Ex situ evaluation on genetic diversity of indigenous taro landraces in North East India

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In this study, 110 taro landraces were characterized using 19 quantitative traits. Statistical tools like descriptive statistics, Shannon–Wiener diversity index, principal component analysis (PCA) and cluster analysis were used to evaluate diversity. Descriptive statistics showed significant variation among the landraces for the 19 quantitative traits studied. The highest coefficient of variation was found in the yield, number of suckers, leaf width and total oxalate. The corm length (H' – 1.06) and starch content (H' – 1.20) had the highest Shannon–Wiener diversity index. PCA resulted in seven principal components (PCs), which explain 70.65% of the total variation. PC1 was mainly associated with plant height, leaf length, leaf width, petiole length and plant spread. PC2 was associated with yield, moisture content, corm length and total oxalate. PC3 was associated with dry matter content and disease index. The cluster analysis using the weighted neighbor-joining method resulted in five major clusters based on geographical location. Cluster IV had a maximum of 54 landraces, and cluster III had a minimum of five landraces. The present study, which identified high genetic diversity and plant height, number of suckers, leaf length, leaf width, corm length, yield, total oxalate content and disease index, can be useful in taro varietal improvement programmes.

Keywords: *Colocasia esculenta*, correlation, descriptive statistics, genetic diversity, landraces.

TARO (*Colocasia esculenta* L. Schott.), the fourth most crucial tuber crop[1], an essential aroid in the family Araceae, probably originated in North East India[2]. It is rich in starch, minerals and dietary fibre. It also has a considerable amount of potassium, magnesium and vitamin-B complex[3]. Taro has a low glycemic index; thereby, its consumption reduces blood glucose levels in diabetic patients. It possesses medicinal properties against fungal infections, stomach ulcers and tuberculosis[4]. Flavonoids and anthocyanins in taro tubers improve blood circulation and prevent cancer development[5]. The corms, cormels, leaves, flowers and petioles are edible[6]. These nutrient-rich, gluten-free tubers play an essential role in the food and nutritional security of indigenous tribes of NE India. Leaves, petioles and tubers in fresh, dried and fermented forms are used to prepare several traditional dishes[7]. Leaves, petioles and damaged tubers are cooked with local edible grasses and fed to pigs[8].

NE India comprises eight states, viz. Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, which greatly vary in topography, climate, language and culture[9]. This region is rich in genetic diversity of taro which is adapted to a wide range of climatic conditions[10]. The farmers in NE India follow jhum or slash and burn cultivation, especially in the hilly areas. Taro occupies a premium position in home gardens and jhum cultivation, where it grows along with paddy, maize and vegetables in a mixed cropping system. Several landraces have been grown in jhum fields or home gardens, which serve as a genetic reservoir of taro[11]. The farmers have inherited a wealth of knowledge on taro germplasm from their ancestors, which is transferred from one generation to the next. Over the ages, farmers have selected landraces suitable to their needs and agro-climatic conditions. Each ethnic group in various regions prefers different landraces according to its needs, particularly for specific cuisines.

Most of the landraces in this region are low yielders, and declining soil fertility, *Phytophthora* leaf blight and climate change hamper taro production. Genetic improvement is the best way to improve yield and quality in taro[12]. The selection of parents is also important. Germplasm characterization is fundamental in selecting the parents for crop breeding programmes[13]. Assessing genetic diversity among indigenous taro landraces needs immediate attention to improve the yield. Several researchers have examined the diversity of taro germplasm in NE India based on morphological traits[14,15] and molecular markers[16,17] and identified wide genetic diversity among the germplasm. However, these studies are confined to a few locations and carried out with limited germplasm and fewer markers. Despite the rich cultural importance and genetic resources, knowledge of the genetic diversity of taro in NE India is limited. Thus, the present study aimed to assess genetic diversity among 110 indigenous taro landraces collected from different states of NE India using agro-morphological and quality traits.

The present study was conducted at ICAR Research Complex for NEH Region, Jharnapani, Nagaland (25°45′N long. and 93°50′E lat., at an altitude of 281 m above msl). The soil was classified as Inceptisol. The pH was 5.7, electrical conductivity (EC) was 0.121 d Sm^{-1} and soil organic carbon was 0.73%. It was low in nitrogen (149.2 kg N ha^{-1}), moderate in phosphorus (18.4 kg P_2O_5 ha^{-1}), and low in potassium (173.6 kg K_2O ha^{-1}). The mean maximum temperature of the site was 33.0°C, minimum temperature was 10.8°C, mean maximum relative humidity was 85%, and minimum humidity was 72%, with a mean annual rainfall of 1200 mm

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Table 1. Geographical location of taro landraces collected from North East India

Landrace no.	Landrace	State
1–14 West Garo Hills	Tamarong Bol, Tamachong Kam, Marakajatong, Tasarang, Takiltom, Tamitdim, Tadura, Tararang, Ringdubi, Tasobok, Tajekjak, Tasarang Ganching, Taring	Meghalaya Latitude: 25°29′–25°35′N Longitude: 90°12′–90°07′E Altitude: 276–495 m amsl
15–21 Imphal West	Mukhi pan, Houpan, Khungupan, Pangong pan, Yarumpan, Bar, Barker	Manipur Latitude: 24°41′–24°45′N Longitude: 93°40′–93°56′E Altitude: 1426–2716 m amsl
22–29 Senapati	Ziiphat, Majangzhii, Ziishow, Abzii Katomei, Tamei, Lairouching, Lairouching	Manipur Latitude: 25°16′–25°23′N Longitude: 94°01′–94°05′E Altitude: 1100–4148 m amsl
30–36 Zunheboto	Mishmeh, Atutu, Cherimeh, Ayekhu, Kanchi, Naghi, Ayi	Nagaland Latitude: 25°59′–26°03′N Longitude: 94°29′–94°31′E Altitude: 1423–1801 m amsl
37–41 Phek	Bishe, Bibu, Tenyibe, Nyisheliibe, Bishow	Nagaland Latitude: 25°49′–25°36′N Longitude: 94°19′–94°23′E Altitude: 1630–1826 m amsl
42–52 Peren	Dzurinuo, Tsophiju, Nukruca dzunuo, Semia, Beugie, Beutei, Beusang, Mbeijukwak, Hepwapuipikam, Beureu, Kungsaibeu	Nagaland Latitude: 25°36′–28°38′N Longitude: 93°40′–93°51′E Altitude: 310–361 m amsl
53–65 Dimapur	Mishieli, Dzurenuno, Kotsa dzuno, Dzuse, Dzurenuno, Balkedoh, Baldosan, Balloupi, Balsan, Balkang, Saikang, Bal Ahtui, Balbom	Nagaland Latitude: 25°40′–25°47′N Longitude: 93°51′–93°55′E Altitude: 310–317 m amsl
66–72 Wokha	Tsarhomo, Vajo, Phila, Shirochu, Yojung, Lifuro, Hanphya	Nagaland Latitude: 26°60′–26°63′N Longitude: 94°14′–94°16′E Altitude: 737–1314 m amsl
73–83 Mon	Baikhi, Nalon, Tungyak, Along, Tungnyak, Tungsho, Laihi, Ganching Kohimathung, Phaksa, Local	Nagaland Latitude: 26°43′–26°46′N Longitude: 95°01′–95°09′E Altitude: 675–1010 m amsl
84–100 West Siang	Ayang Anga, Nyata Taing, Madras Kochu, Dabat, Nyemr, Nyise, Aalo Local, Naeup, Nyita, Angatakang, Libo local, Anyno, Nymar, Nyoile, Darga, Engyo kochu, Noilie	Arunachal Pradesh Latitude: 28°10′–28°15′N Longitude: 94°14′–94°48′E Altitude: 289–648 m amsl
101–106 Dimapur	Obi 1, Obi 2, Obi 3, Obi 4, Obi (Red), Obi (White)	Nagaland Latitude: 25°45′N Longitude: 93°50′E Altitude: 250 m amsl
107–110 Kohima	Thupelie, Dziicha, Tefiiziinuo, Normal	Nagaland Latitude: 25°40′N Longitude: 94°72′E Altitude: 1444 m amsl

(Source: Automatic Weather Station at ICAR Nagaland Centre Agromet Observatory, Jharnapani, Nagaland).

One hundred ten landraces collected from different states of NE India were planted with a spacing of 60 × 60 cm, and 20 plants were grown for each landrace (Table 1). The ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, India, recommended dose of fertilizers for NE India (12 t ha^{-1} FYM, 100 : 60 : 80 kg ha^{-1} N, P_2O_5 and K_2O respectively) were applied uniformly. The tubers were planted in May and grown rainfed. They were harvested from October to November. The experiment was conducted for two consecutive years (2014 and 2015).

The growth characters, viz. plant height (cm), number of leaves, number of suckers, leaf length (cm), leaf width (cm), petiole length (cm) and plant span (cm), were recorded on five plants in each replication at 120 days after planting, and the mean was computed. The yield characters like corm length (cm), corm diameter (cm) and yield (g $plant^{-1}$) were recorded immediately after harvest from five plants in each replication, and the mean was computed. The quality characters like dry matter (%), moisture content (%), starch (%), total sugars (%), potassium (mg 100 g^{-1}), phosphorus (mg 100 g^{-1}), and total oxalate content (mg 100 g^{-1}) were estimated. The dry matter and moisture content[18] and total

Table 2. Diversity analysis for 19 quantitative traits in 110 taro landraces

Characters	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation (%)	Diversity index *H*
Plant height (cm)	28.40	150.90	93.24	22.09	20.43	0.80
No. of leaves (no)	2.10	7.50	4.40	0.94	20.34	0.59
No. of suckers (no)	0.00	7.90	2.38	1.38	47.53	0.44
Leaf length (cm)	11.70	60.70	37.01	9.99	20.35	0.34
Leaf width (cm)	7.60	119.80	28.57	12.46	42.87	0.10
Petiole length (cm)	13.30	112.50	67.71	17.18	20.38	0.45
East–West spread (cm)	11.20	141.60	84.51	20.70	18.45	0.81
North–South spread (cm)	24.30	133.60	83.01	20.20	19.99	0.65
Corm length (cm)	5.00	28.20	9.84	4.20	36.67	1.06
Corm diameter (cm)	3.10	19.20	5.83	1.67	26.64	0.18
Yield (g plant^{-1})	37.60	1319.20	376.9	225.74	47.80	0.62
Dry matter (%)	13.10	42.20	26.75	5.54	19.92	0.62
Moisture content (%)	57.80	86.90	73.25	5.53	7.28	0.85
Starch (%)	12.20	50.00	25.20	8.19	21.57	1.20
Total sugars (%)	1.60	9.00	4.81	1.66	23.73	0.82
Phosphorus (mg 100 g^{-1})	1.10	3.80	2.36	0.68	23.51	0.82
Potassium (mg 100 g^{-1})	1.00	1.50	1.15	0.10	7.39	0.33
Total oxalate (mg 100 g^{-1})	44.50	358.90	1.67	79.45	42.41	0.77
Disease index (%)	11.80	100.00	65.81	21.81	27.54	0.61

sugars and starch content[19] were determined following standard methods. The potassium and phosphorus contents were determined calorimetrically[20]. The total calcium oxalate content was determined based on the method suggested by AOAC[21]. Leaf blight disease incidence was recorded with the onset of disease symptoms in the field and continued at weekly intervals until harvest. *Phytophthora* leaf blight disease incidence was assessed using the following formula[22]:

$$\text{Disease incidence (\%)} = \frac{\text{Total infected plants}}{\text{Total number of plants observed}} \times 100.$$

Descriptive statistics was performed using STAR 2.0.1 developed by the International Rice Research Institute, Philippines. The Shannon–Wiener diversity index was calculated in Microsoft Office Excel 2010 using the formula

$$H = -\sum_{i=1}^{s} (pi * \ln\ pi),$$

where H is the diversity index and Pi is the fraction of the entire population made up of species i. Principal component analysis (PCA) was carried out using 19 quantitative traits in SPSS 16.0 (ref. 23). Cluster analysis between 110 landraces was done using the continuous dissimilarity index method with Euclidean on standardized variables employing the default DICE method. The tree was constructed using the weighted neighbor-joining method in Darwin 6.0 (ref. 24).

This study characterized 110 indigenous taro landraces collected from Arunachal Pradesh (17 landraces), Manipur (15 landraces), Meghalaya (14 landraces) and Nagaland (64 landraces) for agro-morphological and quality traits. The study found significant variation for the 19 quantitative traits for all the 110 taro landraces. Table 2 gives the minimum, maximum, mean, standard deviation and coefficient of variation (CV) values recorded for all the traits. CV ranged from 7.28% to 47.80%, indicating rich genetic diversity among the taro landraces. Yield (CV = 47.8%), number of suckers (CV = 47.53%), leaf width (CV = 42.87%) and total oxalate content (CV = 42.41%) showed larger variation, while moisture content (CV = 7.28%) and potassium content (CV = 7.39%) showed least variation. Higher CV values (CV > 40%) indicate that the four traits, viz. yield number of suckers, leaf width and total oxalate content, have good breeding potential. Low CV values (CV < 10%) indicate that the two traits, viz. phosphorus content and moisture content, have good genetic stability. The larger the CV value, the higher the level of genetic dispersion. So, in any taro varietal improvement programme, the breeders should consider traits with higher CV values.

The Shannon–Wiener diversity indexes (H') exhibited 19 quantitative traits ranging between 0.10 and 1.20 (Table 2). Among the quantitative traits, the highest diversity index was corm length ($H' - 1.06$) and starch content ($H' - 1.20$), which displayed a significantly higher level of genetic diversity than the other traits. The lowest diversity index was for leaf width ($H' - 0.10$) and corm diameter ($H' - 0.18$), which displayed low genetic diversity. The other traits like plant height, number of leaves, plant spread, yield, dry matter content, moisture content, total sugars, total oxalate and disease index exhibited a high diversity index ($H' > 0.5$), indicating these traits are highly variable.

PCA identifies the relationship between variables. PCA of the 110 indigenous taro landraces based on 19 quantitative traits resulted in seven principal components (PCs; Table 3).

Table 3. Eigenvectors from principal component analysis of agro-morphological and yield traits in taro landraces

Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Plant height	0.836	0.047	0.060	–0.160	–0.130	–0.029	–0.073
No. of leaves	0.386	–0.140	–0.120	–0.080	0.548	0.232	0.282
No. of suckers	0.290	0.170	–0.052	0.133	0.549	–0.236	0.513
Leaf length	0.855	–0.006	0.024	0.040	–0.231	–0.025	–0.080
Leaf width	0.624	–0.017	–0.003	0.069	–0.253	0.150	–0.029
Petiole length	0.887	–0.032	0.075	–0.010	–0.034	0.013	–0.003
East–West spread	0.895	0.060	0.023	0.018	0.070	–0.039	–0.012
North–South spread	0.868	0.041	–0.057	–0.119	0.037	–0.099	–0.077
Corm length	0.000	0.430	0.416	0.140	–0.472	0.241	0.315
Corm diameter	0.010	0.328	0.206	0.332	0.325	0.005	–0.513
Yield	0.021	0.644	0.509	0.134	–0.021	–0.130	0.111
Dry matter	0.035	–0.789	0.591	0.079	0.064	–0.046	0.053
Moisture content	–0.038	0.789	–0.591	–0.080	–0.063	0.043	–0.054
Starch	0.013	0.308	0.198	–0.665	0.265	–0.233	–0.201
Total sugars	0.086	0.292	0.077	0.023	0.119	0.583	0.244
Phosphorus	0.239	–0.110	–0.203	0.526	0.112	–0.012	–0.280
Potassium	–0.034	0.251	0.141	0.097	–0.152	–0.668	0.219
Total oxalate	–0.047	0.348	0.324	0.501	0.261	0.043	–0.141
Disease index	–0.086	0.200	0.488	–0.471	0.150	0.223	–0.211
Eigenvalues	4.473	2.425	1.654	1.433	1.291	1.116	1.032
% Total variance	23.544	12.761	8.707	7.543	6.793	5.873	5.432
% Cumulative variance	23.544	36.304	45.011	52.554	59.347	65.220	70.652

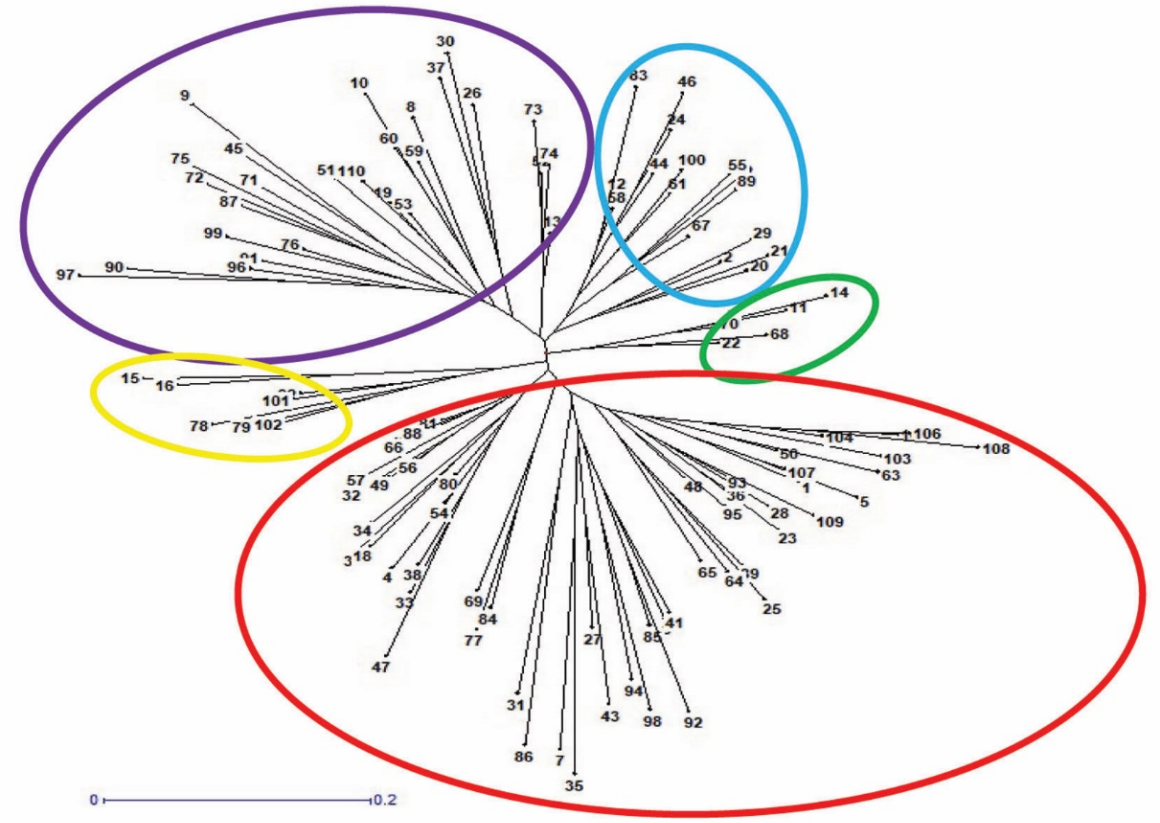

Figure 1. Cluster analysis of 110 taro landraces based on 19 quantitative traits.

These seven PCs exhibited 70.65% of the total variation. The first component (PC1) explained 23.54% of the total variation, and plant growth characteristics such as plant height, leaf length, petiole length, plant spread (E–W, N–S) and leaf width contributed more to genetic variation among the landraces. PC2 explained 12.76% of the total variation and

was mainly associated with yield, moisture content, corm length and total oxalate. Yield, dry matter content and disease index contributed more to the variation among taro in PC3, which explained 8.7% of the total variation. Earlier studies on taro germplasm in Ghana, India and China reported that the first three PCs contributed more to the variation and were mainly associated with plant growth and yield characters[25–29]. In PCA, the first three PCs are important, and their associated traits contribute more to the genetic variation[30]. These traits could be helpful in crop improvement programmes.

The cluster analysis between the 110 taro landraces based on weighed neighbor-joining method using 19 quantitative traits formed 5 major clusters (Figure 1). Cluster IV had the maximum landraces (54), followed by cluster I (28) and cluster II (16). Cluster III (five) and cluster V (seven) had the minimum number of landraces. The analysis formed clusters based on geographical location. In general, landraces that shared close state boundaries and similar agro-ecological conditions were grouped in one cluster. However, few landraces from close geographical locations representing different agro-eco-regions were grouped in different clusters. This indicates the movement of taro landraces to other adjoining states, and a similar clustering pattern has been reported for taro germplasm in NE India[15]. PCA and cluster analysis showed high genetic diversity. The results indicate that PCA is a more precise indicator than cluster analysis for genetic diversity. Further, this study highlights the incongruence between landraces and geographic location. The agro-morphological variation in taro landraces has resulted due to mutations and geographical speciation[31]. It may not reflect genotypic variation at the molecular level, so breeders must be cautious. However, agro-morphological variation provides basic information about the indigenous taro landraces. The breeders should pay attention to growth and yield traits, total oxalate content and *Phytophthora* leaf blight disease index for selecting the parents in taro improvement. It is also suggested that selecting parents from diverse clusters for specific traits aid in taro improvement.

Taro is one of the important components in the cuisine of the ethnic people of NE India. The future of taro production depends on acrid-free, high-yielding genotypes. Understanding the genetic diversity is essential to exploit taro in this region. Hence, the present study analysed the diversity among 110 germplasms collected from NE India. A high level of genetic diversity was found among the taro collections, as evidenced by the high Shannon–Wiener diversity index (up to $H' - 1.20$). PCA analysis resulted in seven components that exhibited 70.65% variability. Cluster analysis resulted in five major clusters based on geographical location. This study reveals that traits like growth, yield, corm length, starch, dry matter, total oxalate content and the *Phytophthora* leaf blight disease index influence the diversity, and these breeders should consider these traits in taro improvement programmes to select superior genotypes. Further, molecular characterization is necessary to assess the extent of genetic diversity present in the taro germplasms of NE India.

1. Revill, P. A. *et al.*, Incidence and distribution of viruses of taro (*Colocasia esculenta*) in Pacific Island countries. *Australas. Plant Pathol*., 2005, **34**, 327–331.
2. Matthews, P. J., A possible tropical wild type taro (*Colocasia esculenta* var. *aquatilis*). *Indo Pac. Prehist. Assoc. Bull*., 1991, **11**, 69–81.
3. Balagopalan, C., Nayar, T. V. R., Sundaresan, S., Premkumar, T. and Lakshmi, K. R., *Tropical Tuber Crops in Food Security and Nutrition*, Oxford & IBH Publishing Co Pvt Ltd, New Delhi, 1999.
4. Singh, S., Singh, D. R., Faseela, F., Kumar, N., Damodaran, V. and Srivastava, R. C., Diversity of 21 taro (*Colocasia esculenta* (L.) Schott) accessions of Andaman Islands. *Genet. Resour. Crop Evol.*, 2012, **59**(5), 821–829.
5. Wagner, H., New plant phenolics of pharmaceutical interest. In *Annual Proceedings of Phytochemistry Society in Europe, The Biochemistry of Plant Phenolics* (eds Van Sumere, C. F. and Lea, P. J.), Clarendon Press, Oxford, UK, 1985, vol. 25, p. 401.
6. Bose, T. K., Kabir, J., Maity, T. K., Parthasarathy, V. A. and Som, M. G., In *Vegetable Crops, Vol. 2*, Naya Udyog Publishers, Kolkata, 2013, pp. 413–442.
7. Sivakumar, P. S., Thirugnanvel, A. and Chakruno, M., Understanding the mechanisms of achieving food and nutritional security through traditional tuber crop foods: a case study among Konyak tribes of Nagaland, India. *J. Root Crops*, 2014, **40**(2), 49–57.
8. Thirugnanavel, A., Rangnamei, L., Chakruno, M. and Deka, B. C., Genetic diversity of taro (*Colocasia esculenta* L.) in Mon district, Nagaland, needs attention for its conservation. *Curr. Sci.*, 2013, **105**(8), 1036–1037.
9. Deka, B. C., Thirugnanavel, A., Patel, R. K., Amit Nath and Deshkukh, N. A., Horticultural diversity in North-East India and its improvement for value addition. *Indian J. Genet. Plant Breed*., 2012, **72**(2), 157–167.
10. Buragohain, J., Angami, T., Choudhary, B. U., Singh, P., Bhatt, B. P., Thirugnanavel, A. and Bidyut, C. D., Quality evaluation of indigenous taro (*Colocasia esculenta* L.) cultivars of Nagaland. *Indian J. Hill Farm.*, 2013, **26**(2), 16–20.
11. Thirugnanavel, A., Deka, B. C., Rangnamei, L., Meyase, M. and Patel, J. K., Colocasia and its genetic diversity in Northeast India. Technical Bulletin, ICAR Research Complex for NEH Region, Barapani, 2015.
12. Banjaw, D. T., Review of taro (*Colocasia esculenta*) genetics and breeding. *J. Hortic.*, 2017, **4**, 1–4.
13. Pitoyo, A. R. I., Prameta, A. A., Marsusi, M., Suratman, S. and Suranto, S., Morphological, anatomical and isozyme variability among taro (*Colocasia esculenta*) accessions from southeastern part of Central Java, Indonesia. *Biodivers. J. Biol. Divers*., 2018, **19**(5), 1811–1819.
14. Choudhary, V. K., Suresh Kumar, P., George, J., Kanwat, M. and Saravanan, R., Genetic diversity and character association in taro (*Colocasia esculenta* (L.) Schott.) under mid-hills of Arunachal Pradesh. *J. Root Crops*, 2011, **37**(2), 155–161.
15. Vinutha, K. B., Devi, A. A. and Sreekumar, J., Morphological characterization of above ground characters of taro (*Colocasia esculenta* (L.) Schott.) accessions from North East India. *J. Root Crops*, 2015, **41**(1), 3–11.
16. Mezhii, T. L., Changkija, S., Pattanayak, A., Chaturvedi, H. P., Vimala Devi, S. and Kole, P. R., Genetic characterization of locally cultivated taro germplasm from eleven districts of Nagaland. *Int. J. Curr. Microbiol. Appl. Sci*., 2017, **6**(8), 3338–3348.
17. Khatemenla, Alam S., Phookan, D. B., Khatila, P., Barooah, M. and Talukdar, M. C., Morphological characterization of some upland taro (*Colocasia esculenta*. Schott) cultivars of north-east India. *Int. J. Curr. Microbiol. Appl. Sci*., 2019, **8**(6), 1944–1964.
18. AOAC, *Official Method of Analysis*, Association of Official Agricultural Chemists. Washington DC, USA, 1980, 13th edn.

19. DuBois, M., Gilles, K., Hamilton, J. K., Rebers, P. A. and Smith, F., A colorimetric method for the determination of sugars. *Nature*, 1951, **168**(4265), 167–16.
20. Piper, C. S., *Soil and Plant Analysis*, Hans Publishers, Bombay, 1950.
21. AOAC, *Official Method of Analysis*, Association of Official Agricultural Chemists. Washington DC, USA, 1984, 14th edn.
22. Chaube, H. S. and Pundhir, V. S., *Crop Diseases and their Management*, PHI Learning Pvt Ltd, New Delhi, 2005.
23. SPSS for Windows, Version 16.0, SPSS Inc., Chicago, USA, 2007.
24. Perrier, X. and Jacquemoud-Collet, J. P., DARwin Software, 2006; http://darwin.cirad.fr/darwin
25. Naskar, S. K. and Sreekumar, J., Evaluation of taro (*Colocasia esculenta* (L.) Schott.) germplasm using multivariate analysis. *J. Root Crops*, 2011, **37**(2), 150–154.
26. Tewodros, M. B., Morpho-agronomical characterization of taro (*Colocasia esculenta*) accessions in Ethiopia. *Plant*, 2013, **1**(1), 1–9.
27. Boampong, R., Aboagye, L. M., Nyadanu, D. and Esilfie, M., Agro-morphological characterization of some taro (*Colocasia esculenta* (L.) Schott.) germplasms in Ghana. *J. Plant Breed. Crop Sci.*, 2018, **10**(8), 191–202.
28. Kathayat, K., Kushwaha, M. L. and Rawat, M., Genetic diversity among taro (*Colocasia esculenta* (L.) Schott var. antiquorum) germplasm – a review. *Agric. Rev.*, 2018, **39**, 255–258.
29. Xia, H. O. N. G., Yongbin, Z. H. A. O., Weidong, Q. U., Yinlong, C. H. E. N., Liping, Q. I. U. and Jiaoyang, W. A. N. G., Comparative analysis on genetic diversity of *Colocasia esculenta* germplasm in Zhejiang Province based on phenotype and simple sequence repeats markers. *Acta Agric. Zhejiangensis*, 2020, **32**(9), 1544.
30. Guei, R. G., Sanni, K. A. and Fawole, A. F. J., Genetic diversity of rice (*O. sativa* L.). *Agron. Afr.*, 2005, **5**, 17–28.
31. Singh, D. *et al.*, Assessment and rationalization of genetic diversity of Papua New Guinea taro (*Colocasia esculenta*) using SSR DNA fingerprinting. *Genet. Resour. Crop Evol.*, 2008, **55**, 811–822.

ACKNOWLEDGEMENTS. We thank the Protection of Plant Varieties and Farmers' Right Authority, New Delhi for financial assistance. We also thank the Director, ICAR Research Complex for NEH Region, Umiam for providing the necessary facilities to conduct this study.

Received 2 September 2022; accepted 11 December 2022

doi: 10.18520/cs/v124/i6/748-753

REE-mineral phases in Indian red mud from the east coast bauxite deposit

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Red mud is often considered a prospective secondary resource of rare earth elements (REE). The Indian red mud samples were characterized using XRD, WD-XRF, ICP-OES and SEM-EDS to study their REE mineralogy and REE content. A major fraction (77%) of the sample was below 45 μm, with total REE content of 433 ppm. There was an enrichment of LREE over HREE, and La, Ce, Nd and Sc were the main contributors to the total REE value. REE-bearing minerals like monazite and zircon occurred as discrete mineral phases in the bauxite residue.

Keywords: Bauxite deposit, monazite, rare earth elements, red mud, zircon.

RED mud or bauxite residue is a solid waste that is produced by aluminium industries during the extraction of alumina from bauxite. It mainly comprises iron oxide, aluminium oxide, silicon oxide and titanium oxide. Generally, it is reddish-brown in colour, and the characteristic red colour is due to the presence of large amounts of iron oxide. The average composition of red mud is Fe_2O_3 (48–54%), Al_2O_3 (17–20%), TiO_2 (3–4%), SiO_2 (4–6%), CaO (1–2%), Na_2O (3–5%)[1]. It also contains many trace elements such as Ga, V, Mn, Cr, Ni, Cu, Pb, Zn, Cd, P, Mg, Hf, Zr, Th, U, Nb, Ba, Sr, K and rare earth elements (REEs) in varied proportion[2,3]. However, the mineralogical and chemical composition of red mud varies widely depending on the source of bauxite and the technological processing conditions applied to recover alumina[4,5]. It is reported that 0.8–1.5 tonnes of red mud is generated per tonne of alumina produced from bauxite[6]. World inventory of red mud shows that about 60–120 million tonnes are produced annually from the bauxite industry. India is one of the largest producers of red mud, producing about 2 million tonnes[7]. The production of red mud has been rising rapidly[8–10] and its disposal is one of the major concerns as red mud is highly alkaline and is a potential threat to air, water and land. Hence, red mud is a source of environmental pollution on the one hand[11,12] and a promising source for obtaining valuable elements on the other[13]. It can be utilized to recover Fe, Al, Ti, Na and REE[3,14]. It is reported that bauxite residue contains a high amount of scandium (70–260 ppm) that is close to its primary resources[15,16]. The approximate range of total REE content in red mud is about 500–1700 ppm (ref. 17). Several studies have reported that red mud is a secondary source

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