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Discriminating geographical origins of Indian jackfruit (*Artocarpus heterophyllus* Lam.) through multivariate analysis of physico-chemical characters

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Abstract
Seventy jackfruit accessions collected from seven prominent regions of India *viz.* North 24 Parganas (West Bengal), Nadia (West Bengal), West Tripura (Tripura), Khowai (Tripura), Panruti (Tamil Nadu), Varkala (Kerala) and South Sikkim (Sikkim) were assessed for physico-chemical characteristics to ascertain the linkage between the quality characteristics and their geographical locations. The samples were collected on a yearly basis, between May to June of 2016 and 2017. Principal component analysis (PCA) and linear discriminant analysis (LDA) were applied to discriminate geographical origin of the accessions. Based on PCA, accessions from Panruti could be distinguished with high amount of TSS, total sugar, fruit length and fruit weight and moderate values of number of flake, flake weight, pulp weight, seed weight and fruit width followed by accessions from Varkala, Nadia and Khowai with all moderate values. Linear discriminant analysis (LDA) revealed that, accessions of Panruti could be distinguished even at ninety five percent confidence level.

Keywords: geographical origin, jackfruit, physico-chemical characteristics; multivariate analysis, PCA and LDA

Introduction
Jackfruit (*Artocarpus heterophyllus* Lam.) is native to parts of South and Southeast Asia and is believed to have originated in the rainforests of Western Ghats of India (Morton, 1987 and Purseglove, 1968) [8, 9] and is cultivated throughout the low lands in South and Southeast Asia. In India, it has wide distribution in states of Assam, Tripura, West Bengal, Bihar, Uttar Pradesh, foothills of the Himalayas and South Indian States of Kerala, Tamil Nadu and Karnataka (Wangchu *et al*., 2013) [13]. Assam, Tripura and West Bengal produces major share of jackfruit in India (APAARI, 2012) [1]. Jackfruit plays a significant role in Indian agriculture with increasing their nutritional value in human diet and these fruit are gaining commercial importance (Salunkhe and Desai, 1984) [12].
Jackfruit is a cross pollinated crop and it is propagated by seeds. (Haq, 2006; Haque *et al.*, 2004 and Wangchu *et al.*, 2013) [3, 4, 13]. Jackfruit is a multipurpose tree and all parts of the plant are equally important (Wangchu *et al.*, 2013) [13]. It is a good source of vitamins like A, C, thiamine, riboflavin, niacin and minerals like calcium, potassium, iron, sodium and zinc (Azad, 2000; Haq, 2006 and Swamy *et al.*, 2012) [3]. In spite of such a vast potential and usefulness, jackfruit remains an underutilized fruit species and deserves to be given the needed thrust for research and development. Jackfruit exhibits great economic traits, which is considered pre- requisite for any crop improvement program. Therefore, it is a need to identify and locate areas of rich genetic diversity of jackfruit. Haque (1999) [5] emphasized the need for enhanced utilization of the available genetic diversity along with improving the productivity and quality of jackfruit. Most of the commercial jackfruits are identified based on the place of their origin. Hence, the uniqueness of Jack fruits from each geographical origin has to be verified and linked. Such an attempt was made in the present study based on physico-chemical characteristics of jack fruits using multivariate analysis tools like principal component analysis (PCA) and linear discriminant analysis (LDA).

Materials and Methods
Sample collection: Seventy accessions of jackfruit (Table 1) from seven geographical locations famous for jack fruit production belonging to five states of India *viz.* North 24 Parganas District (West Bengal),

Table 1: Location details of sample collected

Accessions	Place of collection	Latitude	Longitude
PARJ 1	North 24 Parganas (West Bengal)	22^{O} 55.458	088^{O}32.489
PARJ 2	North 24 Parganas (West Bengal)	22^{O} 55.448	088^{O}32.476
PARJ 3	North 24 Parganas (West Bengal)	22^{O} 55.452	088^{O}32.533
PARJ 4	North 24 Parganas (West Bengal)	22^{O} 55.452	088^{O}32.533
PARJ 5	North 24 Parganas (West Bengal)	22^{O} 55.452	088^{O}32.524
PARJ 6	North 24 Parganas (West Bengal)	22^{O} 55.455	088^{O}32.522
PARJ 7	North 24 Parganas (West Bengal)	22^{O} 55.454	088^{O}32.634
PARJ 8	North 24 Parganas (West Bengal)	22^{O} 55.431	088^{O}32.622
PARJ 9	North 24 Parganas (West Bengal)	22^{O} 54.991	088^{O}33.282
PARJ 10	North 24 Parganas (West Bengal)	22^{O} 54.973	088^{O}33.284
NADJ 11	Nadia (West Bengal)	22^{O} 58.223	088^{O}31.143
NADJ 12	Nadia (West Bengal)	22^{O} 58.233	088^{O}31.095
NADJ 13	Nadia (West Bengal)	22^{O} 58.240	088^{O}31.036
NADJ 14	Nadia (West Bengal)	22^{O} 58.241	088^{O}31.027
NADJ 15	Nadia (West Bengal)	22^{O} 58.241	088^{O}31.015
NADJ 16	Nadia (West Bengal)	22^{O} 58.255	088^{O}30.905
NADJ 17	Nadia (West Bengal)	22^{O} 58.216	088^{O}31.346
NADJ 18	Nadia (West Bengal)	22^{O} 58.218	088^{O}31.333
NADJ 19	Nadia (West Bengal)	22^{O}58.223	088^{O}31.345
NADJ 20	Nadia (West Bengal)	22^{O} 58.004	088^{O}32.758
WDTJ 21	West Tripura (Tripuara)	23^{O} 52.708	091^{O}20.134
WDTJ 22	West Tripura (Tripuara)	23^{O} 52.783	091^{O}20.502
WDTJ 23	West Tripura (Tripuara)	23^{O} 52.812	091^{O}20.551
WDTJ 24	West Tripura (Tripuara)	23^{O} 52.906	091^{O}20.385
WDTJ 25	West Tripura (Tripuara)	23^{O} 52.989	091^{O}20.397
WDTJ 26	West Tripura (Tripuara)	23^{O} 54.004	091^{O}20.333
WDTJ 27	West Tripura (Tripuara)	23^{O} 52.068	091^{O}18.612
WDTJ 28	West Tripura (Tripuara)	23^{O} 52.073	091^{O}18.603
WDTJ 29	West Tripura (Tripuara)	23^{O} 51.954	091^{O}18.665
WDTJ 30	West Tripura (Tripuara)	23^{O} 51.962	091^{O}18.645
KHWJ 31	Khowai (Tripuara)	23^{O} 57.964	091^{O}35.298
KHWJ 32	Khowai (Tripuara)	23^{O} 58.271	091^{O}35.346
KHWJ 33	Khowai (Tripuara)	23^{O} 58.275	091^{O}35.366
KHWJ 34	Khowai (Tripuara)	23^{O} 58.014	091^{O}35.366
KHWJ 35	Khowai (Tripuara)	23^{O} 57.991	091^{O}35.199
KHWJ 36	Khowai (Tripuara)	23^{O} 57.293	091^{O}34.556
KHWJ 37	Khowai (Tripuara)	23^{O} 57.019	091^{O}34.191
KHWJ 38	Khowai (Tripuara)	23^{O} 57.097	091^{O}34.083
KHWJ 39	Khowai (Tripuara)	23^{O} 57.120	091^{O}33.738
KHWJ 40	Khowai (Tripuara)	23^{O} 57.952	091^{O}35.310
PANJ 41	Panruti (Tamil Nadu)	11^{O}44.684	079^{O}31.436
PANJ 42	Panruti (Tamil Nadu)	11^{O}44.689	079^{O}31.431
PANJ 43	Panruti (Tamil Nadu)	11^{O}44.690	079^{O}31.412
PANJ 44	Panruti (Tamil Nadu)	11^{O}44.692	079^{O}31.395
PANJ 45	Panruti (Tamil Nadu)	11^{O}44.689	079^{O}31.385
PANJ 46	Panruti (Tamil Nadu)	11^{O}44.665	079^{O}31.376
PANJ 47	Panruti (Tamil Nadu)	11^{O}44.676	079^{O}31.374
PANJ 48	Panruti (Tamil Nadu)	11^{O}44.692	079^{O}31.381
PANJ 49	Panruti (Tamil Nadu)	11^{O}43.792	079^{O}31.418
PARJ 50	Panruti (Tamil Nadu)	11^{O}43.788	079^{O}31.486
VARJ 51	Varkala (Kerala)	08^{O}44.589	076^{O}43.170
VARJ 52	Varkala (Kerala)	08^{O}44.580	076^{O}43.178
VARJ 53	Varkala (Kerala)	08^{O}44.446	076^{O}43.185
VARJ 54	Varkala (Kerala)	08^{O}44.441	076^{O}43.132
VARJ 55	Varkala (Kerala)	08^{O}44.448	076^{O}43.065
VARJ 56	Varkala (Kerala)	08^{O}43.821	076^{O}43.644
VARJ 57	Varkala (Kerala)	08^{O}43.781	076^{O}43.667
VARJ 58	Varkala (Kerala)	08^{O}43.770	076^{O}43.778
VARJ 59	Varkala (Kerala)	08^{O}43.779	076^{O}43.773
VARJ 60	Varkala (Kerala)	08^{O}43.991	076^{O}42.776
SDTJ 61	South Sikkim (Sikkim)	27^{O}10.923	088^{O}30.793
SDTJ 62	South Sikkim (Sikkim)	27^{O}10.940	088^{O}30.851
SDTJ 63	South Sikkim (Sikkim)	27^{O}10.922	088^{O}30.833
SDTJ 64	South Sikkim (Sikkim)	27^{O}10.921	088^{O}30.990
SDTJ 65	South Sikkim (Sikkim)	27^{O}10.917	088^{O}30.910
SDTJ 66	South Sikkim (Sikkim)	27^{O}10.911	088^{O}30.759

SDTJ 67	South Sikkim (Sikkim)	27^{O}10.758	088^{O}30.746
SDTJ 68	South Sikkim (Sikkim)	27^{O}10.752	088^{O}30.746
SDTJ 69	South Sikkim (Sikkim)	27^{O}10.763	088^{O}30.732
SDTJ 70	South Sikkim (Sikkim)	27^{O}10.770	088^{O}30.706

Nadia District (West Bengal), West District (Tripura), Khowai District (Tripura), Panruti (Tamil Nadu), Varkala (Kerala) and South District (Sikkim) were collected to study the physico-chemical characters of jackfruit. The samples were collected on a yearly basis, in the month of May to June of 2016 for the first year and May to June of 2017 for the second year.

Parameters observed: The morphological characters like fruit weight, fruit length, fruit width, number of flakes, flakes weight, pulp weight, seed weight and chemical characteristic like Total Soluble Solids (TSS) by refractometry, titratable acidity by titremetry and total sugar by anthrone method (Jayaraman, 1981) [7] were studied.

Statistical analysis: The physico-chemical characters of seventy accessions of jackfruit from seven regions of India were analyzed using two di-mensional multivariate methods such as Principle Component Analysis (PCA) and Linear Discriminant Analysis (LDA)

Results and Discussion

Morphological characters of jackfruit: Each morphological parameter in the jackfruit samples from different regions showed significant differences (Table. 2 and Table. 3). The maximum fruit weight was recorded in PANJ 48 (17.3 kg; 16.45 kg) followed by PANJ 47 (15.2 kg; 14.76 kg) in both the years of study. The least fruit weight was recorded in SDTJ 61 (1 kg; 0.92 kg) during first year and second year. Lengthiest fruit was observed in PANJ 48 (73.6 cm; 75.20 cm) and NADJ 13 (73.1 cm; 75.30 cm) and the minimum value was recorded in SDTJ 61 (17.3 cm; 21.10 cm). Width wise highest value was recorded in PANJ 47 (86.2 cm; 87.30 cm) followed by PARJ 1 (74.5 cm; 75.73 cm) for both the years and the lowest fruit width was recorded in SDTJ 61 (29.5 cm) for the first year and in the second year minimum value was recorded in SDTJ 63 (39.60 cm). The maximum numbers of flakes were found to be in PANJ 48 (223; 236) and PANJ 47 (205; 218) and minimum was recorded in SDTJ 61 (27; 40) during the first and second year. Highest flake weight (47.22 g) and pulp weight (38.41 g) was observed in PANJ 47. However, in the second year highest values of flake weight (47.52g) and pulp weight (40.80 g) was observed in PANJ 42. Lowest value of flake weight (10.3 g; 9.52 g) and pulp weight (6 g; 4.99) was recorded on SDTJ 63 for both the years. Highest seed weight (9.07 g; 9.13g) was recorded on PANJ 46 and lowest seed weight (2.7 g; 2.89g) was observed in SDTJ 61.

Table 2: Physico-chemical characters of seventy accessions from different jackfruit geographical locations of India (1st year)

Accessions	Fruit weight (Kg)	Fruit Length (cm)	Fruit Width (cm)	Number of Flake	Flake Weight (g)	Pulp Weight (g)	Seed Weight (g)	TSS (ºBrix)	Titrable Acidity (%)	Total Sugar (%)
PARJ 1	5.2±0.7	30.6±1.75	74.5±3.97	103±12.16	24.7±0.30	21.01±0.25	3.69±0.13	16.02±0.19	0.53±0.06	17.23±0.87
PARJ 2	3.6±0.46	26.1±2.78	60.1±3.38	66±8.18	12.9±1.80	8.90±0.71	4.0±0.026	20 ± 1.20	0.6±0.10	13.2±0.43
PARJ 3	3.8±0.12	22.5±0.66	61.6±3.32	59±0.57	12.7±0.66	9.81±0.39	2.9±0.17	14.8 ± 0.53	1.00±0.20	14.75±0.65
PARJ 4	5.7±0.50	38.5±0.82	71.0±2.66	73±9.54	17.9±1.57	12.00±0.16	5.9±0.26	12.2 ± 0.80	0.9±0.173	12.26±0.57
PARJ 5	4.2±0.30	33.3±1.45	66.4±0.90	64±6.56	18.8±1.57	14.61±0.57	3.69±0.19	16.2 ± 10	1.00±0.1	15.93±0.78
PARJ 6	4.8±0.43	32.4±1.56	59.4±2.96	94±10.53	15.94±1.25	10.04±0.25	5.90±0.19	18.2 ± 1.52	0.89±0.11	16.26±0.58
PARJ 7	4.3±0.40	38.9±0.87	52.1±2.10	97±3.00	16.06±1.15	12.58±0.26	3.48±0.36	18.4 ± 0.72	0.52±0.25	16.73±1.41
PARJ 8	2.0±0.20	24.1±1.26	44.4±1.31	36±5.03	12.60±1.15	8.69±0.49	3.91±0.78	12.5 ± 0.46	0.85±0.07	11.32±0.66
PARJ 9	2.3±0.40	19.5±1.82	54.8±1.47	61±4.00	11.46±0.99	8.56±0.20	2.9±0.13	14.9 ± 0.26	1.00±0.24	13.92±0.43
PARJ 10	3.3±0.30	27.3±1.35	54.3±1.21	53±3.60	13.32±0.94	9.22±0.14	4.1±0.13	16.5 ± 0.89	0.43±0.05	14.92±0.78
NADJ 11	3.3±0.10	26.3±0.87	48.5±2.46	46±6.56	21.52±1.18	16.48±0.39	5.04±0.39	20.2 ± 0.72	0.5±0.05	16.92±0.95
NADJ 12	5.3±0.44	37.3±1.14	65.2±2.05	109±11.79	24.05±2.06	19.75±0.70	4.75±0.17	16.5 ± 0.65	0.6±0.06	13.71±0.64
NADJ 13	6.3±0.42	73.1±1.90	49.2±2.36	118±7.00	28.63±0.92	21.06±0.37	7.57±0.30	16.8 ± 0.72	0.4±0.05	14.23±0.93
NADJ 14	3.7±0.57	28.4±1.07	44.2±1.08	78±30.0	22.84±0.50	19.06±0.15	3.76±0.54	20.8 ± 0.60	0.6±0.06	15.62±0.99
NADJ 15	2.1±0.17	24.1±1.11	60.0±4.33	41±2.00	21.62±0.44	18.22±0.44	3.4±0.24	19.8 ± 0.40	0.4±0.06	16.14±0.37
NADJ 16	2.9±0.21	30.2±0.26	54.6±1.93	42±3.00	20.81±0.87	17.61±0.52	3.2±0.23	25 ± 0.53	0.5±0.07	17.02±0.69
NADJ 17	2.5±1.73	28.2±2.45	54.7±2.87	46±4.36	24.67±0.91	21.70±0.54	2.9±0.29	21.9 ± 0.85	0.63±0.05	16.23±0.49
NADJ 18	5.1±1.04	37.3±2.68	60.0±2.40	146±19.0	30.26±0.37	25.78±1.33	4.48±0.18	18.4 ± 0.20	0.6±0.12	14.63±1.11
NADJ 19	3.9±0.10	35.1±1.45	62.2±1.54	81±8.00	33.92±0.71	29.80±0.67	4.12±0.24	17.2 ± 0.91	1.0±0.10	13.76±0.78
NADJ 20	1.8±0.43	25.2±0.98	51.4±3.57	50±2.65	22.02±0.09	18.73±1.59	3.29±0.25	22.5 ± 0.30	0.8±0.13	15.83±0.72
WDTJ 21	2.8±0.30	31.2±2.56	60.9±2.24	52±3.61	16.16±0.16	12.46±0.41	3.7±0.78	14.8 ± 1.71	1.02±0.13	12.24±0.30
WDTJ 22	4.0±0.56	35.8±0.95	59.6±0.78	81±8.33	29.33±0.97	24.15±0.44	5.2±0.19	12.2 ± 1.51	0.7±0.1 0	11.33±0.90
WDTJ 23	4.9±0.31	22.5±1.30	59.3±3.26	83±9.85	36.62±0.73	32.70±0.81	3.9±0.97	11.5 ± 0.55	0.9±0.06	14.05±0.42
WDTJ 24	2.1± 0.10	22.3±0.46	59.2±3.05	61±6.56	31.92±0.12	26.90±0.17	5.02±0.33	14.7 ± 1.45	0.6±0.07	10.62±0.54
WDTJ 25	2.8±0.40	36.1±1.93	69.5±1.69	101±12.77	19.2±0.82	12.50±0.38	6.7±0.46	11.5 ± 0.30	0.9±0.10	13.26±0.48
WDTJ 26	4.0±0.96	27.3±1.13	65.2±5.53	89±2.66	35.6±0.66	31.00±0.09	4.6±0.62	13.3±0.43	0.6±0.06	16.23±0.55
WDTJ 27	5.0±0.87	36.2±0.26	66.0±0.56	103±13.53	34.58±0.62	29.52±0.44	5.06±0.23	16.2±0.46	0.7±0.10	11.05±1.05
WDTJ 28	3.0±0.28	24.5±0.98	65.3±2.28	76±9.54	34.33±0.70	29.73±0.53	4.6±0.62	11.9±0.10	0.7±0.07	16.23±0.49
WDTJ 29	3.5±1.0	24.6±0.70	47.4±2.46	66±4.58	14.73±0.84	11.16±0.54	3.57±0.63	16.2±0.72	0.6±0.08	15.92±0.63
WDTJ 30	4.2±0.40	27.8±0.89	65.2±0.52	82±3.61	20±0.10	19.22±0.41	5.78±0.57	11.9±0.46	1.0±0.15	16.81±0.69
KHWJ 31	5.6±0.66	33.6±0.98	61.6±2.04	124±4.58	39±2.18	33.40±0.42	5.6±0.38	18.2±0.53	0.9±0.28	17.23±0.48
KHWJ 32	5.3±0.76	34.1±0.56	69.1±0.96	105±4.36	28.9±1.00	25.70±0.55	3.2±0.39	14.9±0.61	0.5±0.03	14.62±0.44
KHWJ 33	4.3±0.18	27.9±0.36	64.6±1.74	87±7.55	28.7±6.28	22.60±0.83	6.1±0.13	12.2±0.91	1.1±0.20	12.32±0.59
KHWJ 34	4.2±0.12	33.3±1.12	62.7±1.61	80±3.61	35.22±0.29	29.32±0.36	5.9±0.24	10.0±1.20	0.6±0.08	10.14±0.54

KHWJ 35	5.2±0.16	33.4±7.19	62.5±1.06	77±4.00	34.6±0.54	30.90±0.93	3.7±0.41	21.2±0.35	0.5±0.05	17.36±0.78
KHWJ 36	4.9±0.56	29.8±1.11	64.3±0.95	82±3.60	29.24±0.51	34.64±0.56	4.6±0.33	15.2±0.53	1.2±0.34	15.31±0.61
KHWJ 37	2.1±0.18	30±1.45	54.4±0.96	79±4.00	23.39±0.36	19.29±0.44	4.1±0.21	12.9±0.50	0.6±0.05	11.09±0.79
KHWJ 38	3.2±0.61	29.1±1.25	55.6±0.61	61±5.13	27.9±0.67	25.20±0.32	2.7±0.67	18.5±1.05	0.4±0.08	17.04±0.51
KHWJ 39	4.5±0.15	27.3±0.56	59.6±0.80	63±2.00	34.5±1.23	27.60±0.32	6.9±0.56	12.2±0.72	0.6±0.05	12.06±0.40
KHWJ 40	2.3±0.17	25.1±1.85	53.2±2.88	53±8.66	20.01±0.89	16.40±0.45	3.7±0.41	14.8±0.61	0.7±0.10	14.13±0.83
PANJ 41	7.0±0.20	48.5±4.51	72.0±1.25	203±6.08	23.23±0.42	17.44±0.46	5.79±0.33	18.5±0.55	0.4±0.09	17.23±0.41
PANJ 42	10.0±2.55	52.3±1.65	71.5±0.79	115±8.72	46.19±0.26	29.42±0.39	6.77±0.36	18.6±0.53	0.6±0.05	17.02±0.55
PANJ 43	12.0±1.08	45.9±3.03	72.4±0.76	160±4.58	36.92±0.89	30.91±0.32	6.01±0.22	16.3±0.79	0.5±0.09	16.32±1.51
PANJ 44	13.2±1.20	49.6±4.95	66.6±1.54	180±3.00	37.71±0.62	29.04±0.69	7.1±0.55	19.2±0.72	0.3±0.05	15.12±0.48
PANJ 45	7.5±0.52	50.3±1.91	73.5±2.53	130±10.44	32.9±0.90	28.60±0.51	4.3±0.23	16.8±0.52	0.5±0.07	17.16±0.34
PANJ 46	9.6±0.56	50.6±3.08	65.4±1.94	122±5.00	45.67±0.63	14.60±0.81	9.07±0.14	19.6±0.52	0.4±0.06	17.01±0.24
PANJ 47	15.2±1.73	66.3±1.02	86.2±0.30	205±9.16	47.22±0.69	38.41±5.23	7.8±0.67	19.2±0.87	0.4±0.06	16.24±0.41
PANJ 48	17.3±1.21	73.6±1.99	65.0±2.60	223±5.29	42.65±0.49	36.65±0.96	6.0±0.20	16.5±0.70	0.6±0.08	15.27±0.88
PANJ 49	8.2±0.36	47.2±2.23	66.1±0.26	121±14.64	39.92±0.86	34.02±0.29	5.9±0.19	18.9±1.34	0.7±0.11	17.06±0.43
PANJ 50	6.7±0.62	47.0±2.22	69.6±1.61	109±6.56	41.32±0.30	35.29±0.38	6.03±0.66	22.6±1.71	0.4±0.05	16.97±0.96
VARJ 51	2.1±0.11	42.1±2.41	55.7±0.66	79±12.49	34.22±0.27	28.31±0.64	6.01±0.15	19.23±1.55	0.7±0.05	16.76±0.79
VARJ 52	3.1±0.17	39.8±1.90	53.2±1.85	62±14.64	31.22±0.77	27.50±0.38	3.7±0.25	14.2±0.53	0.6±0.07	14.23±0.90
VARJ 53	2.7±0.36	36.2±1.40	43.2±0.90	57±5.29	28.00±0.92	23.97±0.10	4.03±0.21	21.04±1.65	0.6±0.07	17.11±0.56
VARJ 54	2.3±0.30	39.1±3.11	53.2±2.74	52±4.58	25.63±0.59	22.33±0.39	3.3±0.30	16.78±1.52	0.5±0.06	15.23±0.76
VARJ 55	2.2±0.20	39.5±3.12	59.0±0.95	63±6.00	23.24±0.45	19.34±0.59	3.9±0.22	20.8±1.20	0.7±0.07	16.93±0.96
VARJ 56	2.1±0.36	20.5±1.09	52.8±0.75	49±5.00	20.02±0.42	17.0±0.14	3.03±0.12	19.2±1.11	0.4±0.05	16.11±0.32
VARJ 57	3.1±0.36	46.6±2.40	54.7±0.70	80±5.50	31.23±0.16	14.96±0.35	4.12±0.10	22.2±2.30	0.5±0.06	16.76±0.79
VARJ 58	3.7±1.021	49.2±1.68	60.8±1.48	83±6.24	31.23±0.17	26.53±1.17	4.7±0.19	24.8 ± 0.72	0.6±0.08	17.03±0.37
VARJ 59	2.1±0.20	34.8±1.23	52.4±1.08	29±3.46	37.20±0.23	31.15±0.33	6.05±0.43	25.4 ± 0.71	0.6±0.07	17.26±0.96
VARJ 60	2.9±0.360	36.5±1.76	62.1±0.62	37±5.29	35.04±0.08	29.81±0.24	5.23±0.28	23.9 ± 1.30	0.6±0.05	15.33±0.63
SDTJ 61	1.0±0.20	17.3±0.85	29.5±1.28	27±5.29	11.6±0.53	8.90±0.36	2.7±0.24	19.5±0.65	1.0±0.11	14.62±0.62
SDTJ 62	2.9±0.40	24.5±1.21	74.1±0.95	69±2.00	14.2±0.77	10.5±0.42	3.7±0.53	22±1.11	0.8±0.07	13.24±0.27
SDTJ 63	1.5±0.20	28.6±0.95	41.5±1.18	52±4.58	10.3±0.41	6.0±0.19	4.3±0.20	18.8±0.91	0.9±0.06	15.26±0.89
SDTJ 64	2.5±0.46	27.8±0.36	51.4±0.82	65±5.57	16.24±0.21	12.34±0.67	3.9±0.21	19.2±1.44	0.7±0.12	14.12±0.32
SDTJ 65	1.2±0.26	25.5±0.95	52.1±0.43	31±3.05	14.06±0.46	9.46±1.23	4.6±0.33	18.5±0.65	0.6±0.05	13.62±0.65
SDTJ 66	3.1±0.47	30.6±1.65	56.2±2.16	72±5.57	16.06±0.19	11.46±0.36	4.1±0.11	23.5±0.40	0.9±0.07	16.33±0.60
SDTJ 67	3.3±0.23	31.4±2.09	43.8±0.52	81±2.645	12.23±0.19	8.2±0.67	4.03±0.15	21.9±0.46	0.5±0.06	17.12±0.67
SDTJ 68	2.9±0.55	32.4±1.44	48.2±1.76	27±1.53	13.26±0.23	9.34±0.86	3.92±0.48	19.2±0.41	1.2±0.33	17.01±0.33
SDTJ 69	2.5±0.62	34.2±0.91	54.2±2.38	61±4.59	14.04±0.97	9.96±0.95	4.08±0.16	21.4±0.20	0.7±0.05	17.06±0.52
SDTJ 70	3.0±0.36	39.0±2.08	34.9±2.25	74±3.00	15.33±1.08	11.21±1.16	4.12±0.10	13.6±1.40	0.8±0.06	15.32±0.63

Values are represented as mean ±SD

Table 3: Physico-chemical concentration of seventy accessions from different jackfruit geographical locations of India (2nd year)

Accessions	Fruit Weight (Kg)	Fruit Length (cm)	Fruit Width (cm)	Number of Flake	Flake Weight (g)	Pulp Weight (g)	Seed Weight (g)	TSS (ºBrix)	Titrable Acidity (%)	Total Sugar (%)
PARJ 1	4.82±0.92	32.00±1.00	75.73±1.10	112 ± 3.60	27.07±0.22	23.05±0.64	4±0.11	17.60±0.72	0.61±0.91	17.52±0.92
PARJ 2	3.76±1.09	28.81±7.22	61.30±1.53	73 ± 7.21	13.2±0.85	8.64±0.60	4.56±0.36	21.80±0.59	0.59±1.02	14.34±1.02
PARJ 3	4.25±0.94	20.35±4.30	60.10±2.70	65 ± 6.55	12.11±0.36	9.35±0.87	2.76±0.29	15.00±0.20	0.88±0.77	15.21±0.78
PARJ 4	5.83±0.18	39.16±1.76	69.20±1.11	81 ± 2.64	18.64±0.71	13.19±1.24	5.45±0.26	16.67±1.70	0.92±0.91	12.05±0.93
PARJ 5	5.20±0.72	30.96±2.26	67.11±1.73	66 ± 6.55	18.05±0.17	9.64±0.66	4.13±0.14	18.00±1.90	0.96±0.99	15.39±0.99
PARJ 6	4.12±0.50	31.42±2,83	61.40±2.70	91 ± 2.64	15.24±0.85	14.08±0.67	5.93±0.90	19.20±0.72	0.78±0.99	17.16±1.00
PARJ 7	3.96±0.40	39.24±1.99	53.70±1.05	95 ± 4.00	18.52±1.41	9.72±0.58	4.09±0.21	12.8±1.31	0.56±0.71	16.21±0.72
PARJ 8	2.62±0.69	25.11±1.46	47.60±2.94	41 ± 3.46	13.82±0.16	9.52±0.52	4.11±0.50	15.2±0.52	0.79±1.22	11.05±1.23
PARJ 9	3.06±0.31	18.91±1.49	56.70±1.66	60 ± 3.47	12.36±0.56	9.63±1.76	2.84±0.26	17.93±.80	0.92±1.05	14.12±1.06
PARJ 10	3.81±0.42	25.03±6.43	55.30±0.79	56 ± 2.64	13.52±0.49	9.87±0.55	3.87±0.65	21.40±0.72	0.45±0.61	14.33±0.61
NADJ 11	2.56±0.51	27.40±1.15	50.30±3.45	41 ± 5.29	22.31±1.26	16.82±2.09	5.49±0.41	17.20±0.91	0.60±0.48	17.36±0.49
NADJ 12	5.62±1.17	36.10±1.41	63.70±4.78	122 ± 4,35	25.16±0.39	20.10±0.34	5.23±0.55	16.60±1.44	0.52±0.55	13.24±0.56
NADJ 13	5.98±0.70	75.30±2.61	51.20±1.15	127 ± 9.16	27.89±1.72	20.07±0.33	7.82±0.18	21.20±1.21	0.46±0.77	15.43±0.78
NADJ 14	4.13±0.39	27.10±1.22	30.72±2.47	75 ± 5.56	22.67±0.56	19.41±1.00	4.31±0.58	20.80±1.50	0.61±0.94	15.20±0.95
NADJ 15	2.37±0.32	25.30±0.8	62.50±4.78	48 ± 4.35	22.05±1.51	19.41±0.66	3.26±0.24	24.80±0.20	0.65±0.72	17.29±0.72
NADJ 16	2.71±0.58	31.40±0.86	53.70±3.23	23 ± 5.56	20.17±1.17	17.20±0.90	2.97±0.45	22.40±0.72	0.60±0.47	18.10±0.47
NADJ 17	2.58±0.47	27.92±2.20	54.60±1.63	49 ± 4.58	25.93±0.80	22.92±0.96	3.01±0.62	19.60±0.91	0.40±0.61	17.33±0.61
NADJ 18	4.82±0.56	35.70±2.58	59.20±1,11	132 ± 3.46	27.92±5.91	26.67±0.42	4.56±0.33	18.20±0.72	0.40±0.81	15.12±0.81
NADJ 19	4.10±0.42	36.50±0.88	63.90±1.07	99 ± 3.60	34.19±0.46	29.36±0.87	4.83±0.61	23.20±0.52	0.67±0.84	14.43±0.84
NADJ 20	2.05±0.26	26.10±0.43	62.47±1.00	55 ± 5.56	21.88±0.41	18.23±0.28	3.65±0.54	15.40±0.52	0.60±1.37	13.36±1.38
WDTJ 21	3.05±0.25	33.40±1.47	61.35±1.20	56 ± 1.73	17.24±0.73	13.38±0.26	4.19±0.16	13.20±0.72	0.99±1.02	13.26±1.03
WDTJ 22	3.72±0.53	36.10±1.90	60.80±1.17	90 ± 1.50	28.56±0.91	23.2±0.72	5.36±0.70	12.60±0.36	0.82±0.53	11.53±0.54
WDTJ 23	4.13±0.42	20.00±2.62	60.70±3.24	95 ± 6.92	37.68±0.56	32.31±1.16	4.31±0.43	15.20±0.91	0.78±0.75	15.29±0.76
WDTJ 24	2.52±0.38	23.10±0.95	57.30±2.78	69 ± 21.12	32.31±0.61	27.78±1.52	5.53±1.19	11.40±0.52	0.60±0.56	11.36±0.57
WDTJ 25	3.14±0.43	35.30±2.00	58.70±2.56	110 ± 2.64	19.67±1.45	12.78±0.71	6.89±0.31	14.20±0.72	0.84±0.81	12.89±0.82
WDTJ 26	4.26±0.44	28.10±2.72	70.30±1.53	82 ± 4.93	36.72±0.78	31.66±0.68	4.73±0.35	15.80±1.24	0.95±.47	17.06±0.47

WDTJ 27	5.17±1.011	38.20±1.44	66.10±1.49	107 ± 8.54	35.36±0.64	30.03±0.60	5.33±0.66	12.70±0.11	0.70±0.61	12.33±0.62
WDTJ 28	2.99±0.90	25.10±1.17	67.20±1.58	81 ± 7.00	35.22±0.55	31.33±0.56	3.89±0.88	17.6±0.60	0.72±0.32	17.11±0.33
WDTJ 29	3.11±0.60	28.00±1.87	63.10±3.39	63 ± 4.35	15.02±1.06	11.73±0.63	3.47±0.25	11.60±0.40	0.62±0.77	15.23±0.77
WDTJ 30	4.76±0.65	28.1±1.15	50.10±2.06	85 ± 5.56	21.63±1.26	16.25±0.78	5.38±0.43	18.60±1.11	0.64±0.87	17.47±0.88
KHWJ 31	6.14±6.14	28.9±0.85	63.50±1.94	132 ± 4.35	40.36±0.70	34.47±0.46	5.89±0.52	16.20±2.42	0.60±1.49	15.33±1.50
KHWJ 32	5.73±0.76	34.80±1.50	67.30±2.42	111 ± 7.00	27.83±0.70	24.21±0.91	3.60±0.36	13.20±1.05	1.00±0.96	12.09±0.97
KHWJ 33	4.19±0.37	35.10±1.15	60.10±0.55	89 ± 10.53	28.61±0.58	21.71±0.66	6.32±0.34	11.40±0.60	0.62±0.65	11.26±0.65
KHWJ 34	3.75±0.40	29.10±1.60	65.11±2.47	75 ± 6.00	36.15±0.66	30.07±0.39	6.08±0.16	10.60±0.95	0.52±0.62	10.56±0.40
KHWJ 35	4.94±1.42	34.70±1.21	60.50±3.74	70 ± 4.58	35.09±1.017	31.48±1.05	3.61±0.45	15.80±0.34	1.10±0.62	16.37±0.62
KHWJ 36	5.33±1.15	35.10±1.15	66.30±2.08	88 ± 2.64	33.05±5.72	25.28±0.79	4.87±0.68	13.40±0.87	1.2±0.39	17.92±0.62
KHWJ 37	2.21±0.32	30.19±0.70	51.70±2.36	81 ± 3.60	24.11±0.28	20.27±0.98	3.84±0.59	19.40±1.21	0.50±0.52	16.16±0.53
KHWJ 38	3.46±0.71	30.2±0.91	53.90±3.38	66 ± 1.73	28.03±0.89	25.22±0.70	2.81±0.34	12.80±0.72	0.60±0.79	17.32±0.80
KHWJ 39	5.11±0.40	30.17±1.45	56.70±2.01	60 ± 3.60	34.16±0.77	27.63±0.35	6.51±0.71	15.20±0.72	0.73±0.44	11.65±0.44
KHWJ 40	1.95±0.27	26.30±1.15	52.10±2.74	57 ± 2.00	20.18±0.54	16.29±0.79	3.89±0.48	20.40±0.52	0.66±0.71	14.83±0.72
PANJ 41	8.36±0.67	50.63±2.12	75.10±1.95	150 ± 3.60	25.45±0.88	19.70±1.23	5.92±0.79	21.20±1.05	0.50±0.72	18.26±1.41
PANJ 42	10.41±0.73	53.10±0.79	73.20±3.10	81 ± 2.08	47.52±0.82	40.80±1.40	6.39±0.34	19.40±0.60	0.67±1.40	17.39±0.73
PANJ 43	11.94±1.34	47.00±3.60	70.10±3.26	107 ± 4.58	34.45±2.49	29.07±1.10	6.42±1.09	21.40±0.60	0.52±0.39	17.18±0.39
PANJ 44	14.39±1.34	50.10±4.53	65.50±1.90	181 ± 4.00	38.16±1.03	30.80±1.67	7.35±0.58	21.20±0.80	0.46±0.48	16.33±0.49
PANJ 45	8.29±0.61	53.20±2.88	70.50±1.15	132 ± 4.35	33.17±0.59	28.70±0.81	4.47±0.49	21.20±0.80	0.52±0.75	17.83±0.75
PANJ 46	10.27±0.74	51.09±2.19	51.51±2.29	117 ± 4.45	46.14±0.29	37.06±1.04	9.13±0.26	21.60±1.44	0.40±0.50	17.46±0.50
PANJ 47	14.76±0.23	67.40±1.01	87.30±3.23	218 ± 4.00	47.35±0.78	39.17±0.62	8.16±0.77	19.20±0.60	0.60±0.82	16.93±0.83
PANJ 48	16.45±1.64	75.20±1.08	64.90±3.29	236 ±11.35	36.43±22.32	30.15±1.26	6.46±0.84	18.20±0.72	0.58±0.58	16.47±0.50
PANJ 49	9.1±0.84	49.1±2.81	68.10±1.81	127 ± 5.56	40.08±0.47	33.57±1.56	6.18±0.64	20.40±0.78	0.70±0.55	17.87±0.56
PARJ 50	6.02±1.18	48.71±3.49	70.60±1.92	113 ± 3.00	40.21±0.68	33.86±1.33	6.33±0.71	23.80±1.80	0.50±3.38	18.10±3.38
VARJ 51	2.77±0.23	40.20±2.95	66.10±0.95	83 ± 4.35	35.39±0.61	29.13±0.64	6.23±0.64	22.40±0.87	0.60±0.79	17.91±0.79
VARJ 52	3.25±0.61	38.20±3.10	55.30±0.60	56 ± 1.73	32.13±0.41	28.37±1.49	3.46±0.42	15.80±0.20	0.60±0.65	15.32±0.65
VARJ 53	2.34±0.41	37.50±1.80	60.32±2.16	51 ± 2.64	28.14±0.23	23.62±0.35	4.52±0.60	22.90±0.95	0.61±0.58	17.33±0.58
VARJ 54	2.67±0.27	40.45±2.95	55.14±2.47	55 ± 4.50	54.67±0.68	22.24±0.68	3.92±0.69	17.20±0.72	0.63±0.86	16.26±0.87
VARJ 55	2.00±0.36	41.23±3.10	61.27±2.30	68 ± 4.35	23.01±0.91	18.87±1.46	4.07±0.27	21.40±1.31	0.65±0.54	16.43±0.54
VARJ 56	2.31±0.52	40.13±2.13	55.17±4.30	47 ± 3.00	21.67±1.47	18.42±0.54	3.23±0.20	22.80±1.38	0.50±0.55	17.73±0.56
VARJ 57	3.94±0.80	46.70±2.13	63 50±3.77	81 ± 3.60	32.08±0.95	28.81±1.49	3.88±0.80	24.33±1.52	0.60±0.43	17.31±0.44
VARJ 58	4.16±0.33	51.20±2.98	56.70±2.02	89 ± 4.58	33.10±0.59	28.80±0.98	4.27±0.26	25.60±0.60	0.50±0.73	17.81±0.73
VARJ 59	1.82±0.28	38.97±0.95	50.1±1.01	28 ± 3.00	38.39±1.07	32.23±0.68	6.16±0.27	27.80±0.72	0.55±0.58	18.32±0.59
VARJ 60	3.12±0.64	28.60±3.43	63.16±3.07	41 ± 3.00	36.21±0.66	30.89±0.30	5.32±0.61	23.63±0.85	0.60±0.80	16.14±0.81
SDTJ 61	0.92±0.32	21.10±1.31	43.20±0.72	40 ± 4.58	12.23±0.78	9.34±0.33	2.89±0.39	12.40±0.52	1.20±0.65	15.32±0.65
SDTJ 62	2.51±0.52	22.160±1.65	70.11±1.03	57 ± 3.46	15.36±0.61	11.73±0.95	3.62±0.19	21.60±0.52	0.92±0.60	14.61±0.60
SDTJ 63	1.36±0.64	29.30±3.62	39.60±3.07	55 ± 4.50	9.52±0.42	4.99±0.32	4.53±0.51	19.20±0.52	0.80±0.61	15.33±0.62
SDTJ 64	2.21±0.17	25.30±1.17	47.30±1.15	61 ± 2.64	17.32±0.31	13.96±0.93	3.63±0.34	19.80±0.69	0.70±0.57	15.36±0.58
SDTJ 65	1.00±0.11	26.10±1.10	55.13±0.85	33 ± 3.00	15.24±0.88	10.32±0.49	4.25±0.19	18.00±0.91	0.80±0.86	12.92±0.87
SDTJ 66	2.99±0.87	33.20±1.31	57.36±2.3	67 ± 1.73	16.63±0.39	10.32±0.48	4.13±0.54	23.60±1.50	0.93±0.70	15.81±0.71
SDTJ 67	3.36±0.99	29.90±3.46	45.50±2.23	84 ± 4.58	12.36±0.59	12.50±0.51	3.93±0.33	22.20±0.72	0.53±1.28	17.37±1.29
SDTJ 68	2.16±0.27	32.50±2.52	49.11±2.81	31 ± 1.76	13.92±0.52	8.43±0.44	4.65±1.66	20.30±1.17	1.20±0.70	17.81±0.71
SDTJ 69	2.07±0.47	35.30±0.62	50.16±2.72	60 ± 4.58	14.55±0.97	8.57±3.55	4.73±0.22	20.20±0.72	0.77±0.96	16.61±0.96
SDTJ 70	2.74±0.94	37.80±4.01	52.22±2.03	71 ± 4.35	16.41±0.72	12.05±0.10	4.36±0.30	14.20±0.72	0.70±0.86	16.02±0.86

Values are represented as mean ±SD

Chemical characters of jackfruit: The highest total soluble solids was found in accessions collected from Varkala at VARJ 59 (25.4º Brix; 27.80º Brix) followed by VARJ 58 (24.8 4º Brix; 25.60º Brix) and the lowest was found in KHWJ 34 (10º Brix; 10.60º Brix) from Khowai during the first and second years. The titratable acidity was highest in SDTJ 68 (1.2 %) and KHWJ 36 (1.2 %) for both the years and the lowest value was observed in PANJ 44 (0.3%) in first year and PANJ 46 (0.4%) in second year. VARJ 59 (17.26 %; 18.32%) followed by PANJ 41 (17.23 %; 18.26 %) were recorded highest amount of total sugar and the lowest concentration of total sugar was found in KHWJ 34 (10.14 %; 10.56%)) during both the years of study (Table. 2 and Table. 3).

Multivariate analysis and geographical discriminant: Principle component analysis (PCA) was performed on the physico-chemical characters of 70 accessions collected from different jackfruit growing regions of India. The first principle component covered 45.8% and 47% of variables and the second component covered 18.2% and 17.2% of variables for the first and second year respectively (Fig. 1A and 1B). PCA has differentiated the jack fruit accessions into major groups with interlinking relations. Based on the linear discriminant analysis (LDA) of physico-chemical charecters of jackfruit we could distinguish accessions collected from the Panruti as separate entity with most of the positive parameters. Further, accessions of West Tripura, Nadia, Khowai, Varkala, North 24 Parganas and South Sikkim had overlapping physico-chemical characters. Among these, accessions of West Tripura, Nadia, Khowai and Varkala had very close relationship. In addition, accessions from North 24 Parganas and South Sikkim had highly overlapping characteristics (Fig. 2A and Fig. 2B).

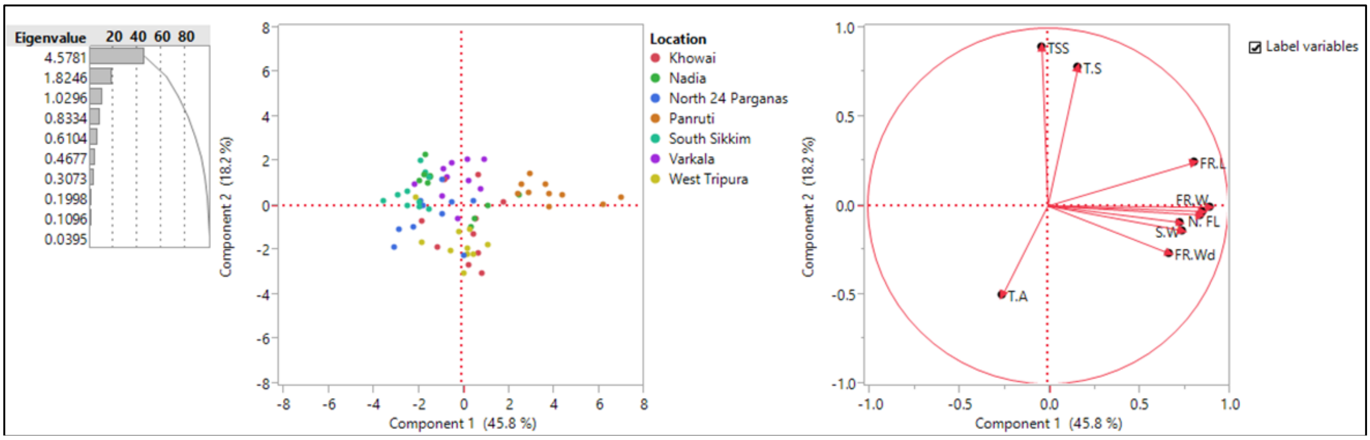

Fig. 1 A. PCA of seventy jack fruit accessions collected from different geographical locations of India (1st year)

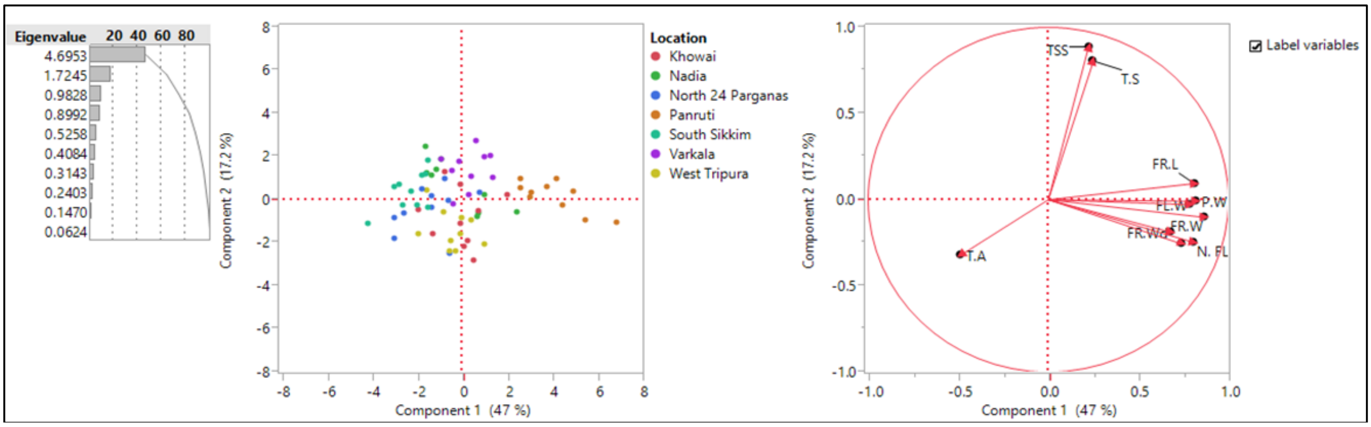

Fig. 1 B. PCA of seventy jack fruit accessions collected from different geographical locations of India (2nd year)

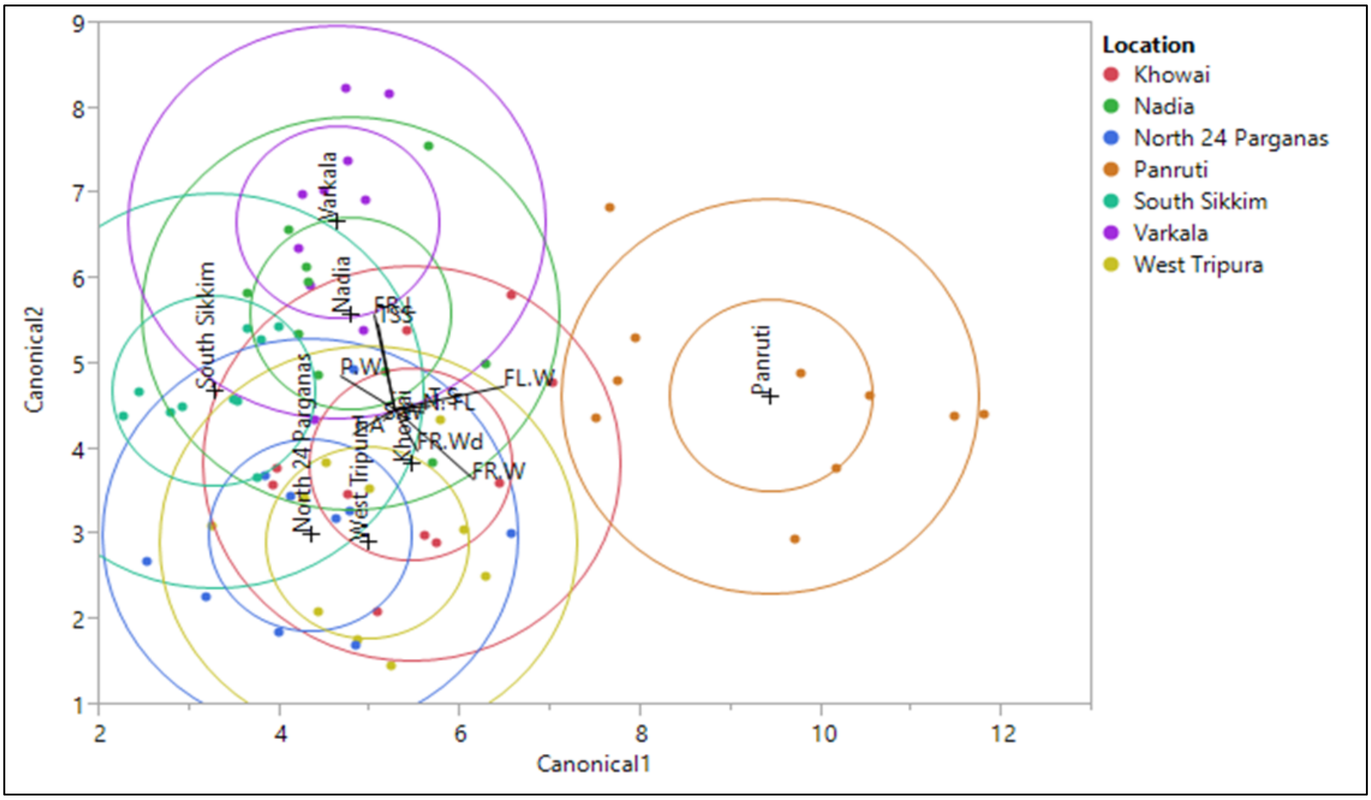

Fig. 2 A. LDA of seventy jack fruit accessions collected from different geographical locations of India (1st year)

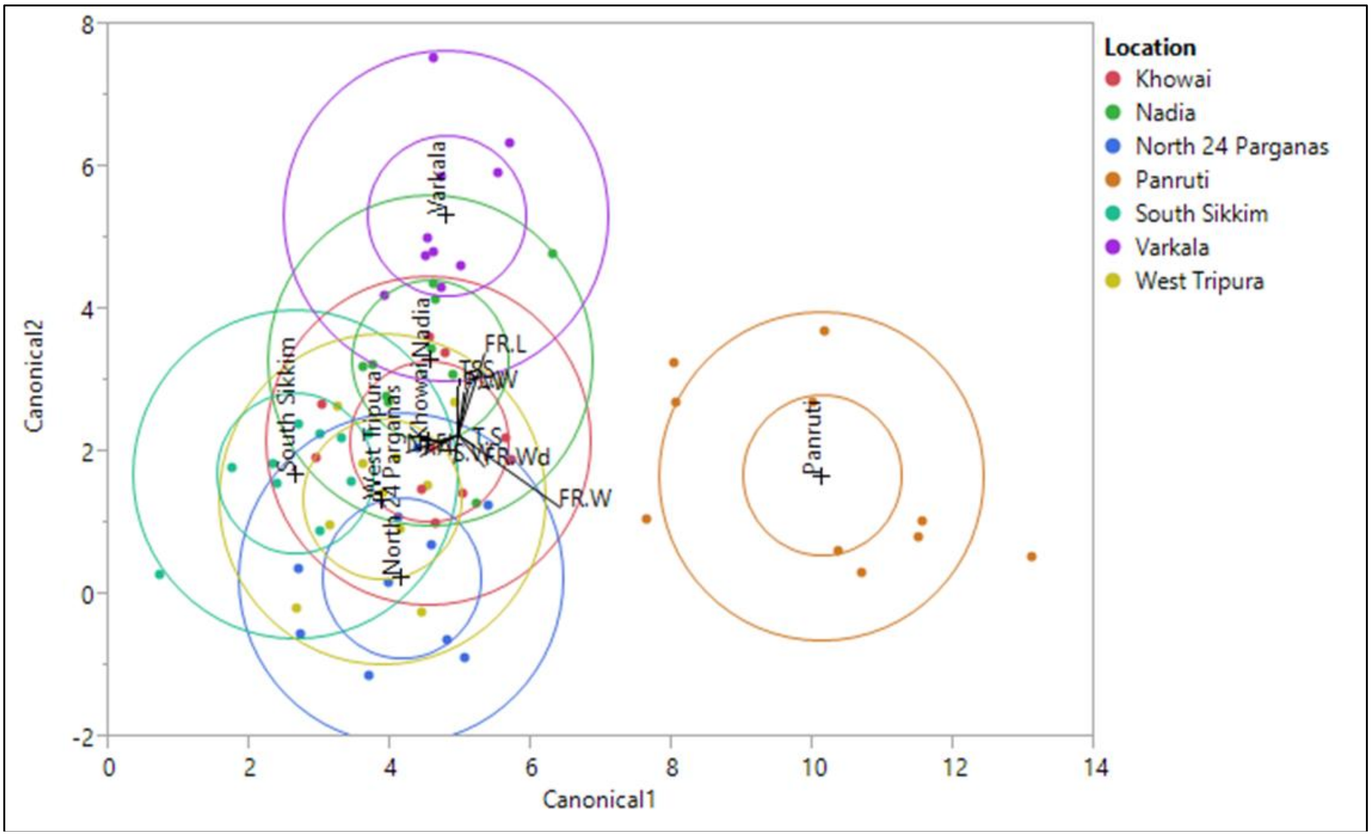

Fig. 2 B. LDA of seventy jack fruit accessions collected from different geographical locations of India (2nd year)

In the previous research works, Wangchu *et al.*, (2013) [13] analyzed forty four genotypes of superior jackfruit from three district of West Bengal who reported jackfruit in the range of 1.6 to 16.47 kg in fruit weight and the study of Reddy *et al.*, (2004) on jackfruit clones of south Karnataka reported that the range of fruit weight was at 7 to 20 kg, pulp weight was between 21.25 to 49.25g and seed weight measured at 5 to 12.30 g. However, in the present study fruit weight varied from 0.92 to 17.3 kg pulp weight from 4.99 to 40.80g and seed weight at 2.7 to 9.13 g. Wangchu *et al.*, (2013) [13] reported the range of TSS was 20 to 28.67 ºBrix, total sugar 8.3 to 20.3 % and titratable acidity 0.13 to 0.42% from 44 genotypes. Jagadeesh *et al.*, (2007) [6] studied on inter tree variability for fruit quality in jackfruit selections of Western Ghats of India and obtained highest values for TSS at 34.33 ºBrix , total sugar at 13.37% and titratable acidity at 0.768 %. In the present investigation, range of TSS was 10 to 27.80 ºBrix, total sugar (10.14 to 18.32 %) and range of titratable acidity was 0.3 to 1.2 %.

PCA has revealed that the all accessions from Panruti could be distinguished with high amount of TSS, total sugar, fruit length and fruit weight and moderate values of number of flake, flake weight, pulp weight, seed weight and fruit width followed by accessions from Varkala, Nadia and Khowai with all moderate values. The accessions collected from West Tripura, North 24 Parganas and South Sikkim were grouped with low values for all parameters.

From LDA it could be inferred that based on the physico-chemical characteristics the accessions could be linked with the geographical location at which they are growing. This parameter could be applied specially for the jackfruits which are commercially derived from Panruti. Further, the results revealed that even though the geographical location Varkala is closer to Panruti than other locations, there were no overlapping characteristics. On the contrast, accessions of Varkala had closer relationship with Nadia and then with Khowai. It may be due to the jack fruit could have been introduced from one region to another. Later secondary diversification could have taken place. Hence, it could be concluded that based on Physico–chemical characteristics of accessions of Panruti could be distinguished even at ninety five percent of the confidence level. Further, based on PCA and LDA the accessions of Panruti specially PANJ 48 and PANJ 47 could be used as a breeding stock for all other accessions of North East India and Kerala.

Conclusion

The present investigation was carried out to analyze the Physico-chemical characters of jackfruit (*Artocarpus heterophyllus* Lam.) based on their geographical locations of India. It could be concluded that physico-chemical characters may be an effective tool for jackfruit geographical location authentication for accessions from Panruti, Tamil Nadu. This information would be helpful for selecting best quality jackfruit in further crop improvement program.

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