INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print); 2222-5234 (Online)
Website: https://www.innspub.net
Email contact: info@innspub.net
Vol. 27, Issue: 1, p. 343-354, 2025

RESEARCH PAPER OPEN ACCESS

Study on physico-morphological characteristics of Betel vine cv. Khasia pan genotypes grown in northeastern hilly region of Bangladesh

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Key words: Betel vine, *Piper betle*, Genotypic variation, Morphological features, Yield

DOI: https://dx.doi.org/10.12692/ijb/27.1.343-354 Published: July 20, 2025

ABSTRACT

The current study was conducted over two consecutive growing seasons (2021 and 2022) at the Spices Research Sub-Station, Citrus Research Station, Jaintapur, Sylhet, Bangladesh to evaluate the growth, morphology, and yield attributes of the betel vine cv. Khasia pan genotypes. The experimental design employed was a Randomized Complete Block Design (RCBD) with three replications. Data were collected five times throughout the leaf harvesting period. Five khasia pan genotype designated as PB Jai-001 through PB Jai-005 were collected from different locations of Bangladesh. The results highlight significant variations in vine height, girth, internodal length, branching patterns, leaf morphology, and yield attributes. PB Jai-002 showed the most vigorous growth, with the tallest vines, thickest girths, highest number of lateral branches, and largest leaf area across two consecutive growing seasons (2021 and 2022). PB Jai-004 also performed strongly, particularly in leaf size and overall leaf yield, producing the highest number of leaves per hectare. In contrast, PB Jai-005 consistently lagged behind in all growth and yield parameters, including vine height, branching, leaf size, and yield, indicating significant genotypic variation among the evaluated genotypes.

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INTRODUCTION

The betel vine (*Piper betle* L.), a member of the Piperaceae family, is valued for its attractive, glossy, heart-shaped leaves (Upoma *et al.*, 2024), that are typically chewed or consumed as betel quid (Biswas *et al.*, 2022). It is believed to have originated in central or eastern Malaysia, as well as in South and Southeast Asia. It is widely consumed in several Asian countries, including Bangladesh, India, Indonesia, Malaysia, Thailand, Myanmar, Laos, Cambodia, Vietnam, Nepal, the Philippines, Sri Lanka, and Papua New Guinea (Bajpai *et al.*, 2010; Sudjaroen, 2012). The cultivation area and production of betel leaf in Bangladesh have been increasing over time.

Currently, approximately 21,850 hectares are dedicated to betel leaf farming, yielding an estimated annual production of 206,994 metric tons, with an average yield of 3,836 kg per acre (BBS, 2023).

Betel leaf is an important cash crop in the northeastern hilly regions of Bangladesh, particularly in Sylhet, Moulvibazar, and Habiganj, where the Indigenous Khasia community cultivates a traditional cultiver known as Khasia Pan. In this region, the total area under betel leaf cultivation was 113,361 acres, with a total production of 70,050 metric tons and an average yield of 655 kg per hectare (BBS, 2021). Since the early 1950s, when the Sylhet Forest Division settled the Khasia people as forest villagers, they have practiced their traditional agroforestry method for growing khasia pan in the northeastern hill forests of Bangladesh (Nath and Inoue, 2009; Zakaria and Majumder, 2019). Betel leaf cultivation by the Khasia not only contributes primarily to domestic supply but also enhances household incomes, improving their overall socioeconomic status (Rahman *et al.*, 2009; Zakaria and Majumder, 2019).

Betel vine cultivation in Bangladesh is categorized into two types based on farming practices: plain land betel leaf (boroj pan i.e. an artificially covered structure with bamboo, jute stick and ulu grass) and tree based betel leaf (gach pan). Boroj pan is primarily cultivated in lowland areas such as Jessore, Khulna, Kustia, Bagerhat, Satkhira, Bhola, Barisal, Faridpur, Rajshahi, Rangpur, Gaibandha, Pabna, and Cox's Bazar. Traditionally, betel leaf cultivation using naturally growing trees (known as gach pan) is primarily practiced in the hilly areas of greater Sylhet, where the Indigenous Khasia community has developed expertise in this method (Upoma *et al.*, 2024) and also provides important health and nutritional benefits (Gupta *et al.*, 2023). It supports digestion and helps freshen breath, adding dietary fiber, vitamins, and minerals to the diet (Biswas *et al.*, 2022). The leaf contains high levels of beneficial bioactive compounds with significant pharmacological effects such as anti-bacterial, anti-diabetic, antiulcer, anti-inflammatory, anticancer, anti-mutagenic, and antioxidant activities (Basit *et al.*, 2023; Gupta *et al.*, 2023).

The northeastern hilly region of Bangladesh offers ideal conditions for betel vine cultivation due to its humid climate, ample rainfall, fertile loamy soils and slightly acidic nature (Monshi *et al.*, 2015; Paul *et al.*, 2021; Tabassum *et al.*, 2015). Despite the crop's significance, especially the traditional Khasia Pan genotype, there is a lack of scientific research on its physico-morphological traits, which are crucial for improving yield, adaptability, and preserving genetic diversity. At the same time, the Indigenous Khasia community faces increasing threats from land insecurity (Land Rights Now, 2021), encroachment, and climate change (BARCIK, 2020), putting traditional farming practices at risk. However, data and information regarding physico-morphological traits of various khasia pan genotypes are scarce in the country. A very few studies were undertaken to evaluate the impact of influencing factors on the productivity of betel leaf cultivation. To maximize betel leaf production in the country it is essential to find out better genotype for development of high yielding variety of the crop. Therefore, the present study was undertaken to screen out suitable genotypes for better yield and quality of betel leaf in the study area.

MATERIALS AND METHODS

Description of the experimental sites

The experiment was conducted at Spices Research Sub-Station, Citrus Research Station under Bangladesh Agricultural Research Institute (BARI) located at Jaintapur Upazila of Sylhet district (25.13562° N latitude, 92.13217° E longitude, altitude 36 m from mean sea level). The trials were conducted over a two-year period (2021 and 2022) (Fig. 1).

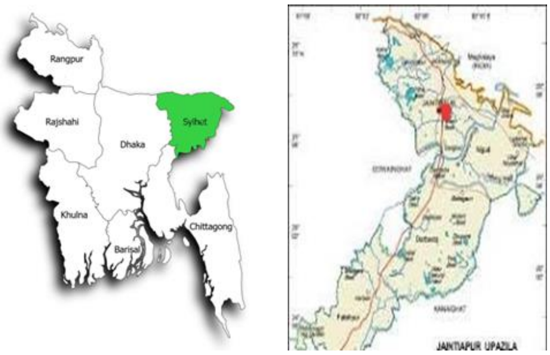

Fig 1. Map showing the experimental sites in the northern and eastern piedmont plains

Climatic variables

The experimental site is characterized by a subtropical climate with wet summer (March to September) and dry winter (November to February). Annual average rainfall ranges from 4500-6000 mm, the average maximum and minimum temperatures are 36°C and 6°C in the month of April and January respectively (Bhuyan *et al.* 2016). The weather data for the experimental location is mentioned in Fig 2.

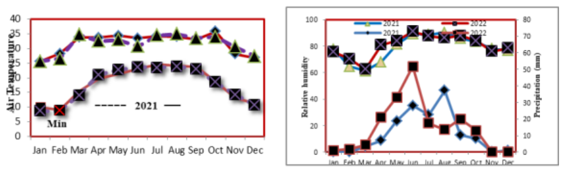

Fig. 2. Weather data for the experimental period 2021-2022

Soil features

The soil of the experimental site is a sandy loam textured soil, strongly acidic nature with very low (4.4) pH (Ahmmed *et al.*, 2018) and the site belongs to the agro-ecological zone-22: Northern and Eastern Piedmont Plains (Brammer *et al.*, 1988). The chemical and physical properties of the soil profile are given in Table 1.

Experimental details

The experiment comprised of five khasia pan evaluation options were compared following randomized complete block design in this study and all treatments were replicated three times in a block. Five khasia pan genotype designated as PB Jai-001, PB Jai-002, PB Jai-003, PB Jai-004, and PB Jai-005. The experiment was initiated in January 2021 and carried out over two consecutive years, 2021 and 2022.

Crop establishment and management

The Khasia pan genotypes were collected from different locations within the Sylhet region and planted in 2015 with a spacing of 3m×3m. The experiment was conducted under established betel nut trees. Cuttings of uniform age and size (20 cm in length) were coiled and partially buried in the soil, leaving one node exposed above ground to promote vegetative growth. Five cuttings were planted at the base of each betel nut tree. A uniform manuring schedule was followed with a dose of 200 kg N, 100 kg P_2O_5, 100 kg K_2O ha^{-1} applied in splits through mustard oil cake, single super phosphate and muriate of potash respectively. Irrigation and other cultural operations were carried out as per recommended package of practice (Maiti *et al.*, 1995; Dey *et al.*, 2003). Mature leaves were harvested when the skin color of the leaf turned to deep green to light green.

Table 1. Initial soil physical and chemical properties at the experimental sites

Texture	p^H	OM	Ca	Mg	K	Total N	P	S	B	Zn	Cu	Fe	Mn
		%	(meq/100g soil)			%	(ug/g soil)						
Sandy loam	4.8	1.12	2.8	0.91	0.28	0.071	28	18	0.11	1.13	0.07	12.2	2.2
Critical level	-	-	2.0	0.8	0.20	-	14	14	0.2	2.0	0.2	10	5

Experimental measurements

Data were carefully collected three times each year, coinciding with the leaf harvesting periods. Information on growth, leaf yield, and quality parameters was recorded from 10 randomly selected vines. Number of lateral branches were counted and expressed in number. Number of leaves of the selected lateral branches were counted and expressed in number. Vine growth was measured at 30 days interval and calculated by deducting the previous length obtained up to beginning of the month from total length obtained up to last date of the specific period. Other growth characters like internodal length were measured each month and mean data over the year was considered for analysis. Leaf parameters like leaf length and width as well as leaf area and peduncle length and diameter was measured and average data is presented. Leaf area was measured by using LI - 3000 leaf area meters and expressed in centimeter squares. Fresh weight of single leaf was taken from freshly harvested 100 leaves without petiole and measured using analytical laboratory digital weighing balance and expressed in grams. Leaf yield was obtained by counting the number of leaves harvested throughout the year. Leaf yield per hectare per year (Lakh) and yield/year (t/ha) represent cumulative observations for leaves harvested. Betel leaf plucked five times in a year from a vine and converted to leaves per hectare. An organoleptic evaluation was carried out by a panel of twenty judges, who were not habitual chewers of betel vine, to assess the pungency of various betel leaf samples using a scoring system.

Experimental design and statistical analysis

The experiment was laid out following randomized complete block design (RCBD) with three replications. All the recorded data on different parameters were statistically analyzed using Statix10 software and Fisher's LSD Test was performed for mean separations of the studied parameters and interpretation of results (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Vegetative growth parameters

The data on vegetative growth of five Khasia pan genotypes over two consecutive years (2021 and 2022) showed notable variation among genotypes (Table 2).

Table 2. Performance of vegetative growth parameters of different Khasia pan genotype

Genotype	Vine height (m)		Base girth (cm)		Internode length(cm)		Lateral branch/ plant (No.)		Leaves per lateral branch (No.)		No. of leaves per meter vine	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
PB Jai-001	3.38d	3.73d	4.52b	4.30c	9.94a	10.00a	13.36bc	12.68bc	36.42c	33.76b	19.27d	20.35d
PB Jai-002	5.58a	5.99a	5.27a	5.13ab	6.87c	6.47c	16.37a	15.54a	41.85b	43.83a	37.41a	35.43a
PB Jai-003	4.44c	4.73c	4.53b	4.50bc	8.80b	8.20b	12.67c	13.74b	32.47c	26.43c	15.73e	18.16e
PB Jai-004	5.11b	5.68b	4.80ab	5.37a	6.43c	6.47c	14.40b	15.72a	45.94a	44.50a	32.43b	30.31b
PB Jai-005	3.00e	3.31e	4.23b	4.27c	9.40ab	9.67a	10.93d	11.95c	25.90d	24.72d	27.54c	25.49c
LSD	23.84	25.77	0.69	0.74	0.97	1.11	1.28	1.18	2.99	1.31	2.04	0.37
CV	2.94	2.92	6.70	8.35	6.23	7.21	5.01	4.50	4.36	2.01	4.10	0.76
SE	10.34	11.18	0.29	0.32	0.42	0.48	0.55	0.51	1.29	0.57	0.89	0.16

Vine height

The tallest vine was obtained from PB Jai-002 (5.58 m and 5.99 m respectively in 2021 and 2022), while the lowest vine height was recorded (3.00 m and 3.31m) in PB Jai-005 respectively in same period. The findings align with Chandini (1989), who reported that betel vine genotypes like Chilanthikarpooram-Red, Tulasikodi, Mulamkodi, Chilenthivella, Chettankodi and Nadankodi were the superior types with regard to plant height. Chilanthikarpooram red recorded a plant height of 386.83 cm at 12 months after planting (MAP) which was supported to present investigation. This might be due to the genetic make-up of the genotypes, environmental conditions, like light, soil fertility, and moisture, and agronomic practices, such as training and pruning under study (Neves *et al.*, 2018).

Base girth

The vine girth of various Khasia pan genotypes ranged between 4.23 cm and 5.37 cm. In 2021, the greatest vine girth was observed in PB Jai-002 (5.27 cm), whereas in 2022, the highest measurement was recorded in PB Jai-004 (5.37 cm). Meanwhile, the smallest vine girth was noted in PB Jai-001 and PB Jai-005 during both years.

Internode length

The internodal length showed significant variation throughout the experimental years, with the shortest lengths observed in PB Jai-002 (6.87 cm) and PB Jai-004 (6.43 cm). In contrast, PB Jai-001 exhibited the longest internodal lengths (9.94cm and 10.0cm) during the same period. The findings align with Alam *et al.* (2023), who reported that longest length (9.09cm) in BL0030 and shortest (7.00cm) in BL0027 in six betel vine genotype. Similar variations were found by Pariari and Imam (2011) and Rahman *et al.* (2020) in 13 betel vine cultivars. Rahman *et al.* (2020) also reported that betel vine genotypes exhibiting longer vine lengths and shorter internodal distances had significantly higher leaf yields compared to those with longer internodes and shorter vine lengths. Therefore, selecting betel vine cultivars with longer vines and shorter internodal gaps can enhance leaf production, benefiting both growers and consumers.

Number of lateral branch

The number of lateral branches in betel vine plays a crucial role in determining leaf yield, plant vigor, and productivity, making it an important factor in cultivation practices. There was significant difference in number of lateral branches among genotypes. In 2021, during the first year of study, the plants of PB Jai-002 grow vigorously and produced maximum number of lateral branches (16.37). But in 2022, during the second year of study, the plants of PB Jai-002 (15.54) and PB Jai-004 (15.72) produced maximum number of lateral branches. In all two years, PB Jai-005 showed minimum number of lateral branches (10.93 and 11.95 respectively). Chandini (1989) reported that the cultiver of betel vine Chilanthikarpooram red recorded lateral branches were 0.60, 1.78, 2.69, 3.59, 4.37 and 4.73 from (2-12) month after planting in two months interval. Similar findings were found by Thomas (2004). Pradhan *et al.* (2013) reported that stem of betel vine was dichotomous, articulate, swollen and rooted at nodes with 3 mm diameter.

Number of leaves per lateral branch

During the first year of the study in 2021, PB Jai-004 produced the highest number of leaves per lateral branch (45.94). In the second year, 2022, both PB Jai-002 (43.83) and PB Jai-004 (44.55) recorded the highest values. Conversely, lowest in PB Jai-005 (25.90 and 24.72) respectively in 2021 and 2022.

Number of leaves per meter vine

PB Jai-002 produced the maximum number of leaves per meter of vine (37.41 and 35.43), While it was noticed minimum in PB Jai-001 (19.27 and 20.35) respectively in 2021 and 2022. Similar results was found by Alam *et al.* (2023), who reported that the BL0027 genotype of betel vine exhibited highest number of leaves (17.50) and lowest (11.83) in BL0028 during a single harvest. Rahman *et al.*(2020) also reported that Gayasur pan produced significantly highest number of leaves (16.35 no.) per meter vine.

Leaf parameters

Leaf length

The genotypes exhibited significant differences in leaf length (Table 3). In 2021, PB Jai-004 recorded the longest leaf (17.42 cm), which was statistically similar to PB Jai-001 (16.46 cm) and PB Jai-002 (16.57 cm). Similarly, in 2022, PB Jai-004 again had the longest leaf (17.31 cm), remaining statistically at par with PB Jai-001 (16.83 cm) and PB Jai-002 (17.55 cm). In contrast, PB Jai-005 consistently produced the shortest leaves in both years, measuring 14.05 cm in 2021 and 13.07 cm in 2022. Alam *et al.* (2023) reported leaf length variation ranging from 9.47 cm to 16.01 cm among six betel vine genotypes. Similar variability was observed by Pariari and Imam (2011), with a range of 10.83 cm to 16.73 cm across 14 genotypes, and by Lakshmi and Naidu (2010) in ten cultivars. Additionally, Pariari and Imam (2012a) identified the longest leaves in six specific genotypes, including Ghanagette (16.73 cm) and Simurali Sanchi (16.71 cm).

Leaf width

Significant differences in leaf width were noted among the genotypes. PB Jai-004 recorded the widest leaves (12.92 cm in 2021 and 12.41 cm in 2022), which were statistically comparable to those of PB Jai-001, PB Jai-002, and PB Jai-003. On the other hand, PB Jai-005 consistently produced the narrowest leaves in both years. Alam *et al.* (2023) reported leaf width ranging from 6.18 to 11.91 cm, supporting the findings of the present study. Similar variation was noted by Pariari and Imam (2011), with a range of 9.43 to 13.25 cm, and by Sheet (2002), who recorded the highest width (12.43 cm) in the cultivar Chandrakona. Comparable results were also reported by Rahaman *et al.* (1997), Herath and Rathnasoma (1998), and Pariari and Imam (2012b).

According to DMI (2013), leaves with 20 cm in length and 15 cm in width are preferred for export.

Table 3. Performance of leaf characteristics of different Khasia pan genotype

Genotype	Leaf length (cm)		Leaf width (cm)		Leaf area (cm^2)		Leaf peduncle length (cm)		Leaf peduncle diameter (cm)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
PB Jai-001	16.46ab	16.83a	11.78ab	11.44ab	130.91b	131.15b	7.72b	7.65bc	0.42b	0.41ab
PB Jai-002	16.57ab	17.55a	11.91ab	12.40a	160.44a	157.24a	8.49b	8.70a	0.47a	0.44ab
PB Jai-003	15.49bc	13.40b	11.73ab	11.95ab	136.08b	124.93bc	8.61b	8.12ab	0.41b	0.43ab
PB Jai-004	17.42a	17.31a	12.92a	12.41a	155.42a	159.77a	9.99a	8.70a	0.47a	0.47a
PB Jai-005	14.05c	13.07b	10.66b	10.34b	124.49b	112.66c	6.57c	6.94c	0.34c	0.37b
LSD	1.66	1.38	1.81	1.75	17.94	16.28	1.01	0.44	0.04	0.08
CV	5.52	4.70	8.16	7.95	6.74	6.31	6.48	6.75	5.15	9.62
SE	0.72	0.59	0.79	0.76	7.78	7.06	0.44	1.02	0.02	0.03

Leaf area

Leaf area is a key trait in betel vine that impacts not only plant growth and yield but also plant health, stress resilience, and overall productivity. In this study, PB Jai-002 recorded the highest leaf area (160.44 cm^2 in 2021 and 157.24 cm^2 in 2022), which was statistically on par with PB Jai-004 (155.42 cm^2 and 159.77 cm^2) across both years. Conversely, the smallest leaf area was observed in PB Jai-005 (124.49 cm^2 and 112.66 cm^2). These findings align with those of Pariari and Imam (2011), who reported a maximum leaf area of 167.82 cm^2 among 14 betel vine genotypes. Leaf area plays a crucial role in determining the photosynthetic efficiency and overall productivity of the vines.

Leaf peduncle length

Leaf peduncle (petiole) length is a key morphological trait in betel vine and notable differences were observed among the genotypes over the two years. In 2021, PB Jai-004 exhibited the longest peduncle (9.99cm), while in 2022, the maximum length was shared by PB Jai-002 and PB Jai-004 (8.70cm). Throughout both years, PB Jai-005 consistently recorded the shortest peduncle length. This result is in conformity with Rahman *et al.* (2020) who reported significant variation in peduncle length from 4.83 cm to 11.45 cm among 13 betel vine genotypes. Alam *et al.* (2023) observed the longest peduncle length (10.24 cm) in genotype BL0027 and the shortest (7.04 cm) in BL0028 among six betel vine genotypes, which align with the findings of the present study.

Leaf peduncle diameter

Significant variation in peduncle diameter was observed among the genotypes across both years. In 2021 and 2022, PB Jai-002 and PB Jai-004 recorded the highest peduncle diameter (0.47 cm), while PB Jai-005 consistently showed the lowest values. These results align with the findings of Rahman *et al.* (2020), who reported a range of 0.28 cm to 0.47 cm in peduncle diameter among 13 betel vine genotypes. Alam *et al.* (2023) also found that, BL0030 exhibited the maximum peduncle width (0.77 cm), while BL0025 had the minimum (0.34 cm) among six betel vine genotypes.

Yield and yield contributing parameters

Monthly vine growth

Vine growth per month refers to the increase in length of the betel vine over a 30-day period, and it is a key indicator of vegetative growth and overall plant vigor. PB Jai-002 recorded the highest monthly vine growth in both 2021 and 2022, while PB Jai-005 showed the lowest in both years. These results are consistent with Rahman *et al.* (2020), who reported vine elongation per month ranging from 37.46 cm to 50.34 cm among 13 betel vine genotypes (Table 4).

Fresh weight of single leaf

The fresh weight of a single leaf is a key trait in betel vine, influencing overall yield, leaf quality, market value, and aiding in genotype selection. In the study, PB Jai-002 recorded the highest individual leaf weight (4.78 g in 2021 and 4.82 g in 2022), closely followed by PB Jai-004 (4.59 g and 4.56 g), with no significant statistical difference. Conversely, PB Jai-005 consistently showed the lowest leaf weight (2.90 g and 2.60 g) across both years. These findings are in line with Rahman *et al.* (2020), who reported the highest fresh weight of 100 leaves with petiole in PB 009 (565.03 g), followed by PB 008, while PB 007 had the lowest (264.38 g). Reddy (1996) observed that the fresh weight of 100 leaves was 300.5 g in Ramtek Bangla and 246.5 g in Godi Bangla. Similar results found by Herath and Rathnasoma (1998) and Das *et al.* (1995). Leaf weight is considered as one of the important parameters, because the price of export leaves is determined by the leaf weight too. So the real quality of "Black betel" was reported to be correlated to weight (Sumanasena *et al.*, 2005).

Number of leaves per plant

Leaf number is a key trait in betel vine, influencing canopy development, light interception, yield, and plant vigor, and is useful for selecting high-yielding genotypes. In the 2021 season, PB Jai-002 recorded the highest number of leaves per plant per year (83.73). However, in 2022, PB Jai-004 produced the most leaves (81.79), which was statistically comparable to PB Jai-002 (78.19). PB Jai-005 consistently had the fewest leaves per plant per year in both years.

Leaf yield

In 2021, PB Jai-004 recorded the highest estimated number of leaves per hectare annually (49.67 lakh), followed by PB Jai-002 (43.34 lakh) and PB Jai-001 (42.70 lakh), while PB Jai-005 had the lowest (38.63 lakh). Similarly, PB Jai-004 also produced the highest estimated leaf yield (23.72 t/ha), with PB Jai-002 (19.67 t/ha) ranking next, and PB Jai-005 producing the least (11.22 t/ha). In 2022, PB Jai-004 again led with the highest number of leaves per hectare (50.61 lakh), closely followed by PB Jai-002 (47.91 lakh). PB Jai-005 remained the lowest producer (37.77 lakh). Leaf yield trends were consistent, with PB Jai-004 producing the highest weight (23.08 t/ha), slightly ahead of PB Jai-002 (22.76 t/ha), while PB Jai-005 had the lowest (11.14 t/ha). These findings highlight the importance of both leaf number and total weight per hectare as key indicators of betel vine productivity. Guha (2006) noted that a good crop yields 60–70 leaves per plant or 6–7 million leaves per hectare annually. Similarly Pariari and Imam (2012a) found significant variation among different cultivars and Simurali Deshi produced maximum number of leaves (58.56/vine), and minimum (37.63/vine) by Simurali Jhal. Sheet (2002) reported a maximum of 62.66 lakh leaves per hectare in cv. Chandrakona, while Rahman *et al.* (2020) found high yields in cultivars PB 006 (23.77 t/ha) and PB 009 (23.82 t/ha). Alam *et al.* (2023) recorded the highest leaf number (51.16 lakh/ha) and yield (15.67 t/ha) in BL0027, and lowest in BL0040 (37.65 lakh leaves and 8.08 t/ha).

Table 4. Yield and yield contributing characters of different Khasia paan genotype

Genotype	Monthly vine growth (cm)		Fresh weight of single leaf (g)		Number of leaves per plant per year		Leaf yield per hectare per year (Lakhs)		Yield/year) (t/ha)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
PB Jai-001	38.49bc	39.98c	3.48b	3.95b	68.38c	71.19b	42.70ab	43.97abc	14.89c	15.85b
PB Jai-002	56.98a	53.36a	4.78a	4.82a	77.25b	78.19a	43.34ab	47.91ab	19.67b	22.76a
PB Jai-003	41.07b	37.48c	3.74b	3.48b	64.39d	62.10c	40.81b	40.31bc	15.25c	14.01bc
PB Jai-004	52.88a	48.17b	4.59a	4.56a	83.73a	81.79a	49.67a	50.61a	23.72a	23.08a
PB Jai-005	35.16c	37.36c	2.90c	2.60b	54.05e	54.65d	38.63b	37.77c	11.22d	11.14c
LSD	4.88	3.49	0.53	0.77	3.90	4.53	7.12	7.93	1.11	3.16
CV	5.77	4.22	7.17	10.49	2.98	3.46	8.79	9.54	7.99	9.66
SE	2.12	1.49	0.23	0.33	1.69	1.96	3.09	3.44	2.55	1.37

Table 5. Physio-morphological characters of different Khasia pan genotype

Genotype	Internode color		Lateral branch pattern	Leaf margin	Leaf color	Leaf lamina shape	Leaf base shape	Leaf apex shape	Leaf pungency
	Orthotropic shoot	Lateral branch							
PB Jai-001	Light green	Dark green	Semi-erect	Even	Green	Ovate - lanceolate	Cordate	Apiculate	Highly pungent
PB Jai-002	Dark green	Violet	Horizontal	Wavy	Green	Ovate-elliptic	Cordate	Apiculate	Medium
PB Jai-003	Green	Light green	Horizontal	Even	Light green	Ovate-elliptic	Cordate	Aristulate	Highly pungent
PB Jai-004	Dark green	Violet	Horizontal	Even	Light green	Ovate-elliptic	Cordate	Apiculate	Medium
PB Jai-005	Greenish with purple line	Green	Semi-erect	Even	Light green	Cordate	Cordate	Aristulate	Highly pungent

Physio-morphological parameters

Internode color

Variation was observed in internode color across both orthotropic shoots and lateral branches among the genotypes (Table 5). The internode color of orthotropic shoot in different genotypes ranged from light green, dark green, and green to greenish with a purple line. PB Jai-002 and PB Jai-004 had dark green internodes, PB Jai-001 showed light green, PB Jai-003 had green, and PB Jai-005 was a greenish with a purple line. In lateral branches, PB Jai-001 exhibited dark green, PB Jai-002 and PB Jai-004 showed violet coloration, PB Jai-003 was light green, and PB Jai-005 appeared green.

Lateral branch pattern

The lateral branch pattern among the genotypes showed noticeable variation. PB Jai-001 and PB Jai-005 exhibited a semi-erect branching pattern, indicating that their lateral branches grew at an upward angle from the main vine. In contrast, PB Jai-002, PB Jai-003, and PB Jai-004 showed a horizontal branching pattern, with branches extending outward more parallel to the ground. This trait can influence canopy structure, light interception, photosynthetic efficiency of vine and ease of harvesting.

Leaf margin

Variation in leaf margin was minimal among the genotypes. PB Jai-001, PB Jai-002, PB Jai-004, and PB Jai-005 had even leaf margins, indicating smooth, uniform edges. However, PB Jai-003 exhibited a wavy margin, with gently undulating edges. According to Pariari and Imam (2012a), leaf lamina of betel vine was smooth and cordate with even surface.

Leaf color

Leaf color varied slightly among the genotypes. PB Jai-001 and PB Jai-002 had green leaves, indicating a deeper or more mature pigmentation. In contrast, PB Jai-003, PB Jai-004, and PB Jai-005 exhibited light green leaves, suggesting a lighter or younger leaf appearance. Leaf color can be an important morphological trait, reflecting factors such as chlorophyll content, plant health, and genotype differentiation. Well matured dark green leaves with high pungency were preferred for export purpose in Sri Lanka (DMI, 2013).

Leaf lamina shape

The leaf lamina shapes varied among the genotypes. PB Jai-001 had an ovate-lanceolate shape, PB Jai-002, PB Jai-003, and PB Jai-004 showed an ovate-elliptic form, and PB Jai-005 displayed a cordate (heart-shaped) lamina. Chaveerach *et al.* (2006) observed ovate lamina for betel vine leaves.

Leaf base shape

All the genotypes exhibited a cordate (heart-shaped) leaf base, indicating uniformity in this trait across the betel vine genotypes. Chaveerach *et al.* (2006) reported leaf base in Piper betle as cordate.

Leaf apex shape

The leaf apex shape varied among the genotypes, with PB Jai-001, PB Jai-002, and PB Jai-004 exhibiting an apiculate apex, characterized by a short, sharp tip. Meanwhile, PB Jai-003 and PB Jai-005 had an aristulate apex, which features a more elongated, bristle-like tip. This variation helps differentiate between the genotypes. Chaveerach *et al.* (2006) indicated that leaf apex was acuminate in betel vine.

Leaf pungency

Leaf pungency varied among the genotypes, PB Jai-001, PB Jai-003, and PB Jai-005 were classified as highly pungent, whereas PB Jai-002 and PB Jai-004 exhibited medium pungency. This trait plays a key role in determining the flavor and appeal to consumers. It affects both the taste and overall quality of betel leaves.

The two-year evaluation of five Khasia pan (betel vine) genotypes revealed notable genetic variation in growth, leaf traits, yield, and morphology. PB Jai-002 and PB Jai-004 consistently showed superior performance across most parameters, indicating strong potential for commercial cultivation and high-yield production in the north-eastern hilly region of Bangladesh. In terms of vegetative growth, PB Jai-002 showed superior performance with the tallest vines, thickest base girth, most lateral branches, and highest leaf density per meter, while PB Jai-004 closely matched or exceeded it in leaf number per lateral branch and vine girth in 2022. Both genotypes also had shorter internode lengths, which support higher leaf density and improved yield potential.

Leaf morphological traits such as leaf length, width, area, peduncle length, and peduncle diameter also showed significant differences among genotypes. PB Jai-004 recorded the longest and widest leaves, while PB Jai-002 exhibited the largest leaf area and peduncle diameter, both of which are crucial indicators of photosynthetic potential and market quality. PB Jai-005 consistently lagged in almost all vegetative and leaf traits, indicating lower vigor and productivity.

Yield and yield-contributing parameters further affirmed the superiority of PB Jai-002 and PB Jai-004, with showing the highest monthly vine growth, fresh leaf weight, number of leaves per plant, and total leaf yield per hectare. In 2022, PB Jai-004 recorded the highest estimated leaf yield (23.08 t/ha), slightly ahead of PB Jai-002 (22.76 t/ha), whereas PB Jai-005 again performed the poorest (11.14 t/ha), confirming its unsuitability for commercial cultivation under the tested conditions.

Physio-morphological traits such as internode color, branching pattern, leaf margin, shape, color, and pungency also varied among genotypes and can aid in identification and consumer preference.

PB Jai-002 and PB Jai-004 had darker green leaves and medium pungency, which are desirable traits for both domestic consumption and export markets. In contrast, PB Jai-005 showed less desirable characteristics such as greenish-purple internodes, fewer branches, and highly pungent but smaller leaves, contributing to its lower yield. The study reaffirms that genotypic variation plays a vital role in determining performance and adaptability in betel vine cultivation. The consistent superiority of PB Jai-002 and PB Jai-004 across a wide range of traits, including vegetative vigor, leaf quality, and yield, suggests their strong adaptability to the local agro-climatic conditions and potential for large-scale production. These findings are in agreement with previous research by Rahman *et al.* (2020), Alam *et al.* (2023), and others, who highlighted similar patterns of variation in other betel vine genotypes. Therefore, PB Jai-002 and PB Jai-004 can be recommended for future breeding programs and commercial expansion in the region, while further multi-location trials and quality assessments should be conducted to confirm their broader adaptability and consumer acceptance. The identification and promotion of such superior genotypes are essential for improving productivity, profitability, and sustainability in betel vine farming in Bangladesh.

CONCLUSION

From the results of the present study it can be concluded that the genotypes PB Jai-002 and PB Jai-004 exhibit superior performance in terms of growth, leaf characteristics, and yield attributes.

Specifically, PB Jai-002 achieved a yield of 22.72 t/ha, while PB Jai-004 reached 23.76 t/ha. These results suggest that these genotypes possess significant potential to enhance agricultural productivity, fulfilling the demands of both farmers and consumers, and offering substantial opportunities for profit through domestic and international trade.

ACKNOWLEDGMENTS

We sincerely express our gratitude to the Director-General of the Bangladesh Agricultural Research Institute (BARI), Joydebpur Gazipur, for providing valuable support and services throughout this study.

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