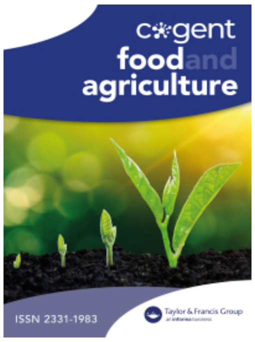

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Nutritional and oil characterization of *Erythrina stricta* Roxb. seeds: a potential resource for functional foods

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ABSTRACT

Erythrina stricta Roxb., an underutilized legume species native to the Indian subcontinent, is traditionally employed in various medicinal applications. This study systematically examines the nutritional quality, encompassing proximate and mineral composition of *E. stricta* seeds, with a focus on characterizing the seed oil. The seeds exhibit commendable proximate composition, with 26.81% protein and 18.71% fibre. Noteworthy mineral elements include 5.0 mg/g DW of calcium and 787.0, 32.7, 36.8 and 497.0 µg/g of iron, copper, boron and zinc, respectively. The seeds yield 13.43% oil, with oleic, palmitic, linoleic and stearic acids as prominent fatty acids, constituting 48.82%, 20.63%, 20.27% and 6.47%, respectively. Antinutrients such as oxalate and phytate are present in concentrations of 26.85 and 16.04 mg/g FW, respectively. In conclusion, this study underscores *E. stricta* seeds as a robust source of both nutrients and oil, warranting further exploration and consideration for potential applications.

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1. Introduction

The genus *Erythrina* L. belongs to the family Fabaceae and encompasses 123 species, predominantly found in tropical regions (POWO, 2023a). The species of *Erythrina* are renowned for their medicinal properties and are utilized in traditional medicine to treat parasitic and microbial infections, inflammation, cancer, wounds and other ailments (Paterson, 1994). The genus reportedly holds an array of phytochemicals, including xanthones, tannins, triterpenoids, saponins, phenols, flavonoids, steroids and catechins, accountable for the activities mentioned above (Rambo et al., 2019). Additionally, *Erythrina* is well-known for its bioactive tetracyclic alkaloids, known as erythrinan alkaloids (Rambo et al., 2019; Fahmy et al., 2020).

Legumes are a rich source of nutrients, particularly proteins, oil, potassium and fiber, with a low glycaemic index. Most legumes are either wild or semi-domesticated, allowing seasonal harvesting by local communities. Their resilience to drought and efficient nitrogen fixation contributes to elevated crop yield and food production (Samtiya et al., 2020; Ayilara et al., 2022). This capacity of legumes presents an opportunity to explore new legume crops to address poverty and malnutrition, especially in our world with a rapidly growing population (Murthy & Paek, 2021). Therefore, exploring the full potential of *Erythrina* species that are being consumed as a nutritional source in various regions of the world is imperative. Species such as *E. variegata*, *E. abyssinica*, *E. arborescens* and *E. corallodendron* are extensively used as fodder for cattle (Paterson, 1994), while the seeds of *E. variegata* and *E. edulis* serve as a nutritional source for humans (Lim, 2014; Vilcanqui-Pérez

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et al., 2022). However, many species within the *Erythrina* genus remain unexplored concerning their nutraceutical value, chemical composition and medicinal attributes, with *Erythrina stricta* Roxb. being a notable example. *E. stricta* is popularly known as the 'Prickly Coral Tree' or 'Indian Coral Tree' which is deciduous, 7–12 tall (Figure 1(A)), branches have short whitish prickles. Flowers are borne on raceme about 15 cm, with flowers arranged in clusters of 3–4 (Figure 1(B)). Flowers are red in colour and attractive, since this plant bears prickles it is called the prickly coral tree. Pods are 7–12 cm long (Figure 1(C)), seeds are more than three in a single pod, light or dark brown, kidney-shaped (Figure 1(D)). *E. stricta* is distributed across its native range, including India, Bangladesh, Cambodia, China, Laos, Myanmar, Nepal, Thailand, Tibet, Vietnam and the Western Himalayas (POWO, 2023b).

Widely acknowledged in many parts of India for their potent medicinal applications, *E. stricta* leaves are employed to alleviate joint pains, earache, toothache and eye infections (Umamaheswari et al., 2009). The bark is beneficial in treating asthma, epilepsy, rheumatism, itch, stomachache and dysentery. The bark paste is also applied externally to cure eczema, dermatitis and other skin diseases (Umamaheswari et al., 2009; Kichu et al., 2015; Akter et al., 2016). However, the nutritional, phytochemical composition and biological activities of *E. stricta* remain unrecognized. Thus, this study reports the proximate and mineral composition of *E. stricta* seeds. We also provide insights into seed oil's physicochemical properties, fatty acid composition and antinutritional components such as oxalate and phytate. *E. stricta* stands out as an underutilized legume in India, holding potential for exploration due to its medicinal and nutritional benefits. This pioneering study reveals the noteworthy nutritional and phytochemical composition of *E. stricta* seeds. Additionally, the research delves into the seed oil's fatty acid profiling and physicochemical characterization.

2. Materials and methods

2.1. Plant materials and chemicals

The pods of *E. stricta* were collected from the trees grown near Shiggavi, Haveri district, Karnataka, India (15.010372N, 75.129678E) in March 2022. The seeds (Figure 1(D)) were separated from the pods and dried to make them moisture-free in an oven at 40 ± 2 °C. Dried seeds were powdered using a mechanical grinder and stored in air-tight polythene bags at room temperature until further use. Chemicals, such as Folin-Cicalteau reagent, BF_3-methanol, anthrone and standard chemicals, such as bovine serum albumin, glucose and sodium phytate used in this study were procured from Himedia laboratories, Mumbai, India, whereas heptadecanoic acid was purchased from Sigma-Aldrich, Bengaluru. All the other chemicals and solvents used were of analytical grade.

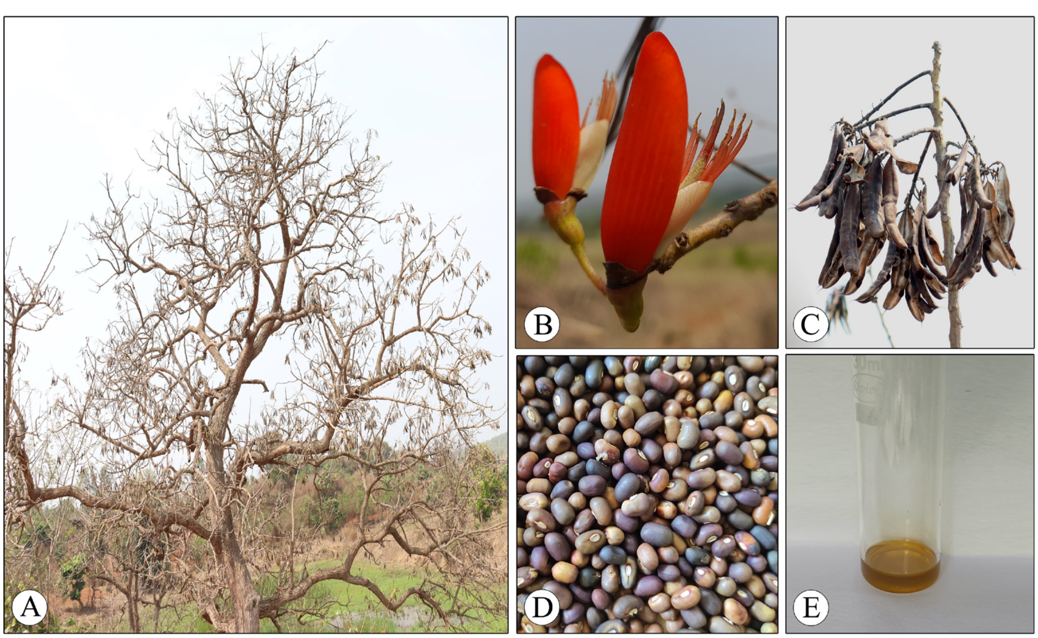

Figure 1. Morphology of *Erythrina stricta*. A. Habit; B. Flowers; C. Mature pods; D. Seeds; E. Seed oil.

2.2. Proximate analysis

The seeds' moisture, fat, ash and protein contents were analysed as mentioned in AOAC (2000). Briefly, the moisture content was gravimetrically determined by recording the weight difference of oven-dried sample at 102 °C for 6 h; the oil content (Figure 1(E)) of the sample was obtained gravimetrically – to detail, finely ground powder of seeds was extracted with petroleum ether (40–60 °C) in a Soxhlet apparatus at 65 ± 2 °C for 8 h to get the oil and the solvent fraction was evaporated using a rotary evaporator (Buchi, Rotavapor R-100, Flawil, Switzerland). The oil was kept in an oven at a temperature of 40 ± 2 °C to remove the traces of the solvents until the weight become constant. Further, the oil content was determined gravimetrically and stored at − 20 °C until further analysis; ash content of the samples was determined by igniting the oven-dried samples in the muffle furnace at 750 °C. For protein content analysis, 500 mg of defatted samples were grounded with 5–10 mL of buffer. The known volume of sample extract was taken and made to 1 mL with the distilled water, to which 4.5 mL of reagent C (It is a mixture of 50 mL solution of 2% sodium carbonate in 0.1 N sodium hydroxide and 1 mL of 0.5% copper sulphate ($CuSO_4.5H_2O$) in 1% potassium sodium tartarate) was added. After the incubation period of 10 min, 0.5 mL of reagent D (Folin-Cicalteau reagent) was added, and tubes were allowed to stand in the dark at room temperature for 30 min to develop blue colour. The colour developed was measured at 660 nm spectroscopically. Bovine serum albumin was used as a standard (Sadashivam & Manickam, 2008). The carbohydrate was quantified by anthrone reagent method and fibre content was by digesting samples with acid and alkali (Sadashivam & Manickam, 2008). The energy value was calculated using Atwater-specific conversion factors, as FAO (2003) mentioned.

2.3. Mineral composition analysis

NOVA 400 atomic absorption spectrophotometer (model Analytic Jena, Germany) with an air or acetylene flame was used for the analysis of potassium, phosphorous, sulphur, sodium, calcium, boron, manganese, magnesium, copper, iron and zinc and the absorbance was carried using hollow cathode lamps (AOAC, 2000; Fernandez-Hernandez et al., 2010). For the nitrogen estimation, a two-step digestion-UV spectrophotometric method was adopted (Liu et al., 2013).

2.4. Seed oil characterization

2.4.1. Physicochemical characterization

The colour and physical state of the extracted oil were observed after 4 hours of incubation at room temperature. The density and refractive index of the oil were determined using a specific gravity bottle and Abbe's refractometer, respectively. Free fatty acid (FFA) content, peroxide value (PV), iodine value, and unsaponification values were determined as per the methods of AOCS (2003). Lignans and carotenoids were quantified by using spectrophotometric methods as described by Manasa et al. (2021).

2.4.2. Fatty acid profiling

Fatty acid methyl esters (FAME) were synthesized through the esterification process as outlined in AOCS (2003) guidelines. In this procedure, a 15 mg oil sample was combined with 1 mL of BF_3-methanol and incubated at 60 °C for 30 min. The reaction tubes were promptly transferred to an ice bath and left there for 5 min. Subsequently, 1 mL each of hexane and distilled water was introduced, and the solution was vortexed. The resulting top layer, consisting of undisturbed methyl esters, was then transferred to GC vials. Heptadecanoic acid served as the internal standard. The identification of FAME was accomplished as described by Manasa et al. (2021) using GC-MS (PerkinElmer, Turbo-mass Gold, Mass spectrometer), equipped with a flame ionization detector (FID) and a fused silica Rtx-2330 column (Restek made, 30 m, 90.32 mm ID and 0.20 mm film thickness). The injector port was maintained at 230 °C, the detector temperature was set at 250 °C, and N_2 was employed as the carrier gas. The initial column temperature was 120 °C, gradually increased to 220 °C over 20 min, and held at 220 °C for an additional 10 min. Detection of FAME involved comparing the fragmentation pattern and retention time with established standards and the NIST library.

2.5. Antinutritional factors analysis

2.5.1. Phytate

The defatted seed cake (0.5 g) was extracted with 10 mL of 2.4% HCl for 16 h with constant agitation, and the mixture was filtered. The filtrate was added with 1 g NaCl and constantly shaken for 20 min. The mixture was centrifuged at 1000 g for 20 min at 10 °C, and the known volume of the supernatant obtained was diluted to 3 mL using distilled water, followed by the addition of Wade's reagent (0.03% $FeCl_3{\cdot}6H_2O$ +

0.3% sulfosalicylic acid). The absorbance of the colour developed was read at 500 nm in a UV–Vis spectrophotometer. A control was prepared without the addition of a sample. Sodium phytate was used as a standard (Gao et al., 2007).

2.5.2. Oxalate

Oxalate was quantified as per the method of Dye (1956). Defatted seed cake (2 g) was added to 190 mL distilled water and 10 mL of 6 N HCl and heated in a water bath at 90 °C for 4 h. Mixture was filtered, made the volume up to 250 and 50 mL of this solution was titrated against concentrated ammonia in presence of methyl orange indicator and heated to 95 °C followed by the addition of 10 mL of 5% $CaCl_2$. After 10 min, 6 N NH_4OH was added and the colour change was observed and kept overnight for the calcium oxalate precipitation. The precipitate was filtered and dissolved in hot sulphuric acid, filtrate was made up to 125 mL, heated to 95 °C, and titrated against 0.05 N $KMnO_4$. Oxalate was determined using following equation;

$$\text{Oxalate}(\%) = \frac{(\text{mL KMnO4})(0.05)(45.02)(100)(5)}{(1000)(\text{Wt of sample in gram})}$$

2.6. Statistical analysis

Each experiment was repeated three times and results are expressed as mean values with standard error. Descriptive statistics including mean and standard error were calculated using Microsoft Excel 2019.

3. Results and discussion

3.1. Proximate and mineral composition

The proximate analysis estimates major nutrient components, including energy value. The proximate composition of seeds of *E. stricta* is found to be impressive, with a good amount of protein, fat and fibre, as presented in Table 1. The seed holds a protein content of 26.81%, fat of 13.43%, fibre of 18.71%, and carbohydrate of 19.34% with 284.15 Kcal/100 g energy value. The moisture and ash content were 15.39% and 6.04%, respectively. The proximate composition of *E. stricta* is comparable to that of two Mexican species, *E. americana* and *E. breviflora* (Sotelo et al., 1993). The protein, fat and fibre content of *E. americana* was 27.2%, 17.7% and 15.3%, respectively, whereas that of *E. breviflora* was 23.3%, 13.9%, and 21.6%, respectively. However, *E. stricta* is richer in ash content than *E. americana* (3.6%) and *E. breviflora* (3.4%), a direct indicator of minerals. Further, *E. stricta* accommodates a higher amount of protein, fat, fibre, and ash than some well-known pulses, such as *Cicer arietinum*, *Phaseolus mungo*, *Pisum sativum* and *Cajanus cajan* (Longvah et al., 2017).

Minerals play a crucial role in supporting the fundamental physiological functions of the human body, including the development of bones, muscle and nerve functioning, as well as the regulation of water balance (Weyh et al., 2022). Legumes are renowned for their mineral-rich composition in seeds; the same holds true for *E. stricta* (Table 1). Specifically, *E. stricta* exhibits high nitrogen, potassium, phosphorous, magnesium and calcium levels, with concentrations of 16.60, 14.0, 6.47, 6.0 and 5.0 mg/g DW, respectively. Additionally, microelements, such as iron, zinc, manganese, boron and copper present at noteworthy levels, measuring 787.0, 497.0, 55.2, 36.8 and 32.7 µg/g DW, respectively. The mineral content of *E. stricta* seed is higher than that of *E. indica*, an allied species, which had 2.35 mg/g calcium, 3.04 mg/g magnesium, 65.7 µg/g iron and 8.1 µg/g copper (Pugalenthi et al., 2004). Comparatively, the mineral content of *E. stricta* seeds surpasses that of commonly consumed pulses such as *Cicer arietinum*, *Phaseolus mungo* and *Dolichos biflorus*. For instance, the calcium content in *C. arietinum, P. mungo* and *D. biflorus* is recorded at 1.50, 0.86 and 2.69 mg/g, respectively, while the magnesium content stands at 1.6, 1.9 and 1.52 mg/g, respectively (Longvah et al.,

Table 1. Proximate and mineral composition of *Erythrina stricta* seeds.

Component	Composition
Proximate (%)	
Moisture	15.39 ± 0.18
Fat	13.43 ± 0.50
Protein	26.81 ± 0.70
Carbohydrate	19.34 ± 2.41
Fiber	18.71 ± 1.21
Ash	6.04 ± 0.28
Energy (Kcal/100 g)	284.15
Macro elements (mg/g DW)	
Nitrogen	16.60 ± 0.17
Phosphorous	6.47 ± 0.18
Potassium	14.00 ± 0.25
Sulphur	2.99 ± 0.07
Sodium	0.30 ± 0.03
Calcium	5.00 ± 0.06
Magnesium	6.00 ± 0.14
Microelements (µg/g DW)	
Iron	787.00 ± 7.62
Copper	32.70 ± 1.01
Manganese	55.20 ± 2.15
Boron	36.80 ± 0.14
Zinc	497.00 ± 6.89

Each value represents the mean ± standard error of three replicates.

2017). Notably, the iron and zinc content of *E. stricta* seeds significantly surpass those of *C. arietinum*, *P. mungo* and *D. biflorus*, with values of 67.8, 59.7 and 87.6 µg/g iron, and 33.7, 30.5 and 27.1 µg/g zinc, respectively (Longvah et al., 2017).

3.2. Seed oil characterization

Some legumes store impressive amounts of oil, besides the rich protein content, with some crops such as *Arachis hypogaea* (ground nut), *Glycine max* (soybean) and *Pongamia pinnata* being grown for the production of seed oil commercially. *E. stricta* holds a significant oil content (Figure 1(E)) in seeds (13.43%) which is rich in carotenoids and unsaturated fatty acids (USFAs). The physicochemical properties and fatty acid composition of the seed oil are presented in Table 2 and GC-MS chromatogram of the fatty acid profiling is presented in Figure 2. The seed oil was liquid and greenish-yellow coloured at room temperature. The refractive index is linked to the molecular weight, degree of unsaturation and length of a fatty acid chain of the oil, and *E. stricta* had a refractive index of 1.471 which is comparable to that of two common edible oils; soybean oil (1.473) and coconut oil (1.448) (Pantzaris & Basiron, 2002; Wang, 2002). The density of *E. stricta* seed oil is 0.910 g/cm^3 and comparable to that of coconut oil (0.914 g/cm^3); (Pantzaris & Basiron, 2002). FFA and PV are essential quality parameters that give a quick impression of their edibility. The FFA content of crude oils would be more compared to that of refined ones, and seed oil with an FFA content of less than 5% could be used for edible purposes (Lamani et al., 2021); the FFA of *E. stricta* was 1.41% and is comparable to that of some commercial edible oils, such as sesame and coconut oil and even less than the mustard (1.9%) and rice bran oil (1.4%) (Prashanth Kumar et al., 2017). The PV of *E. stricta* was 19.91 meq O_2/kg, which is slightly more than that of some commercial edible oils, such as mustard, sesame, peanut, and olive oils (Prashanth Kumar et al., 2017) and much less compared to the unrefined oil of *B. roxburghii* (69.98 meq O_2/kg), an underutilized species (Yadav et al., 2022). The IV (iodine value) indicates the unsaturation level of oil, and it was 79.99 I_2/100 g and is comparable to that of two crucial edible refined oils, olive oil (79.5 I_2/100 g) and mustard oil (66.0 I_2/100 g) (Prashanth Kumar et al., 2017). The unsaponification value of *E. stricta* seed oil was 0.16%, representing the nutraceuticals present in the oil other than the fatty acids. This value is comparable to refined coconut and palm oil, which had values of 0.13% and

Table 2. Physicochemical properties and fatty acid profile of *Erythrina stricta* seed oil.

Parameter	Values
Physicochemical properties	
Color at 25 °C	Greenish yellow
Physical state at 25 °C	Liquid
Density at 25 °C (mg/cm^3)	0.910 ± 0.03
Refractive index at 25 °C	1.471 ± 0.01
Free fatty acid content (%)	1.41 ± 0.11
Peroxide value (meq O_2/kg)	19.91 ± 1.10
Iodine value (I_2/100 g)	79.99 ± 0.60
Unsaponification value (%)	0.16 ± 0.02
Carotenoids (mg/kg)	36.18 ± 3.94
Lignans (mg/100 g SE)	165.47 ± 1.10
Fatty acid composition (%)	
12-Methyltridecanoic acid (14Me-13:0)	0.53 ± 0.06
Palmitic acid (16:0)	20.63 ± 0.23
Stearic acid (18:0)	6.47 ± 0.12
Oleic acid (18:1)	48.82 ± 0.29
Linoleic acid (18:2)	20.27 ± 0.17
Linolenic acid (18:3)	0.81 ± 0.06
Behenic acid (20:0)	1.48 ± 0.09
Paullinic acid (20:1)	1.00 ± 0.06
Total SFA	29.11
Total MUFA	49.82
Total PUFA	21.08

Each value represents the mean ± standard error of three replicates
SE: Sesamol equivalent; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids

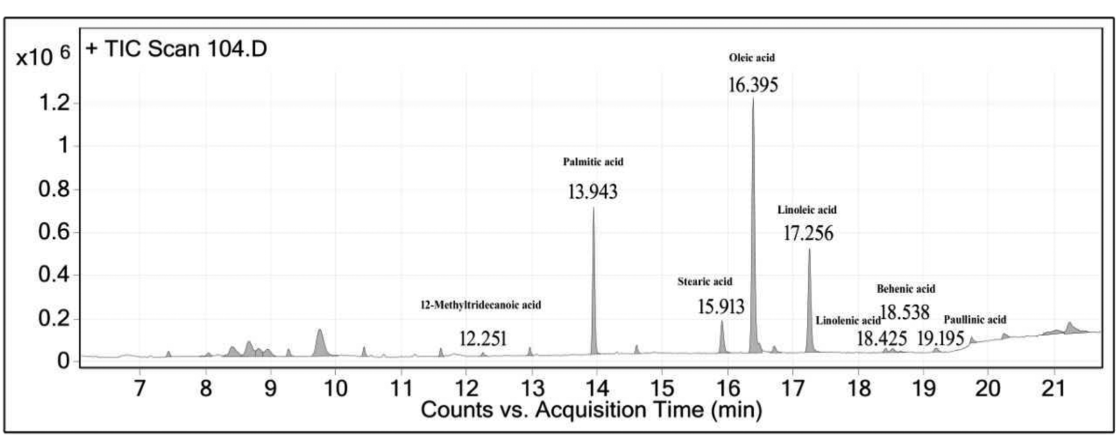

Figure 2. GC-MS chromatogram of fatty acid profiling of *Erythrina stricta* seed oil.

0.28%, respectively (Prashanth Kumar et al., 2017). Carotenoids are tetraterpenoid pigment molecules that stabilize oil against oxidation and have a beneficial role in eye-related problems (Franke et al., 2010). The *E. stricta* seed oil is rich in carotenoids with a value of 36.18 mg/kg oil, and it is much higher than the earlier report of rapeseed, sunflower, and flax seed oil, which had values of 15.2, 1.6 and 3.7 mg/kg oil, respectively (Franke et al., 2010). Lignans are a group of phenolic compounds that are proven to prevent cardiovascular diseases, cancer and cellular oxidative damage, and their presence gives an oil a dietary value (Korhonen, 2002). The total lignan content of the studied oil was 165.47 mg/100 g sesamol equivalent (SE), and it is relatively lower than that of sesame oils (495.9–685.6 mg/100 g SE), which is a rich source of dietary lignans (Bhatnagar et al., 2015).

The fatty acid composition of *E. stricta* was impressive, with a significant portion represented by USFAs. Oleic acid was the prominent fatty acid with a presence of 48.82%, followed by palmitic acid (20.63%), linoleic acid (20.27%) and stearic acid (6.47%). Behenic acid, linolenic acid, paullinic acid and 12-methyltridecanoic acid were in minor quantities. The *E. stricta* seed oil is rich in USFA, which makes up 70.90% of the oil. Matthäus (2007) argues that oils with high monounsaturated fatty acid (MUFA) are more stable to oxidative degradation and are preferable for food frying purposes, and *E. stricta* seed oil could be the best choice for frying purposes as it accommodates 49.82% of MUFA. A similar pattern in the fatty acid composition of *E. variegata* (Samanta & Laskar, 2013) and *E. suberosa* (Singh & Chawla, 1970) was also reported. The palmitic, stearic, oleic and linoleic acid content of presently studied oil is comparable to that of palm oil, with values of 39.1%, 4.1%, 42.4% and 10.1%, respectively (Matthäus, 2007). Seed oils are the primary provider of essential fatty acids, such as α-linolenic acid and linoleic acid that are vital for various biological functions (Yadav et al., 2022). The linoleic and α-linolenic acid content of presently studied oil is more when compared to that of some well-known oils, such as olive, rapeseed, palm and almond oil (Kaur et al., 2014). Considering these facts, the seed oil of *E. stricta*, an underutilized legume, could be explored as a new edible oil source in India.

3.3. Antinutritional components

Antinutritional factors reduce the nutrients' bioavailability and make a food material inefficient. Among the various antinutrients, phytate and oxalate are considered paramount as they bind with minerals and narrow their availability (Samtiya et al., 2020). The phytate and oxalate content of *E. stricta* seeds was 26.85 and 16.04 mg/g FW, respectively (Table 3). The phytate is the molecule that plants use to store phosphorus content in seeds, and if consumed regularly, it is associated with iron deficiency (Samtiya et al., 2020). The phytate content of *E. stricta* is similar to that of some well-known pulses, such as bean (18.74 mg/100 g), fava bean (22.85 mg/100 g) and soybean (22.91 mg/100 g) and wild edible species such as *Diospyros chloroxylon* (20.16 mg/g) and *Balanites roxburghii* (21.71 mg/g) (Samtiya et al., 2020; Yadav et al., 2022; Murthy et al., 2022). The oxalate content of *E. stricta* is comparatively higher than that of the pulses mentioned above and comparable to that of wild edible species mentioned above, *B. roxburghii* (32.01 mg/g) and *Diospyros chloroxylon* (14.33 mg/g) (Yadav et al., 2022; Murthy et al., 2022). However, the adoption of some simple processing methods was proved very effective in reducing them. Shi et al. (2018) able to reduce up to 51.89% and 56.29% of soluble and total oxalates, respectively, and phytate to some extent, by soaking the seeds in distilled water for 4 h. Thus, *E. stricta* seed cake, with impressive mineral composition and other nutraceuticals, could be considered a micronutrient source for humans and cattle.

Table 3. Anti-nutritional factors of *Erythrina stricta* seeds.

Factor	Composition (mg/g FW)
Phytate	26.85 ± 3.30
Oxalate	16.04 ± 3.07

Each value represents the mean ± standard error of three replicates.

5. Conclusions

The investigation into *Erythrina stricta*, an underutilized legume species prevalent in the Indian sub-continent, focuses on unraveling its nutritional value. This exploration unveils the potential of *E. stricta* as a valuable food source. The proximate composition of *E. stricta* seeds aligns closely with globally recognized pulses, boasting notably high levels of proteins and fibres. Moreover, the seeds are a noteworthy reservoir of oil, enriched with carotenoids and USFAs, particularly the essential linoleic acid. The seed residue exhibits substantial concentrations of essential minerals, including calcium, iron, copper, boron and zinc. This study, thus, endeavours to elucidate the nutritional and oil characterization of *E.*

stricta seeds, positioning them as a promising candidate for novel food sources.

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Author contributions

Conceptualization, HNM and GGY.; methodology, HNM, GGY, SSK and SL; software, ASD and MMS; formal analysis, HNM, GGY, SSK, MMS, ASD and SL; investigation, HNM, GGY, SSK, SL, MMS and ASD.; resources, HNM; data curation, HNM, GGY, SSK, SL and MMS.; writing – original draft preparation, HNM and GGY; writing – review and editing, HNM, YHD and KMT; validation, ASD, YHD and KMT; visualization, YHD and KMT. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

The authors declare no conflicts of interest.

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Data availability statement

Data and materials supporting the results or analyses presented in our paper are available upon reasonable request.

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