Chapter- IV

PIXE and PIGE analysis of the medicinal plants

This chapter deals with the elemental analysis of twenty eight (28) traditionally use medicinal plant samples of Manipur by using the PIXE technique. Out of these twenty eight samples, twenty two (22) were analyzed at National Centre for Compositional Characterization of Materials (CCCM), BARC, Hyderabad by using 2.4 MeV proton beams from the 3MV Tandetron accelerator available at the centre, while another six (6) samples were analyzed at Institute of Physics (IOP), Bhubaneswar by using 2.5 MeV proton beams from the 3MV tandem accelerator. The spectral data were analyzed using GUPX software.

Among the twenty two samples studied by PIXE at CCCM, eighteen (18) samples were studied by PIGE technique as well. The light elements Na, Mg, Al and P were quantitatively determined by using PIGE while K, Ca, Mn, Fe, Cu, Zn, Rb and Sr were determined by using PIXE.
4.1. Plan of Investigation

The plant parts which are reported to have medicinal values and commonly used as folk medicine were chosen for the elemental analysis. The samples taken were root, bark, leaf, fruit and seeds of the plants. From the observed data, a few correlations were made between the concentrations of elements in different plants and their reported therapeutic actions. An effort was also made for the definition of the recommended doses of some of these plants for their use in the medicinal purposes.

4.2. Description of the selected plants

Descriptions of the plants were done following R. P. Rastogi et al [1], S.G. Joshi [2], S.C. Sinha [3] and A. Jugindro [4].

Sample no. 1
Scientific name : *Centella asiatica* (Linn.)
Family     : Umbelliferae
Local name : Peruk (M), Khulakhudi (H), Indian pennywort (E)
Part studied : Whole plant
Medicinal use : As a brain tonic; in stomach ulcers; in urinary troubles; in digestive complaints and dysentery.
Sample no. 2

Scientific name: *Zanthoxylem acanthopodium* DC

Family: Rutaceae

Local name: Mukthrubi (M), Darmar (H), Tombul (B)

Part studied: Leaf

Medicinal use: Seeds and leaves are used in chronic fever, indigestion, cough and bronchitis. Oil extracted from the seeds is useful for healthy growth of hairs.

Sample no. 3

Scientific name: *Curcuma domestica* Valeton

Family: Zingiberaceae

Local name: Yaingang (M), Haldi (H & B), Turmeric (E)

Part studied: Rhizomes

Medicinal use: The paste made of rhizomes and leaves of neem is rubbed in the body before bath as antidote for small pox and for skin-care; juice is given in eye diseases; same is inhaled in asthma. Rhizome is aromatic, stimulant, tonic, carminative, blood purifier, externally applied to sprains and wounds. Decoction of rhizomes is used in purulent conjunctivitis; fresh juice is used as antiparasitic for many skin affections.
**Sample no. 4**

Scientific name: *Ocimum sanctum* Linn.

Family: Labiatae

Local name: Tulsi (M, H & B),
Sacred basil (E)

Part studied: Leaf

Medicinal use: Leaf juice is given in fever, cough, cold, congestion of lungs. Root decoction is given in malaria.

**Sample no. 5**

Scientific name: *Hedychium marginatum* C.B.Clarke

Family: Zingiberaceae

Local name: Takhetlei angangba (M)

Part studied: Rhizomes

Medicinal use: Decoction of rhizome is given in bronchitis and stomach complaints.

**Sample no. 6**

Scientific name: *Kaempferia galanga* Linn

Family: Zingiberaceae

Local name: Yaithamna- manbi (M),
Bhui-champa (H&B)

Part studied: Rhizomes
Medicinal use: Extract of rhizomes is applied to head for proper growth of hairs; also used as an ingredient of an indigenous hair-care lotion (chenghi). Plant is powdered and used as ointment in healing wounds; taken internally removes coagulated blood or purulent matter. Rhizomes are considered stomachic and used in gastric complaints; as powder used for application in mumps. Juice of the tubers is used in dropsical affections. Also widely used as a local application on tumours, swellings and wounds.

Sample no. 7
Scientific name: Acacia farnesiana Willd
Family: Mimosaceae
Local name: Chinggonglei (M), Vilayati Kikar (H), Gaya babul (B)
Part studied: Seeds
Medicinal use: Bark is astringent and demulcent, gum from stem is a good tonic; decoction of pods is used in urinogenital diseases.

Sample no. 8
Scientific name: Zingiber cassumunar (Roxb.)
Family: Zingiberaceae
Local name: Tekhao yaikhu (M)
Part studied: Rhizomes
Medicinal use: Rhizomes are prescribed in cold and cough.
Sample no. 9

Scientific name: *Lemanea australis* Atkins

Family: Vitaceae

Local name: Nungsum (M)

Part studied: Filaments

Medicinal use: Boiled extract of fresh filaments is prescribed as a abortificant drug, particularly for removing placenta when it is obstructed after a child birth. Also use for relieving the urinary troubles due to stones. Prescribed for better blood circulation to pregnant and nursing mothers.

Sample no. 10

Scientific name: *Leucas aspera* Spreng

Family: Labiatae

Local name: Mayanglambum (M), Chota halkusa (H&B)

Part studied: Leaf

Medicinal use: Leaf-juice is used in the treatment of stomach complaints; also applied to poisonous insect-bites; paste of tender shoots is applied to relieve headache. Leaves are also given in constipation problems.

Sample no. 11

Scientific name: *Andrographis paniculata* Wall. Ex Nees

Family: Acanthaceae
Local name : Vubati (M), Kirayat (H), Kalmegh (B), Creat (E)

Part studied : Leaf

Medicinal use : Leaves are used in asthma, chronic fevers, bronchitis and worm diseases. Plant is also used in dysentery, Cholera, diabetes, influenza, itches and piles. Decoction is used for the treatment of jaundice.

Sample no. 12

Scientific name : Melothria purpusilla (Blume) Cogn
Family : Curcurbitaceae
Local name : Lamthabi (M)
Part studied : Leaf
Medicinal use : The plant is useful in the treatment of jaundice and kidney affection other than stones.

Sample no. 13

Scientific name : Aegle marmelos Correa ex Roxb
Family : Rutaceae
Local name : Herikhagok (M), Bel (H&B), Bael Tree (E)
Part studied : Fruit
Medicinal use : Pulp of roasted green fruit is given in chronic stomach disorders. Pulp of the ripe fruit is also used for the same purpose.

Sample no. 14

Scientific name : *Celtis timorensis*
Family : Ulmaceae
Local name : Heikreng
Part studied : Leaf
Medicinal use : Boiled extracts of leaves is given in gall bladder and kidney stone problems.

Sample no. 15

Scientific name : *Meriandra bengalensis* Benth
Family : Labiatae
Local name : Lomba (M)
Part studied : Inflorescence
Medicinal use : It is tonic, carminative, astringent and antiseptic. Leaves-infusion is served as a mouthwash for sore throat. Decoction of leaves, flowers are given in tonsillitis. Plant is also considered very useful in failing memory.

Sample no. 16

Scientific name : *Polygonum posumba* Bach
Family : Polygonaceae
Local name : Phakpai (M)
<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Scientific name</th>
<th>Family</th>
<th>Local name</th>
<th>Part studied</th>
<th>Medicinal use</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td><em>Cissus javana</em> DC</td>
<td>Vitaceae</td>
<td>Kongngouyen (M)</td>
<td>Leaf</td>
<td>Boiled extract of leaves is given in urinary bladder and kidney stone problems; also useful in burning sensation during urination.</td>
</tr>
<tr>
<td>18</td>
<td><em>Zingiber officinale</em> Rosc</td>
<td>Zingiberaceae</td>
<td>Sing (M), Adrak (H), Ada (B), Ginger (E)</td>
<td>Rhizome</td>
<td>Rhizome-extract, mixed with honey is given in catarrh, asthma, cough and useful in rheumatism. Outer layer of the rhizome is given in paralysis, to improve blood circulation.</td>
</tr>
<tr>
<td>19</td>
<td><em>Xylosum longifolia</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Family : Flacourtiaceae
Local name : Nongleisang (M), Dandal (H)
Part studied : Leaf
Medicinal use : Fresh leaves wrapped in cloth are warmed on steam and the packet is applied on the protruded piles as fomentation for cure.
Alcoholic extract (ethyl) of fresh leaves when applied on the protruded piles around the anus also heals them.

Sample no. 20
Scientific name : *Bryophyllum pinntum* (Lam.) Kruz
Family : Crassulaceae
Local name : Manahidak (M), Zakhm-haiyat (H), Koppata (B)
Part studied : Leaf
Medicinal use : Expressed extract of leaves is given in dysentery. Leaf after warming is applied to boils for early suppuration.

Sample no. 21
Scientific name : *Elaeocarpus floribundus* Blume
Family : Elaeocarpaceae
Local name : Chorphone (M), Jalpai (B)
Part studied : Leaf
Medicinal use: Fruits are highly antiseptic.
Infusion of bark and leaves is used as mouth-wash in inflamed gum.

Sample no. 22

Scientific name: *Curcuma caesia*
Family: Zingiberaceae
Local name: Yaimu (M)
Part studied: Rhizome
Medicinal use: Rhizomes are stimulant, carminative, used externally for sprains and bruises. Prescribed for cold and fever.

Sample no. 23

Scientific name: *Ficus glomerata*
Family: Moraceae
Local name: Heibong (M)
Part studied: Bark
Medicinal use: Bark and root extract are given in dysentery and diabetes. Fruit is also prescribed in lung diseases. Latex is applied to boils.

Sample no. 24

Scientific name: *Ficus palmate Forsk*
Family: Moraceae
Local name: Heibam (M), Anjiri (H)
Part studied: Leaf
Medicinal use: Leaves are used in healing obstruction of urine flow and extraction of pus. Fruits are demulcent and laxative, used in diseases of lungs and bladder.

Sample no. 25
Scientific name: *Oroxylum indicum* Vent.
Family: Bignoniaceae
Local name: Shamba (M), Sona (B)
Part studied: Bark
Medicinal use: Decoction of leaves and bark is used in muscular pains and general weakness. Leaves are used in epilepsy. Root bark is tonic and astringent, used in diarrhoea and dysentery; also useful in rheumatism. Tender fruits are stomachic; seeds are purgative. Decoction of leaves is given in stomachache and rheumatism; leaves are externally used for enlarged spleen.

Sample no. 26
Scientific name: *Terminalia arjuna* (Roxb)
Family: Combretaceae
Local name: Maiyokpha (M), Arjuna (H), Arjun (B)
Part studied : Bark

Medicinal use : Bark and leaf extract is given in liver complaints, piles, heart complaints and hypertension.

Sample no. 27

Scientific name : *Panax gingseng*

Family : Araliaceae

Local name : Ginseng (M)

Part studied : Root

Medicinal use : Tubers are aphrodisiac, stimulant, used in dyspepsia, vomiting; expectorant and antipyretic, helps body to adapt to situations of stress, fatigue, cold, hunger, temperature extremes and mental/emotional stress.

Sample no. 28

Scientific name : *Plumeria acuminata* Ait.

Family : Apocynaceae

Local name : Khagleihao (M), Golainchi (H), Dalan phul (B), Pagoda or Temple Tree (E).

Part studied : Bark
Medicinal use: Leaves are crushed and given in stomach pains and diarrhea. The fruits are carminative, prescribed in stomach disorders and cancer. Bark is stimulant; decoction is useful in dropsical and venereal affection.

[Note: M-Manipuri; H-Hindi; B-Bengali; E- English]

4.2.1. Sample collection and target preparation

Fresh samples of different medicinal plants were collected from various areas of Manipur. The samples were thoroughly washed with distilled water, dried in an oven at 40°C and subsequently ground into fine powder.

(a) Target preparation at CCCM

The powdered samples were thoroughly mixed with high purity graphite powder in the ratio 4:1 by weight. The samples thus obtained were further mixed with 200 μl of 2-wt % polyvinyl alcohol, a binder, dried under an IR-lamp and subsequently pressed into pellet of 18 mm diameter and 2 mm thickness. The thick targets of Certified Reference Materials (CRMs) of cabbage (GBW 08504, China), wheat flour (NIST-8436) and bovine liver (NIST-1577b) were also prepared in a similar way standardization and verification of the results [5].

(b) Target preparation at IOP

150 mg of each of the sample powder was mixed thoroughly with 65mg of high purity graphite powder. Pellets (10 mm diameter, 1 mm thickness) were
prepared from this mixture using a hydraulic press (110kg/cm² pressure). These pellets were used as targets. Pellet of apple leaf standard (NIST-1515) was also prepared in a similar way for standardization of the PIXE set up.

The purpose of mixing graphite was to make the sample electrically conducting, so that total charge incident on the target during irradiation could be measured [6]. Pressed pellet preparation prior to PIXE analysis has the advantages of minimal sample preparation with large specimen size allowing one to make representative and replicate determinations on the same pellet. A graphite pellet of the same amount as the target was also prepared in both the cases to make the necessary background correction.

4.3. PIXE Analysis

4.3.1. Experimental System and Data Collection

(a) At CCCM

PIXE measurement for twenty two samples (sample no.1 to sample no.22) was performed at Surface and Profile Measurement Laboratory at National Centre for Compositional Characterization of Materials (CCCM), BARC, Hyderabad, India using the 3 MV tandemron accelerator. A well collimated 2.4 MeV proton beams of diameter 5 mm and current 5-7 nA was incident normally on targets placed inside a scattering chamber. The aluminum sample holder can be moved in the vertical direction, which allows the irradiation of
different targets without changing the measuring geometry. The vacuum inside the scattering chamber, pumped by a turbomolecular pump, was about $2 \times 10^{-6}$ torr. An electron suppressor with $-900$ V was placed in front of samples. The X-rays were detected by a planer high purity germanium (HPGe) detector (Eurisys Measures type EGX100-01, Be window thickness of 40 µm, FWHM of 150 keV at 5.9 keV) placed at $45^\circ$ to the beam axis [5,7]. A 150 µm thick polyethylene sheet was used as absorber and kept in front of the detector to attenuate the bremsstrahlung background and dominant low energy X-ray peaks. A 25 µm mylar foil served as the X-ray exit window. The data were recorded on a PC based MCA. The standards were run just before and immediately after running the samples in the same experimental conditions in order to check the accuracy of the results. The PIXE spectra were calibrated using Cu (8.05 keV) and Mo (17.48 keV) foils.

(b) At IOP

PIXE measurements of the remaining six samples (sample no. 23 to sample no.28) was done at IOP by using collimated proton beam of diameter 2mm and energy 2.5 MeV obtained from the 3 MV Tandem Pelletron Accelerator. A schematic diagram of the accelerator is shown in Fig 4.1. A cesium sputtered negative ion source (SNICS) was used to obtain the 2.5 MeV proton beam. The PIXE chamber was maintained at a vacuum of $10^{-6}$ torr. The targets were mounted on an octagonal multiple target holder ladder oriented at $45^\circ$ to the beam axis and positioned vertically. The ladder was moved
vertically in the vacuum for selecting and bombarding different targets maintaining the same projectile-target-detector geometry and the vacuum inside the PIXE chamber. An electron suppressor with -200 V was placed in front of the samples. Photographs of the beam line and scattering chamber at Institute of Physics, Bhubaneswar, are shown in Plate 4.1 and Plate 4.2. An aluminum funny filter of 64 μm thickness with a hole diameter of 0.2mm was used. The X-rays produced from the beam-target interaction were extracted from the chamber through a 25 μm mylar window. A Si(Li) detector (Canberra SL 30160, active area of 30.2 mm²) with full-width at half-maxima (FWHM) of 170eV at 5.9 KeV placed at 90° to the beam axis and in front of the mylar window, was used to detect these characteristic X-rays. Spectra were recorded on a PC based MCA (WINMCA). The system was calibrated using a 55Fe radioisotope standard X-ray source, for the identification of the X-ray peaks.

4.3.2. Data Analysis

Analysis of unknown sample by using PIXE technique consists of two parts:

(i) Qualitative analysis: - identification of all elements that are present in the material from the characteristic X-rays (K, L etc.) that are emitted.

(ii) Quantitative analysis: - to find the quantity of each element in the material, from the area under the peak.
Fig. 4.1. Schematic diagram of the 3 MV Pelletron Accelerator at the Institute of Physics, Bhubaneswar, India.
Plate 4.1. Beam line for PIXE set up at Institute of Physics, Bhubaneswar, India

Plate 4.2. A closer view of PIXE set up
4.3.2.1. Qualitative Analysis

By qualitative analysis, we find all the elements that are present in the sample. When the sample is irradiated with the proton beam, the protons interact with the electrons to create inner-shell vacancies in the atoms present in the sample material. The energies of the X-rays which are emitted when these vacancies are filled again are characteristic of the elements from which they originate. Thus, the elements present in the samples are easily identified from the spectral lines recorded by using an X-ray energy chart.

The prominent lines in PIXE spectra, for most of the elements, are $K_\alpha$ and $K_\beta$ lines. In the K-series, the $K_\alpha$ peak is the strongest and $K_\beta$ is very small, about 5-times less than that of $K_\alpha$. So in order to identify any element in the spectra, one must look for all these series of lines. Any absence of the peaks must be accounted for quantitative analysis. For example, if one of the peaks is believed to be $K_\alpha$, then the weaker $K_\beta$ should also be identified, if not the absence must be accounted. In case $K_\alpha$ is itself very weak, then $K_\beta$ may not be obtained appreciably, to be distinguished from the background, sometimes it may happen that the $K_\alpha$-line of another element merges with the $K_\beta$ of a particular element. Here also one has to reduce the contribution due to the combination of two lines in order to do quantitative analysis.

The relative intensities of the lines must be considered and the anomalies in the intensities of the spectral lines must be accounted. If for example, a line
is assumed to be that of $K_\alpha$ while the intensity of $K_\beta$ is more than $\frac{1}{4}$ of the $K_\alpha$ intensity, this may be due to two reasons:

(i) the $K_\beta$ is superimposed on another peak of some other element, giving an abnormally large intensity.

(ii) Or a matrix element (i.e. other element in the sample) is preferentially absorbing the $K_\alpha$ line of the particular element.

To check for this, we have to scan the spectrum to see for peaks of such elements which contribute for the abnormally large intensity or preferential absorption. If those peaks could not be found, then one has to decide that the peaks are not $K_\alpha$ and $K_\beta$ at all and hence has to search in the other series.

Thus, by considering the energies and taking into account the overlap of peaks and that of relative intensities of the various lines, all the lines in the spectrum are identified. Fig. 4.2 to Fig 4.29 shows the PIXE spectra of the samples studied.

4.3.2.2. Quantitative Analysis

The determination of amount or concentration present in a specimen is perhaps the most important factor in the characterization of a material. The spectral data recorded were analysed using GUPIX software [8-10]. This software provides non linear least square fitting of the spectrum together with subsequent conversion of X-ray peak intensities to elemental concentrations.
Fig. 4.2. PIXE spectrum of *Centella asiatica* (Linn)

Fig. 4.3. PIXE spectrum of *Zanthoxylum acanthopodium* DC
Fig. 4.4. PIXE spectrum of *Curcuma domestica* Valeton

Fig. 4.5. PIXE spectrum of *Oscimum sanctum* Linn
Fig. 4.6. PIXE spectrum of *Hedychium marginatum* CB Clarke

Fig. 4.7. PIXE spectrum of *Kaempferia galanga* Linn
Fig. 4.8. PIXE spectrum of *Acacia farnesiana* Willd

Fig. 4.9. PIXE spectrum of *Zingiber cassumunar* (Roxb.)
Fig. 4.10. PIXE spectrum of *Lemania australis* Atkins

Fig. 4.11. PIXE spectrum of *Leucas aspera* Spreng
Fig. 4.12. PIXE spectrum of *Andrographis paniculata* Wall. Ex. Nees

Fig. 4.13. PIXE spectrum of *Melothria purpusilla* (Blume) Cogn
Fig. 4.14. PIXE spectrum of *Agele marmelos* Correa ex Roxb

Fig. 4.15. PIXE spectrum of *Celtis timorensis*
Fig. 4.16. PIXE spectrum of *Meriantra bengalensis* Benth

Fig. 4.17. PIXE spectrum of *Polygonum posumba* Bach
Fig. 4.18. PIXE spectrum of *Cissus javana* DC

Fig. 4.19. PIXE spectrum of *Zingiber officinale* Rosc
Fig. 4.20. PIXE spectrum of Xylosum longifolia

Fig. 4.21. PIXE spectrum of Bryophyllum pinntum (Lan.) Kruz
Fig. 4.22. PIXE spectrum of *Elaeocarpus floribundus* Blume

Fig. 4.23. PIXE spectrum of *Curcuma caesia*
Fig. 4.24. PIXE spectrum of *Ficus glomerata*

Fig. 4.25. PIXE spectrum of *Ficus palmate* Forsk
Fig. 4.26. PIXE spectrum of *Oroxylum indicum* Vent

Fig. 4.27. PIXE spectrum of *Terminalia arjuna* (Roxb)
Fig. 4.28. PIXE spectrum of *Panax ginseng*

Fig. 4.29. PIXE spectrum of *Plumeria acuminata* Ait
For the samples analysed at CCCM, Hyderabad, GUPIX-99 [10] was used to get the X-ray peak intensities. In thick target PIXE (TT-PIXE), calibration standards having matrix composition identical to that of the sample under investigation are required for quantification with better accuracy. Therefore three biological standard reference materials, as mentioned earlier, were used as calibration standards for the analysis of the samples at CCCM. In order to ascertain the accuracy of the analysis, the calibration standards were analysed against each other. The overall uncertainty in the estimation of all elements except Fe, on repetitive measurements, was observed to be 3-8%. It may be ascribed to errors in the measurement of peak areas and relative accumulated charges. In the case of Fe, the uncertainty was about 15%, which may be largely due to its inhomogeneous distribution in the targets. It is to be noted that sufficient care was exercised to avoid contamination during the preparation of the samples [7]. Table 4.1 shows the elemental concentrations of the twenty two samples analysed at CCCM.

At IOP, GUPIX-96 software was used for analyzing the spectral data [9]. The process involves two main steps. First a model spectrum is fitted to the measured spectrum to ascertain the peak areas. Then these areas are converted to elemental concentrations using measured instrumental constant, the known characteristics of the detector and absorber and matrix correction that account for the role of major elements for slowing down the incident proton beam and attenuating the emitted X-rays. The X-ray intensity or yield (principal line) $Y(Z, M)$ for an element $Z$ in a matrix $M$ is given by [11, 12]
\[ Y(Z, M) = Y_{tt}(Z, M) \cdot C_z \cdot Q \cdot f_q \cdot \omega \cdot \varepsilon \cdot T \quad (4.1) \]

where, \( Y_{tt}(Z, M) \) is the theoretical intensity or yield per micro coulomb of charge per unit concentration per steradian; \( C_z \) is the actual concentration of the element \( Z \) in the matrix \( M \); \( \omega \) is the detector front face solid angle in steradian; \( Q \) is measured beam charge or a fraction thereto (as the exact measure of charge is a tedious job); if the later case, then \( f_q \) converts \( Q \) to microcoulombs, if former then \( f_q \) is taken as 1.0 assuming proper electron suppression at the target; \( \varepsilon \) is the intrinsic efficiency of the Si(Li) detector (close to 1.0 for energy between 5.0 and 20.0 keV) and \( T \) is the transmission through any filter or absorber between sample and detector.

GUPIX code makes use of top hat digital filter, which is widely used in the treatment of electron microprobe X-ray spectra [13], to suppress the linear background entirely and to modify Gaussian peak shape (as shown in the Figure 4.30 below).

![Figure 4.30](image)

**Fig. 4.30** The "Top hat" digital filter used to suppress background together with its effect upon a simple spectrum.
Table 4.1. Concentrations of twenty two medicinal plant samples analysed by PIXE at CCCM in ppm

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Plant name</th>
<th>K</th>
<th>Ca</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
<th>Rb</th>
<th>Sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Centella asiatica (Linn)</td>
<td>24900</td>
<td>9600</td>
<td>134.26</td>
<td>144.23</td>
<td>10.12</td>
<td>76.1</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>2</td>
<td>Zanthoxylem acaanthopodium DC</td>
<td>19800</td>
<td>9800</td>
<td>50.32</td>
<td>41.16</td>
<td>4.73</td>
<td>26.4</td>
<td>ND</td>
<td>54.48</td>
</tr>
<tr>
<td>3</td>
<td>Curcuma domestica Valeton</td>
<td>48400</td>
<td>2900</td>
<td>24.05</td>
<td>141.75</td>
<td>8.08</td>
<td>45.9</td>
<td>5.28</td>
<td>ND</td>
</tr>
<tr>
<td>4</td>
<td>Oscinium sanctum Linn</td>
<td>33800</td>
<td>17600</td>
<td>25.43</td>
<td>384.12</td>
<td>21.99</td>
<td>49.56</td>
<td>31.96</td>
<td>109.46</td>
</tr>
<tr>
<td>5</td>
<td>Hedychium marginatum CB Clarke</td>
<td>26000</td>
<td>5600</td>
<td>450.87</td>
<td>295.29</td>
<td>1.93</td>
<td>155.7</td>
<td>11.61</td>
<td>59.24</td>
</tr>
<tr>
<td>6</td>
<td>Kaempferia galangal Linn</td>
<td>39200</td>
<td>2200</td>
<td>631.52</td>
<td>176.77</td>
<td>8.35</td>
<td>66.52</td>
<td>16.37</td>
<td>ND</td>
</tr>
<tr>
<td>7</td>
<td>Acacia farnesiana Willd</td>
<td>30700</td>
<td>2500</td>
<td>18.14</td>
<td>190.15</td>
<td>17.65</td>
<td>43.34</td>
<td>19.96</td>
<td>ND</td>
</tr>
<tr>
<td>8</td>
<td>Zingiber cassumunar (Roxb.)</td>
<td>23300</td>
<td>1900</td>
<td>203.46</td>
<td>82.53</td>
<td>2.68</td>
<td>44.93</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>9</td>
<td>Lemanea australis Atkins</td>
<td>5800</td>
<td>1000</td>
<td>314.2</td>
<td>1531.3</td>
<td>6.71</td>
<td>87.3</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>10</td>
<td>Leucas aspera Spreng</td>
<td>32200</td>
<td>14200</td>
<td>57.83</td>
<td>315.3</td>
<td>6.87</td>
<td>33.6</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>11</td>
<td>Andrographis paniculata Wall. Ex. Nees</td>
<td>14100</td>
<td>24300</td>
<td>30</td>
<td>201</td>
<td>12.8</td>
<td>67.5</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Sample no.</td>
<td>Plant name</td>
<td>K</td>
<td>Ca</td>
<td>Mn</td>
<td>Fe</td>
<td>Cu</td>
<td>Zn</td>
<td>Rb</td>
<td>Sr</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------</td>
<td>----</td>
<td>-----</td>
<td>-----</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>12</td>
<td><em>Melothria purpusilla</em> (Blume) Cogn</td>
<td>46900</td>
<td>12500</td>
<td>34.5</td>
<td>176.7</td>
<td>7.33</td>
<td>49.83</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>13</td>
<td><em>Agele marmelos</em> Correa ex Roxb</td>
<td>11700</td>
<td>1300</td>
<td>5</td>
<td>43.55</td>
<td>3.34</td>
<td>6.54</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>14</td>
<td><em>Celtis timorensis</em></td>
<td>1500</td>
<td>1400</td>
<td>61.1</td>
<td>51.93</td>
<td>1.81</td>
<td>6.02</td>
<td>ND</td>
<td>45.93</td>
</tr>
<tr>
<td>15</td>
<td><em>Meriandra bengalensis</em> Benth</td>
<td>16700</td>
<td>5100</td>
<td>127.9</td>
<td>170.1</td>
<td>9.78</td>
<td>46.47</td>
<td>ND</td>
<td>46.05</td>
</tr>
<tr>
<td>16</td>
<td><em>Polygonum posumba</em> Bach</td>
<td>13000</td>
<td>8600</td>
<td>722.9</td>
<td>112.5</td>
<td>6.23</td>
<td>66.21</td>
<td>9</td>
<td>ND</td>
</tr>
<tr>
<td>17</td>
<td><em>Cissus javana</em> DC</td>
<td>21400</td>
<td>10500</td>
<td>167</td>
<td>265.3</td>
<td>5</td>
<td>193.01</td>
<td>6.5</td>
<td>61.08</td>
</tr>
<tr>
<td>18</td>
<td><em>Zingiber officinale</em> Rosc</td>
<td>7700</td>
<td>1700</td>
<td>313.42</td>
<td>216.64</td>
<td>4.47</td>
<td>72.53</td>
<td>12.85</td>
<td>ND</td>
</tr>
<tr>
<td>19</td>
<td><em>Xylosom longifolia</em></td>
<td>9900</td>
<td>14400</td>
<td>185.06</td>
<td>75.56</td>
<td>4.15</td>
<td>67.77</td>
<td>5.28</td>
<td>106.77</td>
</tr>
<tr>
<td>20</td>
<td><em>Bryophyllum pinntum</em> (Lan.) Kruz</td>
<td>12100</td>
<td>18900</td>
<td>12.77</td>
<td>138.68</td>
<td>4.72</td>
<td>35.59</td>
<td>3.19</td>
<td>71.22</td>
</tr>
<tr>
<td>21</td>
<td><em>Elaeocarpus floribundus</em> Blume</td>
<td>2400</td>
<td>7000</td>
<td>65.87</td>
<td>169.8</td>
<td>2.6</td>
<td>13.12</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>22</td>
<td><em>Curcuma caesia</em></td>
<td>16200</td>
<td>687</td>
<td>215.15</td>
<td>27.07</td>
<td>3.4</td>
<td>153.53</td>
<td>8.15</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND-Not Detected
The theoretical spectrum is compared with the digitally filtered data and tested via the chi-square criterion (non linear least squares fitting) for checking the goodness of the fit on the basis of the channel weighting.

In this software package, \( f_q \) and \( \phi \) are considered as instrumental constant \( H \) and thus equation 4.1 may be written as

\[
Y(Z, M) = Y_{it}(Z, M)C_ZQH\varepsilonT
\]

Or,

\[
C_Z = \frac{Y(Z, M)}{Y_{it}QH\varepsilonT} \tag{4.2}
\]

Thus the X-ray peak intensities are converted to elemental concentrations via a defined standardization technique involving X-ray energy dependent \( H \) value, relative charge and user-defined instrument constant. The \( H \) values are dependent on the X-ray energies because of imperfect suppression of secondary electrons, error in the absorber thickness and detector efficiency [12]. The \( H \) values were standardized with respect to the NIST (National Institute of Standards & technology) apple leaf standard (SRM 1515). The standardized \( H \) values were subsequently used in the data analysis of the samples. Matrix effect, proton stopping power, X-ray mass attenuation co-efficient and secondary fluorescence contributions for spectrum fitting were taken into consideration. Table 4.2 shows the elemental concentrations of the six samples analysed at IOP.

From tables 4.1 and 4.2 we see that K and Ca are found to be most abundant elements in all the samples analysed by PIXE. PIXE spectra of most of the samples also shows that presence of Ti, V, Cr and Ni just below the detection
level. Among the samples studied at CCCM, K content is highest in sample no. 3 (Curcuma domestica Valeton) and least in sample no. 22 (Curcuma caesia). Sample no. 21 (Elaeocarpus floribundus Blume) contains the highest amount of Ca and least amount is present in sample no. 20 (Bryophyllum pinntum (Lan) Kruz). An appreciable amount of Mn (722.9ppm) is present in sample no. 16 (Polygonum posumba Bach). Sample no. 9 (Lemania australis Linn) contains the highest amount of Fe (1531.3ppm). Sample no. 4 (Oscimum sanctum) contains highest amount of Cu and Sr among the studied sample. Zn content is highest in sample no. 17 (Cissus javana DC). Rb is found to be containing in sample no. 3, 4,5,6,7,16,17,18,19,20 and 21 in different quantities while Sr is contained in sample no. 2,4,5,14,15,17,19 and 21.

The six samples analysed at IOP also shows the presence of K, Ca, Mn, Fe, Ni, Cu, Zn, Rb and Sr in varying concentrations. Here also, K and Ca form the major constituents. Br is detected in sample no. 24, Rb in sample no. 26 and 27.

4.4. PIGE Analysis

Proton induced gamma-ray emission (PIGE) is a rapid, nondestructive technique that, in principle, could be used in the analysis for light elements. It utilizes high-resolution gamma ray spectrometry for measuring the prompt gamma rays from the ensuing nuclear reaction products, when the sample is irradiated with ion beams, generally protons. PIGE is a complementary technique and enables sensitive determination of elements upto Z < 20. Experimental conditions and set
up are often favourable for performing both PIXE and PIGE simultaneously on the same targets.

In the present work, out of the twenty two samples analysed by PIXE at CCCM eighteen samples were also studied by PIGE technique.

4.4.1. Experimental System and Data Collection

PIGE measurements were done on the same targets prepared as mentioned in section 4.2.1 (a). The targets and the three standards mentioned earlier for PIXE measurements were bombarded with 3 MeV proton beam in the same scattering chamber and the resulting γ-rays produced from the beam target interaction were taken out to the detector from the chamber through 40 mm beryllium (Be) window. A high purity germanium (HPGe) detector (Eurisys) of 40% with a full-width at half maximum (FWHM) of 1.80 keV at 1332 keV placed at 90° to the beam axis was used to detect these characteristic gamma rays. The detector was properly shielded with lead, in order to avoid γ radiation originating from the collimators. The gamma ray peaks were identified by calibrating the multiparameter analyser, using standards Co$^{60}$ (γ-ray energies 1173 keV and 1332.5 keV) and Cs$^{137}$ (energy 661.7 keV) gamma ray sources. The measurements were carried out with a maximum beam current of 10 $nA$, other experimental conditions remaining same as that mentioned in PIXE measurement.
<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Plant name</th>
<th>K</th>
<th>Ca</th>
<th>Mn</th>
<th>Fe</th>
<th>Ni</th>
<th>Cu</th>
<th>Zn</th>
<th>Br</th>
<th>Rb</th>
<th>Sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td><em>Ficus glomerata</em></td>
<td>3680.6± 5.5</td>
<td>29467.86± 0.8</td>
<td>12.8± 27.5</td>
<td>69± 2.2</td>
<td>3.3± 25.1</td>
<td>5.5± 16.1</td>
<td>21.1± 7.5</td>
<td>ND</td>
<td>ND</td>
<td>175.3± 5.3</td>
</tr>
<tr>
<td>24</td>
<td><em>Ficus palmate</em> Forsk</td>
<td>4908.39± 0.8</td>
<td>21347.9± 1.4</td>
<td>233.2± 2.8</td>
<td>385.6± 1.7</td>
<td>6.1± 24.4</td>
<td>17.4± 9</td>
<td>23.5± 7</td>
<td>5.6± 21.3</td>
<td>ND</td>
<td>100± 8.1</td>
</tr>
<tr>
<td>25</td>
<td><em>Oroxylum indicum Vent</em></td>
<td>9126.58± 2.3</td>
<td>11750.36± 1.5</td>
<td>28.2± 15.9</td>
<td>419.4± 1.5</td>
<td>31.4± 6.7</td>
<td>60.5± 4.0</td>
<td>92.5± 13.3</td>
<td>ND</td>
<td>16.4± 16.6</td>
<td>621.0± 2.8</td>
</tr>
<tr>
<td>26</td>
<td><em>Terminalia arjuna</em> (Roxb)</td>
<td>11682.12± 1.8</td>
<td>27103.23± 3.7</td>
<td>57.3± 6.8</td>
<td>210.9± 1.8</td>
<td>9.5± 13.3</td>
<td>34.7± 5.1</td>
<td>49.5± 1.6</td>
<td>ND</td>
<td>13.5± 18.0</td>
<td>27.4± 15.9</td>
</tr>
<tr>
<td>27</td>
<td><em>Panax gingseng</em></td>
<td>6633.53± 2.5</td>
<td>42232.26± 2.5</td>
<td>121.3± 4.8</td>
<td>211.1± 1.9</td>
<td>2.8± 37.6</td>
<td>18.3± 7.6</td>
<td>59.9± 3.9</td>
<td>ND</td>
<td>ND</td>
<td>82.4± 7.9</td>
</tr>
<tr>
<td>28</td>
<td><em>Plumeria acuminate</em> Ait</td>
<td>53091.14± 2.9</td>
<td>28571.67± 3.3</td>
<td>116.7± 4.0</td>
<td>166.4± 2.0</td>
<td>46± 23.9</td>
<td>59.1± 3.7</td>
<td>24.3± 7.5</td>
<td>ND</td>
<td>ND</td>
<td>38.7± 12.3</td>
</tr>
</tbody>
</table>

ND-Not Detected
4.4.2. Data Analysis

Analysis of unknown sample by using PIGE technique consists of two parts:

(i) Qualitative analysis - identification of all elements that are present in the material from the emitted gamma ray energy which are characteristic of the element.

(ii) Quantitative analysis - to find the quantity of each element in the material, from the area under the peak.

Elements are identified from the energy of the prompt gamma rays emitted from nuclei that are in an excited state following a charged particle induced nuclear reaction. The energy of the gamma ray is indicative of the isotope present and the intensity of the gamma ray is a measure of the concentration of the isotope in the sample. The gamma ray energy chart of some elements along with their nuclear reaction is given in Table 4.3 [14]. Fig. 4.31 to Fig. 4.49 shows the PIGE spectra of the eighteen samples analysed at CCCM.

The quantitative PIGE analysis was performed by measuring, apart from the unknown sample, reference samples that contain the elements of interest in well-certified concentrations. The concentration of the actual sample is deduced by using the expression [15]

\[
\frac{Y_{\text{samp}}}{Y_{\text{ref}}} = \frac{C_{\text{samp}}}{C_{\text{ref}}} \times \frac{S_{\text{ref}}(E)}{S_{\text{samp}}(E)}
\]

(4.3)

where \(Y\), \(C\) and \(S\) are the yield, concentration and stopping power of the sample and the reference material, respectively.
Table 4.3. The gamma-ray energy chart of elements along with their nuclear reaction

<table>
<thead>
<tr>
<th>Element</th>
<th>$\gamma$-rays (keV)</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>429</td>
<td>$^7$Li ($p,\alpha\gamma$)$^3$Be</td>
</tr>
<tr>
<td></td>
<td>478</td>
<td>$^7$Li ($p,\gamma$)$^7$Li</td>
</tr>
<tr>
<td>B</td>
<td>429</td>
<td>$^{10}$B($p,\alpha\gamma$)$^7$Be</td>
</tr>
<tr>
<td></td>
<td>718</td>
<td>$^{10}$B($p,\gamma$)$^{10}$B</td>
</tr>
<tr>
<td></td>
<td>2125</td>
<td>$^{11}$B($p,\gamma$)$^{11}$B</td>
</tr>
<tr>
<td>N</td>
<td>2313</td>
<td>$^{14}$N($p,\gamma$)$^{14}$N</td>
</tr>
<tr>
<td>F</td>
<td>110</td>
<td>$^{19}$F($p,\gamma$)$^{19}$F</td>
</tr>
<tr>
<td></td>
<td>197</td>
<td>$^{19}$F($p,\gamma$)$^{19}$F</td>
</tr>
<tr>
<td></td>
<td>1236</td>
<td>$^{19}$F($p,\gamma$)$^{19}$F</td>
</tr>
<tr>
<td></td>
<td>1357</td>
<td>$^{19}$F($p,\gamma$)$^{19}$F</td>
</tr>
<tr>
<td>Na</td>
<td>440</td>
<td>$^{23}$Na($p,\gamma$)$^{23}$Na</td>
</tr>
<tr>
<td></td>
<td>1369</td>
<td>$^{23}$Na($p,\gamma$)$^{24}$Mg</td>
</tr>
<tr>
<td></td>
<td>1636</td>
<td>$^{23}$Na($p,\alpha\gamma$)$^{20}$Ne</td>
</tr>
<tr>
<td>Mg</td>
<td>585</td>
<td>$^{25}$Mg($p,\gamma$)$^{25}$Mg</td>
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<td></td>
<td>1369</td>
<td>$^{24}$Mg($p,\gamma$)$^{24}$Mg</td>
</tr>
<tr>
<td>Al</td>
<td>1013</td>
<td>$^{27}$Al($p,\gamma$)$^{27}$Al</td>
</tr>
<tr>
<td></td>
<td>1369</td>
<td>$^{27}$Al($p,\gamma$)$^{27}$Al</td>
</tr>
<tr>
<td>Si</td>
<td>1273</td>
<td>$^{29}$Si($p,\gamma$)$^{29}$Si</td>
</tr>
<tr>
<td></td>
<td>1779</td>
<td>$^{28}$Si($p,\gamma$)$^{28}$Si</td>
</tr>
<tr>
<td>P</td>
<td>1266</td>
<td>$^{31}$P($p,\gamma$)$^{31}$P</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{31}$P($p,\gamma$)Si</td>
</tr>
<tr>
<td>S</td>
<td>1219</td>
<td>$^{34}$S($p,\gamma$)$^{35}$Cl</td>
</tr>
<tr>
<td></td>
<td>2127</td>
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</tr>
<tr>
<td></td>
<td>2230</td>
<td>$^{32}$S($p,\gamma$)$^{32}$S</td>
</tr>
<tr>
<td>Cl</td>
<td>1219</td>
<td>$^{35}$Cl($p,\gamma$)$^{35}$Cl</td>
</tr>
<tr>
<td></td>
<td>1763</td>
<td>$^{35}$Cl($p,\gamma$)$^{35}$Cl</td>
</tr>
<tr>
<td>Fe</td>
<td>845</td>
<td>$^{56}$Fe($p,\gamma$)$^{56}$Fe</td>
</tr>
</tbody>
</table>
Fig. 4.31. PIGE spectrum of *Centella asiatica* (Linn)

Fig. 4.32. PIGE spectrum of *Zanthoxylum achantopodium* DC
Fig. 4.33. PIGE spectrum of *Curcuma domestica* Valeton

Fig. 4.34. PIGE spectrum of *Oscimum sanctum* Linn
Fig. 4.35. PIGE spectrum of *Hedychium marginatum* C.B.Clarke

Fig. 4.36. PIGE spectrum of *Kaempferia galanga* Linn
Fig. 4.37. PIGE spectrum of *Acacia farnesiana* willd

Fig. 4.38. PIGE spectrum of *Zingiber cassumunar* (Roxb.)
Fig. 4.39. PIGE spectrum of *Agele marmelos* Correa ex Roxb

Fig. 4.40. PIGE spectrum of *Celtis timorensis*
Fig. 4.41. PIGE spectrum of *Merandra bengalensis* Benth

Fig. 4.42. PIGE spectrum of *Polygonum posumba* Bach
Fig. 4.43. PIGE spectrum of *Cissus javana* DC

Fig. 4.44. PIGE spectrum of *Zingiber officinale* Rose
Fig. 4.45. PIGE spectrum of *Xylosum longifolia*

Fig. 4.46. PIGE spectrum of *Bryophyllum pinnatum* (Lam.) Kruz
Fig. 4.47. PIGE spectrum of *Elaeocarpus floribundus* Blume

Fig. 4.48. PIGE spectrum of *Curcuma caesia*
Fig. 4.49. PIGE spectrum showing Laboratory background

Fig. 4.50. PIGE spectrum showing Laboratory background with and without Lead Shield
From the PIGE spectra 440 keV γ-ray line of Na, 585 keV γ-ray line of Mg, 1013 keV γ-ray line of Al and 1266 keV γ-ray line of P are simultaneously detected in all the samples. Apart from the elements of interest the spectra also contains a number of background lines; the most prominent one being the 511 keV; others are due to laboratory background and beam apertures. A PIGE spectrum showing the background lines is given in Fig. 4.49. in order to understand the various background lines obtained in the spectra of the samples. Fig. 4.50 shows the background lines with and without lead shields. Table 4.4 shows the elemental concentrations of the eighteen medicinal plants analysed by PIGE technique.

**Table 4.4** Elemental concentrations of the eighteen medicinal plants analysed by PIGE in ppm

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Plant name</th>
<th>Na</th>
<th>Al</th>
<th>Mg</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Centella asiatica</em> (Linn)</td>
<td>413</td>
<td>1191</td>
<td>52738</td>
<td>1417</td>
</tr>
<tr>
<td>2</td>
<td><em>Zanthoxylem acanthopodium</em> DC</td>
<td>301</td>
<td>36</td>
<td>6533</td>
<td>5940</td>
</tr>
<tr>
<td>3</td>
<td><em>Curcuma domestica</em> Valeton</td>
<td>338</td>
<td>743</td>
<td>4057</td>
<td>7653</td>
</tr>
<tr>
<td>4</td>
<td><em>Oscimum sanctum</em> Linn</td>
<td>6030</td>
<td>8249</td>
<td>43700</td>
<td>6830</td>
</tr>
<tr>
<td>5</td>
<td><em>Hedychium marginatum</em> CB Clarke</td>
<td>313</td>
<td>348</td>
<td>3013</td>
<td>1106</td>
</tr>
<tr>
<td>6</td>
<td><em>Kaempferia galanga</em> Linn</td>
<td>530</td>
<td>729</td>
<td>2586</td>
<td>1318</td>
</tr>
<tr>
<td>7</td>
<td><em>Acacia farnesiana</em> Willd</td>
<td>159</td>
<td>242</td>
<td>882</td>
<td>9790</td>
</tr>
<tr>
<td>8</td>
<td><em>Zingiber cassumunar</em> (Roxb)</td>
<td>610</td>
<td>1191</td>
<td>71500</td>
<td>6279</td>
</tr>
<tr>
<td>13</td>
<td><em>Agele marmelos</em> Correa ex Roxb</td>
<td>131.7</td>
<td>285.6</td>
<td>202</td>
<td>1154</td>
</tr>
<tr>
<td>14</td>
<td><em>Celtis timorensis</em></td>
<td>319</td>
<td>379</td>
<td>1264</td>
<td>3500</td>
</tr>
</tbody>
</table>
Table 4.4 Contd...

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Plant name</th>
<th>Na</th>
<th>Al</th>
<th>Mg</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td><em>Meriandra bengalensis</em> Benth</td>
<td>292</td>
<td>134</td>
<td>4174</td>
<td>5980</td>
</tr>
<tr>
<td>16</td>
<td><em>Polygonum posumba</em> Bach</td>
<td>243</td>
<td>1191</td>
<td>4606</td>
<td>4274</td>
</tr>
<tr>
<td>17</td>
<td><em>Cissus javana</em> DC</td>
<td>300</td>
<td>640</td>
<td>13760</td>
<td>3380</td>
</tr>
<tr>
<td>18</td>
<td><em>Zingiber officinale</em> Rosc</td>
<td>266</td>
<td>60</td>
<td>9188</td>
<td>1658</td>
</tr>
<tr>
<td>19</td>
<td><em>Xylosum longifolia</em></td>
<td>88</td>
<td>108</td>
<td>482</td>
<td>6510</td>
</tr>
<tr>
<td>20</td>
<td><em>Bryophyllum pinntum</em> (Lan.)</td>
<td>137</td>
<td>616</td>
<td>6600</td>
<td>7690</td>
</tr>
<tr>
<td>21</td>
<td><em>Elaeocarpus floribundus</em> Blume</td>
<td>677</td>
<td>374</td>
<td>4391</td>
<td>1882</td>
</tr>
<tr>
<td>22</td>
<td><em>Curcuma caesia</em></td>
<td>331</td>
<td>93.9</td>
<td>4900</td>
<td>4701</td>
</tr>
</tbody>
</table>

From table 4.4 it is seen that Mg and P are abundant in all the samples studied by PIGE except in sample no. 20 and 22. Na and Al are also present in all the samples in varying concentrations. The results obtained in table 4.1, 4.2 and 4.4 are discussed in the next chapter and the medicinal values of the plants are correlated with their elemental contents.
References


