Oleic Acid Rich Tree-borne Oilseeds from Forests of Assam, India

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Abstract: North East India is a home of tremendous and versatile vegetative oil bearing materials because of the subtropical climatic conditions. Screening, characterization, and domestication of high yielding tree-borne oilseeds rich in oleic acid and tocopherol are highly demandable from industrial aspects. As very few studies have been carried out in this regard from this region, our investigation aims to exploit new sources of tree-borne oilseeds rich in omega fatty acids for edible and non-edible purposes from both known and unknown plants. Six lesser-known tree-borne oilseeds were characterized based on oil content, tocopherol composition and metal content. The fatty oil was found more in \textit{Dysoxylum procerum} (50\%). The dominating fatty acid was oleic acid ranged between 38.4 to 64\%. The oil of \textit{Terminalia bellirica} showed high content of tocopherol (0.05\%). Among eleven metals (Ca, Cu, Zn, Mg, Mn, Fe, Pb, Cd, As, Na, K) in all the six fatty oil contents, Pb and Cu showed high concentrations as compared to the codex standard while Fe values of all the oil contents were below the permissible concentrations.

Key words: fatty acids, oleic acid, tocols, trace elements, SFA, MUFA and PUFA

1 Introduction

Edible oils are structurally composed of tri-acylglycerol molecules formed by unsaturated (oleic, linoleic, linoleic acids etc.) and saturated fatty acids (capric, lauric, myristic, palmitic, stearic etc.) esterified to Glycerol units\textsuperscript{1}. As oils of seeds contain mainly unsaturated fatty acids therefore seed oils are preferred more as an alternative to saturated animal fats like bacon, butter and hydrogenated vegetable products.

Linoleic, linolenic and oleic acids are called the essential fatty acids (EFAs) as they provide nutrition to the human body. Among the fatty acids, oleic acid is considered most important fatty acid particularly during gestation-lactation period\textsuperscript{2}. Oleic acid is naturally occurring and is classified as a mono-unsaturated omega-9 fatty acid. It is the most common monounsaturated omega fatty acid in human cells incorporated into cell membrane phospholipids, where it is important for proper membrane fluidity. Membrane fluidity is responsible for elongation of other fatty acids which are precursors for eicosanoids (prostaglandins). Thus, deficient oleic acid status may also indicate deficient eicosanoid production, signifying a need for EFAs\textsuperscript{3}.

Scientific studies have established that oleic acid has beneficial effect on cancer, autoimmune, and inflammatory diseases\textsuperscript{4}. High proportion of monounsaturated acid especially oleic acid in the diet is linked with a high reduction

Abbreviations: ATP: Adenosine triphosphate, Ca: Calcium, Cd: Cadmium, Cu: Copper, DHA: Docosahexaenoic acid, DWB: Dry Weight Basis, EFAs: Essential fatty acids, EFSA: The European Foods Safety Authority, EPA: Eicosapentaenoic acid, FA: Fatty acids, FAME: Fatty Acid Methyl Ester, FDA: Food and Drug Administration, GC-MS: Gas chromatography–mass spectrometry, HDL: High density lipoprotein, HPLC-FLD: High Performance Liquid Chromatography with fluorescence detection, ICP–AES: Inductively coupled plasma atomic emission spectroscopy, IPNI: The International Plant Names Index, K: Pottasium, LDL: Low density lipoprotein, Mg: Magnesium, Mn: Mangenese, MUFA: Monounsaturated fatty acids, Na: Sodium, Pb: Lead, PUFA: Polynsaturated fatty acids, SFA: Saturated fatty acids, WHO: World Health Organization, Zn: Zinc, \(\omega\)-3: Omega-3 fatty acids (n-3), \(\omega\)-6: Omega-6 fatty acids (n-6), \(\omega\)-9: Omega-9 fatty acids (n-9), ppm: parts per million

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in the risk of coronary heart disease and it is effective in lowering LDL cholesterol content.

To access the quality quotient of the selected oilseeds and to determine the inorganic profile of these oils, physico-chemical properties, trace elements, tocopherol (vitamin E) content, etc are important along with their chemical properties because of the metabolic role of some elements in the human organism. These elements act as co-factors of enzymes and as organizers of the molecular structure of the cell and its membrane. In excess amount they can be toxic and also their insufficiency may lead to metabolic disorders. The various trace elements present in edible oil such as Na, K, Ca, Mg, Cu, Zn and Mn are essential micro-nutrients for human growth. Pb and Cd being toxic elements are well known for causing various disorders in humans. Pb and Cd are toxic elements which occur in plants in variable amounts and their biological antioxidative activity varies between individual compounds. Vegetable oils provide the best sources of vitamin E.

The utility of oils depend on their properties and these compositions. Lack of information on their composition and utilization can be considered as a barrier than real shortage of oils. Hence, in the present approach, a detailed investigation has been performed on the physico-chemical properties, metal composition and tocol content of six tree-borne oilseeds from North-East India which are found to be rich in oleic acid and have been attempted to understand their commercial exploitation in future. The six plants that have been selected for study were confirmed in IPNI. Among the six plants studied, only two have been reported earlier for their fatty oil content (Table 1). The six species are quite known locally for their medicinal uses by various people. The folklore uses are listed below (Table 2).

### 2 Materials and Methods

Matured fruits of the selected six treeborne oilseed species were collected from Gibbon and Nambar Reserve forest of Jorhat and Golaghat district, Assam, India respectively and stored in normal room temperature. The seeds were separated from the fruits by scraping the fruits pulp manually. Later the seeds were sun dried for about three days and whole seeds were powdered in grinding machine (Hammer mill). The powdered samples were than subjected to oil extraction with petroleum ether (60°C-80°C) as solvent in Soxhlet apparatus as per standard methods. The oil was thus obtained after the solvent was removed under reduced temperature and pressure through rotavapour. The oil samples thus obtained were immediately analyzed, where delay is anticipated oils are stored in refrigerator at 4°C. Physico-chemical properties like refractive index, saponification value and acid value of the oils were determined following the established method. Refractive index was determined at room temperature using Abbe’s Refractometer. Iodine value was determined by Wijs’ Method. Fatty Acid Methyl Ester (FAME) was prepared from the oil using Indian standard methods. The FAME was identified

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### Table 1

| Sl No | Scientific Name | Local Name | Family | Distribution | Flowering Time | Fruiting Time | Weight /Seed (Gm.) | Availability (Tons/Hectare /Annum) | Locality | Oil source |
|-------|-----------------|------------|--------|--------------|----------------|---------------|-------------------|-------------------------------------|----------|------------|
| 1.    | *Chrysophyllum ruxburgii* G.Don | Kolmow | Sapotaceae | Lakhimpur, Nowgong, Mizoram, Cachar, N.C.Hills, Khasis & Jayantia Hills | April-May | Nov-Dec | 1.2-2.4 | 8-10 | Jorhat | Kernel |
| 2.    | *Dysoxylum procerum* Hiern. | Amari' Lali | Meliaceae | Assam and Meghalaya | Dec-Jan | May-July | 1.0-3.5 | 10-12 | Nambor Reserve Forest, Golaghat | Kernel |
| 3.    | *Elaeocarpus robustus* Roxb. | Poreng | Elaeocarpaceae | Fairly common throughout the province except perhaps in the N.E. frontier district | April-May | Aug-Sept | 0.3-1.7 | 2-3 | Jorhat | Seed |
| 4.    | *Clausena sufruticosa* Wight & Arn | Kalamaricha | Rutaceae | Khasi Hills, Lushai hills, Assam, Chittagong hill tracts | March-June | July-August | 0.7-1.9 | 4-5 | Nambor Reserve Forest, Golaghat | Seed |
| 5.    | *Eucalyptus citriodora* Hook. | Lemon scented gum | Myrtaceae | Cultivated in certain parts of the province. | Jan-March | Jan-March | 0.1-1.5 | 7 -10 | Jorhat | Seed |
| 6.    | *Terminalia bellirica* (Gaertn.) Roxb. | Bhumora | Combretaceae | Throughout the province Hot season after new leaves | Dec-February | 0.3-0.9 | 3.5-4 | Jorhat | Kernel |

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Table 2 Folklore uses of the studied oilseed trees.

| Sl. No. | Species Name             | Medicinal Property                                   | Plant Parts Used       | Common Uses                                                                 |
|--------|--------------------------|-----------------------------------------------------|-----------------------|----------------------------------------------------------------------------|
| 1.     | Chrysophyllum roxburghii | The seed formulations are used to treat pneumonia at Sivasagar district of Assam<sup>11</sup>. The fruit contains a significant amount of amino acids and minerals<sup>12</sup>. The leaves are antibacterial<sup>13</sup>. | Seeds, fruit, leaves   | In Mizoram, the plant is called Theipabuan and the ripen fruits are eaten locally<sup>14</sup>. |
| 2.     | Dysoxylum procerum       | Tender twigs and leaves decoction are taken for diarrhea and dysentery<sup>15</sup>. | Leaves, twigs, wood    | The wood is reddish in colour and used in furniture.                        |
| 3.     | Elaeocarpus robustus     | Plant parts are used in diarrhoea and dysentery, mouth-wash for inflammation of gums<sup>16</sup>. | Fruits, Leaves, bark   | Unripe fruits are used as pickles<sup>17</sup>.                            |
| 4.     | Clausena suffruticosa    | Dried whole plant powder is mixed with water, and sprayed over the face to get sense from unconsciousness. Root juice is applied over forehead to get rid of high fever and also used to relieve stomach pain<sup>18</sup>. | Whole plant, roots     | Stem bark is pounded and used as rope. It is used as firewood.             |
| 5.     | Eucalyptus malacata var. | The leaves are aboriginal traditional herbal remedy. The leaf essential oil is a powerful antiseptic and used all over the world for relieving coughs and colds, sore throats and other infections. Also used locally as preservatives in food and drugs<sup>19</sup>. | Leaves                 | A lemon-scented essential oil is obtained from the leaves which are used both in perfumery and medicine. |
| 6.     | Terminalia bellirica     | Its fruit has been used in traditional medicinal system for asthma, cancer, anemia, constipation, colic, diarrhea, painful urination, headache, hypertension, inflammations and rheumatism<sup>20-22</sup>. | Fruit                  | Tree parts used as animal fodder and fuel wood. Bark used for making dye.   |

by comparison of the retention time and peak enhancement with known FAME mixture<sup>23</sup>.

2.1 Mineral composition

The oil extracted from the oil seeds were further analyzed for their mineral composition. The oil samples were transferred to a digestion vessel and weighed (approx.0.3 gm) accurately. The samples were digested using a mixture of supra-pure conc. HNO₃ and H₂O₂ following microwave digestion system (Model- START-D Milestone, Italy) for 10-30 minutes at 210°C. The aliquots thus prepared were used for trace metal estimation using Atomic Absorption Spectroscopy (Model-A Analyst-700, Perkin Elmer). The analysis was performed using the software Win Lab 32 (version G.S.O.0266, Perkin Elmer Inc.). Most of the metals were estimated by ICP-AES technique. The Flame technique was used to determine various metals like Cu, Ca, Fe, Mg, Na, K, Zn, As and Mn. Graphite Furnace was used for determination of Cd and Pb.

2.2 HPLC Analysis of Tocopherol

The different oil samples were analyzed for tocopherols and tocotrienols by HPLC-FLD. The tocopherol and tocotrienol content of oil or fat was determined in the sample by the same procedure as described by Chaliha et al. and expressed in ppm<sup>20</sup>.

3 Results and Discussion

Physico-chemical analyses of oils are presented in Table 3(a). The highest oil content was recorded in Dysoxylum procerum (50%) followed by Terminalia bellirica (38%) and Chrysophyllum roxburghii (35%) and minimum fatty oil was observed in Eleocarpus robustus (10%), Clausena suffruticosa (8.7%) and Eucalyptus citriodora (8.5%). Refractive index, Iodine value, Acid value and Saponification value of oil were also recorded in Table 3(a). Saponification value was recorded maximum in Chrysophyllum roxburghii (204.73) and lowest in Eucalyptus citriodora (70.0). Saponification value is an indication of the molecular weight of triglycerides in oil and high proportion of saponification value suggests that the oil is a good raw material for soap industries. Iodine value of the oils was recorded highest in Eucalyptus citriodora (107) and lowest in Terminalia bellirica (47.34). Higher the iodine value, better the quality of oil.
number, the more will be the degree of unsaturation in the fat or oil \( \frac{\text{ الغذاء}}{\text{脂肪}} \). Acid value and percentage of free fatty acid of the oils were estimated and highest amount was recorded in *Elaeocarpus robustus* 38.74 and 27.32 \( \frac{\text{غيل}}{\text{脂}} \) respectively. A high acid value may indicate a higher tendency to become rancid \( \frac{\text{腐敗}}{\text{变质}} \). The oil is less rancid owing to the fact that the free fatty acid contain is less than 1.15 \( \frac{\text{غيل}}{\text{脂}} \). In the present study, oil of *Clausena suffruticosa* was found to be less rancid compared to the other studied oils.

The Pearson correlation matrix [Table 3(b)] showed highly significant correlations among the physico-chemical properties at 0.01 and 0.05 levels.

Gas chromatography analysis of methyl ester derived from these seed oil revealed that Oleic acid is the dominant fatty acid [Table 4(a)]. The highest oleic acid content observed in *Dysoxylum procerum* (64%) followed by *Chrysophyllum roxburghii* (55.6%), *Terminalia bellirica* (47.3%), while lowest in *Eucalyptus citriodora* (21.8%). The other fatty acid content in these seeds oil are palmitic \( \frac{\text{饱和的}}{\text{饱和的}} \), stearic \( \frac{\text{饱和的}}{\text{饱和的}} \), linoleic \( \frac{\text{多不饱和的}}{\text{多不饱和的}} \) and linolenic \( \frac{\text{多不饱和的}}{\text{多不饱和的}} \). Other fatty acids were found in very less amount [Table 4(a)]. The high oleic acid content in these seed oils suggested that these oilseeds may serve as valuable source of raw materials for industrial purposes and it can be used as an alternative substitute for other oils. Oleic acid is also reported to have importance in

| Name of the species         | Moisture content (%) | Oil Yield (%) | Colour of oil     | Refractive Index | Saponification value | Acid value | Free Fatty acid (%) | Ester value | Iodine value |
|-----------------------------|----------------------|---------------|-------------------|-----------------|----------------------|------------|---------------------|------------|-------------|
| *Chrysophyllum roxburghii*  | 68.29                | 35.20         | Golden yellow     | 1.4654\(^\circ\)C at 34.0\(^\circ\)C | 204.73    | 17.13             | 12.08      | 187.60      | 63.16       |
| *Dysoxylum procerum*        | 48.32                | 50.31         | Amber yellow      | 1.4664\(^\circ\)C at 22.8\(^\circ\)C | 186.80    | 4.30              | 3.04       | 182.50      | 55.96       |
| *Elaeocarpus robustus*      | 47.50                | 9.58          | Olive green       | 1.4668\(^\circ\)C at 23.1\(^\circ\)C | 170.40    | 38.74             | 27.32      | 131.66      | 75.67       |
| *Clausena suffruticosa*     | 69.85                | 8.62          | Reddish brown     | 1.4912\(^\circ\)C at 22.8\(^\circ\)C | 191.48    | 1.34              | 0.94       | 190.14      | 85.81       |
| *Eucalyptus citriodora*     | 40.00                | 8.50          | Golden brown      | 1.4892\(^\circ\)C at 24.5\(^\circ\)C | 72.00     | 34.75             | 24.50      | 37.25       | 91.72       |
| *Terminalia bellirica*      | 10.20                | 38.94         | Light yellow      | 1.4670\(^\circ\)C at 32.8\(^\circ\)C | 191.62    | 7.05              | 4.96       | 184.56      | 47.34       |
| Mean                        | 47.36                | 25.19         | –                 | 26.67           | 169.51    | 17.22             | 12.14      | 152.29      | 69.94       |
| Variance                    | 475.97              | 343.41        | –                 | 27.74           | 2403.98  | 258.59            | 128.60     | 3658.64     | 302.25      |

**Table 3 (a)** Physico-chemical analysis of the extracted oils.

| Source of Variation | SS          | df | MS            | F          | P-value | F crit |
|---------------------|-------------|----|---------------|------------|---------|--------|
| Between Groups      | 162041.85   | 7  | 23148.84      | 24.37      | 1.505E-12 | 2.25   |
| Within Groups       | 37995.94    | 40 | 949.90        |            |          |        |
| Total               | 200037.79   | 47 |               |            |          |        |

Significance level: \( p < 0.05 \), \( N=6 \)

**Table 3 (b)** Pearson Correlation among studied oils.

| Moisture content (%) | Oil Yield (%) | Refractive Index | Saponification value | Acid value | Free Fatty acid (%) | Ester value | Iodine value |
|----------------------|---------------|------------------|----------------------|------------|---------------------|------------|-------------|
| Moisture content (%) | 1             | -0.26            | 0.44                 | 0.21       | 0.52                | 0.35       | 1           |
| Oil Yield (%)        | -0.26         | 1                |                      | -0.07      | -0.56               | -0.16      | -0.63       | 1           |
| Refractive Index      | -0.26         | 0.44             | 1                    | 0.98**     | 0.78                | -0.78      | 1           |
| Saponification value | 0.21          | 0.52             | 0.35                 | 1         |                     |            |             |
| Acid value            | -0.07         | -0.56            | -0.16                | -0.63      | 1.00**              | 1         |             |
| Free Fatty acid (%)   | -0.07         | -0.56            | -0.16                | -0.63      | 1.00**              | 1         |             |
| Ester value           | 0.19          | 0.57             | 0.32                 | 0.98**     | -0.78               | -0.78      | 1           |
| Iodine value          | 0.47          | -0.90*           | -0.58                | -0.65      | 0.48                | 0.48       | -0.65       | 1           |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed), \( N=6 \).
soap making\(^{27}\). A large quantity of unsaturated fatty acid in the oil indicates its effectiveness to reduce the risk of cardiovascular problems in human beings\(^{6,26}\). Oleic acid also plays an important role in building cellular membranes, attracting oxygen to tissues to transform energy into nerve impulses and as precursors to molecules of cellular communication such as prostaglandins or eicosanoids. It also has great importance in terms of their nutritional implication and the effect on oxidative stability of oils\(^{28}\).

Chemical characteristics of studied oils have close similarity to those of groundnut oil, sunflower oil and corn oil.

The Pearson correlation matrix for fatty acid compositions showed a strong correlation at 0.01 significant levels [Table 4 (b)].

A total of eleven trace elements (Ca, Cu, Zn, Mg, Mn, Fe, Pb, Cd, As, Na, K) were determined in the fatty oils using AAS, the results of which are shown in Table 5(a). Results reveal that Ca, Mg, Na, K were the major elements of the six oil bearing seeds. Eucalyptus citriodora was found high in Na (222 ppm), Mg (415 ppm) and Ca (6473 ppm) while Clausena suffruticosa was found high in K (185.06 ppm) in comparison to the other oil bearing seeds. The CODEX standard (CODEX-STAN 211-1999)\(^{29}\) shows the maximum permissible concentration for Lead 0.1 mg/kg, Iron 1.5 mg/kg and Copper 0.4 mg/kg. The table clearly shows that the concentration of Lead and Copper values were high in all the oils as compared with the codex standard while Iron values of all the oils were below the permissible concentration. Inorganic arsenic is considered to be the most toxic to human health. Arsenic is a known carcinogen in human causing lung, liver, skin and bladder cancer\(^{30}\). But in our study arsenic level is very low (1 µg/kg). So these six oils can be considered as arsenic free oil.

The quality of oils regarding their freshness, storability

### Table 4 (a) Fatty acids compositions of the seed oils of the 6 studied oilseeds.

| Species Name               | 12:0 | 14:0 | 14:1 | 16:0 | 16:1 | 17:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 22:0 | 24:0 |
|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Chrysophyllum roxburghii  | −    | −    | −    | 20.1 | 0.1  | −    | 14.9 | 55.6 | 6.1  | −    | 0.6  | 0.4  | 0.7  | −    |
| Dysoxylum procerum        | −    | 0.1  | −    | 18.7 | 0.3  | −    | 5.5  | 64.0 | 6.0  | 2.3  | 1.5  | 0.6  | 0  | −    |
| Elaeocarpus robustus      | 0.4  | 0.1  | −    | 23.1 | 3.1  | −    | 9.1  | 40.3 | 22.4 | 0.2  | 0.4  | 0.3  | 0.1  | 0.3  |
| Clausena suffruticosa     | −    | −    | −    | 4.0  | 1.0  | −    | 3.3  | 34.8 | 1.0  | −    | 0.4  | 1.7  | −    | −    |
| Eucalyptus citriodora     | −    | 0.2  | −    | 12.4 | 0.2  | −    | 3.3  | 21.8 | 13.0 | 0.8  | 2.3  | 1.1  | 1.0  | −    |
| Terminalia bellirica      | −    | 0.06 | 0.4  | 22.5 | 0.5  | 0.04 | 10.6 | 47.3 | 17.1 | −    | 0.8  | −    | −    | −    |

\* Clausena suffruticosa unknown compounds were found 53.8% and in Eucalyptus citriodora unknown compounds were 44.1%.

### Table 4 (b) Pearson Correlation among fatty acids compositions.

|          | 12:00 | 14:00 | 14:01 | 16:00 | 16:01 | 17:00 | 18:00 | 18:01 | 18:02 | 18:03 | 20:00 | 20:01 | 22:00 | 24:00 |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 12:00    | 1     |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 14:00    | 0.56  | 1     |       |       |       |       |       |       |       |       |       |       |       |       |
| 14:01    | −0.2  | 0.16  | 1     |       |       |       |       |       |       |       |       |       |       |       |
| 16:00    | 0.42  | 0.64  | 0.38  | 1     |       |       |       |       |       |       |       |       |       |       |
| 16:01    | 0.96**| 0.51  | −0.16 | 0.23  | 1     |       |       |       |       |       |       |       |       |       |
| 17:00    | −0.2  | 0.16  | 1**   | 0.38  | −0.16 | 1     |       |       |       |       |       |       |       |       |
| 18:00    | 0.14  | 0.06  | 0.30  | 0.71  | 0.01  | 0.30  | 1     |       |       |       |       |       |       |       |
| 18:01    | −0.12 | 0.49  | 0.11  | 0.58  | −0.19 | 0.11  | 0.53  | 1     |       |       |       |       |       |       |
| 18:02    | 0.70  | 0.51  | 0.38  | 0.68  | 0.60  | 0.38  | 0.24  | −0.22 | 1     |       |       |       |       |       |
| 18:03    | −0.19 | 0.47  | −0.30 | 0.06  | −0.27 | −0.30 | −0.41 | 0.40  | −0.20 | 1     |       |       |       |       |
| 20:00    | −0.39 | −0.12 | −0.13 | −0.12 | −0.51 | −0.13 | −0.49 | −0.29 | −0.00 | 0.60  | 1     |       |       |       |
| 20:01    | −0.30 | −0.57 | −0.54 | −0.98**| −0.14 | −0.54 | −0.75 | −0.52 | −0.65 | 0.02  | 0.16  | 1     |       |       |
| 22:00    | −0.22 | 0.62  | 0.34  | 0.09  | −0.39 | −0.34 | 0.06  | −0.44 | −0.01 | −0.09 | 0.58  | 0.13  | 1     |       |
| 24:00    | 1**   | 0.56  | −0.20 | 0.42  | 0.96**| −0.2  | 0.14  | −0.12 | 0.70  | −0.19 | −0.39 | −0.30 | −0.22 | 1     |

**. Correlation is significant at the 0.01 level (2-tailed), N=6
and toxicity can be evaluated by the determination of several trace metals. Levels of trace metals like Cu, Zn, Fe, Mn, and Ni are known to increase the rate of oil oxidation while other elements such as As, Cd and Pb are very important on account of their toxicity and metabolic role. So, in this study attempt has been made to determine the concentration of metal like Cu, Zn, Mn, Cd and Pb in vegetable oils to understand its potential for human use. These minerals are known to play vital role in plants and animals.

Statistical analysis for trace elements of the six oilseeds revealed the major elements to be significantly correlated at 0.01 and 0.05 significance levels (P-value is 0.005). Mg showed strong positive correlation (80-100%) with Na, Zn, Ca and Mn, Ca as indicates in the Table 5(b). Mn is also positively correlated (80-100%) with Na, Mg, Zn and Ca and Na is with Mg, Zn, Mn, and Ca. Fe showed 100% negative correlation with As at 0.01 significance level indicating good quality of metals in studied oilseeds.

The tocol content of the six studied seed oils are presented in Table 6(a). Tocopherols are considered to be one of the most powerful natural fat soluble antioxidants. Oil extracts with high tocol content can be used in applications where a high level of anti-oxidant protection is needed. On the other hand tocopherols present in foods, have shown highest vitamin E activity making it as one of the most important components for human health and biological activity. In our study Terminalia bellirica (585.0) contains highest amount of tocols while no tocols are present in Clausena suffruticosa and Eucalyptus.
Table 6 (a) Tocopherols and tocotrienols analysis of the 6 tree-borne seed oils.

| Species Name            | $\alpha$-T | $\gamma$-T | $\delta$-T | $\alpha$-T3 | $\gamma$-T3 | $\delta$-T3 | TOTAL TOCOLS (T+T3) PPM (WT%) |
|-------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-----------------------------|
| Chrysophyllum roxburghii| 5.0         | -           | -           | -           | -           | -           | 225.0 230.0 (0.023%)         |
| Dysoxylum procerum      | 5.0         | 22.13       | 26.20       | -           | -           | -           | 53.32 8.15 (0.0053%)         |
| Elaeocarpus robustus    | 4.0         | -           | -           | -           | -           | -           | 4.15                         |
| Clausena suffruticosa   | -           | -           | -           | -           | -           | -           | No Tocols Present            |
| Eucalyptus citriodora   | -           | 124.0       | 23.0        | -           | -           | -           | 438.0                         |
| Terminalia bellirica    | -           | -           | -           | -           | -           | -           | 585.0 (0.05%)                 |

ANOVA

| Source of Variation      | SS          | df | MS            | F        | P-value | F crit |
|--------------------------|-------------|----|---------------|----------|---------|--------|
| Between Groups           | 131538.24   | 5  | 26307.65      | 1.19     | 0.353   | 2.77   |
| Within Groups            | 398094.87   | 18 | 22116.38      |          |         |        |
| Total                    | 529633.11   | 23 |               |          |         |        |

Significance level: $p < 0.05$, N=4.

Table 6 (b) Pearson Correlation for Tocopherols and tocotrienols of the seed oils.

|       | $\alpha$-T | $\gamma$-T | $\delta$-T | $\gamma$-T3 | $\delta$-T3 | T+T3 |
|-------|-------------|-------------|-------------|-------------|-------------|------|
| $\alpha$-T | 1           | -0.95       | -0.40       | -0.98*      | 0.42        | -0.86 |
| $\gamma$-T | -0.95       | 1           | 0.64        | 0.98*       | -0.41       | 0.90  |
| $\delta$-T | -0.40       | 0.64        | 1           | 0.50        | -0.57       | 0.36  |
| $\gamma$-T3 | -0.98*      | 0.98*       | 0.50        | 1           | -0.34       | 0.93  |
| $\delta$-T3 | 0.42        | -0.41       | -0.57       | -0.34       | 1           | 0.03  |
| T+T3     | -0.86       | 0.90        | 0.36        | 0.93        | 0.03        | 1     |

* Correlation is significant at the 0.05 level (2-tailed), N=4

The Pearson correlation matrix showed the relationships among the analyzed tocol values of tocopherols and tocotrienols for the six tree-borne oilseeds [Table 6 (a) and (b)]. $\gamma$-T3 and $\gamma$-T showed highly positive correlation ($r = 0.98$, i.e. 96% related) at 0.05 significant level, where N = 4. On the other hands $\gamma$-T3 was negatively related ($r = -0.98$ i.e. 96% negative relation) with $\alpha$-T at the significance level of 0.05. The analysis of the results indicated that fatty acids of the 6 tree borne oilseeds contained high compounds of Tocopherols and tocotrienols.

Analysis of the P/S ratio and $\omega_6/\omega_3$ ratio in Table 7(a) revealed that the ratio of $\omega_6/\omega_3$ lies between 5-10 in Chrysophyllum roxburghii, Dysoxylum procerum and Clausena suffruticosa. According to World Health Organisation (WHO), the ideal intake ratio of $\omega_6/\omega_3$ lies between 5-10 (63) and PUFA and SFA lies between 0.8-1 for edible purpose (64). MUFA value was found highest in Dysoxylum procerum (64.9). The total unsaturated fatty acid (MUFA + PUFA) content in all the six studied plants was found higher than the saturated fatty acids. Statistical analysis revealed a very strong positive ($r = 0.89, 0.84 & 0.1$ i.e. 79%, 70% & 100%) correlation among oil percent, predominant oleic acid and mono-unsaturated fatty acid contents at the significance levels of 0.05 & 0.01 where N = 4. The P/S (WHO 0.8-1) was also highly ($r = 0.84$ i.e. 70%) correlated with poly-unsaturated fatty acid contents and the U/S was negatively ($r = -0.84$) correlated with saturated fatty acids contents at the significance level of 0.05 present in the tree borne oil seeds as shown in the Table 7(b). The analysis showed that the oils quality is good and due to high unsaturated fatty acid content prominently oleic acid; they may be used in edible purpose in future.

4 Conclusion

Oil extracts from oil seeds of these six plant species contain a large amount of oleic acid and tocopherol content which may serve as dietary source of natural antioxidant and bear prominent potentiality for commercial purposes. Oleic acids are considered as monounsaturated fatty acids so these oilseeds can serve as novel sources of unconventional edible oils in the near future. This study has evit...
denced that the exploration of the tree borne oil seeds of Assam, India, the biodiversity hot spot area of India and evaluation or characterization of their oil contents may provide valuable information regarding their commercial potentiality in future years to come. Earlier, *Terminalia bellirica* has been reported as a source of biodiesel but after this survey we can conclude that *T. bellirica* can also be used as edible oil due to its high oleic acid content but further analysis is required in this process.

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**Conflict of Interest**

There is no conflict of interest.

| Sl. No. | Name of the Species       | Oil %  | Pre-dominant fatty acid (oleic acid) | Saturated | Mono-unsaturated | Poly-unsaturated | U/S (WHO 0.8-1) | ω6/ω3 (WHO 5-10) | Mean SD CV SEM |
|--------|---------------------------|--------|-------------------------------------|-----------|------------------|------------------|-----------------|-----------------|----------------|
| 1      | Chrysophyllum roxburghii  | 35.20  | 56.6                                | 36.3      | 56.1             | 6.2              | 1.71            | 0.1             | 6.1 24.66 23.93 0.97 8.46 |
| 2      | Dysoxylum procerum        | 50.31  | 64.0                                | 31.801    | 64.9             | 8.3              | 2.30            | 0.1             | 2.60 28.04 28.39 1.01 10.0 |
| 3      | Elaeocarpus robustus      | 9.58   | 40.3                                | 33.5      | 43.7             | 22.6             | 1.98            | 0.5             | 112 33.02 36.02 1.09 12.74 |
| 4      | Clausena suffruticosa     | 8.62   | 34.8                                | 7.7       | 37.5             | 1.0              | 5               | 0.1             | 1.0 11.97 15.27 1.28 5.40 |
| 5      | Eucalyptus citriodora     | 8.5    | 21.8                                | 19        | 23.1             | 13.8             | 1.94            | 0.5             | 16.25 13.11 8.66 0.66 3.06 |
| 6      | Terminalia bellirica      | 38.94  | 47.3                                | 34        | 48.2             | 17.1             | 1.92            | 0.3             | 17.1 25.61 19.18 0.75 6.78 |
| Mean   |                           | 25.19  | 43.97                               | 27.05     | 45.58            | 11.50            | 2.48            | 0.27            | 25.84 25.19 43.97 27.05 45.58 |
| SD     |                           | 16.92  | 13.76                               | 10.31     | 13.32            | 7.17             | 1.14            | 0.18            | 39.03 16.92 13.76 10.31 13.32 |
| CV     |                           | 0.67   | 0.31                                | 0.38      | 0.29             | 0.62             | 0.46            | 0.67            | 1.51 0.67 0.31 0.38 0.29 |
| SEM    |                           | 6.91   | 5.62                                | 4.21      | 5.44             | 2.93             | 0.47            | 0.07            | 15.93 6.91 5.62 4.21 5.44 |

**Table 7 (b)** Pearson Correlation for P/S and Omega 6/ omega 3 ω6/ω3 ratio.

|       | Oil % | Pre-dominant oleic acid | Saturated | Mono-unsaturated | Poly-unsaturated | U/S (WHO 0.8-1) | Omega6/ omega3 |
|-------|-------|-------------------------|-----------|------------------|------------------|-----------------|----------------|
| Oil % | 1     |                         |           |                  |                  |                 |                |
| Pre-dominant oleic acid | 0.89* | 1                       |           |                  |                  |                 |                |
| Saturated | 0.63   | 0.66                    | 1         |                  |                  |                 |                |
| Monoun-saturated | 0.86* | 1.00**                  | 0.65      | 1                |                  |                 |                |
| Polyunsaturated | −0.13 | −0.17                   | 0.52      | −0.19            | 1                |                 |                |
| U/S   | −0.39 | −0.25                   | −0.84*    | −0.22            | −0.65            | 1               |                |
| P/S (WHO 0.8-1) | −0.56 | −0.65                   | 0.07      | −0.64            | 0.84*            | −0.4            | 1              |
| Omega6/omega3 | −0.42 | −0.19                   | 0.31      | −0.14            | 0.79             | −0.3            | 0.69           |

* Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed), N=6.

| Source of Variation | SS   | df  | MS    | F     | P-value | F crit |
|---------------------|------|-----|-------|-------|---------|--------|
| Between Groups      | 12292| 7   | 1755.99 | 5.013152 | 0.000384 | 2.25   |
| Within Groups       | 14011| 40  | 350.2766 |       |         |        |
| Total               | 26303| 47  |       |       |         |        |

Significance level: p < 0.05, N=6.
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