the effects were not always significant at the intermediate moisture level (50% field capacity). Production of edible plant material (edible leaves, stems and branches) was reduced by 14% (not a significant effect) and 59% at 50 and 25% field capacity, respectively. Despite these negative impacts of soil moisture deficit, results indicated that *I. zollingeriana* will grow under quite severe drought conditions and respond when water availability improved following rainfall.

Tolerance of saline soils. Saline soils comprise at least 13.2 million ha of the total land area in Indonesia (Massoud 1974; cited by Ponnamperuma and Bandyopadhya 1980). A large proportion of these soils is unsuited to cropping and alternative land uses have been proposed, including growing FTLs for livestock feeding. The suitability of these soils for the growth of *I. zollingeriana* is still relatively unknown. In a small nursery investigation, Nadir et al. (2018) observed that *I. zollingeriana* seedlings apparently had restricted growth under saline growing conditions, but no quantitative or long-term measurements were taken, limiting the conclusions that could be drawn. Research into suitability of *I. zollingeriana* for growth on saline soils is a priority as, in addition to its potential use as a forage source, it could provide useful protection against erosion in coastal regions.

Tolerance of shading. I. zollingeriana showed some tolerance of shading at 40% intensity, but plant height, stem diameter and number of branches declined progressively as shade intensity increased from 40 to 80% (Saijo et al. 2018). This moderate shade tolerance suggests *I. zollingeriana* may be a useful stop-gap plant to include in integrated livestock-oil palm/coconut tree systems to offset high establishment costs and delayed production of newly planted oil palm or coconut plantations. However, its usefulness may be short-lived as palm trees grow rapidly and thus continually reduce light intensity for understory plants. An investigation of persistence and production of *I. zollingeriana* under frequent defoliation is required before it could be recommended ahead of other shade-tolerant plants.

Feeding value and animal growth responses

Chemical composition. Chemical composition of *I. zollingeriana* in forage grown across different seasonal conditions, soil types and fertility levels, for a variety of plant components and ages is variable (Table 1). The 'edible' components, including leaves, petioles, shoots and succulent branches and their proportion relative to mature stem (leaf:stem ratio) on the branches fed to animals determine the nutritive value and eventual animal production. Some reports cited in Table 1 refer simply to 'forage' without identification of the components analyzed, a serious oversight considering the large discrepancy in quality in favor of leaf over stem material (Minson 1990; Collins and Newman 2017). It is highly likely that the components analyzed in those studies were also edible parts based on the generally high values for key parameters of forage quality, but this cannot necessarily be assumed.

For simplified examination of these effects, forage quality is aligned directly with CP and inversely with fiber [crude fiber (CF), neutral detergent fiber (NDF) and acid detergent fiber (ADF)] concentrations in the forage. Protein concentration in edible forage is of particular importance, given earlier discussion of protein deficits in diets of animals either grazing or being fed forage comprised of mainly mature grasses for much of the year. Low protein concentration in these grasses during the dry season severely limits animal growth and reproduction (Winks 1984; Hunter and Siebert 1985; Poppi and McLennan 1995). For instance, CP concentrations in diets selected by cattle grazing predominantly tropical grass pastures in northern Australia were less than 60 g CP/kg DM for up to 9 months of the year (Dixon and Coates 2010; Hunt et al. 2013; McLennan 2014), whereas the lower threshold for cattle to maintain weight is ca. 60–70 g CP/kg DM (Milford and Minson 1965; Minson 1990). By comparison, average CP concentration in foliage from *I. zollingeriana* was 265 g/kg DM, with a low of 210 g/kg DM (Table 1), all concentrations seemingly sufficient to support high levels of animal performance. This positions *I. zollingeriana* well for use as either the sole diet for cattle and other ruminants or a supplement to low-protein dietary components in a mixed feeding situation.

Table 1. Chemical composition (g/kg dry matter) of foliage of *Indigofera zollingeriana*

Plant part	CP	Fat	NDF	ADF	CF	Lignin	Tannin	Ca	P	IVDMD	IVOMD	Reference
Leaves, petioles, edible twigs	277		436	352			0.8	11.6	2.6	675	603	Abdullah (2010)
Leaves, petioles, succulent branches	210		494	262						692	708	Abdullah and Suharlina (2010)
Shoot tips	234		561	307						786	776	As above
Forage - NS	231	22			167			3.7	1.3	700	689	Suharlina and Sanusi (2020)
Leaves	231		359	251								Ali et al. (2014)
Leaves and twigs	246		341	289		35	0.6	15.9	2.2	755	760	Herdiawan et al. (2014)
Foliage - NS	218	36			231			11.7	3.5	738	762	Herdiawan and Sutedi (2015)
Foliage - NS	252				171			9.4	2.7	677	637	Herdiawan (2016)
Foliage - NS	264	19	292	276								Kumalasari et al. (2017)
Plant shoots	300	33			85			5.2	3.4			Palupi et al. (2014)
Leaves and shoots	248	48			152			20.8	2.7			Ngo et al. (1995)
Foliage - NS	279	62			153							Nurhayu and Ishak (2015)
Leaves and shoots	232	26			164			35.4	3.3			Quintos et al. (2018)
Foliage - NS	283	19			103							Jayanegara et al. (2016)
Leaves	356		333	258								Jayanegara et al. (2019)
Foliage - NS	318	25			168							Jusoh and Nur-Hafifah (2018)
Foliage - NS	312	35	232	208								Putri et al. (2019)
Leaves and petioles	313		422	234		54	A			785		Tscherning et al. (2005)
Leaves and petioles	238		207	178		39	A					Tscherning et al. (2006)
Average	265	33	368	262	158	43	0.4	14.2	2.7	726	705	

CP=crude protein (N × 6.25); NDF=neutral detergent fiber; ADF=acid detergent fiber; CF=crude fiber; IVDMD=in vitro dry matter digestibility (g/kg DM); IVOMD=in vitro organic matter digestibility (g/kg OM); NS=plant component not specified. A=zero (lignin+bound) condensed tannins but polyphenols present.

Norton (1994b) showed that FTLs varied quite widely in tannin concentration, with some plants like *S. grandiflora* and *S. sesban* having no tannin and others like *C. calothyrsus* having high concentrations (96–111 g/kg DM). The average tannin concentration in *I. zollingeriana* is quite low at less than 10 g/kg DM (Table 1). However, the form of tannin is not stated in most cases and Tscherning et al. (2005; 2006) reported that, although *I. zollingeriana* contained polyphenols at low concentration (~50 g/kg DM), it contained no condensed tannin in either soluble or bound form and thus had no protein-binding capacity. This is a significant finding, suggesting that much of the protein in *I. zollingeriana* is available for degradation in the rumen with potential high loss to the animal as excreted urea.

Very high degradability of protein from *I. zollingeriana* was confirmed in the study of Tscherning et al. (2005), who reported that the available N in *I. zollingeriana* declined by almost 90% after 144 h of anaerobic incubation, compared with less than 5% for *C. calothyrsus*. Tscherning et al. (2006) subsequently explored the practical option of combining a high-tannin plant like *C. calothyrsus* with *I. zollingeriana* in the diet to provide a balance of rumen degradable protein (RDP) and undegraded dietary protein (UDP) and reduce combined-N loss to the animal. They compared combinations of prunings (leaves and petioles) of *C. calothyrsus* (CP: 169 g/kg DM) and *I. zollingeriana* (CP: 313 g/kg DM), mixed in the proportions of 100:0, 75:25, 50:50, 25:75 and 0:100 (w/w; DM), and showed a steep, step-wise increase in N disappearance from plant material in an anaerobic fermentation system as the proportion of *I. zollingeriana* in the mixture increased. Only at the high inclusion rate (75%) of *C. calothyrsus* did it apparently reduce N utilization from *I. zollingeriana*, suggesting no protection of protein from digestion through formation of protein-condensed tannin complexes at lower inclusion rates. Availability of any protein bound by condensed tannin for post-ruminal absorption was not determined.

Averaged across studies, the main components (NDF, ADF, CF and lignin concentrations) describing fiber composition and degradability were relatively low in *I. zollingeriana* (Table 1) compared with concentrations expected in mature grasses, but commensurate with values for other FTLs. NDF and ADF concentrations averaged 367 and 260 g/kg DM, respectively, similar to the averages of 353 and 251 g/kg DM for edible forage of a wide range of FTLs collated by Norton (1994a). There are limited observations for lignin concentration in *I. zollingeriana*, but the average concentration of 43 g/kg DM is lower than the 99 g/kg DM average reported by Norton (1994a) for other FTLs.

The importance of fiber concentration lies in its relationship with digestibility, which is in turn directly related to feed intake (Thornton and Minson 1973; Allison 1985; Minson 1990). Low fiber concentration in *I. zollingeriana* was reflected in high in vitro DM and OM digestibilities [in vitro dry matter digestibility (IVDMD) and in vitro organic matter digestibility (IVOMD)] averaging 72.6 and 70.5%, respectively (Table 1). Of the alternative FTLs fed commonly in Indonesia, Norton (1994a) reported similar high average IVDMD (67.5%) for *G. sepium*, *L. leucocephala*, *S. grandiflora* and *S. sesban*, but a much lower value for *C. calothyrsus* (41.5%). Tscherning et al. (2005) also reported very low IVDMD (21.3%) for (oven-dried) *C. calothyrsus*, compared with *I. zollingeriana* (78.5%), the difference being attributed to high condensed tannin and lignin concentrations in this *Calliandra* species relative to *I. zollingeriana*.

Within plant component type, variability in composition may be partly attributed to differences in growing conditions and agronomic practices applied. Nevertheless, these compositional changes need to be considered in conjunction with the effects on total yield of leaf and its proportion relative to stem. As age of cutting of *I. zollingeriana* increased, CP concentration of forage was reduced significantly, and NDF and ADF concentrations increased, in the study of Herdiawan et al. (2014) at 60–120 days harvest, but these constituents were only marginally and variably affected in the studies of Abdullah and Suharlina (2010) cut at 38–88 days and Tarigan et al. (2010) cut at 30–90 days, perhaps reflecting the older harvesting age in the former study. However, by far the largest effect of increasing harvesting age on plant components was the steep reduction in leaf:stem ratio with increasing plant age (Tarigan et al. 2010).

Increasing the shade intensity on *I. zollingeriana* plants by growing them under palm tree canopies of increasing age (2-, 5- and 7-year-old) was associated with increases in both CP (232 to 270 g/kg DM) and CF (136 to 179 g/kg DM) concentrations in forage, but a reduction in leaf:stem ratio of plants (Herdiawan 2016). The forage sampled was not identified but high CP and low CF concentrations suggest it was predominantly leaf material. When increasing amounts of an N, P, K and mineral fertilizer were applied to the leaves of *I. zollingeriana* plants (Abdullah 2010), there was no effect on concentration of CP in leaves and edible twigs, and variable effects on fiber concentration. NDF concentration increased as level of fertilizer increased, to a maximum of 511 g/kg DM, whereas the effects on ADF concentration were variable and appeared random. However, the main effect of applying fertilizer was a quadratic increase in herbage production, supporting the concept that the changes in amounts and proportions of major agronomic plant components, especially leaf, are more important than changes in composition given the generally high quality of this component.

There is limited information in the literature on macro- and micro-element concentrations in *I. zollingeriana* and only Ca and P concentrations are shown in Table 1. Freer et al. (2007) recommends a minimum P concentration in plants for cattle diets ranging from 1.0 to 2.7 g P/kg DM, unless for lactating animals, when a higher allowance may be required. The corresponding minimum requirement for Ca is 2.0–3.9 g Ca/kg DM. On the basis of these recommendations, P (average 2.7 g/kg DM) and Ca (average 14.2 g/kg DM) concentrations in *I. zollingeriana* are adequate (Table 1), although these will depend on the physiological status of consuming animals and whether FTL is fed as a complete diet or as a supplement to low-quality forage. Mineral composition of plant material might be expected to reflect growing conditions, but when Abdullah (2010) applied increasing amounts of foliar fertilizer to *I. zollingeriana*, including both P and Ca in the mix in addition to N, K, Mg, Cu, Fe, Zn, Mo and B, P concentration in leaf and edible twigs varied only slightly (2.6–3.1 g/kg DM), while there were variable and inconsistent effects on Ca concentrations (range 11.6–17.8 g/kg DM).

Presence of secondary plant compounds. Indospicine, a highly toxic non-protein amino acid found in some *Indigofera* species, is an arginine analogue and has the potential to disrupt arginine metabolic pathways in mammalian species. The occurrence and toxicity for grazing animals of indospicine have been reviewed recently by Fletcher et al. (2015), who reported that livestock ingesting species of *Indigofera* containing indospicine could suffer both hepatotoxicity and embryo-lethal effects and suggested that indospicine may be an often-undiagnosed cause of poor livestock performance, including reproductive losses. Fletcher et al. (2018) showed that indospicine accumulated in muscle and liver tissues of cattle consuming *I. spicata*, so animals consuming these tissues, including humans, could potentially suffer secondary poisoning. Microorganisms in the rumens of herbivores possess the capacity to detoxify indospicine, by absorption and deamination, but the high solubility of indospicine means that some toxin will escape the rumen undegraded and be available in the intestines for tissue absorption (Loh Zhi Hung et al. 2020). The extent of transfer of indospicine to the intestines is likely to increase as retention time in the rumen decreases, i.e. as the quality of the diet improves. Thus, by increasing the proportion of *Indigofera* sp. in the diet, the positive effects of reduced rumen retention time associated with a high-quality diet may be counterbalanced by the higher concentration of indospicine in the total diet and greater post-ruminal absorption of the toxin.

There is limited information currently available on the indospicine status of *I. zollingeriana*. Miller and Smith (1973), using material from a seed collection, found no detectable concentrations of indospicine in the seeds of *I. zollingeriana*, nor in those of 15 of 16 other species of *Indigofera* tested. However, the effects of long-term storage of seeds on indospicine concentration are unknown. We found no other reports on indospicine presence in *I. zollingeriana*, possibly due to the lack of testing to date for this species. At the same time, when researchers in India fed *I. teysmannii* (syn. *zollingeriana*) leaves ad libitum as the sole diet to sheep for 4 weeks, they observed haematuria and damage to liver and kidneys on post-mortem examination of the sheep, which they suggested was strongly indicative of indospicine toxicosis (Singh et al. 1985; Krishna et al. 1986). Although no analyses for indospicine presence in plant material were undertaken in either study to support this presumption, these researchers advised against longer-term feeding of *I. zollingeriana* as a major component of the diet. It seems imperative that a systematic analysis of *I. zollingeriana* for indospicine concentration be undertaken to include different regional, ecoclimatic, growth stage and cultivational regimes, all of which may influence both presence and concentration of the toxin in components of plant material (Fletcher et al. 2015).

Intake by ruminants. Low fiber and high protein concentrations, recognized attributes of *I. zollingeriana* forage (see above), generally support high rates of intake by ruminant animals by stimulating microbial growth and activity in the rumen and promoting rapid digestion and passage of fibrous material through the digestive tract.

There are conflicting reports, both published and anecdotal, on the palatability or acceptance of *I. zollingeriana* by ruminants. Abdullah and Suharlina (2010) report the species as 'highly relished by livestock', while Nurhayu and Pasambe (2016) state that low acceptance of *I. zollingeriana* is an impediment to its general use. Herdiawan and Krisnan (2014) suggest palatability of *I. zollingeriana* is low in the rainy season but higher in the dry season. In some feeding experiments, high intakes of *I. zollingeriana* have been reported where it has been fed in conjunction with tropical grass or concentrates to goats. Boerka (Boer × Kacang) male goats consumed 29–31 g DM/kg BW/day of *I. zollingeriana* when fresh leaves were fed with either high-energy or high-protein concentrate (Ginting et al. 2010), suggesting no acceptance issues with *I. zollingeriana* for goats. In a trial assessing the acceptance by goats of various legumes fed individually or free-choice in conjunction with elephant grass (Ngo et al. 1995), *I. zollingeriana* was consumed at about 36% of the diet, similar to the selection for *G. sepium* (42%) but less than for *L. leucocephala* (53% of diet). Subsequently, Sirait et al. (2012) showed the intake of forage of *I. zollingeriana* by Boerka goats was equivalent to that of *L. leucocephala*, when both legumes were provided free-choice in a palatability study. More observations are required to truly document the acceptance of *I. zollingeriana* by ruminants under varying conditions.

Production responses by ruminants. Responses by herbivores to inclusion of *I. zollingeriana* in the diet are found in only a single published report (Nurhayu and Pasambe 2016) containing statistically analyzed data on the effects of feeding *I. zollingeriana* to cattle (Table 2). In a small study in south Sulawesi with 12 castrated male cattle, the basal diet of elephant grass (65 g CP/kg DM) supported growth rates of 0.36 kg/day. Substitution of *I. zollingeriana* at 40 or 60% (DM basis) for grass in the diet increased growth rate by about 30%. In the absence of other such reports with cattle, further assessment of feeding value of *I. zollingeriana* is based on feeding studies with goats. Where *I. zollingeriana* was increasingly substituted for a low-quality tropical grass (65–81 g CP/kg DM) in the diet of goats, growth rate increased but responses appeared to peak at about 30–40% legume inclusion (DM basis) in the diet (Tarigan and Ginting 2011; Nurhayu and Ishak 2015). By contrast, Simanihuruk and Sirait (2009) recorded no effects on growth rates of male Boerka goats from replacing 25, 50 or 75% of the basal diet of *Ottochloa nodusa* (slender panicgrass; 93 g CP/kg DM) with *I. zollingeriana*. DM intakes did not differ between treatments (mean 3.1% BW/day), perhaps because total feed offered was the same for all groups and restricted to only ca. 3.5% BW/day DM (based on average BW), thereby possibly limiting the expression of intake and weight gain differences between diets.

Other experiments have shown that *I. zollingeriana* can at least partially replace concentrate in rations for goats. For female Etawah × Kacang goats fed a mixed soybean husk-commercial concentrate diet (35:65, DM basis; 129 g CP/kg DM), incorporation of wafers prepared from *I. zollingeriana* into the diet (husks:concentrate:wafers, 30.8:57.1:12.1; DM basis), with only a small change in total CP concentration (144 g/kg DM), increased growth rate from 47 g/day to 73 g/day (Dianingtyas et al. 2017). Growth responses were similar for wafers made from *L. leucocephala* or *C. calothyrsus* when they were prepared to present similar total diet CP concentration. When *I. zollingeriana* was fed ad libitum as sole forage in conjunction with either a high-carbohydrate (70% corn) or high-protein (70% soybean meal) concentrate (both provided at 1.5% BW/day) and constituting about 68% of total DM in the diet of male Boerka goats, growth rate was greater when the legume was fed with high-protein concentrate, despite total CP concentrations of both rations being high at 204 and 274 g/kg DM, respectively (Ginting et al. 2010). This result is surprising and conflicts with the proposal of Poppi and McLennan (1995) of the benefits for rumen microbes of a source of readily degraded energy in the rumen to capture some of the excess ammonia produced from highly-degraded protein sources such as *I. zollingeriana*. Rumen ammonia-N concentration and N retention were higher in goats fed the high-protein versus the high-carbohydrate concentrate as was to be expected. Energy in the soybean meal may have been more readily degraded in the rumen than that in corn, allowing the goats to capture and utilize the additional N from the higher protein diet. A highly fermentable energy source such as cassava may be more suitable to capture excess nitrogen from legumes such as *I. zollingeriana* (Tudor et al. 1985; Harper et al. 2019).

Table 2. Growth rate responses (average daily gain; ADG) by ruminants to inclusion of *I. zollingeriana* in the diet.

Animal species/ genotype	Gender/ class	Age	Initial live weight (kg)	Basal diet	Basal diet CP (g/kg DM)	Legume	Legume inclusion rate (% of diet DM)	ADG (g)	Reference
Cattle/NR[1]	castrated males	1.5–2 yr	172	*Cenchrus purpureus*	65	*I. zollingeriana*	0	360a[2]	Nurhayu and Pasambe (2016)
							40	460b	
							60	500b	
Goats/Boerka	male	6–7 mo	11	*Ottochloa nodusa*	93	*I. zollingeriana*	0	37	Simanihuruk and Sirait (2009)
							25	41	
							50	44	
							75	43	
Goats/Boerka	male	3–4 mo	10.2	*Urochloa ruziziensis*	81	*I. zollingeriana*	0	28a	Tarigan and Ginting (2011)
							15	39b	
							30	51c	
							45	52c	
Goats/Kacang	females - lactating	NR	23	Native grass	65	*I. zollingeriana*	0	33a	Nurhayu and Ishak (2015)
							40	82b	
							60	91b	
	kids	NR	1.4	Native grass	65	as above	0	57a	
							40	72b	
							60	76b	
Goats/Etawah × Kacang	female	4 mo	13	35% Forage (F) /65% concentrate (C)	na[3]	*I. zollingeriana*	0	47a	Dianingtyas et al. (2017)
				30.8% F/57.1% C	na		12.1	73b	
Goats/Boerka	male	6 mo	16	High-carbohydrate concentrate	94	*I. zollingeriana*	68	60a	Ginting et al. (2010)
				High-protein concentrate	317	*I. zollingeriana*	69	81b	

CP=crude protein (N × 6.25); DM=dry matter; [1]NR=not reported; [2]Within experiments, means within a column followed by the same letters are not different (P>0.05); [3]na=not applicable.

General conclusions

Published work suggests that *I. zollingeriana* may have a role to play in improving productivity of ruminants in Indonesia and other tropical countries. This review assessed the potential of *I. zollingeriana* for use as a high-quality forage for feeding cattle in Indonesia, for how well *I. zollingeriana* is suited to the varied growing conditions in Indonesia, and what it offers nutritionally to cattle that other FTLs, already well-established in agro-ecological production systems there, do not already provide.

I. zollingeriana provides an extremely high yield of leaf and other edible components under good growing conditions but also survives and is productive in less-ideal conditions, including under drought stress, in saline conditions and, most importantly, on acidic soils. These Al-toxic acidic soils, which constitute a substantial proportion of the total landscape in Indonesia, perhaps represent a major ecological niche for *I. zollingeriana*, since it is more suited to these soils than other FTLs currently used in the country. Further studies to determine its long-term performance under regular harvesting on these soils are warranted. An additional advantage is the apparent absence of pests and diseases. The nutritive value of the edible components of the plant is at least equal to that of other FTLs currently in use, as indicated by its high protein, low fiber and low condensed tannin concentrations and high digestibility. The high protein concentration of *I. zollingeriana* foliage alone underlines its potential as a protein supplement for herbivores otherwise restricted to consuming low-quality tropical grasses or crop by-products. Although there are limited studies to date on feeding of *I. zollingeriana* to cattle, positive performance responses when fed to goats indicate the likelihood that it will substantially improve production of cattle. Well-designed feeding experiments with cattle to provide information on optimum dietary inclusion rates of *I. zollingeriana* (dose response) and comparisons against other FTLs are a high research priority. Most current indications are that *I. zollingeriana* will be a valuable alternative FTL for use in cattle production systems in parts of Indonesia and may contribute to the desired increase in local beef production.

There are conflicting reports on palatability of the plant material for herbivores, which needs further elucidation, although acceptance may be enhanced through a process of education and experience with target animals. However, research is necessary to resolve whether or not *I. zollingeriana* contains the hepatotoxin indospicine, common to some species of this genus and, if so, in what concentrations. The presence of high levels of indospicine can have a major influence on the longer-term health of the animals and has profound implications on the health of humans consuming animal products. This question can be resolved through a systematic analysis of plant material from different sources from a range of growing conditions (soils and seasons) and is highly recommended before further widespread dissemination of the plant is undertaken.

Acknowledgments

We gratefully acknowledge the financial support of the Australian Centre for International Agricultural Research (ACIAR) and the Indonesian Agency for Agricultural Research and Development (IAARD) in the preparation of this manuscript. We also thank Mr Lyle Winks and Dr Dennis Poppi for helpful comments on early drafts of the manuscript.

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(Note of the editors: All hyperlinks were verified 21 September 2023).

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(Received for publication 2 June 2022; accepted 31 August 2023; published 30 September 2023)