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Growth, yield, physiological and biochemical traits of different accessions of bird of paradise (*Strelitzia reginae* L.)

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ABSTRACT

Twenty one accessions of bird of paradise (*Strelitzia reginae* L.) were characterized for various traits at ICAR-IIHR, Bengaluru, India during 2011 – 2017. Among different accessions, there were significant differences in number fans and leaves, leaf area, leaf biomass, spike yield and vase life. Maximum number of fans were recorded in IC-0624431 and lowest in IC-0624411. The IC-0624427 accession recorded maximum leaf area (311.92 cm^2 $leaf^{-1}$). Cumulative spike yield was significantly higher in IC-0624431 (153 spikes) followed by IC-0624412 (131.0 spikes). There was significant variability in plant height and leaf characteristics such as petiole length, leaf length, and lamina length/breadth. Maximum vase life of 10 days was registered with IC-0624427. Spike length (cm) was maximum in IC-0624433 (149.13) followed by IC-0624419 (130.12). The genotype IC-0624433 recorded higher inflorescence stalk length (128.66 cm) followed by IC-0624419 (108.44 cm) with lowest stalk length of 56.32 cm in IC-0624420. The variation among genotypes for wax content was significant and the wax content was significantly higher in IC-0624433 (0.62 mg cm^{-2}). Anthocyanin content varied from 40. 9 to 12 4.0 mg. Genotype IC-0624419 recorded maximum anthocyanin content of 124.65 mg that was on par with IC-0624433 (122.25 mg). The maximum quantity of carotenoid in florets was recorded in IC-0624410 (22.31 mg) followed by IC-0624430 (19.06 mg). Total annual maintenance cost was estimated at Rs. 96,200 per hectare. IC-0624431 registered maximum net returns of 5.61 per rupee investment followed by IC-0624434 (4.71), IC-0624410 (3.80), IC-0624416 (3.69) and IC-0624414 (3.59). Overall, the accession IC-0624431 of bird of paradise registered better traits in all aspects. Bird of Paradise has low input requirement with less pest and disease load and is economical.

1. Introduction

Specialty flowers like bird of paradise, anthurium, heliconia, orchids and ginger occupy a small segment of international flower trade although they are considered as niche products and exclusive flowers for bouquets and flower arrangements. Bird of paradise (*Strelitzia reginae* L.) is a monocot and perennial flowering shrub and is commonly known as crane flower. It belongs to the family *Strelitziaceae*, with a diploid chromosome number, 2n = 22. It is an exotic specialty cut-flower crop with flowers of brilliant colours and unusual appearance. It has much importance in domestic as well as international markets due to its attractive, remarkably shaped crested head of bird, and a combination of orange and purple coloured flower clusters (Hensley et al., 1998; Singh, 2006). It is cultivated on a commercial scale in many parts of the world *viz*., USA, Israel and South Africa. In North America, California is the largest producer of bird of paradise followed by Hawaii (USDA, 2003). African countries *viz*., Jamaica, Guatemala and other Caribbean countries export it in small quantities. In temperate regions like Netherlands, Poland, China, Japan *etc*., it is grown in controlled greenhouses with heating facilities.

India ranks second in flower cultivation next to China. India's present share in the global floricultural export market is negligible (~0.61 %). Europe continues to be the prominent destination for Indian floriculture exports. However, India is endowed with diverse agro-climatic conditions and congenial for growing of a variety of flower crops throughout the year. Indian floriculture industry has been shifting from traditional flowers to cut flowers to meet export demand. Export of floriculture products has been growing at the rate of 12 % over the past decade. In India, bird of paradise is grown in sub-temperate and sub-tropical regions like Himachal Pradesh, Kalimpong and Darjeeling in West Bengal, Nilgiri hills and Western Ghats, Bengaluru and adjoining areas in Karnataka, Andhra Pradesh, Tamil Nadu, Kerala and Maharashtra.

The *Strelitzia*genus comprises five species and *S. reginae* is very

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popular flowering species, growing to a height of 90 cm with a leaf-stalk about 45 cm long. The plant is compact with clustering habit exhibiting slow growth with fleshy roots. The flowers are large with 6–12 florets per inflorescence. The bird of paradise has clump pattern of growth with 4–6 feet height and 3–4 feet width mature clump (Burgess, 2004). The thick and stiff leaves arise from the base of the clump in a fan-like pattern and are greyish green, smooth, and waxy, resembling small banana leaves on longer petioles (Hensley et al., 1998). Mature plants propagated from seedlings start flowering only fourth year onwards (Kantharaju et al., 2008). The flowers are long-lasting and can be used as cut flowers. The vase life of flowers will be nearly two weeks when water is changed regularly (Gendy and Mahmoud, 2012; Jeevitha et al., 2013; Koley et al., 2016).

Seed propagation would be helpful in hastening planting material multiplication as vegetative propagation is time consuming (Van Der Walt, 2000). Large scale propagation with better seed germination (72–78 %) and seedling survival of bird of paradise is possible due to seed treatment with methyl ethane sulphonate at lower doses and GA_3 (Sane and Janakiram., 2010; Swagath Kumar et al., 2018). The genetic variability in vegetative parameters among hundred genotypes of bird of paradise resulted in higher phenotypic coefficient of variation (PCV) than genotypic coefficient of variation (GCV) for all of the characters studied and observed high heritability with high genetic advance as per cent of mean for plant height, stem girth, leaf length, leaf width and number of leaves per plant (Angadi and Archana, 2014). However, comprehensive characterization of all parameters in bird of paradise are lacking. Characterization of genetic diversity to identify the superior one is easy and cheapest way in any crop improvement programme. As bird of paradise is gaining commercial cut flower status, identification of genotypes for high spike yield and longer vase life is need of the hour. Keeping this in view, the present investigation was conducted mainly to characterize the twenty one accessions of bird of paradise based on morphological, physiological and biochemical traits.

2. Materials and methods

2.1. Description of study site

The experiment was carried out at ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Hesaraghatta Lake, Bengaluru, Karnataka, India (13°7′N latitude and 77° 29′E longitude, 890 m above MSL) during 2011 − 2017. The climate is semi-arid with average annual rainfall of 900 mm. The mean maximum temperature ranged from 27.3 °C to 35.0 °C and minimum temperature was 15.4 °C–21.1 °C.

2.2. Experimental details

About fifty one accessions were collected initially during 2011 − 12 and maintained in field gene bank. Planting of different accessions of bird of paradise was done during monsoon season in 2011 in pits of 60 cm^3 at a spacing of 2 m × 2 m, which allows adequate space for suckering and flowering. These accessions were screened for all traits during 2012–2017 and IC numbers were obtained for trait specific 21 genotypes in 2018.

Twenty one genotypes replicated three times in Randomized Block Design were used in the present study. The details of the twenty one genotypes with their accession and IC numbers obtained from NBPGR, New Delhi are IC-0624410, IC-0624411, IC-0624412, IC-0624413, IC-0624414, IC-0624416, IC-0624417, IC-0624418, IC-0624419, IC-0624420, IC-0624422, IC-0624424, IC-0624425, IC-0624427, IC-0624428, IC-0624429, IC-0624430, IC-0624431, IC-0624433, IC-0624434 and IC-0624435.

Every year, major nutrients @ 110:35:70 kg NPK ha^{-1} yr^{-1} were applied in four split doses in January, April, July and October months. About 12 kg FYM per plant per year was applied. In summer, drip irrigation once in 3–4 days is practiced and once a week in cooler months. For controlling scales, aphids, white flies and mealy bugs, spraying of systemic insecticide (Rogor @ 2 g/l) was done. For controlling bacterial wilt, Krosin AG (Streptomycin Sulphate)-3000 ppm + Blitox-3 g/l) was drenched in soil.

2.3. Morphological characters

Morphological observations were recorded every year. The plant height was measured from the ground level to the tip of longest leaf. Number of side fans was counted and recorded every year. Total number of leaves in each plant was recorded. Leaf length (n= 6–10) was measured from the base of the petiole to the tip of the leaf. Leaf breadth was measured at the broader part of leaf where breadth was found maximum. The length of the leaf from the ground level to distal end of leaf was taken as petiole length. About four leaves of different sizes from each accession were collected and fresh weight was recorded. The leaf samples were oven dried at 60 °C to a constant weight and dry weight was recorded after drying. The number of leaves was multiplied with dry weight of single leaf to arrive at total leaf biomass.

2.4. Yield and quality parameters

Total number of inflorescences (spikes), number of florets per spike and spike length in each genotype were recorded. In each plant, five spikes were selected for recording yield attributes. Spike length was measured from the ground level to the tip of the spathe. The diameter of the spike and spathe was measured using Vernier calipers at the middle of the inflorescence stalk and middle portion of the spathe, respectively. Total length of the first opened floret, and length and width of orange and blue petal of first opened floret were also measured. Vase life was measured as number of days taken for wilting of the last opened floret.

2.5. Physiological and biochemical parameters

Photosynthetic parameters *viz*., net photosynthesis, stomatal conductance and transpiration rate were measured using portable photosynthesis system (LCpro+, ADC Bio Scientific limited, UK) in top third fully opened matured leaf during sunny day between 9–12 a.m. Leaf area was measured using digital leaf area meter.

An impression of epidermal surface of the leaves was taken using clear nail polish and observed under light microscope under 40× magnification. The average number of stomata per mm^2 area was worked out. Epicuticular wax was estimated using the colorimetric based assay (Ebercon et al., 1977). For quantification of relative water content (%), fresh weight, turgid weight and dry weight of ten discs each from middle portion of the top third fully opened matured leaf was recorded (Barrs and Weatherley, 1962).

For leaf chlorophyll estimation, leaf sample from the middle portion of the top third fully opened matured leaf was used. Absorbance were recorded using spectrophotometer at 663, 647 and 470 nm (Hiscox and Israelstam, 1979). Anthocyanin content in florets was estimated from freshly opened blue petal as per standard procedure (Fuleki, 1969). Total carotenoids and lycopene were analyzed by spectrophotometer method (Lichtenthaler, 1987).

2.6. Economic analysis

By following annuity value approach (Gattinger, 1981), annual cost of production was estimated by adding annuity value (total establishment cost for first two years was amortized in to an annuity value bearing 12 % interest rate) to annual maintenance cost. For working out the cost and return, a period of two years has been considered as establishment period and economic life span has been assumed as 10 years. Establishment cost included land clearing, digging of pits, planting and planting material and bore well in case of drip irrigation and labor cost for all operations. The annual cost of production

included cost of inputs like fertilizers, manure, pesticides *etc* and labour cost for different operations like application of inputs, spraying, weeding, irrigation and harvesting.

Annual fixed cost for drip and the annuity value thus obtained were added to annual maintenance cost to arrive at total annual cost of cultivation. The local market price of Rs. 10 per flower spike was considered for computing the gross returns of the produce obtained from each accession. The net returns were worked out after deducting the cost of cultivation from the gross returns and expressed in Rs ha^{-1}. The net profit per rupee investment for different accessions was worked out as the quotient of total cost of cultivation over the net profit per hectare and expressed in Rs Re^{-1}.

2.7. Statistical analysis

All data were analyzed using SPSS and Microsoft Excel. The significant differences between the two means are indicated by LSD (5%) values in the tables. Correlations among some parameters were worked out for better understanding of results.

3. Results and discussion

3.1. Number of fans, leaf attributes, spike yield and vase life

Among different accessions, there were significant differences in number fans and leaves, leaf area, leaf biomass, spike yield and vase life (Table 1). Fans or suckers are the prime material for propagation in bird of paradise. Number of fans per plant varied among the genotypes from 5.33 to 29.67. The highest number of fans was recorded in IC-0624431 and lowest in IC-0624427. Production of high and quality shoot/suckers is one of the important objectives in heliconia breeding programmes (Costa et al., 2011). These results are in line with that of Jawaharlal et al. (2001) and Hossain et al. (2011) in heliconia. The number of leaves were significantly higher in IC-0624431 (389) and lower number (16.33) was noticed in IC-0624411 (Table 1). Among the different genotypes, leaf area varied significantly from 87.07 to as high as 311.92 cm^2 $leaf^{-1}$. The genotype IC-0624427 recorded maximum leaf area (311.92 cm^2 $leaf^{-1}$) that was on par with IC-0624424 (306.15 cm^2 $leaf^{-1}$) whereas minimum recorded for IC-0624434 (87.07 cm^2 $leaf^{-1}$).

Spike yield decides the significance of a particular genotype. Number of spikes produced per plant ultimately determines the vigor of the genotype or variety for the flower production. Spike production varied significantly among genotypes ranging from 4.33 to 41.33 (Table 1). Genotype IC-0624431 produced higher number of spikes (41.33), while least spike yield of 4.33 was noticed in IC-0624428 and IC-0624418. This variation in the production of number of spikes per plant might be due to the genetically controlled factor and also due to the hereditary traits of different cultivars under prevailing environment. Cumulative flower yield for three years (2014 − 2017) showed significant variability across different accessions with average yield of 55.95 spikes $plant^{-1}$ yr^{-1}. Cumulative spike yield was significantly higher in IC-0624431 (153 spikes) followed by IC-0624412 (131 spikes). The time required for stabilized yield in terms of spike production varied depending on the rate and number of leaves and number of fans produced per plant.

Fig. 1 illustrates the significant variability in plant height and leaf characteristics such as leaf length, petiole length, lamina length and breadth. The accession IC-0624431 registered maximum height of 166.33 cm, while IC-0624434 had minimum height (91.00 cm). Leaf lamina length varied from 27.83 cm in IC-0624434 to 40.51 cm in IC-0624427 (Fig. 1). Leaf lamina breadth was higher in IC-0624427 (13.67 cm) followed by IC-0624412 (11.29 cm) and lower in IC-0624428 (6.76 cm) (Fig. 1).

Maximum vase life of 10 days was registered in IC-0624427, while minimum vase life of 4.5 days was noticed in in IC-0624411 and IC-0624414 (Table 1). Maximum vase life of 10 days with highest initial fresh weight (140.09 g) and maximum water uptake (43.25 mL) in IC-0624427 accession might be due to the thickness of the spike and more absorption area at the stem end. This is in conformity with the findings of Karsten et al. (2015) where thick stemmed spikes showed longevity of 8 days and maximum water uptake than the flower spikes of thin size due to more absorption area. On the contrary, vase life of 8.5 days was observed in IC-0624412 that registered lowest initial fresh weight of 68.99 g among all the genotypes with comparatively good water uptake (34.25 mL) and 1.23 numbers of opened florets. The accession IC- IC-

Table 1
Variability in parameters, spike yield and vase life among different accessions of bird of paradise.

Accession No. (Indigenous collection No.)	Number $plant^{-1}$				Leaf biomass (g $plant^{-1}$)	Leaf area (cm^2 $leaf^{-1}$)	Vase life (days)
	Fans	Leaves	Spikes (2017)	Cumulative spike yield (2014 − 2017)			
IC-0624420	16.67	164.33	18.67	36.4	986	158.61	8.50
IC-0624424	7.33	47.67	12.67	70.7	286	306.15	7.50
IC-0624435	9.67	79.67	11.00	69.7	478	230.98	5.00
IC-0624433	21.00	234.33	23.00	95.0	1406	265.18	6.50
IC-0624425	22.00	210.00	16.67	94.0	1260	135.39	6.50
IC-0624419	18.00	212.00	22.67	56.4	1272	211.04	6.50
IC-0624410	25.67	272.67	30.00	73.3	1636	159.14	5.00
IC-0624412	16.00	234.00	23.00	131.0	1404	129.33	8.50
IC-0624427	5.33	45.67	7.33	49.0	274	311.92	10.00
IC-0624422	18.33	194.33	20.67	107.0	1166	154.70	6.50
IC-0624414	13.33	158.67	28.67	123.4	952	204.19	4.50
IC-0624413	18.00	263.33	8.00	102.0	1580	192.34	5.00
IC-0624429	15.67	65.00	24.33	41.0	390	139.51	6.00
IC-0624434	20.67	95.00	35.67	81.3	570	87.07	5.50
IC-0624411	11.67	16.33	6.33	28.3	98	135.50	4.50
IC-0624417	18.67	25.00	9.33	29.3	150	241.50	5.00
IC-0624430	28.33	60.00	22.67	49.7	360	117.57	7.50
IC-0624416	27.33	78.33	29.33	50.0	470	198.43	6.00
IC-0624428	8.33	65.67	4.33	65.3	394	91.08	6.00
IC-0624431	29.67	389.00	41.33	153.0	2334	203.43	5.50
IC-0624418	9.33	95.67	4.33	99.7	574	136.10	5.50
Mean	13.71	143.17	19.05	76.5	859	181.39	6.26
S.Em ±	1.10	7.01	1.17	12.03	44.0	23.95	0.72
CD($p = 0.05$)	3.16	20.03	3.33	34.24	125.4	68.44	2.11

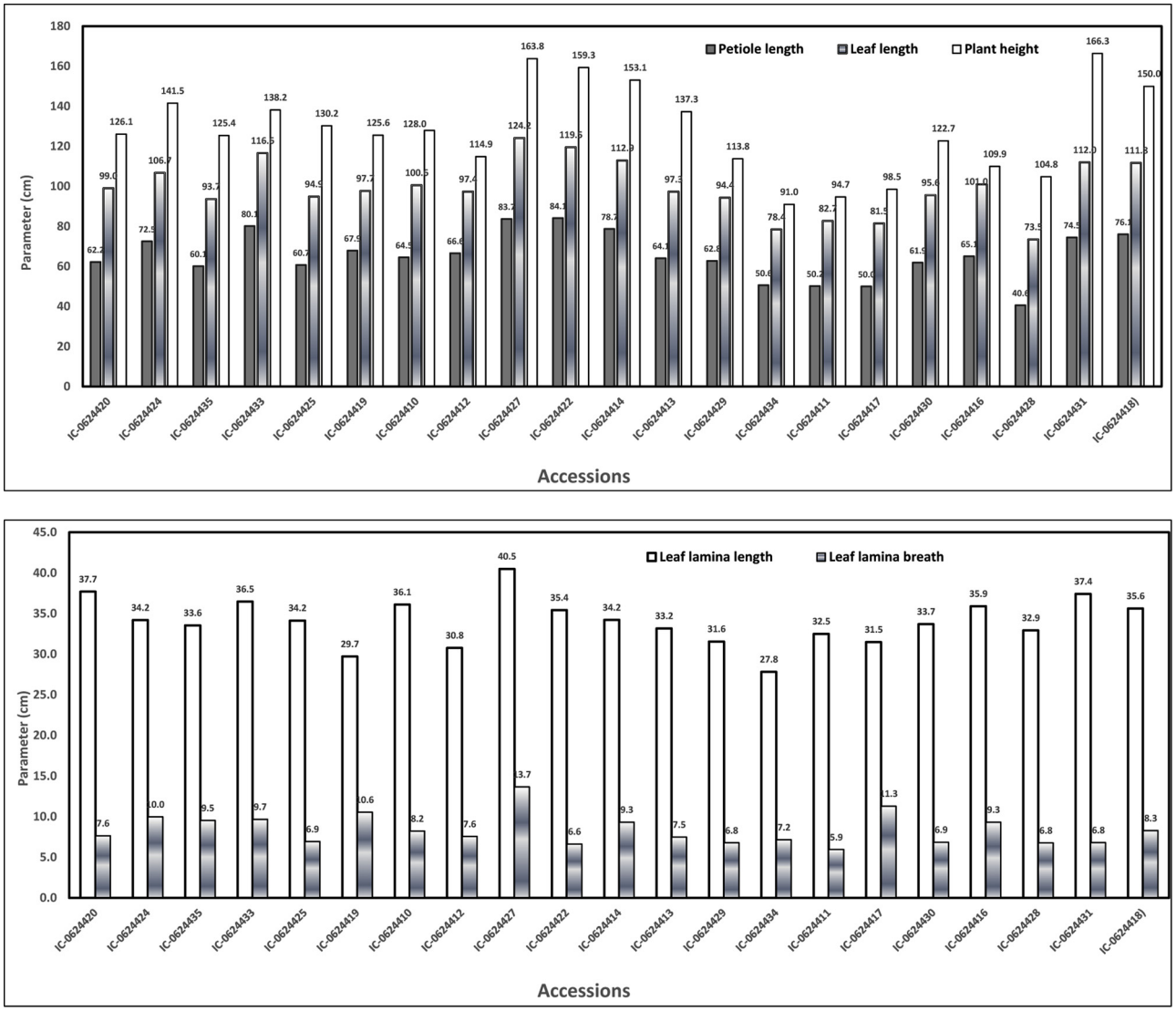

Fig. 1. Variability in leaf characteristics and plant height among different accessions of bird of paradise.
C.D. ($p = 0.05$) for plant height 21.3; Leaf length 13.37; Petiole length 11.70; Leaf lamina length 3.81; Leaf lamina breath 1.18.

0624412 was found to be promising due to lower flower stem weight and comparatively higher vase life.

This is in line with reports of Pizano (2005) where fresh weight of the flower stems affected the transportation costs thus acting as a limiting factor for the export of tropical flowers such as heliconia. However, although lighter stems reduce transport costs, Nowak and Rudnicki (1990) pointed out that flower stems with greater weight contain a higher amount of carbohydrates and are consequently more durable.

3.2. Plant spread (North-South and East-West)

Plant spread varied significantly among the genotypes. The North-South (279.67 cm) and East-West spread of the plant (275.33 cm) was maximum in IC-0624431 and minimum in IC-0624434 (130 cm North-South) and (129.67 cm East-West). Increased plant spread is probably due to more number of fans and more leaves per plant. Increased plant spread due to increased number of branches is reported by Mishra (1999) and Bantu (2013) in chrysanthemum; Biswal et al. (2017) in gerbera.

The important yield attributes such spike length and diameter, spathe length and diameter, inflorescence stalk length, number of florets per spike and floret length showed significant variations among accessions (Table 2). Spike length (cm) was maximum in IC-0624433 (149.43) followed by IC-0624419 (130.12) and it was minimum in IC-0624420 (74.09). The length of spike is very important parameter for export. The variation in spike length in different genotypes might be due to the genetic differences of the cultivars and superiority of some of the genotypes over the others. The genetic variability in 18 *Heliconia* cultivars resulted in higher phenotypic coefficient of variation than genotypic coefficient of variation with high heritability and genetic advance for spike length and number of bracts (Kumar et al., 2011).

Spathe length in different genotypes ranged from 16.03 to 22.77 cm. The longest spathe was noticed in IC-0624416 (22.77 cm) that was on par with IC-0624418 (22.21 cm), while the shortest one was observed in IC-0624412 (16.03). Maximum spathe diameter was recorded in IC-0624427 (23.09 cm) which was followed by IC-0624433 (21.04 cm) and minimum spathe diameter of 14.55 cm was observed in IC-0624416.

The genotype IC-0624433 recorded higher inflorescence stalk length (128.66 cm) followed by IC-0624419 (108.44 cm) with lowest stalk length of 56.32 cm in IC-0624420 (Table 2). Inflorescence stalk length is another important character as the genotype having more stalk length is generally preferred for preparation of bouquets. Variation

Table 2
Variability in yield attributes among different accessions of bird of paradise.

Accession No.	Spathe length (cm)	Spike length (cm)	Inflorescence stalk length (cm)	Floret length (cm)	Spathe diameter (mm)	Spike diameter (mm)	No. of florets per spike
IC-0624420	17.77	74.09	56.32	12.30	15.10	13.68	4.89
IC-0624424	21.54	102.45	80.91	15.47	18.38	15.75	8.00
IC-0624435	16.33	92.89	76.56	13.13	15.63	12.34	5.87
IC-0624433	20.77	149.13	128.66	14.65	21.04	13.52	7.63
IC-0624425	18.04	97.54	79.50	12.97	18.43	12.20	5.93
IC-0624419	21.68	130.12	108.44	13.96	17.97	10.91	7.77
IC-0624410	20.93	84.57	63.63	14.64	17.25	11.42	6.40
IC-0624412	16.03	87.84	71.81	10.53	17.86	9.60	8.24
IC-0624427	21.46	125.55	104.09	14.35	23.09	16.33	6.93
IC-0624422	20.48	110.99	90.51	12.53	15.00	12.45	7.68
IC-0624414	20.84	125.79	104.95	14.05	20.85	15.03	5.47
IC-0624413	19.83	79.98	60.15	13.12	18.81	10.86	8.48
IC-0624429	19.51	109.17	89.66	12.47	16.15	11.78	6.20
IC-0624434	19.27	76.08	56.81	15.68	15.67	11.47	6.53
IC-0624411	17.05	85.47	68.42	12.66	15.96	10.65	6.36
IC-0624417	16.09	90.80	74.71	11.61	19.69	13.39	7.18
IC-0624430	18.41	82.38	63.97	12.57	16.76	11.25	8.42
IC-0624416	22.77	104.35	81.58	16.23	14.55	11.69	6.34
IC-0624428	18.61	91.95	73.34	13.46	16.41	13.33	5.72
IC-0624431	19.47	95.92	76.45	14.00	16.16	12.81	8.07
IC-0624418	22.21	79.10	56.88	14.37	15.49	12.04	7.30
Mean	**19.48**	**98.88**	**79.40**	**13.56**	**17.44**	**12.50**	**6.92**
S.Em ±	**0.52**	**5.50**	**5.22**	**0.22**	**0.65**	**0.41**	**7.44**
CD($p = 0.05$)	**1.47**	**15.73**	**14.91**	**0.63**	**1.87**	**1.17**	**0.85**

with respect to spike diameter among the genotypes was 9.6 mm–16.33 mm (Table 2). Spike diameter was significantly high in IC-0624427 (16.33 mm) and was found on par with IC-0624424 (15.75 mm). Spike with more thickness is preferred as it can bear the weight of inflorescence during full bloom. Strelitzia stems are separated into three grades based on stem length and inflorescence size. (www.afifnet.org). Three grades as per minimum standards and guidelines are 100 cm spike length and > 16 cm bloom size; 80 cm spike length and > 13 cm bloom size and 60 cm spike length and > 10 cm bloom size.

The floret length was significantly higher in IC-0624416 (16.23 cm) and was closely followed by IC-0624434 (15.68 cm) and minimum of 10.53 cm was noticed in IC-0624412 (Table 2). The increased floret length may be due to the higher photosynthesis activity of the plant. The increased floret length might also be attributed to the greater leaf area as well as maximum photosynthetic activity which ultimately results in production of bigger sized flowers. The results are in accordance with the findings of Barman et al. (2007) in Cymbidium, Soocheon et al. (1998) in Dendrobium orchids.

The data pertaining to number of florets per spike showed significantly higher value for IC-0624413 (8.48) which was on par with IC-0624430 (8.42), whereas lowest (4.89) was in IC-0624420 (Table 2). Similarly, number of florets per spike is of important consideration when it is to be used as cut flower and also indicates the quality of spike. The differences in number of florets per spike might be due to the variation in genetic makeup of different cultivars and efficient utilization of natural resources and inputs besides the size of planting material (Shaukat et al., 2013).

3.3. Physiological and biochemical parameters

The variability for physiological and biochemical traits like net photosynthesis, stomatal conductance, transpiration rate, stomatal number, total chlorophyll, wax content, relative water content, anthocyanin and carotenoids was significant among 21 bird of paradise accessions (Table 3). The data pertaining to wax and relative water content (RWC) in different genotypes maintained in the open field condition with regular drip irrigation as presented in Table 4 shows the variation among the genotypes with maximum wax (0.62 mg/cm^2) and relative water content (94.92 %) for IC-0624433 followed by IC-0624413 (0.49 mg/cm^2 of wax and 93.97 % of RWC), and IC-0624414 (0.48 mg/cm^2 of wax and 92.38 % of RWC) whereas, low wax content was recorded in IC-0624425 and IC-0624412 (0.20 mg/cm^2 for each) with RWC 90.91 percent and 92.82 percent respectively. This is in accordance with the findings of Shonherr (1976), where he showed positive relationship between wax and water permeability. Hence, quantity and quality of wax in the plants can be due to the genetic makeup of the plants. At the same time the variation in the genotypes for relative water content may be due to the variation in the thickness of the leaf (Burquez, 1987; Hamissou and Weibel, 2004).

Mohammadian et al. (2007) demonstrated that deposition of epicuticular wax in *Leucadendron lanigerum* is dependent on age of the leaf as well as season and wax regeneration occurred in spring. Epicuticular waxes found to decrease cuticular water loss and consequent decrease in stomatal conductance, transpiration and photosynthesis. In *Citrus aurantium* L., pear *(Pyrus communis* L.) and onion *(Allium cepa* L.), water permeability increased by a factor of 300–500 after cuticular wax extraction from membranes, there by showed the positive relationship between wax and water permeability (Schonherr, 1976). Screening and correlation study on banana cultivars and hybrids for water stress showed significant positive influence of relative water content on yield, number of leaves and chlorophyll content in control plants compared to stress treated plants (Surendar et al., 2013). The correlations among physiological and biochemical traits (Table 4) substantiate the above results.

3.4. Stomatal density and photosynthetic parameters

Stomata density (Table 3) was found significantly higher in IC-0624425 (40.8 per mm^2) which was on par with IC-0624431 (40.13 per mm^2), whereas least stomatal number was recorded in IC-0624435 (22.4 per mm^2) followed by IC-0624433 (23.47 per mm^2). The study of leaf anatomy of the *Heliconia latispatha* under different day length treatments showed significant differences for leaf blade width and mesophyll layers. The stomatal density and index, thickness of the blade found increased with day length with the reduced stomatal size (Ch et al., 2005).

The highest photosynthetic rate was observed in IC-0624416 (7.33 μ mol CO_2 $m^{-2}s^{-1)}$ and IC-0624427 (6.84 μ mol CO_2 $m^{-2}s^{-1)}$ due to

Table 3
Variability in photosynthetic and biochemical parameters among different accessions of bird of paradise.

Accession No.	Stomatal density (mm^{-2})	Stomatal conductance (mol m^{-2} s^{-1})	Transpiration rate (mol m^{-2} s^{-1})	Photosynthesis rate (μmol CO2 $m^{-2}s^{-1}$)	Total chlorophyll (mg g^{-1})	Anthocyanin (mg 100 g^{-1})	Carotenoids (mg 100 g^{-1})	Wax (mg cm^{-2})
IC-0624420	27.27	0.03	1.24	4.65	1.91	57.21	15.35	0.31
IC-0624424	24.40	0.05	2.68	4.30	1.97	100.28	15.17	0.28
IC-0624435	22.40	0.05	2.84	4.99	2.31	49.27	11.69	0.42
IC-0624433	23.47	0.05	1.47	4.47	1.83	122.25	11.18	0.62
IC-0624425	40.80	0.08	2.35	6.30	1.86	90.10	10.57	0.20
IC-0624419	32.74	0.07	2.63	5.90	1.82	124.65	15.11	0.25
IC-0624410	31.40	0.07	3.95	5.89	1.91	68.75	22.31	0.21
IC-0624412	28.07	0.08	4.37	5.69	2.42	51.77	16.07	0.20
IC-0624427	32.93	0.06	3.70	6.84	2.61	103.62	9.52	0.23
IC-0624422	37.00	0.04	2.52	3.96	2.09	102.12	15.55	0.25
IC-0624414	30.80	0.09	3.93	6.19	2.07	74.06	8.77	0.48
IC-0624413	33.47	0.08	2.37	5.35	2.05	40.89	15.08	0.49
IC-0624429	32.87	0.03	1.39	4.02	2.15	100.93	16.44	0.21
IC-0624434	29.87	0.05	2.07	3.00	1.49	98.66	9.17	0.29
IC-0624411	30.40	0.06	2.96	4.73	1.80	105.91	8.95	0.32
IC-0624417	26.8	0.04	2.30	4.44	1.91	87.83	9.54	0.26
IC-0624430	37.93	0.09	3.79	6.35	2.13	116.52	19.06	0.27
IC-0624416	40.13	0.11	5.61	7.33	2.63	66.81	15.25	0.26
IC-0624428	25.33	0.04	2.23	4.26	2.08	60.69	12.10	0.25
IC-0624431	33.53	0.05	3.83	6.29	2.38	121.15	11.21	0.37
IC-0624418	29.07	0.05	3.51	3.45	1.56	73.01	11.86	0.25
Mean	**30.51**	**0.06**	**2.94**	**5.16**	**2.05**	**86.50**	**13.33**	**0.31**
S.Em ±	**1.81**	**0.02**	**0.50**	**0.60**	**0.15**	**3.55**	**0.81**	**0.02**
CD(*p* = *0.05*)	**5.18**	**0.04**	**1.42**	**1.70**	**0.44**	**10.13**	**2.31**	**0.04**

high chlorophyll content (2.63 mg and 2.61 mg) where as low chlorophyll content (1.49 mg) lead to reduction in photosynthesis in IC-0624434 (3 μ mol CO_2 $m^{-2}s^{-1}$). These findings are in confirmity with previous reports (Buttery and Buzzell, 1977; Sugapriya et al., 2012).

The stomatal conductance (mol m^{-2} s^{-1}) differed among genotypes and ranged from 0.03 to 0.11. Genotype IC-0624416 recorded significant value (0.11 mol m^{-2} s^{-1}) and was on par with IC-0624430 and IC-0624414 which had stomatal conductance of 0.09 mol m^{-2} s^{-1}. Significantly higher transpiration rate was recorded in IC-0624416 (5.61 m mol m^{-2} s^{-1}) which was on par with IC-0624412 (4.37 m mol m^{-2} s^{-1}). The lowest transpiration rate was recorded in IC-0624420 (1.24 m mol m^{-2} s^{-1}) which is on par with IC-0624429 (1.39 m mol m^{-2} s^{-1}) and IC-0624433 (1.47 m mol m^{-2} s^{-1}). IC-0624433 recorded lower stomatal density and lower transpiration. Low stomatal density is a desirable trait as it reduces transpiration and suitable for cultivation in low rainfall areas. It is reported that rice with fewer stomata is drought tolerant and more conservative in water use (Caine et al., 2019).

3.5. Anthocyanin and carotenoid contents in florets

Anthocyanin content among the genotypes varied from 40.9 mg to 124.65 mg (Table 3). Genotype IC-0624419 recorded maximum anthocyanin content of 124.65 mg which was on par with IC-0624433 (122.25 mg). The lowest anthocyanin content was recorded in the florets of IC-0624413 (40.80 mg). Nine genotypes have been screened as high anthocyanin producers and may be used to exploit for extraction of anthocyanin as organic color of plant origin. Similar findings were reported by Gantait and Pal (2009) in chrysanthemum cultivars. The variation in the anthocyanin content might be due to the genetic makeup of the plant. The maximum quantity of Carotenoid in florets was recorded in IC-0624410 (22.31 mg) followed by IC-0624430 (19.06 mg) where as minimum was in IC-0624414 (8.77 mg). Pirone et al. (2010) discovered bilirubin in the arils of *Strelitzia nicolai*. It was observed that bilirubin was present in 8 of the 10 species tested but only contributed to colour in species within the *Strelitziaceae*. Cicevan et al. (2016) evaluated three ornamental *Tagetes* species for drought tolerance by inducing stress and reported that *Tagetes erecta* is drought tolerant compared to *T. patula* and *T. tenuifolia* with the retention of higher water content, chlorophyll and carotenoid content. Significant variations are noticed in carotenoid content in calendula cultivars (Pintea et al., 2003) and anthocyanin content in chrysanthemum cultivars (Gantait and Pal, 2009).

The significant positive correlations among spike yield, stomatal

Table 4
Correlations among spike yield, photosynthetic and biochemical traits in Bird of Paradise.

	No. of spikes	Cumulative spike yield	Leaf area	No. of Fans	No. of leaves	Stomatal density	Stomatal conductance	Transpiration rate	Net photosynthesis	Total Ch
Cumulative spike yield	0.397*									
Leaf area	−0.142	−0.057								
Fans	**0.729****	0.194	−0.254							
No. of leaves	**0.532***	0.732**	−0.029	0.523*						
Stomatal density	0.313*	0.057	−0.266	0.550*	0.178					
Stomatal conductance	0.228	0.182	−0.014	0.378*	0.140	0.551*				
Transpiration rate	0.244	0.249	0.059	0.237	0.069	0.384	**0.737***			
Net photosynthesis	0.248	0.084	0.277	0.366*	0.266	0.533*	**0.749***	0.667*		
Total Ch	0.110	0.083	0.337*	0.052	0.047	0.238	0.326	0.548*	0.671**	
Wax	0.063	0.303*	0.351*	0.031	0.274	−0.363	0.036	−0.209	−0.040	−0.079

* Significance at 0.05 level.
** Significance at 0.01 level.

Table 5
Range of leaf nutrient concentrations among different accessions of bird of paradise and soil fertility status in 2017.

Plant nutrient status								
Total concentration (%)					Total concentration (ppm)			
N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
1.35–1.48	0.23 – 0.26	2.20 – 2.40	0.46 – 0.66	0.26 – 0.33	52.0–64.0	16.0 – 19.5	229.3 – 414.2	92.1 – 93.2

Soil fertility status in Bird of Paradise in 2017										
pH	EC (ds/m)	SOC (%)	Available nutrient concentration (ppm)							
			N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
6.20 – 6.58	0.09 – 0.13	1.20 – 1.80	194.4 – 291.6	12.3–25.3	182.5 – 232.5	1215 – 1466.5	121.0 – 128.5	1.78 – 3.65	15.0 – 34.5	65 – 83	20.5 – 30.2

Table 6
Identified accessions with desirable traits.

Accession	Traits
IC-0624433	More spike length, inflorescence stalk length, spike diameter (16 mm), spathe diameter (> 21 cm) and vase life (10 days). More specific leaf area, low stomatal density, low transpiration, more wax content, and high anthocyanin content, suitable for commercial cultivation.
IC-0624431	Tall type, large canopy with more number of fans and leaves per plant, high yield, higher net returns, suitable for commercial cultivation
IC-0624434	Dwarf habit with plant height of 91 cm and less leaf length, less plant spread and more floret length (16 cm). Amenable for high density planting.

density and photosynthetic parameters and negative correlation between stomatal number and wax content were noticed (Table 4). The correlations among spike yield, photosynthetic and biochemical traits substantiate the results. The leaves of bird of paradise accessions were good source of all nutrients as indicated by leaf nutrient status for macro, secondary and micronutrients (Table 5). The general soil fertility status was optimum in bird of paradise as indicated by the near to neutral soil pH, high soil organic carbon and optimum nutrient availability (Table 5). The data indicates bird of paradise is not a heavy feeder and maintains ecosystem indicators. The accessions identified for specific traits are given Table 6. Three accessions (IC-0624433, IC-0624431 and IC-0624427) with desirable flower traits such as more spike yield, spike length, spike diameter, Spathe size and vase life in addition to other desirable traits namely more specific leaf area, high chlorophyll with high photosynthetic rate, low stomatal density with low transpiration, more wax content, and high anthocyanin content have been identified that are suitable for monoculture and commercial cultivation. One accession (IC-0624434) with dwarf stature (plant height 91 cm), with less leaf length, leaf area and plant spread in addition to desirable flower traits and suitable for high density planting and recorded high net return.

3.6. Economic analysis

The establishment cost for two years was estimated at Rs. 300,000 per hectare (Table 7). The annuity on establishment cost was Rs. 58,500/ha. Total annual maintenance cost was estimated at Rs. 96,200 per hectare. The total cost of cultivation (annuity value + annual maintenance cost) was Rs. 156,200 per hectare per year. At the existing market rate of Rs. 10 per flower spike, IC-0624431 registered maximum net return of 5.61 per rupee investment followed by IC-0624434 (4.71), IC-0624410 (3.80), IC-0624416 (3.69) and IC-0624414 (3.59). Six accessions registered net return of Rs. 2.31–2.89 per rupee invested. The net return per rupee invested was either negative or less than unity in seven accessions that were poor yielders. Thus, eleven accessions were considered profitable (2.31–5.61 Rs.Re^{-1}) out of 21 accessions tried in the present study.

Table 7
Estimated economic analysis for different accessions for bird of paradise.

Accession No.	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	Net return per rupee investment (Rs Re^{-1})
IC-0624420	466,750	310,550	1.99
IC-0624424	316,750	160,550	1.03
IC-0624435	275,000	118,800	0.76
IC-0624433	575,000	418,800	2.68
IC-0624425	416,750	260,550	1.67
IC-0624419	566,750	410,550	2.63
IC-0624410	750,000	593,800	3.80
IC-0624412	575,000	418,800	2.68
IC-0624427	183,250	27,050	0.17
IC-0624422	516,750	360,550	2.31
IC-0624414	716,750	560,550	3.59
IC-0624413	200,000	43,800	0.28
IC-0624429	608,250	452,050	2.89
IC-0624434	891,750	735,550	4.71
IC-0624411	158,250	2050	0.01
IC-0624417	233,250	77,050	0.49
IC-0624430	566,750	410,550	2.63
IC-0624416	733,250	577,050	3.69
IC-0624428	108,250	−47950	−0.31
IC-0624431	1,033,250	877,050	5.61
IC-0624418	108,250	−47950	−0.31
Particulars of cost of production			(Rs.ha^{-1})
1. Establishment cost (2 years) including drip system			300,000
2. Annuity value for establishment cost			58,500
3. Total annual maintenance cost			96,200
4. Total cost of production per annum			156,200

4. Conclusions

There were significant variations in growth, yield physiological and biochemical traits among 21 accessions of bird of paradise. The accession IC-0624431 of bird of paradise registered better traits in all aspects. The phytochemicals in flowers of bird of paradise can be exploited for industrial uses. The industrial value needs to be worked out as genotypes have variable wax content (200 – 1400 μg/cm^2), carotenoids, anthocyanins *etc*. Besides, bird of paradise has low input requirement and highly economical with less pest and disease load. This crop needs to be promoted as monocrop and intercrop in low rainfall areas due to climate change scenario and less scope for horizontal

expansion of cultivable area and for doubling the income. This flower crop has flexibility for input application and yields throughout the year.

Author's contribution

Dr. Anuradha Sane: Collection and establishment of field gene bank, overall general maintenance, recording growth and yield parameters, literature collection.

Dr. S. Sujatha: Recording growth and yield parameters during 2016–2017, compilation and analysis of six year data, literature collection.

Ms. K N Shilpa: Recording growth, yield parameters during 2017 and analysis of biochemical parameters, literature collection.

Dr. R.H. Laxman: Recording physiological parameters, chlorophyll analysis.

Dr. K.S. Shivashankara: Analysis of wax content, relative water content.

Declaration of Competing Interest

None.

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