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CHARACTERIZATION AND DIVERSITY ANALYSIS OF HYACINTH BEAN COLLECTIONS IN BANGLADESH

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Abstract

The experiment was conducted with 150 accessions of Hyacinth bean (*Lablab purpureus* L. Sweet) of which 104 were from Bangladesh and 46 accessions from 17 countries of Asia, Africa and Europe for characterization and diversity analysis. Low to high Shannon-Weaver Diversity Index (0.14 to 0.99) were observed among the 16 qualitative characters. The genotypic and phenotypic coefficient of variations of 19 quantitative characters ranged from 3.59 to 4.08 % and 5.30 to 43.87%, respectively. The accessions were grouped into ten clusters ranging from 8 to 25 accessions. Accessions collected from the same districts in Bangladesh or countries were distributed into different clusters. The results obtained by D^2 analysis were also confirmed by canonical analysis. Crosses between accessions belonging to maximum divergent clusters of CPI 106548 (India), ILRI 14437 (Zimbabwe) and TOT 7905 (Uzbekistan) from cluster IX with accessions of BD 122 (Hobiganj, Bangladesh) and BD 8785 (Feni, Bangladesh) from cluster I, and BD 8770 (Gazipur, Bangladesh) from cluster VI for obtaining better variability to the subsequent generation. The breeder can use the selected accessions for varietal improvement of hyacinth bean.

Keywords: *Lablab purpureus*, characterization, cluster analysis, Bangladesh.

Introduction

Hyacinth bean is one of the important crops grown throughout the tropics and sub-tropics. It is a diploid legume (2n=2x=24), and a native to Asia and Africa. In Bangladesh, it is known as country bean or shim. It is consuming in various ways such as s young pods and immature seeds for vegetable purpose, dry seed is used as pulse soup. The most preferred types for vegetable are long pods, bold seeded with high pod fragrance (Venkatesha *et al*., 2013). Though vegetable production in Bangladesh is increasing day by day, it fails to keep pace with the ever increasing requirement. As hyacinth bean has a wide adaptability and immense genetic variability, there is an ample scope to breed for development of new varieties for winter as well as other season of the year. BARI released 8 varieties

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of hyacinth bean for winter and two varieties (BARI Shim-3 and BARI Shim-7) for both for summer and winter. Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh released 13 varieties of hyacinth bean. In addition, there are lots of landraces are cultivated all over the country. Hyacinth bean grown on approximately 17,126 ha of land across the country during the winter season and the average yield is 5.50 t/ha of fresh pods and total production is about 94,356 t (BBS, 2014). Bangladesh is rich in hyacinth bean diversity. Systematic research such as collection, conservation, characterization, evaluation, diversity, profitability study and utilization of hyacinth bean has been done at BARI (Islam *al.*, 2002; Islam, 2008; Islam *et al.*, 2010; Islam *et al*. 2014; Moniruzzaman *et al*. 2022). Characterization consists of recording those characters which are highly heritable, can be easily seen by the eye and are expressed in all environments. A number of plant exploration have been organized and a sizeable number of hyacinth bean germplasm collections have been made and maintained at various centres and countries. PGRC of BARI conserved 751 accessions including 46 exotic accessions in the gene bank. Few studies at both morpho-genetic and molecular level have been already done in different countries but none or few reports included germplasm from Bangladesh (Maass *et al*., 2005; Wang *et al*., 2007; Venkatesha *et al.*, 2013). A better utilization and a fuller exploitation of collected germplasm require better knowledge of the variability existing among the collections. The purpose of the study was to characterize the Bangladeshi and exotic accessions to know the genetic diversity and identify the important traits for varietal improvement of hyacinth bean.

Materials and methods

The experiment was conducted at Plant Genetic Resources Centre of BARI, Joydebpur, Gazipur, Bangladesh during August 2006 to May 2007. The location was at 24.00^0 N latitude, 90.26^0 E longitudes and 8.40 meter above sea level altitude. The mean temperature was 10.6^0C to 33^0C and relative humidity from 68.3% to 97.64% during the experiment. The soil of the experimental field was silty clay having a pH of 6.5. One hundred and four accessions from 39 districts of Bangladesh and 46 accessions from 16 countries of Asia, Africa and Europe were used in this study (Table 1and Fig.1). BARI Hyacinth bean-1 (BD 7774) and BARI Hyacinth bean-2 (BD 7775) were used as check variety. The accessions were selected from 20º35' to 26º75' N latitude and 88º03' to 92º75' E longitude in Bangladesh and on the basis of geographical location, qualitative and quantitative characters (Islam *et al*., 2002; Islam, 2008). The exotic accessions (1 to 8) were collected from AVRDC based on geographic origin namely, India, Lao Republic, Philippines, Thailand, Cambodia, Malaysia, Viet Num, Indonesia, Taiwan, Ethiopia, Zambia, Zimbabwe, Kenya, Mozambique, Denmark and Uzbekistan (Table 1 and Table 4). Among them, nine accessions namely CPI 34777, CPI 81626, CPI 106548, CPI 35894, CPI 52508, CPI 76996, CPI 100602, ILRI 13695 and ILRI 14437 were selected from core collection developed by Pengelly and

Maass (2001). All the accessions were conserved at the genebank of PGRC. Three seeds per accession were planted in polyethylene bag (6 cm in diameter approx.) containing a mixture of sandy-loamy soil and decomposed cow dung (1: 0.25) on 9 October 2006. The seedlings were transplanted on 17 October 2007. The experiment was conducted in Alpha Lattice Design with three replications and each replication consisted of three plants.

Table 1. Collection of hyacinth bean accessions from different country

Name of district	Number of accession	Name of district	Number of accession
Bangladesh			
Chittagong	14	Noakhali	2
Gazipur	7	Rajbari	2
Pabna	6	Rajshahi	2
Sirajganj	6	Sherpur	2
Cox's Bazar	5	Bandarban	1
Kushtia	5	Barguna	1
Natore	5	Barisal	1
Hobiganj	4	Comilla	1
Rangamati	4	Dinajpur	1
Jamalpur	3	Faridpur	1
Naogaon	3	Gaibandha	1
Nawbabgonj	3	Gopalganj	1
Chuadanga	2	Jessore	1
Feni	2	Jhalakati	1
Khagrachhari	2	Magura	1
Lakshmipur	2	Narail	1
Meherpur	2	Panchagarh	1
Moulvibazar	2	Patuakhali	1
Mymensingh	2	Rangpur	1
Netrakona	2	**Bangladesh total**	**104**
Exotic country			
Asia		Uzbekistan	1
India	8	**AFRICA**	**7**
Laos	6	Ethiopia	2
Philippines	6	Zambia	2
Thailand	5	Zimbabwe	1
Cambodia	4	Kenya	1
Malaysia	3	Mozambique	1
Viet Nam	2	**EUROPE**	**2**
Indonesia	1	Denmark	2
Taiwan	1	**Total-Country-17**	**150**

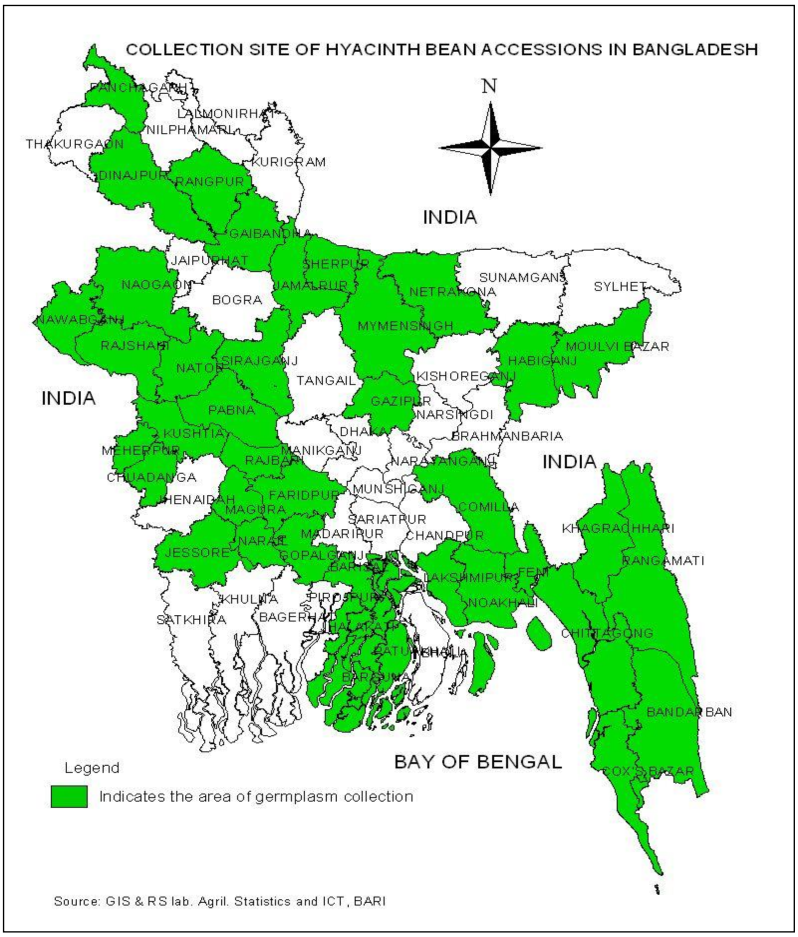

Fig.1. Collection site of 104 accessions of hyacinth bean from 39 districts in Bangladesh.

There were 15 blocks and each block consisted of 10 plots in each replication. The unit plot size was 2.2 X 2.5 m. The plants were given support of two meter height bamboo stick. The plants were initially irrigated by pipe and later on surface irrigation was given whenever required. The insecticides admire (0.5 ml per litre) was applied for controlling aphids and Vitavax-200 (2g per litre) was applied in the soil for controlling foot rot diseases. Manure and fertilizers were applied as 6 ton/ha cow dung, 50 kg N, 30 kg P, 45 kg K, 9 kg S and 1.5 kg B per hectare in the form of urea, triple super phosphate, murate of potash, gypsum and borax, respectively. Qualitative (16) and quantitative (19) characters were recorded as per AVRDC-GRSU data recording sheet (Table 2 and Table 3). Quantitative data were recorded from 30 randomly selected nine plants. Shannon-Weaver Diversity Index (SWDI) was measured in qualitative characters. H' ranges from 0 to 1, where 1 indicates the maximum diversity and was classified as low (H'<0.50), intermediate (H'=0.50-0.75) and high (H'≥0.75) based on Jamago (2000). Range, mean, genotypic and phenotypic coefficient of variation were calculated. Analysis of Variance, Principal Component Analysis, Principal Coordinate Analysis, Canonical Vector analysis and Cluster analysis were performed with MSTAT-C and Genstat 5 software.

Results and discussion

(i) Phenotypic diversity of qualitative characters

Light green (77%) and light purple (23%) hypocotyle and epicotyl colours were found among the 150 accessions of 17 countries in Asia, Africa and Europe (Table 2). The maximum percentage of accessions exhibited green colour (68-70%) and the minimum accessions showed purple colour (30-32%) of stem and leaf vein. Absent (2%) and present (98%) of leaf anthocyanin were observed. The colours of the hyacinth bean leaf were classified as light green (8%), medium green (68%) and dark green (24%). Green and purple colours were found in hypocotyl, epicotyl, main stem and leaf vein from the accessions of Bangladesh, Laos, Philippines and Thailand with different percentage. Only the green colour was found in all the accessions from India (8 accessions), Cambodia (4), Malaysia (3) and all the countries from Africa and Europe. Purple colour was found in the accessions from Indonesia (1), Taiwan (1), Uzbekistan (1) and Viet Nam (2). Ovate (11% accessions) and round (89%) terminal leaflet shapes were found. Pengelly and Maass (2001) was found green, purple and reddish stem among the 249 accessions of hyacinth bean from 5 countries in Asia and 13 countries in Africa. Sultana *et al.* (2001) reported light green, green, purple, red purple, light green with purple and green with purple stem, and green and purple leaf vein among the 107 accessions from 20 countries in Asia, Africa, South America and Europe. But in this study, both stem and leaf vein showed green and purple. Pengelly and Maass (2001) was found green and purple leaf while Sultana *et al.* (2001) and this study found light, medium and deep green leaf among the accessions. Indeterminate climber (99%) and determinate bushy (1%) growth habit were exhibited among the 150 accessions. Two determinate accessions such as BD 8529 and CPI 106548 were found in Ethiopia and India, respectively. Indeterminate character appeared to be the most abundant growth habit of lablab bean in Bangladesh. Shivashankar and Kulakarani (1989) classified the growth pattern into determinate types (156 accessions), indeterminate (50 accessions) and semi-determinate (15 accessions). They also concluded that the cultivated field types were mostly determinate and photo-insensitive while indeterminate types were spreading and photo-sensitive. Sultana *et al.* (2001) was found one determinate accession in India of their 107 accessions on morphological and physiological variation study in lablab bean. In an Indian lablab bean collection of 255 accessions, 11.37% determinate accession was reported by Shivashankar *et al.* (1977) while 1% determinate accession was found in this study. White and purple flowers were exhibited in the accessions in Bangladesh, India, Cambodia, Laos, Philippines, Thailand and Zambia. But only the white flower colour was noted from Malaysia and Denmark. Purple flowers were observed in Indonesia, Taiwan, Viet Nam and Uzbekistan. White, purple, mauve and pale lilac flowers were found by Pengelly and Maass (2001), where white, light purple and purple flowers were reported by Sultana *et al.* (2001) while white and purple flowers were found by the authors. The distribution of edible pod shape was flat (64.67%), elongate (20.67%), elongate-wavy (14%) and round (0.67%) while the curvatures of edible pod were slightly curved (78%), straight (15.33%) and curved (6.67%). Elongate and flat are the common edible pod shape of hyacinth bean among the countries. Elongate-wavy pods were found only in Bangladesh and it was about 14% of the total accessions. However, all the accessions from Malaysia, Indonesia, Laos, Taiwan, Uzbekistan, Viet Nam were exhibited flat shape and those from all other countries from Africa and Denmark. Only one accession (TOT 2465) from Thailand showed round pod. Slightly curved pod curvature was common for almost all the countries. Short, medium, long and thick edible pods were observed in the hyacinth bean population. Eight distinct seed colours viz black, brown, yellow-white, grayed-orange, purple, black with brown and cream, and brown with cream were observed at maturity stage after sun drying. Black and or grayed-orange seeds were found in all the 17 countries. Two accessions, CPI 81626 and CPI 106548A having purple seed colour were found in India. Three types of mosaic seeds such as black with brown or cream, and brown with cream were found only in Bangladesh. The shape of dry seeds was classified as cuboid, flat, kidney, ovoid and round. Flat seeds (41.33%) dominated the population and were followed by the ovoid seeds (39.33%). Flat and or ovoid seeds were found in all the countries. Four accessions of kidney shape were exhibited in Bangladesh. Small, medium and large seeds were observed in Bangladesh while the small and medium seeds were exhibited in India, Laos, Malaysia, Philippines, Thailand and Viet Nam. Only small seeds were found in Indonesia, Cambodia, Uzbekistan, Ethiopia, Kenya, Mozambique, Zambia, Zimbabwe and Denmark. Small, medium and large seeds were reported by Sultana *et al.* (2001) while the similar seed sizes were reported by the authors. Shannon Weaver Diversity Index was estimated for the phenotypic diversity in the vegetative and reproductive characters of hyacinth bean. The high phenotypic diversities ($\geq$0.75) was observed in hypocotyle colour, epicotyle colour, main stem colour, leaf vein pigmentation, flower colour, pod beak shape, seed shape and seed size. Moderate diversities (0.50-75) were observed in leaf colour intensity, terminal leaflet shape, pod colour, pod shape, pod curvature and seed colour. While low diversities (<0.50) were observed in case of leaf anthocyanin and plant growth pattern (Table 2).

Table 2. Distribution and Phenotypic diversity index of qualitative characters in hyacinth bean accessions

Name of descriptor	Descriptor state	Frequency distribution	Frequency distribution (%)	SWDI
Hypocotyle colour	L.green L.purple	115 35	77 23	0.78 (H)
Epicotyle colour	Light green Light purple	115 35	77 23	0.78 (H)
Main stem colour	Green Purple	102 48	68 32	0.90 (H)
Leaf vein pigmentation	Green Purple	105 45	70 30	0.88 (H)
Leaf anthocyanin	Absent Present	147 3	98 2	0.14 (L)
Leaf colour intensity	Dark green Medium green Light .green	36 102 12	24 68 8	0.73 (I)
Terminal leaflet shape	Ovate Round	17 133	11 89	0.51 (I)
Plant growth pattern	Indeterminate climber Determinate bushy	148 2	99 1	0.10 (L)
Flower colour	Purple White	72 78	48 52	0.99 (H)
Pod colour	Green Green with purple sutuer Purple Yellow-green Yellow green with purple sutuer Violate	90 20 7 23 9 1	60.00 13.33 4.67 15.33 6.00 0.67	0.73 (I)
Pod shape	Elongate Elongate-wavy Flat Round	31 21 97 1	20.67 14.00 64.67 0.67	0.66 (I)
Pod curvature	Curved Straight Slightly curved	10 23 117	6.67 15.33 78.00	0.60 (I)
Pod beak shape	Long beak Medium beak Short beak Thick beak	41 33 41 35	27.33 22.00 27.33 23.33	0.99 (H)
Seed colour	Black Brown Yellow-white Grayed-orange Purple Black+brown Black+cream Brown+cream	65 54 5 20 2 1 1 2	43.33 36.00 3.33 13.33 1.33 0.67 0.67 1.33	0.62 (I)

Name of descriptor	Descriptor state	Frequency distribution	Frequency distribution (%)	SWDI
Seed shape	Cuboid	15	10.00	0.77 (H)
	Flat	62	41.33	
	Kidney	4	2.67	
	Ovoid	59	39.33	
	Round	10	6.67	
Seed size	Large	19	12.67	0.82 (H)
	Medium	93	62.00	
	Small	38	25.33	

Where, SWDI-Shannon-Weaver Diversity Index (H'); L=Low (H'<0.50), I= Intermediate (H'=0.50-0.75) and H= High (H'≥ 0.75)

(ii) Phenotypic and Genotypic Coefficient of Variability in Quantitative characters

The phenotypic and genotypic coefficient of variability among 19 quantitative characters are shown in Table 3. Analysis of variance indicated highly significant difference among the accessions for all characters. The highest terminal leaflet length was exhibited in BD 59 (14.34 cm, Natore, Bangladesh) while the lowest 8.43 cm in BD 8830 (Chittagong, Bangladesh). This indicated that leaflet length of BD 59 was almost two times larger than BD 8830. On the other hand, terminal leaflet width ranged from 8.23 (TOT 7217, Malaysia) to 12.95 cm (BD 59, Bangladesh) with an average of 10.28 cm. Terminal leaflet length and width ratio ranged from 0.97 to 1.23. The accessions produced first flower from 55 days (BD 7775, Bangladesh) to 107 days (BD 7967, Sirajganj, Bangladesh). On average, rachis length and peduncle length both were approximately 11.72cm. The accessions produced 1.71 (BD 8757, Rajshahi) to 14 flowering nodes per rachis (BD 8748, Rajshahi) with an intensity of node per cm was 1.53. The accessions exhibited 2.47 (PD 11, India) to 14 (BD 8748, Rajshahi) pods per rachis in the population. The edible pod length ranged from 4.92 to 16.74 cm in CPI 52508 (Mozambique) and BD 8808 (Sherpur, Bangladesh), respectively. On the contrary, pod width ranged from 1.35 to 4.36 cm in CPI 106548 (India) and BD 8018 (Kushtia, Bangladesh), respectively. The accessions produced pod weighing 2.1 to 17.07g in CPI 106548 and BD 8757, respectively. Such the lowest pod weight might be inherent characteristics of the accessions. The pod length and width ratio ranged from 1.94 to 9.09. The accessions produced 84 to 537 pods per plant from BD 8776 and TOT 3932 (Viet Nam), respectively while 2.83 to 5.57 seeds per pod were obtained from ILRI 13695 (Ethiopia) and BD 8738, respectively. The accessions produced an average of 300 pods per plant and 5 seeds per pod. The variation in number of pods per plant might be due to differences in number of inflorescence per plant, pods per raceme, flower dropping tendency and also due to the inherent potential of accessions (Mollah *et al.*, 1995). The accessions exhibited 0.90 to 1.60 cm seed length from CPI 106548 (India) and BD 8813, respectively while 0.68 to 1.21cm seed width was obtained from BD 8802 and BD

59, respectively. The seed length and width ratio ranged from 1.21 to 1.74 in BD 117 and BD 7974, respectively. The accessions exhibited 13.33g (CPI 106548) to 62g (BD 8770) of hundred seed weight with an average of 33.74g. The maximum phenotypic co-efficient of variation (PCV) was found in number of pods per plant (43.83%) followed by rachis length (40.98%), peduncle length (40.22%) and number of flowering nodes per rachis (38.57%), and minimum PCV was exhibited in leaf ratio (L:W) (5.30%). Sufficient variability was recorded among the Bangladesh accessions for the characters which could be used for genetic improvement of this crop. All the characters exhibited higher estimates of PCV than corresponding GCV. A similar situation was also noticed for genotypic and phenotypic variance. The relative efficiency of Alpha Lattice design over RCB design was more than 0.90. The LSD value of 19 characters are shown in Table 3.

Table 3. Phenotypic and genotypic coefficient of variability in hyacinth bean

Name of quantitative character	Range	Mean	GCV (%)	PCV (%)	LSD (5%)	F. Sign	REF F
Leaf length (cm)	8.43 - 14.34	11.15	7.25	9.38	1.07	1	0.94
Leaf width (cm)	8.23 - 12.95	10.28	6.94	8.96	0.94	1	0.95
Leaf ratio (L:W)	0.97 - 1.23	1.09	3.59	5.30	0.07	1	0.96
Days to 1st flowering	54 - 107	83.97	13.39	14.16	6.20	1	0.96
Rachis length (cm)	1.14 - 22.59	11.74	40.08	40.98	1.61	1	0.95
Peduncle length (cm)	1.69 - 22.86	11.72	39.01	40.22	1.84	1	0.99
No.of flowering nodes/ rachis	1.71 - 14.00	7.78	37.52	38.57	1.12	1	1.00
Node density (cm)	0.29 - 2.71	1.53	19.76	23.12	0.30	1	0.95
Number of pods per rachis	2.47 - 13.70	8.11	30.36	31.62	1.18	1	1.00
Edible pod length (cm)	4.92 - 16.74	9.48	22.01	22.87	0.95	1	0.97
Edible pod width (cm)	1.35 - 4.36	2.33	22.37	23.36	0.25	1	0.93
Edible pod weight (g)	2.10 - 17.07	7.04	33.82	34.93	0.99	1	0.94
Pod ratio (L:W)	1.94 - 9.09	4.32	36.35	36.92	0.45	1	0.94
Number of seeds per pod	2.83 - 5.57	4.51	9.30	11.56	0.50	1	0.94
Seed length (cm)	0.90 - 1.60	1.30	7.30	8.18	0.08	1	0.95
Seed width (cm)	0.68 - 1.21	0.90	8.61	9.49	0.06	1	0.95
Seed ratio (L:W)	1.21 - 1.74	1.44	6.67	8.02	0.10	1	0.95
Hundred seed weight (g)	13.33 - 62.00	33.74	26.90	28.34	4.83	1	0.96
Number of pods per plant	84.00 - 537	300.12	32.88	43.87	140.14	1	0.95
Number of pods per plant (Log transformation)	1.88 - 2.73	2.40	7.24	9.92	0.26	1	0.96

Where, REFF- Relative efficiency RCBD/Alpha Lattice adjusted; SWDI-Shannon Weaver Diversity Indices; F-Significance, 1= Significant at 1% level.

Pengelly and Maass (2001) found 4.0 to 16.5cm leaf length and 3.0 to 15.5cm leaf width while the authors observed 8.43 to 14.34 cm leaf length and 8.23 to 12.95cm leaf width. Comparatively higher rachis length (17.5cm in Australia and 28.1cm in Ethiopia), peduncle length (42.4 cm in Australia and 27.3cm in Ethiopia), lower flowering node density per rachis (0.6), pod length (2.5 to 14.0cm), pod width (1.6 to 3.2cm), pod ratio (2.2 to 7.3), seeds per pod (1 to 7) and hundred seed weight (5.7 to 10.35g) were reported by Pengelly and Maass (2001) than the present study. A good number of *Lablab purpureus* subsp. bengalensis were found among the 104 accessions from Bangladesh. They are characterized by elongated and elongated wavy types of edible pods. Probably, for this reason higher pod length, width, weight and number of seed per pod were exhibited in Bangladesh than the remaining region of the world. The higher rachis length and peduncle length in Australia and Ethiopia might be due to the longer vegetative growth in the field. Das (1990) recoded high variability among 92 accessions collected from Maharashtra State India and found late maturing groups were taller, had more leaves and with high green fodder yield. In Australia, much of the researches for the genetic improvement in lablab have been focused on improving the forage attributes (White bread and Pengelly, 2004). Likewise, much of the research efforts in Africa is towards development of cultivars for improving the soil properties by use as green manure crops (Maass *et al.*, 2010). Under Indian conditions, where the crop is mainly grown under specific short duration conditions for vegetable purpose, the most preferred traits would be short duration, photo insensitive, high pod and seed yield and higher test weight of seed (Venkatesha *et al.* 2013). Substantial variation for agro-morphological traits among lablab accessions was reported (Mahadevu and Byre Gowda, 2005; Islam 2008; Girish and Byre Gowda, 2009). The estimate of the higher PCV than corresponding GCV might be due to the higher degree of genotype x environment interaction. Little difference between GCV and PCV (<3.5%) were observed for the 18 characters studied indicating that the variability for these characters were primarily due to genotypic differences and selection for these characters were expected to be more effective. For the remaining character (i. e. number of pods per plant), big difference was observed between GCV and PCV (10.99%), environmental influences was pronounced and selection should be performed carefully considering environmental factors.

(iii) Genetic diversity in hyacinth bean

Genetic diversity of 150 accessions from 17 countries was grouped into 10 clusters using D^2 values (Table 4). Maximum number of accessions fell in 25 (Cluster-III) and the lowest 8 accessions was in Cluster VI . Clusters I, II, VI and VII contained the accessions of Bangladesh only. Cluster III was composed of the 18 accessions from Bangladesh and 7 accessions from 5 Asian countries like Cambodia (1 acc.), Laos (2), Thailand (2), Viet Nam (1) and Philippines (1). Cluster IV composed of the accessions from Bangladesh (8) and Thailand (1) and cluster V formed with the accessions of Bangladesh (15), India (2) and Thailand (1). Cluster VIII was formed with the accessions from Bangladesh (7 acc), India (CPI 81626), Kenya (CPI 100602) and Philippines (2 acc). Cluster IX was composed with 18 accessions from 11 countries from Asia like India (4), Cambodia (3), Indonesia (1), Malaysia (1), Taiwan (1) and Uzbekistan (1), from Europe, Denmark (2) and Africa, Ethiopia (1), Mozambique (1), Zambia (2) and Zimbabwe (1) and none accession from Bangladesh. It is mentioned that the six accessions of this cluster such as CPI 34777 and CPI 106548 (India), CPI 39894 (Denmark), CPI 52508 (Mozambique), CPI 76996 (Zambia) and ILRI 14437 (Zimbabwe) were aggregated the accessions from core collection (Pengelly and Maass, 2001). Cluster X was composed of the accessions from Bangladesh (7), Ethiopia (1), India (1), Laos (4), Malaysia (2), Philippines (3), Thailand (1) and Viet Nam (1). The maximum of 15 accessions from Chittagong districts (Bangladesh) were distributed among five clusters such as cluster I (3acc.), II (5), IV (1), VII (5) and VIII (1). Seven accessions from Gazipur were distributed among four clusters viz. cluster II (1), VI (4), VIII (1) and X (1) (Table 4). It may be mentioned that the two BARI released varieties namely BARI Hyacinth bean-1 and BARI Hyacinth bean-2 were distributed in clusters X and VIII, respectively. Accessions collected from the same geographic origin (districts or countries) were distributed into different clusters. In many cases, the accessions from different districts in Bangladesh or countries were accommodated in the same cluster indicating their close affinity. This result suggested that the accessions within a cluster might have some degree of ancestral relationship. The rich morphological diversity reported among the Bangladesh accessions in the present study can be effectively used for genetic improvement. Clustering of genotypes from different eco-geographic locations into one cluster was attributed to the free exchange of breeding materials from one place to another. The intra-cluster distance ranged from 0.88 (Cluster VI) to 1.62 (cluster VIII) (Table 5). This showed cluster VIII to be more heterogeneous than the other clusters.

Table 4. Distribution of different accessions in different clusters of hyacinth bean

Cluster	BD	Exotic	Total	Accessions with their origin (Country or district in Bangladesh)
Clu-I	13	0	**13**	BD 31-Pabna; BD 57, BD 60-Natore; BD 82-Rangpur; BD 90-Naogaon; BD 137, BD 799-Chittagong; BD 8001-Rangamati; BD 1739-Luxmipur; BD 1740-Noakhali; BD 8044, BD 122 (15)-Hobiganj; BD 8785 (84)-Feni
Clu-II	17	0	**17**	BD 113, BD 117-Hobiganj; BD 1785-Netrakona; BD 1830-Lakshmipur; BD 2880, BD 2917, BD 7995, BD 7998, BD 8855-Chittagong; BD 2884-Khagrachhari; BD 7999, BD 8857-Cox's Bazar; BD 8812-Moulvibazar; BD 8816-Bandarban; BD 8823, BD 8830-Rangamati; BD 8870-Gazipur
Clu-III	18	7	**25**	BD 128-Dinajpur; BD 1780, BD-7985-Mymensingh; BD 1816-Gopalganj; BD 7974, BD 7977-Sirajganj; BD 7988-Faridpur; BD 7992-Rajbari; BD 8005-Jessore; BD 8022-Kushtia; BD 8027-Meherpur; BD 8729-Pabna; BD 8738-Natore;

Cluster	BD	Exotic	Total	Accessions with their origin (Country or district in Bangladesh)
				BD 8746, BD 8749, BD 8752-Nawabganj; BD 8748-Rajshahi; BD 8787-Jamalpur; Bangladesh, CAM-372-Cambodia; TOT 7016, TOT 7017-Laos; TOT 2465, TOT 5648-Thailand; TOT 4772-Viet Nam; PHL 2663-Philippines
Clu-IV	8	1	**9**	BD 1792-Netrakona; BD 7967, BD 7968, BD 7978-Sirajganj; BD 8006-Narail; BD 8725-Chittagong; BD 8726-Pabna; BD 8802- Jamalpur; TOT 2454-Thailand
Clu-V	15	3	**18**	BD 6-Comilla; BD 86-Gaibandha; BD 1809-Jhalakati; BD 7982-Sirajganj; BD 7993-Rajbari; BD 8008, BD 8018, BD 8020, BD 8023-Kushtia; BD 8033-Meherpur; BD 8034, BD 8039-Chuadanga; BD 8737-Natore; BD 8757-Rajshahi; BD 8797-Jamalpur; PD-11, PER-12-India; TOT 0583-Thailand
Clu-VI	8	0	**8**	BD 59-Natore; BD 101-Naogaon; BD 114-Hobiganj; BD 8767, BD 8770 (81), BD 8775, BD 8776-Gazipur; BD 8813-Moulvibazar
Clu-VII	11	0	**11**	BD 100-Naogaon; BD 132, BD 135, BD 2907, BD 8832, BD 8867-Chittagong; BD 2887-Rangamati; BD 8815, BD 8831, BD 8849-Cox's Bazar; BD 8849-Khagrachhari
Clu-VIII	7	4	**11**	BD 130-Panchagarh; BD 1799-Barguna; BD 1818-Barisal; BD 7775-Gazipur; BD 8727-Pabna; BD 8808-Sherpur; BD 8810-Chittagong; CPI 81626 A-India; CPI 100602-Kenya; PHL 2622, PHL 263-Philippines
Clu-IX	0	18	**18**	BD 8529-Ethiopea; CPI 34777, CPI 81626 B, CPI 106548 A, CPI 106548 (111)-India; CPI 35894, CPI 35894 B-Denmark; CPI 52508-Mozambique; CPI 76996 A, CPI 76996 B-Zambia; CAM-177, CAM-177, CAM-372-Cambodia; ILRI 14437 (122)-Zimbabwe; LV 4018-Indonesia; TOT 7217-Malaysia; TOT 4881-Taiwan; TOT 7905 (148)-Uzbekistan
Clu-X	7	13	**20**	BD 111-Magura; BD 1805-Patuakhali; BD 1839-Noakhali; BD 8733, BD 8735-Pabna; BD 8809-Sherpur; BD 8835-Gazipur. ILRI 13695-Ethiopia; PD-13-India; TOT 4008 A, TOT 4008 B, TOT 4008 C, TOT 7654-Laos; TOT 0072, TOT 7118-Malaysia; PHL 2635, PHL 2648, PHL 3107-Philippines; TOT 2464-Thailand; TB-90-Viet Nam
Total	**104**	**46**	**150**	

*BD **Accession number:** 'BD' letter has been used before the number to identify the accession that comes from the PGRC, BARI, Gazipur, Bangladesh.

Table 5. Intra-and Inter cluster distance of different accessions in hyacinth bean

Name of cluster	Cluster-I	Cluster-II	Cluster-III	Cluster-IV	Cluster-V	Cluster-VI	Cluster-VII	Cluster-VIII	Cluster-IX	Cluster-X
Cluster-I	**1.06**									
Cluster-II	2.63	**0.97**								
Cluster-III	7.53	4.92	**1.15**							
Cluster-IV	5.57	4.32	5.19	**1.36**						
Cluster-V	9.69	8.06	6.27	4.14	**1.38**					
Cluster-VI	6.02	6.39	8.84	3.71	6.41	**0.88**				
Cluster-VII	4.05	1.45	3.49	3.79	7.06	6.64	**1.05**			
Cluster-VIII	11.22	9.02	5.33	6.24	3.30	9.35	7.68	**1.62**		
Cluster-IX	12.14	9.65	4.97	8.01	5.98	11.50	8.20	2.80	**1.12**	
Cluster-X	9.18	6.70	2.33	5.36	4.74	9.01	5.26	3.05	2.96	**1.15**

Where, Diagonal and bold indicate intra cluster distance

Maximum inter cluster distance was estimated between clusters I and IX (12.14) followed by clusters VI and IX (11.50), suggesting wide diversity between the accessions of these groups. On the contrary, the minimum inter-cluster distance was observed between clusters II and VII (1.45) indicated close relationship. Accessions in cluster VI showed maximum of leaf length, width and leaf ratio, fresh pod length, pod weight and pod ratio (L:W) and number of seeds per pod (Table 6). This cluster exhibited minimum for length of rachis and peduncle, number of flowering nodes per rachis and pods per rachis. White flower (88%), elongate with green edible pod (100%) and brown seed (100%) were exhibited from cluster VI. The accessions are *L. purpureus* ssp. bengalensis type and thus must be considered useful parental material. Cluster IX exhibited minimum for leaf length, width and leaf ratio, pod length, width, weight and pod ratio, number of seeds per pod, seed length and width, hundred seed weight and number of pods per plant. This cluster exhibited maximum for flowering node density. White and purple flower (both 50%); green (50%), yellow-green (32%), yellow-green with purple suture, purple and violate (each 6%) types edible pod colour; black (50%), grayed-orange (38%), yellow-white (6%) and purple (6%) seed colour were exhibited from cluster IX. The 18 accessions from 11 countries of Asia, Africa and Europe including 5 accessions from core collection were aggregated into this cluster. Clusters I and II exhibited for late flowering and the maximum number of pods per rachis, respectively. Narrow pod width was exhibited from clusters III and IX. The broad pod was from cluster IV. Neither a maximum nor a minimum value of the characters was exhibited from the accessions of clusters V and X. The highest length of rachis and peduncle, number of flowering nodes per rachis, length and width of seed, hundred seed weight and number of pods per plant were found in cluster VII. Early flowering accessions including BARI hyacinth bean-2 were observed in cluster VIII (Table 6).

Table 6. Cluster mean of different characters in hyacinth bean

Name of characters	Cl.-I	Cl.-II	Cl-II	Cl-IV	Cl.-V	Cl.-VI	Cl.-VII	Cl-VIII	Cl-IX	Cl-X
Leaf length (cm)	11.79	11.48	11.52	11.04	10.81	**13.05****	10.86	11.09	**9.81***	11.01
Leaf width (cm)	10.65	10.51	10.74	10.37	10.11	**11.52****	9.71	10.10	**9.28***	10.18
Leaf ratio (L:W)	1.11	1.09	1.07	1.06	1.07	**1.13****	1.12	1.10	**1.06***	1.08
Days to 1st flowering	**102.53****	93.90	89.34	100.97	79.26	93.03	76.93	**63.47***	69.56	77.82
Rachis length (cm)	11.55	13.41	15.44	5.57	4.81	**4.29***	**16.67****	10.99	14.52	12.97
Peduncle length (cm)	12.10	14.55	15.10	4.95	4.96	**4.24***	**17.48****	11.07	13.12	12.90
Number of flowering nodes per rachis	8.68	10.05	10.18	3.82	3.28	**2.71***	**10.77****	7.17	7.74	8.83
Flowering node density (cm)	**1.34**	1.35	1.53	1.54	1.48	1.61	1.55	1.51	**1.89****	1.51
Number of pods per rachis	7.87	**9.88****	9.60	5.39	4.57	**4.09***	8.94	7.12	9.82	9.50
Pod length (mm)	8.42	8.91	10.44	10.90	9.96	**12.76****	9.53	10.83	**6.26***	9.18
Pod width (mm)	2.50	2.55	**1.98***	**2.76****	2.72	2.21	2.26	2.40	1.98*	2.28
Pod weight (g)	7.16	7.58	5.93	9.05	8.92	**10.82****	7.56	8.69	**3.24***	6.00
Pod ratio (L:W)	3.40	3.55	5.66	4.26	4.08	**6.00****	4.29	4.86	**3.16***	4.24
Number of seeds per pod	4.18	4.30	4.77	4.55	4.66	**5.03****	4.37	4.79	**4.03***	4.54
Seed length (cm)	1.40	1.37	1.27	1.31	1.30	1.46	**1.48****	1.29	**1.11***	1.22
Seed width (cm)	1.04	0.99	0.84	0.89	0.89	1.03	**1.06****	0.88	**0.77***	0.84
Seed ratio (L:W)	**1.35***	1.38	**1.52****	1.46	1.47	1.43	1.39	1.47	1.43	1.46
Hundred seed weight (g)	51.89	45.64	24.69	30.23	30.28	52.88	**53.76****	30.08	**18.20***	25.14
Number of pods plant (log2)	2.13	2.37	2.52	2.26	2.40	2.05	**2.26****	2.43	**2.58***	2.56
Flower colour	1.38	1.53	1.28	1.44	1.83	**1.12***	1.27	**1.73****	1.50	1.55
Pod colour	1.62	1.94	1.56	1.56	1.94	**1.00***	2.09	2.09	2.00	**2.10****
Seed colour	**2.69****	2.12	1.76	1.67	**1.44***	2.00	2.27	1.64	2.17	1.90

Within rows, * and ** indicate minimum and maximum cluster mean values, respectively.

Both PC1 and PC2 were heavily weighted by length and width of leaf and seed, and leaf ratio (Table 7). However, PC1 heavily weighted for fresh pod width and PC2 for number of pods per plant. The cluster constellations obtained by D^2 analysis were confirmed by canonical analysis. Cluster constellations were also independently derived by using principal component analysis (PCA) to verify grouping obtained through D^2 statistic in a two-dimensional chart (PC1-PC2). In principal component analysis PC1, PC2 and PC3 were observed to contribute 56.29, 23.61 and 13.68%, respectively of the total divergence. Accession scores obtained for the first two components were plotted on two main axis and then superimposed on the clustering found from D^2 analysis (Fig. 2), showing the similar results. The maximum distance was observed between accessions BD 8785 (84) of cluster I collected from Feni district (Bangladesh) and CPI 106548 (111) of cluster IX from India (Fig.2). The accessions were comparatively close to each other in cluster VI and those in cluster VIII were most heterogeneous through scatter diagram. The results obtained by principal component analysis were reconfirmed by D^2 analysis. Accessions collected from the same geographic origin (districts or countries) were distributed into different clusters. The absence of relationship between genetic and geographic diversity suggests that forces other than geographic origin, such as exchange of breeding material, genetic drift, variation, natural and artificial selection are responsible for diversity. Similar findings were obtained in previous study by Sultana *et al.* (2001). Basavarajappa and Gowda (2000) grouped the 144 germplasm lines from India into 15 clusters based on D^2 values. The clustering pattern followed their respective geographic origin and variation between clusters might have resulted from the possible genetic drifts and selection. Plant populations restricted to small geographic areas or subjected to identical environmental pressures help to evolve adaptive gene complexes. These gene complexes are conserved by genetic linkages or stringent natural or human selections. The clustering of accessions from different ecographic locations into one cluster could be attributed to the free exchange of breeding materials between regions.

The magnitude of heterosis and potential for transgressive segregation largely depends on the degree of genetic diversity in the parental lines. The greater distance exists between two clusters, the wider the genetic diversity between their accessions. Good variation for genetic improvement of vegetative traits have been found among the Bangladesh accessions. The diverse accessions from exotic collections may be used in breeding programs to introduce novel genes/traits such to the Bangladesh accessions. Apart from exotic collections, some Bangladesh accessions such as BD 122, BD 8785, BD 8770 were placed near to yield attributing traits indicating their superiority for these traits. The result suggests scope for using these germplasm in breeding programmes for developing of lines with high yield and related traits. The results of phenotypic diversity analysis using qualitative traits were equally effective and promising for detecting of diversity at morphological level.

Table 7. Relative contribution of different characters in hyacinth bean

Name of characters	PC1	PC2
Leaf length (cm)	0.834	0.968
Leaf width (cm)	-0.924	-0.943
Leaf ratio (L:W)	-2.847	-2.115
Days to 1st flowering	-0.175	-0.047
Rachis length (cm)	0.140	-0.166
Peduncle length (cm)	0.031	-0.153
Number of flowering nodes per rachis	-0.288	-0.169
Node density (cm)	-0.117	1.054
Number of pods per rachis	-0.068	-0.151
Fresh pod length (mm)	0.114	-0.175
Fresh pod width (mm)	0.619	0.425
Fresh pod weight (g)	-0.084	0.147
Fresh pod ratio (L:W)	-0.053	0.376
Number of seeds per pod	0.202	0.215
Seed length (cm)	-1.934	-1.438
Seed width (cm)	1.295	-1.084
Seed ratio (L:W)	0.187	0.166
100- seed weight (g)	-0.137	0.080
Number of pods plant	0.322	0.896
Flower colour	-0.004	0.336
Fresh pod colour	-0.143	-0.002
Seed colour	-0.090	-0.016

Where, PC1-Principal component one, PC2- Principal component two

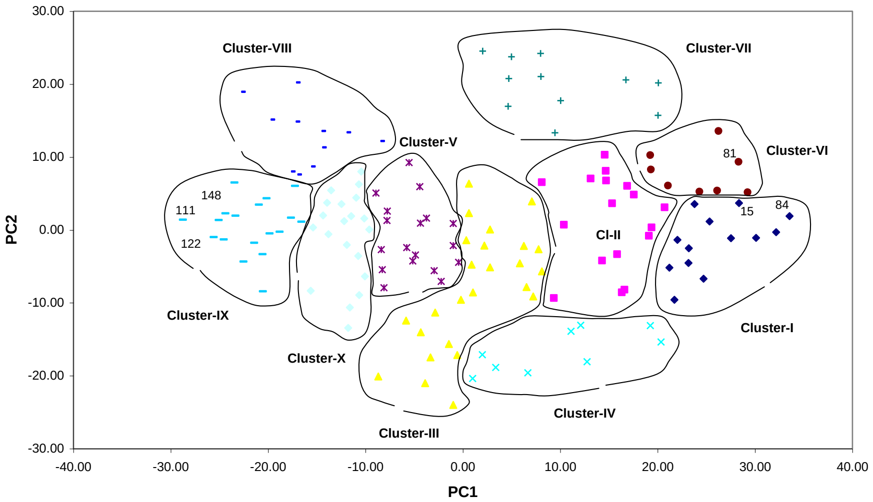

Fig. Distribution of different accessions in different clusters in hyacinth bean.

Conclusion

One hundred and fifty accessions from 17 countries of Asia, Africa and Europe showed low to high Shannon-Weaver Diversity Index (0.14 to 0.99) among the qualitative characters. The GCV ranged from 3.59 to 32.88% among the quantitative characters indicated considerable variability in hyacinth bean accessions. The accessions were grouped into ten clusters. Genetic diversity of the accessions did not show clear relationship with their place of collection. The crosses should be made between the accessions in cluster IX with accessions in cluster I and cluster VI. The breeder can use the selected accessions for varietal improvement of hyacinth bean.

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PRESENT STATUS AND CONSTRAINTS TO SHITALPATI HANDICRAFTS AND POLICY OPTIONS FOR IMPROVEMENT IN BANGLADESH

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Abstract

The study was conducted at the selected weaving areas of shitalpati or cooling mat handicrafts in Bangladesh during 2019-2021 to know the present situation of the handicrafts, existing constraints and formulate policy options for its improvement in the country. Although the traditional art of shitalpati weaving of Bangladesh was recognized as “Intangible Cultural Heritage” by the United Nations Educational, Scientific and Cultural Organization (UNESCO), but presently the glory of the cottage industry is in declining trend due to lack of research and development activities on "murta" plant (*Schumannianthus dichotomus* L.) cultivation (stem cane of this plant, which is used for shitalpati weaving). Quality murta cane production and processing, and unfair market price of the products, competing with plastic mats, lacking of diversification and value addition of handicrafts, lack of promotional activities of the stakeholders etc. are also responsible. It was observed that the murta plant has wide adaptability that can be cultivated easily in submerged or fallow lands. Murta plant can tolerate salinity and waterlogging environments and prevents soil erosion, which would be an adaptation option under changing climate in Bangladesh. Therefore, policy formulation and suitable action plan (short, medium and long term basis) should be done for recapturing the glory of shitalpati handicrafts in Bangladesh.

Keywords: Shitalpati handicrafts, intangible cultural heritage, constraints, policy options, craftsman livelihood.

Introduction

Shitalpati or cooling mat is a traditional handicraft of Bangladesh, which is highly valued in rural area of the country as it is soothing in hot weather condition. The herbaceous plant from which shitalpati is made is called "murta" plant (*Schumannianthus dichotomus* L.). The murta is a shrub and perennial plant under the family of Marantaceae. Depending on the growing region, the murta plant is also called as *paitra, mustaq, patibet, patipata, muktagach, patigacha, murtha, ratagacha, patijong, shitalpati* plant etc. The murta plant is considered as minor forest in Bangladesh that looks like a thin bamboo but is not as hard as a bamboo, grows into a bush. According to data obtained from Bangladesh Forest Research Institute, seedlings can be propagated through rhizomes, branch cutting, rooted cutting and seedling (Siddiqi *et al*., 1998). The murta plant flowers in March-April

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and the fruit/seed matures in June-July (Merry *et al*., 1997). Murta plant can grow up to 3-5 meters in length. The main part of this plant for making mat is the long stem without node which tends to get shorter as the plant grows older (Mia *et al*., 2018). Once planted, good yields are obtained for about forty consecutive years (Chowdhury *et al*., 2007). The murta cane is prepared by processing the outer covering or bark of the stem of “murta plant” in various natural ways. Shitalpati is also weaved with design of herbs, animals and different motifs. It has red, blue, green, black and purple colors (Banglapedia, 2014). The mat decorated with artwork or decoration is also called nakshi pati (Banu, 2012). At once, shitalpati was made with silver and ivory leaves. The person who makes shitalpati is called patikar, patiyal or pati industrial worker. Shitalpati is a traditional handicraft product that is about 350 years old. The greater Sylhet region is traditionally famous for making shitalpati. In addition, murta also grown in Tangail, Sirajganj, Jhalokati, Barishal, Cumilla, Noakhali, Chandpur and Feni and make shitalpati. Shitalpati are also used in making other handicraft products. The United Nations Educational, Scientific and Cultural Organization (UNESCO) has given recognition the traditional art of shitalpati weaving of Sylhet region of Bangladesh as world's most important “Intangible Cultural Heritage” in 2017 (Anon., *2017*). The value of shitalpati is a little higher in rural Bengal as it is soothing in hot weather. In villages it is used instead of mats and in urban areas it is used as show-piecesThe shitalpati based handicrafts and the livelihoods of craftsman are facing many challenges due to lacking of proper management of cultivation, widespread expansion of plastic mats, limitations in making good quality shitalpati products and lacking of proper marketing and promotional activities. However, it is necessary to intensify research and development works on the production of murta plant, quality patibet (murta cane) and the manufacture of diversified shitalpati handicrafts in order to retaining the past heritage of the shitalpati based cottage industry. Therefore, the aims of this study was to explore the present status and existing constraints of shitalpati (cooling mat) handicrafts as well as formulating policy options towards sustainable development of the pre-glorious handicraft industry in Bangladesh.

Materials and Methods

Scientists of Bangladesh Agricultural Research Institute discussed and made interview with the shitalpati stakeholders like patikar, artisans, pati industrial workers, Shitalpati Shilpa Youth Foundation (Nalchiti, Jhalokati), Pati industrial workers cooperative Society Ltd. (Kalihati, Tangail) in different parts of the country regarding the current situation, problems and possible solutions of the shitalpati handicrafts in Bangladesh.

Study areas

The study was conducted in eight districts (10 upazilas) viz., Jhalokathi (Nalchiti sub-district), Sylhet (Goainghat and Golapganj), Moulvibazar (Rajnagar and

Barlekha), Tangail (Kalihati), Sirajganj (Kamarkhand), Cumilla (Barura), Chandpur (Shahrasti) and Feni (Feni Sadar), during 2019-2021 for gathering different information about the present situation of the handicrafts, existing constraints towards formulating policy options for its sustainable development in the country. Bangladesh Forest Research Institute (BFRI), Sholashahar, Chattrogram was also visited for collecting information about the previous and existing research activities on murta cultivation and weaving of shitalpati handicrafts in Bangladesh. The study areas along with the geographical coordinates of the sub-districts are given in Table 1.

Table 1. Study areas with geographical coordinates of upazila in Bangladesh

Division	Name of district	Name of upazila	Geographical coordinates
Barishal	Jhalokathi	Nalchiti	22°36′00″ N & 90°17′06″ E
Sylhet	Sylhet	Goainghat	25°04′18″ N & 91°57′48″ E
		Golapganj	24°51′20″ N & 92°00′58″ E
	Moulvibazar	Rajnagar	24°31′36″ N & 91°51′20″ E
		Barlekha	24°43′47″ N & 92°09′35″ E
Dhaka	Tangail	Kalihati	24°21′26″ N & 89°56′03″ E
Rajshahi	Sirajganj	Kamarkhand	24°22′31″ N & 89°38′31″ E
Chattogram	Cumilla	Barura	23°20′32″ N & 91°02′44″ E
	Chandpur	Shahrasti	23°13′41″ N & 90°56′57″ E
	Feni	Feni Sadar	22°59′09″ N & 91°24′32″ E

Selection of stakeholders

Different categories of shitalpati (cooling mat) stakeholders were selected randomly in the study areas like researchers, local entrepreneurs, craftsman/shitalpati worker/ patikar (men and women), murta growing farmers, handicrafts supplier, businessman, salesman, end users, local people etc. Shitalpati shilpa youth foundation and shitalpati industrial workers cooperative society were selected for taking interviews in the concerned study areas.

Data collection

Data collected consisted of both quantitative and qualitative information from the target stakeholders on murta cultivation, planting time, propagation methods, agronomic management, fertilizer management, insect-pest and disease management, stem harvesting and post-harvest processing, use of murta plant in weaving shitalpati handicrafts income and expenditure on murta cultivation, making and processing of murta cane (patibet), types and sizes of shitalpati, income and cost of weaving of shitalpati handicrafts etc. Information were also collected about the current problem of shitalpati industry and possible ways to improve it. Primary data were collected through household survey as well as Participatory Rural Appraisal (PRA) tools like Focus Group Discussion (FGD) and Key Informant Interviews (KII). Besides, secondary information was also collected from different books, journals, booklets, factsheets, magazine, research reports, scientific articles, web pages, and so on to validate and support the primary information.

Collection of murta plant samples

During the study period, different samples of murta plant such as stem *peet* (upper green part of murta stem), *ati* (lower part of *peet*), *chhota* (lower layer of *ati*), buka (inner soft pith), whole plant (including *peet*, *ati*, *chhota* and *buka*) and leaf were collected randomly for laboratory analyses of their composition. It can be mentioned that stem of murta plant consisted of four layers viz., *peet*, *ati*, *chhota* and *buka*.

Laboratory analysis of murta plant leaf samples

The samples of murta leaf were analysed in the Laboratory of Animal Production Research Division of Bangladesh Livestock Research Institute (BLRI), Savar, Dhaka, Bangladesh for determining its chemical composition as livestock fodder and the results have been presented in Table 2.

Data processing and analysis

Data processing and analysis were done using computer based Microsoft Excel software. Economic analyses were also done of shitalpati handicrafts based on existing local market prices of inputs and products.

Results and discussion

Cultivation of murta plant

The murta plants are usually grown in the low-lying and wetland areas of Sylhet, Sunamganj, Moulvibazar, Habiganj, Chattogram, Noakhali, Feni, Lakshmipur, Chandpur, Cumilla, Brahmanbaria, Barishal, Jhalokati, Pirojpur, Jashore, Munshiganj, Narsingdi, Tangail, Mymensingh, Natore, Sirajganj districts of Bangladesh since hundreds of years ago. The murta plant is generally cultivated without any advanced care such as proper planting time, planting distance and method, weed cleaning, pruning or sharing, fertilizer management, pest and insect control, timely harvesting of stem/doga, etc. Murta plant grows well in waterlogged soils where silt accumulates. In some areas of Bangladesh, many people grow new murta plants on the banks of canals or ponds to prevent soil erosion. No good quality land is required for cultivating murta plants. Murta can be easily grown on abandoned lands around houses, ditches, canal, beels or ponds which are always wet or low lands where the lands remain wet or damp (Alam, 2007). It is grown in Assam and West Bengal of India, the Malay Islands and the Philippines. Some people collect the stems (*doga*) of murta plants throughout the year. However, when the stems are collected during the rainy season, less number new shoots are produced ultimately reducing the yield. After planting the seedlings, it takes about 3 years to collect the doga/stems for making shitalpati. It was informed that one can makes 5-6 number of shitalpati (1.52 m x 2.13 m size) by using the murta plants of one decimal of land in a year. Due to lack of knowledge or awareness about the diversified use of murta plant, lack of proper management and maintenance of murta plant, the murta garden is declining day by day. However, with better care, it is possible to increase the yield and quality of murta.

Establishment of Ratargul Swamp Forest in Bangladesh

In Bangladesh, the Ratargul Swamp Forest has been established in Gowainghat upazila of Sylhet district with an area of about 1346 hectares. In the local language of Sylhet, murta or patigach is known as "*Rata plant*". The name of this forest is Ratargul (Anon. 2016) after the name of that Rata plant. In addition, 204 hectares of forest land was declared as special biodiversity conservation area by the Forest Department of Bangladesh in 2015 (www.bforest.gov.bd). This forest has been conserved under the Forest Department of the Government of Bangladesh (Anon., 2011). There are murta mahals in Ratargul area covering an area of about 40.50 ha and murta garden covering an area of about 25 square km in south Sylhet range (BFRI, 1993). A new murta garden has been established on 25 hectares of land in 2018-19 at the initiative of Sylhet Forest Department. In addition, the Bangladesh Forest Department has adopted a plan to plant bamboo, cane and murta plants in 7171 hectares of land from 2017 to 2036 (Forestry Master Plan 2017-2036).

Chemical composition of murta leaf sample as livestock fodder

As nutritive value of livestock fodder, the leaf samples contained dry matter 26.23%, ash 11.76%, organic matter digestibility 88.24%, acid detergent fiber 56.02%, crude protein 13.84%, neutral detergent fiber 79.86%, ether extract 2.23%, lignin 29.57% and **gross energy** 17.46 kcl /kg. Results further indicated that murta leaves are very nutritious fodder for livestock particularly for cattle, goat and sheep (Table 2). Fasae *et al*. (2010) also reported that chemical composition of murta leaves were dry matter 20.50%, crude protein 25.43%, ether extract 6.60%, ash 12.61%, neutral detergent fibre 63.27%, acid detergent fibre 41.17% and acid detergent lignin 22.67%, which indicated that it is highly digestible and their inherent nutrients are higher than the range recommended for maintenance in ruminant production. These fodders can be fed as supplements to low protein forage and can alleviate feed shortages experienced for ruminants in dry season.

Table 2 Chemical composition of murta leaf sample as fodder for livestock (2020-2021)

Sample name	Nutritive value status as livestock fodder								GE (kcl/kg)
	DM	Ash	OM	ADF	CP	NDF	EE	Lignin	
	%								
Murta leaf	26.23	11.76	88.24	56.02	13.84	79.86	2.23	29.57	17.46

Source: Bangladesh Livestock Research Institute, Savar, Dhaka, Bangladesh

Note: DM = Dry matter, OM = Organic Matter digestibility, ADF = Acid Detergent Fiber, CD = Crude Protein, NDF = Neutral Detergent Fiber, EE = Ether Extract, GE = Gross Energy

Use of different parts of murta plant for shitalpati handicrafts

Stem and branch of murta

Three types of stem and branches are available for making cane from murta plant. These are locally known as doga (long stem without knot), dala (top portion of doga) and jhara (short mature branch on the side of *doga*). Long and good quality *doga* (1.52-2.13 m in length) quality mat cane and large shitalpati (1.52 m x 2.13 m in size) can be made. It takes 100-120 long stems or *doga* to make a 1.52 m x 2.13 m size of mat (*pati*) which costs around Tk. 1200-1500. The market price of these carpets is much higher. However, a short and low-quality cane is made from dala and jhara stems or branches. It is said that the mat made of these canes is smaller and its market value is also lower at the local market. However, even if a large size shitalpati is made with joined short cane, its market value is reduced. The discarded parts of *dala* and *jhara* stem or branches can also be used as cooking fuel.

Layers of murta plant stem and making of *patibet* (murta cane)

Patibet (murta cane) is made from the bark of murta plant. The stem of murta plant consists of four layers, which are locally as *peet* (upper green part), *ati* or *auti* (lower part of *peet*), *chhota* (lower layer of *ati*) and *buka* or *feuta* (inner soft pith). Of the stem layers, only *peet* cane (*peet* bet) is used to make quality mat. Patibet is usually soaked and boiled with rice starch, hog plum leaves, cowa leaves, chukai or chukur leaves, etc. to make it durable, soft, whitening and increase luster and smoothness. *Patibet* is then dried well in the sun so that it can be stored for a long time. In order to making colored cane, the green part of the stem is painted with different colored paints or the green part of the stem is scraped off with a knife and is boiled with different dye (red, pink, green, blue, yellow etc.) mixing water. The *ati* or *auti* bet (lower part of *peet*) is made colored by mixing dyes in hot water (1 teaspoon dye/10 liters of water) and heating it with cane for half an hour. The colored cane is used to make ornamental or design of the shitalpati.

Shitalpati weaving areas of Bangladesh

Primarally group discussions with *patikars* (shitalpati weavers), pati industrial workers and members of shitalpati industrial workers cooperative society related to weaving shitalpati in Bangladesh and reviewing information obtained from other secondary sources (reports, journals, bulletins, online papers, books, Banglapedia-database, articles, etc.) revealed that shitalpati are weaved traditionally in the districts of Sylhet, Moulvibazar, Habiganj, Jhalokati, Barishal, Pirojpur, Jashore, Faridpur, Sunamganj, Netrokona, Nilphamari, Kurigram, Tangail, Mymensingh, Narsingdi, Munshiganj, Sirajganj, Comilla, Chandpur, Feni, Lakshmipur and Noakhali (Table 3). However, Rajnagar, Balaganj, Baralekha and Molla Bazar of Sylhet region, Sonagazi, and Raipur of Noakhali, Swarupkathi and Nilgati of Barishal and Satche of Faridpur produced high quality of shitalpati (Banglapedia, 2014). However, shitalpati in Sylhet region is traditionally famous for its artistic and dexterity. Besides the Sylhet region, the patikars of Jhalokati district have also been famous for their shitalpati for hundred years.

Craftsman (patikar) involved in shitalpati weaving in Bangladesh

It is very difficult to determine the actual number of craftsman (locally known as *patikar, patial, paital, shitalpati shilpa sromic* etc.) in Bangladesh. Analyzing the data obtained from primary discussions with the members of shitalpati industrial workers' cooperative society and other secondary sources. It is learned that there are about 7916 craftsman families in the country who are directly or indirectly involved in this cottage industry and living in Sunamganj, Sylhet, Moulvibazar, Habiganj, Barishal, Jhalokathi, Pirojpur, Jashore, Mymensingh, Netrokona, Nilphamari, Kurigram, Tangail, Narsingdi, Munshiganj, Faridpur, Pabna, Sirajganj, Cumilla, Chandpur, Feni, Noakhali, Lakshmipur and Chattogram districts (Table 3). On the other hand, Forestry Master Plan (1992) showed that about eight thousand people in the country are involved in making shitalpati (GoB, 1992). Banglapedia (2014) reported that about fifteen thousand artisans are involved in making shitalpati in Bangladesh. However, in low-lying or submerged areas of the country, a large portion of the poor are directly or indirectly involved in the shitalpati handicrafts making for their livelihoods.

Table 3. Murta plant growing and shitalpati weaving areas, and number of craftsman (patikar) involved in shitalpati handicrafts of Bangladesh

Division	District	Murta plant growing and shitalpati weaving areas (Upazila)	No. of craftsman family
Sylhet	Sunamganj	Doarabazar, Jamalganj, Rajapur, Tahirpur	431
	Sylhet	Goainghat, Jaintapur, Companiganj, Golapganj, Fenchuganj, Balaganj, Beanibazar, Zakiganj	215
	Moulvibazar	Rajnagar, Barlekha, Srimangal, Kamalganj	120
	Habiganj	Baniachang, Chunarughat	80
Barishal	Barishal	Bakerganj	495
	Jhalokathi	Nalchiti, Rajapur, Jhalokati Sadar	570
	Pirojpur	Kaukhali, Nesarabad	175
Khulna	Jashore	Monirampur	25
Mymensingh	Mymensingh	Phulbaria, Gafargaon, Haluaghat, Muktagacha	220
	Netrokona	Mohanganj, Kendua	230
Rangpur	Nilphamari	Kishoreganj	150
	Kurigram	Bhurungamari	30
Dhaka	Tangail	Kalihati, Ghatail, Gopalpur, Delduar, Basail, Mirzapur, Nagarpur	2985
	Narsingdi	Manohardi	20
	Munshiganj	Sirajdikhan	60
	Faridpur	Boalmari	30
Rajshahi	Pabna	Atgharia	100
	Sirajganj	Sadar, Kamarkhand, Raiganj	370
Chattogram	Cumilla	Barura, Chandina, Burichang	140
	Chandpur	Shahrasti, Kachua, Hajiganj	410
	Feni	Sadar, Sonagazi	180
	Noakhali	Kabirhat, Sadar	650
	Lakshmipur	Raipur, Ramgati	180
	Chattogram	Anwara, Mirsarai	50
-	-	**Total**	**7916**

Sources: 1) Shitalpati Shilpa Youth Foundation, Nalchiti, Jhalokati; 2) Shitalpati industrial workers cooperative Society Ltd., Kalihati, Tangail; 3) Interview with patikar or pati industrial workers of the concerned district.

Types of shitalpati handicrafts in Bangladesh

Although the Shitalpati is made in different districts of Bangladesh, and there are many differences in their types, shapes, designs, artistic and dexterity. Again, there is a difference in the quality, size, shape, and design of shitalpati as many patikars do not have good idea or knowledge on making or processing of patibet, design of shitalpati, artistic and dexterity, and demand of the buyers. Observing the Shitalpati made in different areas, it was found that the quality, artistic, and dexterity of shitalpati of Sylhet region is relatively better than that of other parts of the country. However, if proper training or skill development programme is to be provided to the craftsmanship, it is possible to make quality shitalpati in other districts like Jhalokati, Tangail, Sirajganj, Cumilla, Chandpur, Feni, Noakhali, Lakshmipur etc. The following are the types of shitalpati (along with their key characteristics, size and price ranges) that are usually made and marketed by the patikars in different parts of Bangladesh are given below (Table 4).

Table 4. Types of shitalpati handicrafts, key characteristics, size and price

Sl. No.	Types of shitalpati	Key characteristics of shitalpati	Size (Length x Width)	Price range (Taka)
1) Based on the usage of different layers of stem of murta plant				
a)	Shitalpati (Cooling mat)	• Made with *peet bet* (top layer of stem) • Top surface of the mat is smooth and shiny • Used for lying or sitting • Export quality and high in price	152cm × 213 cm	1200-1500
b)	*Ati pati / Chati / Chatai /Dao / Bukar pati*	• Made with *ati or auti bet* (2nd layer of stem) • Upper surface of the mat is rough or uneven • Used for drying paddy or roof material for RCC • Poor quality and price is cheaper	152cm × 213 cm or bigger	500-700
c)	*Dala pati*	• Made from short cane of dala stem • Small in size and low in price	91cm × 137cm	250-300
d)	Thick mat	• Made with thick *peet or ati bet* • Used for drying paddy or other crops • Used for seating on it • Large or small size and low in price	152cm × 213 cm or bigger	500-700

Sl. No.	Types of shitalpati	Key characteristics of shitalpati	Size (Length x Width)	Price range (Taka)
2) Based on artistic, dexterity and design				
a)	*Nakshi Pati* (Chikan)	• Made with thin or narrow *peet bet* • Artistic and smooth • Designed with animals, herbs and surroundings motifs • Included in the list of World Intangible Cultural Heritage of the UNESCO • Exportable in abroad and very high price	152cm × 213 cm or any size	20000-25000
b)	*Nakshi pati* (General)	• Artistic and smooth • Made of white and colored *peet bet* • Price is high	152cm × 213 cm or any size	2000-2500
c)	White carpet (Chikan)	• White, smooth and shiny • Made of thin and white peet bet • Price is high	152cm × 213 cm	2000-2500
d)	White carpet (General)	• White, smooth and shiny • Made with some thick white peet bet • Price is relatively low	152cm × 213 cm	1200-1500
e)	Grameen check	• Prepared in the form of Grameen check design • Made of white and colored *peet bet* • Smooth, shiny and high price	152cm × 213 cm	1300-1500
f)	*Jamdani pati*	• Made in the style of Jamdani saree design • Made of white and colored *peet bet* • Smooth, shiny and high price	152cm × 213 cm	1200-1500
3) Based on the size and use of the mat				
a)	Bedding mat	• Made with white or colored *peet bet* • Smooth and shiny • Used for sleeping on it • Larger in size and more expensive	152cm × 213 cm or bigger	1200-1500

Sl. No.	Types of shitalpati	Key characteristics of shitalpati	Size (Length x Width)	Price range (Taka)
b)	Prayer mat	• Made with white or colored *peet bet* • Smooth and shiny • Used for religious prayers • Small in size and low in price	91cm × 137cm	300-400
c)	Seating mat	• Made with *peet bet* • Used to sit on the ground • Small in size and low in price	91cm × 137cm	250-300
d)	Table mat	• Made with white or colored *peet bet* • Smooth and shiny • Used on table • Small in size and low in price	91cm × 137cm	300-400

Economic return of shitalpati weaving

Shitalpati artisans or patikar families usually make their own shitalpati or other handicrafts. In that case, from the cultivation of murta plant to the making and processing of patibet, dyeing of cane, design and weaving of shitalpati and its marketing all are almost done by themselves. As there is no alternative arrangement for employment, patikars are usually do shitalpati weaving during the rainy season. It was observed that to make a shitalpati of large size (152cm × 213cm) 6-7 man-days are required. But each of these ordinary sizes is sold at Tk. 1200-1500. It revealed that every artisan earned a wage of Tk. 170-180 per day (in 8 hours) for making the shitalpati (Table 5).

Table 5. Economic return from an ordinary quality of shitalpati (152cm × 213cm)

#	Input of shitalpati	Number	Making cost (Tk./unit)	Selling price (Tk/unit)	
				White mat	Colored mat
a)	Murta doga or stem	120	200	1200	1500
b)	Family labour (*patibet* making, processing, weaving of shitalpati etc.)	6-7 man-day (8 hrs. /day)	-		
c)	Painting of *Patibet*	-	100		
-	Total	-	300	-	-

Marketing place of shitalpati handicrafts

The patikar families (artisans) are usually selling shitalpati handicrafts at local warehouses, showrooms, fairs, to moneylenders, middlemen and by ferries. The moneylenders, foremen or middlemen also purchase the shitalpati products directly from the house of the patikars at a much lower price. Later it sells to users at a much higher price. This deprives the patikar family from fair price of shitalpati.

Economic importance of murta/shitalpati in Bangladesh

The only raw material for making shitalpati in Bangladesh is patibet made from the stem of murta. Murta plant play an important role in the economy of the country. The Bangladesh Forest Department receives a large amount of revenue from murta resources. It was reported that the average annual revenue of the Bangladesh government from the sale of murta is about five thousand United States Dollar (USD) during the period of 1981-91 (Banik, 2001). Most of shitalpati is used in the country and a small amount is exported abroad. In the country, 175 processing units of shitalpati products worth USD 0.10 million at a production cost of about USD 0.05 million (BSCIC, 1992). The shitalpati handicrafts has provided employment to the artisans or patikars involved in this profession. It was reported the annual value of murta and hogla plants in 1992 was about USD 0.11 million (Basit, 1995). In the country, about 15,000 artisans based in karupara or patikar produce shitalpati from murta with an annual value of around USD 0.59 million (Banglapedia, 2014).

Importance of murta cultivation in the agro-ecosystem of Bangladesh

Murta plant prevents soil erosion and the decaying leaves of the plant mix with the soil and add organic matter to increase the fertility of the soil. It is possible to increase the productivity of land by cultivating this plant on the side of the house, on the side of road, river or canal, in submerged or fallow lands. Murta plant can tolerate salinity and waterlogging. Due to its wide adaptability, the plant can be easily cultivated on any land up and down (Ahmed *et al*., 2007). Abandoned stems or branches of the murta are used as fuel for cooking which reduces deforestation and protects the environment. The leaf sample contained dry matter 26.23%, ash 11.76%, organic matter 88.24%, acid detergent fiber 56.02%, crude protein 13.84%, neutral detergent fiber 79.86% and ether extract 2.23%. The leaves of murta can also be used as fodder for livestock through mixing it with rice straw. However, excess feeding of livestock with murta leaves may cause indigestion of the animal because it contains higher amount of crude protein. The murta plant protect the environment by creating green fences in wetlands. Therefore, it has huge potential to be cultivated in the coastal and low lying areas of the country.

Present status of shitalpati handicrafts in Bangladesh

Analyzing the data obtained from preliminary information, it was observed that in the low-lying areas of the country where the murta plant grows, the patikars (about eight thousand families across the country) are involved in this profession from their ancestors. Talking to the local patikars, it was known that the activities of this cottage industry have been going on for centuries. A huge number of shitalpati had been made before but many patikars have left the business due to low demand and the unfair market price of the shitalpati products. Many artisans make shitalpati products just to meet their needs. Again, if someone orders, they make the products according to the demand. Although the traditional art of shitalpati weaving of Bangladesh has been included by UNESCO in the list of important intangible cultural heritage of the world in 2017 but the shitalpati handicraft is on the verge of extinction due to lack of modern technology, lack of fair price of the products, proper recognition and lack of necessary cooperation in making the products. However, there is a huge demand for environmental friendly natural products (like shitalpati) as an alternative to the non-eco-friendly plastic products. Therefore, it is necessary to promote, export and use advanced technologies for the development of shitalpati based handicrafts in Bangladesh.

Research works so far conducted on shitalpati or murta plant in Bangladesh

Scientists of Regional Agricultural Research Station, Rahmatpur, Barishal of Bangladesh Agricultural Research Institute visited the Bangladesh Forest Research Institute (BFRI), Sholashahar, Chattogram to collect information about the research activities on murta plant by BFRI. According to BFRI, little research work had been conducted on the cultivation of murta plants in the 1980s and 1990s as a minor forest resource. However, research works are yet to be conducted by BFRI on the production of the quality stem of murta plants through improved management practices, management of insect-pests and diseases, making and processing of murta cane and weaving of good quality shitalpati products. As per the directives of Ministry of Agriculture, Bangladesh Agricultural Research Institute, Rahmatpur, Barishal has been executing some research programmes on collection and evaluation of murta germplasm, agronomic research for maximizing the yield and quality of murta plant, and processing (physical and chemical) of murta cane.

Constraints for promotion of shitalpati-based handicrafts in Bangladesh

1) Since there is no research or extension works for the development of shitalpati, the patikars cultivate murta plant and make shitalpati products following traditional practices which is not conducive to the development of shitalpati based cottage industry.

2) In the absence of modern agronomic technologies (in terms of planting of seedlings at the right time, plant spacing, method of planting, fertilizer

management, pruning or sharing, timely harvesting of stem/doga, etc.) the yield of murta plant is low and quality *patibet* (murta cane) is not satisfactory.

3) Murta plants are attacked by different insect-pests like leaf-rolling insects, stem-biting insects, rats, crabs, etc., resulting in reduced yield and quality. Moreover, diseases like stem and foot rot, leaf spots etc. are occurred, which reduce the quality and price of murta cane.

4) Many years old orchards of murta plant (50 years or more) are less productive and do not produce good yield and quality of shitalpati.

5) Due to lacking of modern technology for making and processing patibet, quality patibet is not produced. As a result, the quality of the shitalpati becomes poor and its market value is low.

6) Due to the proliferation of plastic mats in the market at present, the demand and price of shitalpati products are decreasing day by day.

7) The patikars suffer financially as they do not get a fair price for selling their products. That is why the patikars are leaving their original profession and moving to other professions.

8) Although shitalpati is included in the list of important intangible cultural heritage as declared by the UNSECO, but the product is not included in the list of exportable products of the country. That is why the workers involved in making handicrafts are deprived of a fair price and forced to sell at low prices in the country.

9) Absence of proper training, the quality of technique and craftsmanship of patibet production, processing and shitalpati weaving (e.g., weaving technique, design, and craftsmanship is not up to the mark.

10) Most of the patikars make only the shitalpati of traditional design from murta plant stem. However, the patikars do not get high prices for their product due to lacking versatility or diversification of shitalpati products.

11) The patikars usually borrow money (USD 235-588) from various local microfinance and Non- Government Organizations (NGOs) (e.g., Asha, Bangladesh Rural Advancement Committee-BRAC, Uddipan, Thengamara Mohila Sabuj Sangha-TMSS, etc.) at a high-interest rate (13-14%) for the production of shitalpati. Repaying loan installments in every week is very difficult for them.

12) As there is no suitable exhibition or sale center of shitalpati products in the country, local and foreign buyers or tourists are not attracted to buying shitalpati as a part of the world heritage. This hinders the

introduction and development of shitalpati handicrafts at home and abroad.

13) The shitalpati-based cottage industry is located in a very remote area of the country and communications are not well developed. This hinders the development of this industry.

Policy options for improving shitalpati in Bangladesh

1) Integrated research and development programmes should be undertaken on murta plant cultivation, processing, manufacturing, marketing, and promotion of shitalpati products in partnership with the concerned governmental and non-governmental organizations in Bangladesh.

2) Development and extension of suitable modern technologies (e.g., planting time, plant spacing, method of planting, pruning or pruning, fertilizer management, weed control, insect-pest and disease control, stem/doga cutting, cane/beti making, and processing, etc.) for the production of quality murta plant and shitalpati products.

3) The patikars usually weave shitalpati products by hand. It takes a lot of time and labour. Research can be done on mechanization to facilitate the work for making the products with minimum cost, time, and labour.

4) The patikars (workers engaged in making shitalpati) routinely soak and boil the patibet to make it durable and soft and to increase its brightness and smoothness. However, research is needed on the use of other natural or chemical products to make high-quality shitalpati products.

5) Collection, evaluation, and characterization of murta germplasm in different growing areas of the country to develop an improved variety of murta plants for making quality products.

6) Centennial or aged murta gardens are not very productive so they should be removed and new gardens should be established.

7) Instead of shitalpati weaving from murta plant, make versatility or diversification of shitalpati products such as prayer mats, toys, vanity bags, wallets, cushions, seats, wall mats, footwear, vases, pen holder, small boxes, photo frames, mirror frames, table lamps, hand fans, fancy shoes, girls bags, product packaging and so on for value addition of the products. The murta cane can also be used for decorating the walls of the house. This will increase the profitability and income generation of the patikars and other stakeholders involved in the shitalpati handicrafts making.

8) Of the four layers (*peet*, *ati*, *chhota* and *buka*) of murta plant stem, the *peet* and *atibet* can be used for making shitalpati products. The *chhota*

layer can be marketed as a rope for betel leaf garden, cottage shade, shika making and other tying purposes. On the other hand, the buka (pith) layer of murta stem can be used as a raw pulp material for making colorful paper that are used in cottage industries. This will ensure the efficient use of every part of murta plant and the patikars will be benefitted.

9) The murta plant is tolerant to waterlogging and salinity as well as protect soil erosion. Under the changing climatic conditions, the plant will be conducive to the socio-economic development of the poor people living in the low-lying and coastal areas of Bangladesh through the development and adoption of the shitalpati handicrafts. Besides, the cultivation of murta plant will ensure proper use of fallow land, prevent erosion and increase soil fertility.

10) As the production of fodder crops are limited in the waterlogged areas of Bangladesh, therefore murta leaves can be used for livestock fodder purpose.

11) Although the traditional handicrafts of shitalpati weaving have been included in the list of the important intangible cultural heritage of the world by UNESCO, the shitalpati products are not included in the list of export items of Bangladesh. Therefore, for the development of this cottage industry, shitalpati products should be included in the list of exportable items.

12) At present, due to the proliferation of plastic mats, the demand and market price of shitalpati are decreasing day by day. In this case, if people are made aware of the health hazards (allergies, skin diseases, etc.) caused by the use of plastic mat, people will be interested in using shitalpati products made from natural ingredients and the demand for these products will increase.

13) Provide proper training to the stakeholders (e.g. patikars, traders etc.) for enhancing their skills in relation to the production of quality murta cane, cane (*patibet*) making and processing, techniques (weaving, design, and craftsmanship) for making quality shitalpati and other diversified products from murta plant.

14) Infrastructure and road communications should be developed in the industrial areas (such as roads, bridges, culverts, construction of large houses for making cane from murta plants, etc.) for the development of shitalpati-based handicrafts in Bangladesh.

15) Group or association may be formed at local and regional levels with the participation of actual patikars and other stakeholders to supervise or coordinate the activities of the shitalpati-based cottage industry.

16) For the improvement of the shitalpati handicrafts, loans can be provided to the stakeholders (e.g., patikars, traders etc.) with easy terms and conditions or without interest from financial institutions (such as Small and Medium Industries Foundation-SME Foundation, Palli Karma Sahayak Foundation-PKSF, financial assistance from Bangladesh Bank, public-private banks, soft loans from World Bank funds, etc.).
17) For the development of shitalpati handicrafts, all types of products made from murta plants can be exempted from value-added tax (VAT) and income tax.
18) Shitalpati exhibitions or sales centers should be set up in different regions of the country to attract to buy shitalpati at reasonable prices. Besides, stalls of shitalpati products can be set up at the Dhaka International Trade Fair under the direct supervision of patikars and other stakeholders. This will introduce and develop shitalpati-based handicrafts in the country and abroad.
19) Ambassadors or missions of different countries located in Bangladesh can be introduced to the shitalpati handicrafts as the "Intangible Cultural Heritage" declared by UNESCO. This will increase the expansion and export of these natural handicrafts.

Conclusions

The diversification and improvement of the shitalpati handicrafts are essential for maintaining the glorious tradition of the cottage industry in Bangladesh ultimately better socio-economic condition of the shitalpati craftsman. For this, it is necessary to formulate and implement an appropriate action plan (short, medium, and long term) with necessary policies in partnership with various public-private and even international organizations.

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EFFECT OF VARIETY AND PLANT SPACING ON LEAF YIELD OF BOTTLE GOURD IN BANGLADESH

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Abstract

An experiment was conducted in the farmers' field at the Farming System Research and Development site of On-Farm Research Division, Bangladesh Agricultural Research Institute, Elenga, Tangail, during the two consecutive years of *Rabi* (winter) season of 2014-15 and 2015-16 under young Brahmaputra and Jamuna floodplain to find out the suitable variety and planting spacing of bottle gourd for leaf production purpose through increasing twig production and ultimately increasing farmers' income in this region of Bangladesh. The experiment was conducted in Randomized Complete Block Design with six dispersed replications. Three varieties viz., BARI Lau-3, BARI Lau-4, and one local variety were tested with four planting spacing viz., 30 cm × 20 cm, 35 cm × 10 cm, 40 cm ×10 cm, and 40 cm × 20 cm. Among the varieties, the highest average twig yield (37.76 t ha^{-1}) and gross margin (Tk. 468170 ha^{-1}) along with BCR (3.69) were obtained from var. BARI Lau-4 along with 30 cm × 20 cm plant spacing. After the completion of a two-years trial, BARI Lau-4 may be recommended for large scale production following 30 cm x 20 cm spacing for better twig yield and economic benefit.

Keywords: Bottle gourd, spacing, variety leaf yield, gross margin and BCR.

Introduction

Bottle gourd [*Lagenaria siceraria* (Molina) Standl.] is one of the popular vegetables generally grown in the homestead areas of Bangladesh. But now a days it is commercially grown in the crop fields. Bottle gourd cultivation is increasing due to its high yield potential and steady market price. The fruits contain 0.2% protein, 2.9% carbohydrates, 0.5% fat, and 11 mg of vitamin C per 100g fresh weight (Aykroyd, 1963). A 100 g bottle gourd leaves contain 109 Kcal energy, 90.2 g water, 2.5 g protein, 0.6 g fat, 0.6 g carbohydrate, 4.4 g total dietary fibre, 1.7 g ash, 94 mg Ca, 3.1 mg Fe, 69 mg Mg, 28 mg P, 276 mg K, 41 mg Na, 0.49 mg Zn, 0.15 mg Cu, 198 micro gram Vitamin A, 0.07 mg Thiamin, 0.17 mg Riboflavin, 1.4 mg Niacin, 0.19 mg Vitamin B6, 73 micro gram folate, 47.7 mg Vitamin C (Shaheen *et al*., 2013). According to Rahman (2003), among all the cucurbits, the bottle gourd is the only plant that contains the highest choline level

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along with required metabolic precursors for brain function. At present land under vegetable production in Bangladesh is 4,49,742 ha, yielding 45,76225 ton. Among the total vegetable production, bottle gourd leaf contributes 31126 t from 6816 ha of land (BBS, 2021). Recently the leaves and twigs of bottle gourd have become a very popular vegetable all over the country. Its demand is increasing day by day. It has a strong possibility of becoming the most popular leafy vegetable. Farmers' can easily produce and sell this leafy vegetable at a high price and get a higher benefit within a short period of time. There is no recommended variety of bottle gourd available for leaf production. Farmers can grow the following BARI released bottle gourd varieties for leaf production: BARI Lau-2, BARI Lau-3, and BARI Lau-4. The leaf of the bottle gourd can reduce the nutritional deficiency and the farmers will be economically benefitted (Rahman *et. al*., 2008). Spacing is one of the most important factors for crop production. Baloch et al. (2002) observed that wider plant spacing or lowered densities increased the nutrient area per plant which results in developed morphological characters. El-Badaway and Mehasen, 2012, revealed that the closest spacing gave the tallest plant due to greater competition for space and light and thereby forcing the plants to grow taller. On the other hand, wider spacing ensures the basic requirements but decrease the total number of plants as well as total yield. Yield may be increased up to 25% by using optimum spacing (Bansal, et al., 1995). Along with the mentioned benefits there are also other benefits of proper plant spacing like seedling age, soil quality, nutrient intake, disease management, weeding, irrigation, ease of harvest, increased yield, and so on. Therefore, the present study was undertaken to find out the best suitable variety and planting spacing of bottle gourd for leaf purposes in the young Brahmaputra and Jamuna floodplain regions of Bangladesh.

Materials and Methods

The experiment was conducted at the FSRD (Farming System Research and Development) site, of On-Farm Research Division, Bangladesh Agricultural Research Institute, Elenga, Tangail, during rabi 2014-15 and 2015-16 under AEZ# 8 (Young Brahmaputra and Jamuna Floodplain). The study site is located at latitude 24°20'9.2904" North and longitude 89°54'30.6972" East at a height of 15 m above sea level. The maximum, minimum temperature (^{o}C), and total rainfall (mm) are presented in figure 1 (BMD, 2016). The experimental location was prepared one month before transplanting. The land was fertilized with 5 t ha^{-1} cow dung and 81, 35, 75, 18, 5, and 2 kg ha^{-1} of N, P, K, S, Zn, and B, respectively. All cow dung, 1/5 N, P, ½ K, S, Zn, and B were applied during final land preparation. The remaining K and N were applied in four splits after each harvest of twigs. After that, the soil of the site was cleared, ploughed, leveled, and divided into plots. The experiment was laid out in Randomized Complete Block Design with six dispersed replications. The unit plot size was 4 m × 2 m. Three varieties viz., V_1: BARI Lau-3, V_2: BARI Lau-4, and V_3: Local variety with four planting spacing viz., S_1: 30 cm × 20 cm, S_2: 35 cm × 10 cm, S_3: 40 cm × 10 cm and S_4: 40 cm × 20 cm were selected as treatments. The seeds were sown on 27 to 28 October 2014 and 13 to 14 October 2015 in 2014 and 2015, respectively. Weeding and all other intercultural operations were done as and when necessary. Insecticides, fungicides, and other pesticides were applied when required. Data collection started from 35 DAS and continued to 95 DAS. The twigs were harvested five times (at 12-15 days intervals). Data on length of twigs, bundle/plot, and twig yield/plot were recorded during harvesting. After collecting the data from different parameters were statistically analyzed using the R Project for Statistical Computing Software version (4.1.1) (R Core Team, 2021). The cost and return analysis was conducted according to the market value of inputs and produce.

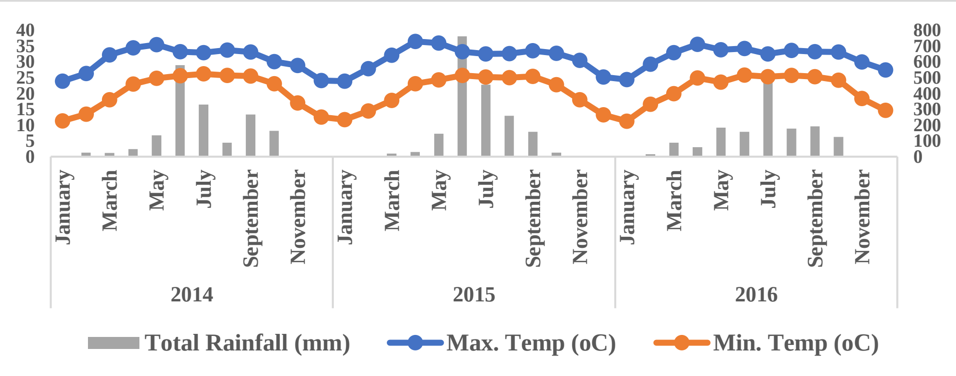

Fig. 1. Maximum, minimum temperature (ºC), and total rainfall (mm) during 2014-15 and 2015-16 at FSRD site, Elenga, Tangail.

Results and Discussion

Effect of variety on yield and yield attributes of bottle gourd

The effect of bottle gourd varieties on yield and yield attributes was analyzed and summarized in table 1. The analysis was found that in season 2014-15, the length of twigs of BARI Lau-3 (V_1), BARI Lau-4 (V_2), and local variety (V_3) was statistically non-significant. But in the 2015-16 seasons it was found that BARI Lau-4 had the highest length of twigs, which is significantly different from other varieties.. In the case of the number of bundles per plot, it was found that in season 2014-15, the highest number of bundles per plot was observed in BARI Lau-4 followed by local variety and BARI Lau-3. However, in season 2015-16, it was observed that the maximum number of bundles of twigs per plot was found in BARI Lau-4, followed by BARI Lau-3 and local variety. In season 2014-15, individual bundle weights of twigs of three varieties were not significantly different but in season 2015-16 performances of varieties were significantly different. The maximum individual bundle weight of twigs was found in BARI Lau-4 followed by BARI Lau-3 and local variety. Twig weight per plot was significantly affected by varieties. In the season 2014-15, analysis of twig weight per plot showed that the higher weight of twig per plot in BARI Lau-4 followed by local variety and BARI Lau-3. In season 2015-16 it was found that higher weight of twig per plot in BARI Lau-4 was similar to the result of the previous season but the performance of BARI Lau-3 was comparatively better than local variety.. Yield analysis revealed that in season 2014-15, yield of twigs was not significantly affected by the variety but season (2015-16) it was observed that the twig yields were significantly affected by the variety. The highest twig yield was found in BARI Lau-4 which was significantly different from the other two varieties. The lowest twig yield was found in the local variety and the moderate twig yield in BARI Lau-3. By analyzing the two season's data it was showed that the highest twig yield was obtained from BARI Lau-4.

Table 1. Twig yield and yield contributing attributes of bottle gourd as influenced by variety at FSRD site, Elenga, Tangail during 2014-15 and 2015-16

Variety	Length of the twig (cm)		Bundle plot^{-1} (no.)		Individual bundle weight (kg)		Twig weight plot^{-1} (kg)		Yield (t ha^{-1})	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
V_1	50.75 a	52.50b	44.90b	63.75b	0.518a	0.516ab	22.27b	32.11b	25.89a	37.10b
V_2	51.75a	54.62a	48.07a	67.75a	0.529a	0.522a	24.43a	34.92a	28.40a	40.60a
V_3	52.25a	52.62b	46.75ab	55.87c	0.524a	0.506b	23.44ab	27.73c	27.25ab	31.66c
$LSD_{0.05}$	2.20	1.62	2.33	3.96	0.01	0.01	1.49	2.48	1.73	3.07
CV (%)	5.88	4.70	4.54	5.76	2.43	2.80	5.80	7.14	6.85	7.64

Note: V= Variety, V_1= BARI Lau-3; V_2= BARI Lau-4 and V_3= Local variety.

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

Effect of planting spacing on yield and yield attributes of bottle gourd

The effect of planting spacing on yield and yield attributes of bottle gourd was analyzed(table 2). The length of twigs was not significantly affected by the planting spacing during 2014-15, but in season 2015-16 it was found that the highest length of twigs was found in 35 cm x 10 cm spacing and the lowest twig length in 40 cm x 20 cm spacing, but in the case of spacing 30 cm x 20 cm and spacing 40 cm x 10 cm was found statistically similar. The number of bundles per plot was also statistically different depending on planting spacing. In 2014-15, the maximum number of bundles per plot was obtained with a 30 cm x 20 cm (S_1) followed by 35 cm x 10 cm (S_2) and 40 cm x 10 cm (S_3) planting spacing. But the minimum number of bundles per plot was obtained using 40 cm x 20 cm (S_4) planting spacing. On the other hand, in season 2015-16, planting spacing of 30 cm x 20 cm, 35 cm x 10 cm, and 40 cm x 10 cm showed a statistically similar but the lowest number of bundles per plot with 40 cm x 20 cm plant spacing. Planting spacing had a significant effect on individual bundle weight. In season 2014-15 the maximum weight of an individual bundle was obtained from 40 cm x 20 cm followed by 40 cm x 10 cm and 35 cm x 10 cm planting spacing and the minimum weight of an individual bundle from 30 cm x 20 cm planting spacing. In season (2015-16) revealed that 40 cm x 20 cm planting spacing provided the maximum performance, followed by 30 cm x 20 cm and 40 cm x 10 cm planting spacing and the lowest from 35 cm x 10 cm planting spacing. Twig yield per plot and twig yield per hectare were also significantly affected by planting spacing. In season 2014-15 was found that the maximum twig yield per plot and per hectare was obtained from a 30 cm x 20 cm followed by 35 cm x 10 cm and 40 cm x 10 cm spacing treatments. But the lowest twig yield per plot and per hectare was obtained from the 40 cm x 20 cm spacing treatment. Whereas, in season 2015-16 was found that the spacing effect was statistically non-significant. In the case of spacing effect on yield and yield attributes of bottle gourd, it can be concluded that the spacing effect S_1 (30 cm x 20 cm) performed better than any other planting spacing treatments. The results of the spacing effect are in conformity with the findings of Kabir *et al*. (2013) and Naher (2015).

Table 2. Yield and yield attributes of bottle gourd as influenced by planting spacing at FSRD site, Elenga, Tangail during 2014-15 and 2015-16

Spacing	Length of the twig (cm)		Bundle plot^{-1} (no.)		Individual bundle weight (kg)		Twig weight plot^{-1} (kg)		Yield (t ha^{-1})	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
S_1	52.50a	53.50ab	51.93a	64.33a	0.510c	0.512ab	25.54a	32.36a	29.69a	37.42a
S_2	51.17a	54.00a	48.47b	65.00a	0.517bc	0.507b	24.09ab	32.35a	28.01ab	37.43a
S_3	50.83a	53.50ab	45.30c	61.83ab	0.529ab	0.512ab	22.98b	31.10a	26.71b	35.82a
S_4	51.83a	52.00b	40.60d	58.67b	0538a	0.529a	20.91c	30.54a	24.31c	35.14a
$LSD_{0.05}$	2.54	1.87	2.69	4.57	0.016	0.02	1.72	2.87	2.00	3.54
CV (%)	5.88	4.70	4.54	5.76	2.43	2.80	5.80	7.14	6.85	7.64

Note: S= Spacing, S_1= 30 cm x 20 cm; S_2= 35 cm x 10 cm; S_3= 40 cm x 10 cm and S_4= 40 cm x 20 cm. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

Interaction effect of variety and spacing on yield and yield attributes of bottle gourd

Interaction effects between variety and spacing of planting were significant for yield and yield attributes, which were analyzed and summarized in Table 3. In the first season (2014-15) analysis was found that the maximum length of the twig was observed in local variety planted at a spacing of 30 cm x 20 cm which was statistically identical to all of the interaction effects except for BARI Lau-3 planted at a spacing of 40 cm x 10 cm. The lowest length of the twig was observed in BARI Lau-3 planted at a spacing of 40 cm x 10 cm. I season (2015-16) maximum twig length was observed in var.BARI Lau-4, planted at a spacing of 30 cm x 20 cm which was at par to same variety planted at 35 cm x 10 cm, 40 cm x 10 cm spacing and with BARI Lau-3 planted at 35 cm x 10 cm, 40 cm x 10 cm, 40 cm x 20 cm and also similar to local variety planted at 30 cm x 20 cm, 35 cm x 10 cm, 40 cm x 10 cm spacing. The lowest length of the twig was observed in bottle gourd local variety planted at a spacing of 40 cm x 20 cm. In season 2014-15, BARI Lau-4 planted at a spacing of 30 cm x 20 cm provided the maximum number of bundles per plot which was statistically identical to the same variety planted at 35 cm x 10 cm spacing and local variety planted at a spacing of 30 cm x 20 cm. The lowest number of bundles per plot was obtained from BARI Lau-3 planted at a spacing of 40 cm x 20 cm. Similarly, in the following season (2015-16), the number of bundles per plot was mximum BARI Lau-4 planted at a spacing of 30 cm x 20 cm while local variety planted at 40 cm x 20 cm provided the lowest number of bundles per plot. In the case of individual bundle weight of twigs, in the first season (2014-15), the highest individual bundle weight of twigs was observed in BARI Lau-4.The lowest individual bundle weight of a twig was obtained from BARI Lau-3 planted at a spacing of 30 cm x 20 cm. In the season 2015-16, the maximum individual bundle weight of twigs was found in BARI Lau-3 followed by BARI Lau-4 planted at a spacing of 40 cm x 20 cm and BARI Lau-3 along with planting spacing of 30 cm x 20 cm, 35 cm x 10 cm, 40 cm x 10 cm, BARI Lau-4 planted at 30 cm x 20 cm, 35 cm x 10 cm, 40 cm x 10 cm and local variety planted at 40 cm x 10 cm, 40 cm x 20 cm spacing. The lowest weight of an individual bundle of the twig was found in local variety planted at a spacing of 30 cm x 20 cm and 35 cm x 10 cm. BARI Lau-4 planted at a spacing of 30 cm x 20 cm gave the highest twig yield per plot and per hectare in both seasons (2014-15 and 2015-16), which was statistically identical to BARI Lau-4 planted at a spacing of 35 cm x 10 cm and local variety planted at a spacing of 30 cm x 20 cm in season 2014-15. In case of season 2015-16, BARI Lau-3 planted at a spacing of 35 cm x 10 cm and BARI Lau-4 planted at a spacing of 35 cm x 10 cm, 40 cm x 10 cm were also statistically identical. But in 2014-15, BARI Lau-3 planted at a spacing of 40 cm x 20 cm gave the lowest twig yield in both cases, and in the case of season 2015-16, local variety planted at 40 cm x 10 cm and 40 cm x 20 cm gave the lowest twig yield per plot and per hectare. Finally, revealed that the maximum average twig yield per hectare was found in BARI Lau-4 planted at a spacing of 30 cm x 20 cm. In the case of the spacing effect similar results were also reported by Samih (2008), Kabir *et al*. (2013), and Shivani *et al*. (2019).

Cost and return analysis for different varietal and planting spacing effects

The fundamental aim of the research was to find out the cost effective and profitable cultivation technique to the farmers. In table 4, showed the comparison of average twig yield, gross margin, and BCR among different treatments. In table 4, the highest average twig yield (37.76 t ha^{-1}) was obtained from the interaction effect of BARI Lau-4 along with planting spacing of 30 cm x 20 cm and the lowest average twig yield (28.28 t ha^{-1}) from the local bottle gourd variety along with planting spacing of 40 cm x 20 cm. In the case of gross margin, it was found that the maximum gross margin (Tk. 468170 ha^{-1}) along with the highest BCR (3.69) was obtained from V_2S_1 treatment (BARI Lau-4 along with planting spacing of 30 cm x 20 cm). The minimum gross margin (Tk. 307095 ha^{-1}) was obtained from the V_3S_4 treatment (Table 4), along with the lowest BCR (2.77).

Table 3. Interaction effects of varieties and spacing on the yield and yield attributes of bottle gourd during 2014-15 and 2015-16

Variety and spacing	Length of the twig (cm)		Bundle plot^{-1} (no.)		Individual bundle weight (kg)		Twig weight plot^{-1} (kg)		Yield (t ha^{-1})		
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	Average
V_1S_1	52.00 ab	51.00 bc	49.40 bcd	64.50 abcd	0.497 c	0.505 ab	23.59 bc	31.52 bcd	27.43 bc	36.45 bcd	31.94
V_1S_2	50.50 ab	53.50 ab	47.90 bcde	70.00 ab	0.520 abc	0.505 ab	23.92 bc	34.40 ab	27.81 bc	40.30 ab	34.05
V_1S_3	49.50 b	52.50 abc	43.70 ef	61.00 cdef	0.530 ab	0.520 ab	22.18 cd	31.16 bcd	25.79 cd	35.82 bcd	30.80
V_1S_4	51.00 ab	53.00 abc	38.60 g	59.50 def	0.525 abc	0.535 a	19.37 d	31.37 bcd	22.52 d	36.12 bcd	29.32
V_2S_1	51.00 ab	55.50 a	54.70 a	71.00 a	0.520 abc	0.530 ab	27.53 a	37.31 a	32.00 a	43.52 a	37.76
V_2S_2	52.00 ab	55.00 a	51.00 abc	68.00 abc	0.520 abc	0.515 ab	25.52 ab	34.64 ab	29.67 ab	40.30 ab	34.98
V_2S_3	52.00 ab	55.00 a	45.20 def	69.50 ab	0.532 ab	0.510 ab	23.08 bc	34.83 ab	26.83 bc	40.52 ab	33.67
V_2S_4	52.00 ab	53.00 abc	41.40f g	62.50 bcde	0.545 a	0.535 a	21.58 cd	32.88 abc	25.09 cd	38.03 abc	31.56
V_3S_1	54.50 a	54.00 ab	51.70 ab	57.50 def	0.512 bc	0.500 b	25.50 ab	28.25 cd	29.65 ab	32.27 cd	30.96
V_3S_2	51.00 ab	53.50 ab	46.50 cde	57.00 def	0.513 bc	0.500 b	22.83 bc	28.00 cd	26.55 bc	31.98 cd	29.26
V_3S_3	51.00 ab	53.00 abc	47.00 cde	55.00 ef	0.525 abc	0.505 ab	23.67 bc	27.30 d	27.51 bc	31.12 d	29.31
V_3S_4	52.50 ab	50.00 c	41.80 fg	54.00 f	0.545 a	0.517 ab	21.77 cd	27.37 d	25.31 cd	31.26 d	28.28
$LSD_{0.05}$	4.40	3.24	4.66	7.92	0.03	0.03	2.98	4.96	3.47	6.13	-
CV(%)	5.88	2.76	4.54	5.76	2.43	2.80	5.80	7.14	5.80	7.64	-

Note: VS= Variety and spacing. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

Table 4. Cost and return analysis of bottle gourd varieties and spacing interaction during 2014-15 & 2015-16

Treatments	Average Twig yield (t ha^{-1})	Gross return (Tk. ha^{-1})	Total cost (Tk. ha^{-1})	Gross margin (Tk. ha^{-1})	BCR
V_1S_1	31.94	542980	173750	369230	3.13
V_1S_2	34.05	578935	173750	405185	3.33
V_1S_3	30.80	523685	173750	349935	3.01
V_1S_4	29.32	498440	173750	324690	2.87
V_2S_1	37.76	641920	173750	468170	3.69
V_2S_2	34.98	594745	173750	420995	3.42
V_2S_3	33.67	572475	173750	398725	3.29
V_2S_4	31.56	536520	173750	362770	3.09
V_3S_1	30.96	526320	173750	352570	3.03
V_3S_2	29.26	497505	173750	323755	2.86
V_3S_3	29.31	498355	173750	324605	2.86
V_3S_4	28.28	480845	173750	307095	2.77

Note: The market price of different inputs (Tk kg^{-1}): Urea- 16, TSP (Triple Super Phosphate)- 22, Muriate of Potash (MoP)- 15, Gypsum-13, Zinc Sulphate-200, Boric acid-400, Cowdung- 2, Labour wage- 300 day^{-1} person^{-1}, land leasing cost Tk.75,000 . ha^{-1}year^{-1}. The market price of twig (Tk. kg^{-1}):17.

Conclusion

The highest average bottle gourd twig yield (37.76 t ha^{-1}) was obtained from bottle gourd var. BARI Lau-4 along with planting spacing of 30 cm x 20 cm and the lowest average twig yield (28.28 t ha^{-1}) from the local bottle gourd variety along with planting spacing of 40 cm x 20 cm.

In the case of gross margin, the maximum gross margin (Tk. 468170 ha^{-1}) along with the highest BCR (3.69) was obtained from V_2S_1 treatment (BARI Lau-4 along with planting spacing of 30 cm x 20 cm). After the completion of a two year trial, var. BARI Lau-4 could be recommended for large scale production following 30 cm x 20 cm spacing in the Tangail region of Bangladesh for better twig yield and economic benefit.

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BROCCOLI CULTIVATION WITH ORGANIC AND INORGANIC SOURCES OF NITROGEN AND ITS EFFECTS ON THE NUTRIENTS BALANCE

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Abstract

The experiment was conducted on broccoli var. Premium Crop at Bangabandhu Sheikh Mujibur Rahman Agricultural University during the period from November, 2014 to March, 2015 with 24 treatment combinations (IPNS based) comprised with 4 inorganic sources of nitrogen as 140, 160 and 180 kg USG N ha^{-1} and 180 kg PU N ha^{-1} and 6 levels of organic nitrogen sources as i) 1 ton mustard oil cake ha^{-1}; ii) 2 ton mustard oil cake ha^{-1}; iii) 2 ton poultry manure ha^{-1}; iv) 3 ton poultry manure ha^{-1}; v) 3 ton cow dung ha^{-1}and vi) 5 ton cow dung ha^{-1} were considered. Results revealed that integration of organic and inorganic N sources have a little influence on soil physical and chemical properties of soil and its affects on soil nutrient balance. Post harvest soil organic carbon content was significantly influenced by the organic-inorganic N management approach, but no influence on soil pH, bulk density and partical density. However, a significant effect was found on post harvest soil nutrient balance where K showed a (-) ve balance but N with a little exception, P, S and B showed (+) ve balance which was affected by the organic-inorganic integrated N management approach. But better soil physical and chemical properties as well as higher (+) ve nutrient balance was found with higher rate of USG-organic manure as compared to that of PU-organic manure integration.

Keywords: Broccoli, Soil Nutrient Status, Nutrient Balance, Organic and Inorganic Nitrogen.

Introduction

Integrated N management approach has a good positive response on improvement of soil fertility as well as soil physical and chemical properties. According to Mishra *et al.* (2014), integrated nutrient management aims to cultivate a land where the soil should remain sustainable with maximum production of quality crop. Soil organic matter is a key factor for sustainable soil

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fertility and crop productivity. Reganold *et al.* (1990) showed that a suitable combination of organic and inorganic source of nutrients is necessary for sustainable agriculture that can ensure high quality food production. Ali *et al.* (2009) reported that organic matter undergoes mineralization with the release of substantial quantities of N, P, and S and smaller amount of micronutrients. Soil nutrient status was influenced by the application of both organic and inorganic sources of N. Bhandari *et al.* (1992) reported that a combined use of organic manure with chemical fertilizer increased organic carbon status of the soil. The 100% NPK fertilizers and their combined use with organic N sources also increased the available N and P by 5.22 and 0.8-3.8 kg

ha^{-1}, respectively from their initial values. Basel *et al*. (2008) observed that electrical conductivity of soil and organic matter were increased by increasing levels of organic fertilizer except soil pH. Priyanka *et al.* (2017) revealed that the integration of organic and inorganic fertilizers had a marked effect in enhancing yield as well as productivity of broccoli with maximum net returns. Nahar *et al.* (2021) reported that among different organic and inorganic sources of nutrients, application of litter showed the best performances regarding all the growth and yield contributing characters of Chinese broccoli. Sarker and Singh (1997) observed that alone or combined application of organic with inorganic fertilizers increased the level of soil organic carbon as well as the total N, P and K content. Hoque *et al.* (2007) reported that various organic manures influenced post-harvest soil pH, organic matter, total N, available P, exchangeable K and available S contents. As soil organic matter were increased by increasing organic fertilizer, efficient management through integrated plant nutrition system (IPNS) is a prerequisite to improve soil productivity for achieving higher yield of broccoli. Therefore, the experiment was undertaken to assess the effect of different levels of organic and inorganic sources of nitrogen on the post harvest soil nutrient status and nutrient balance in broccoli field.

Materials and Methods

Location and soil

The experiment was conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh during November, 2014 to March, 2015. Soil texture of the experimental field is silty clay loam having a poor physical property(Table 1), that belongs to the agro-ecological zone Madhupur Tract (AEZ 28). Initial soil samples were collected from the experimental plots; analyzed to different physical and chemical properties in the laboratory of the Department of Soil Science, BSMRAU and the analytical results are presented in Table 1.

Table 1. Physico-chemical properties of soil of the experimental field

Physical properties of soil		Chemical properties of soil	
Soil properties	Analytical value	Soil properties	Analytical value
Particle size distribution	Sand (%) : 17.8	Soil pH	5.97
	Silt (%) : 45.6	Organic carbon (%)	0.96
	Clay (%) : 36.6	Total N (%)	0.083
Soil texture	Silty clay loam	Available P (µg g^{-1})	15.14
Bulk density (g cm^{-3})	1.34	Exchangeable K (meq $100g^{-1}$ soil)	0.298
Particle density (g cm^{-3})	2.61	Available S (µg g^{-1})	11.878
Porosity (%)	48.7	Available B (µg g^{-1})	0.182
Field capacity (%)	28.67	CEC (meq $100g^{-1}$ soil)	12.67

Fully decomposed mustard oil cake, poultry manure and cow dung were used as organic sources of nitrogen and samples from these organic sources were collected and analyzed. Analytical values of these materials are presented in Table 2

Table 2. Nutrient status and moisture content of cow dung, poultry manure and mustard oil cake

Sample	Nutrient content (oven dry basis)				
	Moisture (%)	N (%)	P (%)	K (%)	S (%)
Mustard oil cake (OC)	18.88	5.32	0.83	0.71	0.66
Poultry litter (PM)	48.57	1.72	1.29	0.82	0.38
Cow dung (CD)	41.53	1.35	1.01	0.68	0.24

The experiment was designed in factorial randomized complete block (RCB) with three replications having 24 treatment combinations. Three doses of USG (@ 140, 160 and 180 kg N ha^{-1}) and one dose of PU (@ 180 kg N ha^{-1}) as inorganic sources of nitrogen combined with 2 levels of 3 organics as i) 1 ton OC ha^{-1}; ii) 2 ton OC ha^{-1}; iii) 2 ton PM ha^{-1}; iv) 3 ton PM ha^{-1}; v) 3 ton CD ha^{-1} and vi) 5 ton CD ha^{-1} were considered. From these levels 24 (IPNS based) treatment combinations were comprised as- T_1: USG-$N_{140}OC_1$; T_2: USG-$N_{140}OC_2$; T_3: USG-$N_{140}PM_2$; T_4: USG-$N_{140}PM_3$; T_5: USG-$N_{140}CD_3$; T_6: USG-$N_{140}CD_5$; T_7: USG-$N_{160}OC_1$; T_8: USG-$N_{160}OC_2$; T_9: USG-$N_{160}PM_2$; T_{10}: USG-$N_{160}PM_3$; T_{11}: USG-$N_{160}CD_3$; T_{12}: USG-$N_{160}CD_5$; T_{13}: USG-$N_{180}OC_1$; T_{14}: USG-$N_{180}OC_2$; T_{15}: USG-$N_{180}PM_2$; T_{16}: USG-$N_{180}PM_3$; T_{17}: USG-$N_{180}CD_3$; T_{18}: USG-$N_{180}CD_5$; T_{19}: PU-$N_{180}OC_1$; T_{20}: PU-$N_{180}OC_2$; T_{21}: PU-$N_{180}PM_2$; T_{22}: PU-$N_{180}PM_3$; T_{23}: PU-$N_{180}CD_3$ and T_{24}: PU-$N_{180}CD_5$. A blanket dose of other fertilizers were used as per recommendation of the crop @ 53, 83, 20, 2.0, 1 and 0.8 kg P, K, S, Zn, B and Mo ha^{-1}, respectively in the form of TSP, MoP, gypsum, zinc oxide, boric acid and sodium molybdate.

Additional nutrients were supplied from inorganic sources adjusting per IPNS based recommendation after getting these from organic sources. Broccoli variety "Premium Crop" a hybrid variety of broccoli by TAKI Seed Company, Japan was used as a test crop. After proper land preparation, 25 day old seedlings were transplanted in lines with a distance from row to row and plant to plant 60 and 45 cm, respectively.

Soil sample collection and analytical procedure

At the beginning of the experiment, soil samples were collected from each unit plots for analysis of both physical and chemical properties. For each plot 5 samples from 0-15 cm depth were randomly collected, mixed well, air-dried, ground and sieved through a 2 mm (10 mesh) sieve. At the same time, undisturbed soil samples from 0-15 cm depth were collected for determination of soil bulk density. Samples were analyzed for particle size distribution, particle density, bulk density, pH, organic C, total N, available P, exchangeable K, available S and B (Table 2). Similarly, post harvest soil samples of 0-15 cm depth were also collected from each plot and samples were air-dried, ground, sieved through a 2 mm (10 mesh) sieve and were analyzed for particle density, bulk density pH, organic matter, total N, available P, exchangeable K, available S and B. Particle size analyses of soil was done by Hydrometer Method (Black, 1965) and the textural class was determined by plotting the values of % sand, % silt and % clay to the Marshall's triangular coordinate following the USDA system

Particle density of soil was determined by Pycnometer Method (Black, 1965) following the formula:

$$\text{Particle density } (\rho_s) = \frac{\text{Weight of oven dry soil}}{\text{Volume of soil (solid)}} \text{ g/cc}$$

Bulk density of soil was determined by Core Sampler Method following the formula

$$\text{Bulk density } (\rho_b) = \frac{\text{Weight of oven dry soil}}{\text{Total volume of soil}} \text{ g/cc}$$

Porosity of soil was calculated from the following formula:

$$\text{Total porosity (\%)} = 1 - \frac{\rho_b}{\rho_s} \times 100$$

Where, ρ_b=Bulk density (g/cc)

ρ_s=Particle density (g/cc)

Analytical procedures of soil chemical properties

Glass electrode pH meter was used to measure soil pH using soil-water suspension of 1: 2.5 as described by Jackson (1962). Soil organic carbon was determined following the wet oxidation method according to Page *et al.* (1982) and the organic matter content was calculated by multiplying the % organic carbon with the Van Bemmelen factor 1.73(Piper, 1950).Flame-photometer (Atomic absorption spectrophotometer, model No. Hitachi, Japan) was used to determine cation exchange capacity (CEC) followed by ammonium acetate extraction method. Total N of soil was estimated following the micro-Kjeldahl method (Jackson, 1973). Available P was determined colorimetrically followed by sodium bicarbonate extraction method (Olsen *et al.*, 1954). Exchangeable potassium of soil was determined from ammonium acetate (1N NH_4OAC) extract as described by Jackson (1973) using flame-photometer (Atomic absorption spectrophotometer, model No. Hitachi, Japan). Available sulphur was determined by extracting the samples with $CaCl_2$ (0.15%) solution tubidimetrically **(**Page *et al.*, 1982). For determination of total B content dried plant materials were digested with concentrated HNO_3 and $HClO_4$ (Par-chloric acid) mixture followed by adding curcumin, H_2SO_4 plus methanol solution (Hunter, 1980) and concentration was measured using double beam spectrophotometer (Model no. 200-20, Hitachi, Japan) at 555 nm wave length.

To calculate apparent or partial N, P, K and S balance a simplified method was used based on major inputs like fertilizer, manures etc and outputs (above ground plant uptake. Calculation of apparent or partial net nutrient balance was done using the following formula:

Apparent/partial nutrient balance (kg ha^{-1}) = Nutrient input (kg ha^{-1}) -Nutrient output (kg ha^{-1})

According to experimental design treatmentwise data on different soil and plant parameters were recorded time to time throughout the cropping season. Collected data were tabulated with the help of Microsoft Office Excel (2010) and analyzed statistically using statistical program MSTATC. Variations among the treatment means were separated using Duncan Multiple Range Test (DMRT) at 5% levels of probability.

Results and Discussion

Effect of organic and inorganic sources of nitrogen on head yield andpost harvest soil physico-chemical properties in broccoli field

Head yield

The head yield was published earlier by Hussain *et al.* (2021). According to them the maximum head yield (14.75 tonha^{-1}) was recorded with USG-N_{160}× OC_2 followed by USG-N_{180}×OC_2 (14.48 ton ha^{-1}), USGN_{160}×PM_3 (13.84 ton ha^{-1}) and PU-N_{180}×PM_3 (13.72 ton ha^{-1}) and the lowest yield (11.87 ton ha^{-1}) from USG-N_{140}×CD_3.

Table 3. Effect of different forms and levels of organic and inorganic sources of nitrogen on soil pH and organic carbon

Treatment	Soil pH		Organic carbon (%)	
	Initial	Post harvest	Initial	Post harvest
USG-N_{140}×OC_1	5.86	5.75	0.95i	1.01c
USG-N_{140}×OC_2	5.91	5.78	0.97fgh	1.05bc
USG-N_{140}×PM_2	5.85	5.76	1.00bc	1.03c
USG-N_{140}×PM_3	5.84	5.81	1.01a	1.04bc
USG-N_{140}×CD_3	5.83	5.86	1.01ab	1.04bc
USG-N_{140}×CD_5	5.84	5.80	0.99c	1.09ab
USG-N_{160}×OC_1	5.83	5.80	0.96fgh	1.04bc
USG-N_{160}×OC_2	5.85	5.82	0.96hi	1.05bc
USG-N_{160}×PM_2	5.86	5.80	0.97fgh	1.03c
USG-N_{160}×PM_3	5.93	5.90	0.98cde	1.13a
USG-N_{160}×CD_3	5.96	5.87	1.00bc	1.01c
USG-N_{160}×CD_5	5.81	5.78	0.98def	1.11a
USG-N_{180}×OC_1	5.78	5.77	0.96ghi	1.01c
USG-N_{180}×OC_2	5.82	5.80	0.97efg	1.05bc
USG-N_{180}×PM_2	5.81	5.78	1.00bc	1.09ab
USG-N_{180}×PM_3	5.82	5.81	1.01ab	1.13a
USG-N_{180}×CD_3	5.85	5.82	1.00bc	1.04bc
USG-N_{180}×CD_5	5.84	5.77	0.97efg	1.11a
PU-N_{180}×OC_1	5.85	5.76	0.97efg	1.05bc
PU-N_{180}×OC_2	5.86	5.78	0.97fgh	1.04bc
PU-N_{180}×PM_2	5.86	5.79	0.94i	1.03c
PU-N_{180}×PM_3	5.95	5.89	0.98cde	1.04bc
PU-N_{180}×CD_3	6.04	5.85	0.99cd	1.01c
PU-N_{180}×CD_5	5.92	5.79	0.98def	1.03c
CV (%)	1.22	1.12	1.29	2.23
SE ± 0.05	0.041	0.037	0.005	0.016

Means followed by common letters are statistically similar to each other at 5% level of provability by DMRT

Soil pH

Soil pH value at the beginning and after harvest are presented in Table 3. The post harvest soil pH showed a little variation among the treatments and it varied within the range of 5.75 to 5.90. The highest post harvest soil pH value (5.90) was recorded from the treatment USG-N_{160}× PM_3 whereas the lowest value (5.75) in treatment USG-N_{140}×OC_1. The result revealed that the lower pH value was noticed where inorganic nutrient was applied with mustard oil cake but with PM its pH increased slightly, whereas cow dung showed the intermediate pH value. The higher values of pH with PM may be due to more base cation (Ca^{+2}). Sanwal *et al.* (2007) also reported that the application of farm yard, poultry and pig manure considerably reduced the soil acidity.This finding also supported by Pathak *et al*. (2005) who found the higher soil pH in organic plots as compared to combine dose of NPK with farm yard manure. Organic sources help in addition of basic cations on its decomposition and production of bi-carbonate ion due to root respiration. This might be due to relatively higher buffering capacity of soil based on its high carbonate contents that can fix any change in soil pH during organic matter decomposition (Wong *et al*., 1999).

Organic carbon

Data on organic carbon content of the initial and post harvest soil presented in Table 3. Effect of organic manures (CD, PM and OC) along with chemical fertilizers was found significant. The maximum organic carbon content (1.13%) in post harvest soil was found in the treatment USG-N_{180}×PM_3 and USG-N_{160}×PM_3 followed by USG-N_{160}×CD_5 (1.11), but lowest (1.01 %) in USG-N_{140}×OC_1 and USG-N_{180}×OC_1. It was seen from the result that among the treatments receiving CD, PM and OC, poultry manure contributed for higher organic matter. Initial soil organic carbon status was ranged from 0.94 to 1.01 %, which increased due to the addition of organic manures. Application of different amounts of organic manure with or without inorganic fertilizer were significantly increased organic matter content in the soil. Similar informations were reported by (Al-Tarawneh, 2005).

Bulk density of soil

Among the physical properties of soil, bulk density is slightly influenced by the applied organic manures. Bulk densities after harvesting of broccoli showed a little difference among the treatments of OC, PM and CD but it was insignificant (Table 4). Initial bulk density varied within the range of 1.33 to 1.36 g cm^{-3}. At 0-15 cm soil depth bulk density of post harvest soil ranged from 1.35 to 1.38 g cm^{-3}. The highest bulk density (1.38 g cm^{-3}) was recorded with USG_{140}×OC_1 and the lowest bulk density (1.35 g cm^{-3}) was noted in treatment $PU_{180}PM_3$ followed by USG_{160}×PM_3 (1.35 g cm^{-3}). It was observed that bulk density of soil reduced under higher rate of application of organic manures. This might be due to impact of addition of large amount of CD, PM and OC, which made the soil loose and friable, increased porosity resulting in decreased bulk density and improved soil physical environment. Swarup (2000) reported that long-term application of organic manures decreased soil bulk density, which was in agreement with this finding.

Particle density of soil

Variations in particle densities of post harvest soils were observed under different treatments of organic manures (Table 4), but it was insignificant and ranged from 2.55 to 2.61 g cm^{-3}. The highest particle density (2.61 g cm^{-3}) was recorded in the treatment $USG_{140} \times OC_1$ followed by $USG_{160} \times OC_1$ and $USG_{180} \times CD_3$ (2.60 g cm^{-3}). The lowest particle density of soil (2.55 g cm^{-3}) was found in the treatment of $USG_{160} \times PM_3$. The treatment receiving higher amount of organic manures always exhibited lower particle density value in each form of organic manures. This result is in agreement with the findings of Anwar (2008).

Table 4. Effect of different forms and levels of organic and inorganic sources of nitrogen on bulk density and particle density of soil

Treatment	Soil bulk density (g cm^{-3})		Soil particle density (g cm^{-3})	
	Initial	Post harvest	Initial	Post harvest
USG-N_{140}×OC1	1.35	1.38	2.62	2.61
USG-N_{140}×OC_2	1.34	1.37	2.63	2.56
USG-N_{140}×PM_2	1.35	1.38	2.62	2.59
USG-N_{140}×PM_3	1.35	1.36	2.61	2.56
USG-N_{140}×CD_3	1.35	1.38	2.60	2.59
USG-N_{140}×CD_5	1.35	1.35	2.62	2.56
USG-N_{160}×OC_1	1.34	1.38	2.60	2.60
USG-N_{160}×OC_2	1.34	1.36	2.61	2.58
USG-N_{160}×PM_2	1.34	1.38	2.59	2.59
USG-N_{160}×PM_3	1.35	1.35	2.62	2.55
USG-N_{160}×CD_3	1.34	1.37	2.61	2.59
USG-N_{160}×CD_5	1.35	1.36	2.61	2.56
USG-N_{180}×OC_1	1.36	1.37	2.60	2.59
USG-N_{180}×OC_2	1.35	1.36	2.61	2.56
USG-N_{180}×PM_2	1.35	1.37	2.59	2.57
USG-N_{180}×PM_3	1.34	1.36	2.59	2.56
USG-N_{180}×CD_3	1.35	1.38	2.63	2.60
USG-N_{180}×CD_5	1.34	1.36	2.63	2.57
PU-N_{180}×OC_1	1.35	1.38	2.62	2.60
PU-N_{180}×OC_2	1.33	1.36	2.59	2.57
PU-N_{180}×PM_2	1.35	1.37	2.61	2.60
PU-N_{180}×PM_3	1.35	1.35	2.58	2.57
PU-N_{180}×CD_3	1.34	1.37	2.61	2.58
PU-N_{180}×CD_5	1.35	1.36	2.60	2.56
CV (%)	1.03	1.77	0.92	0.76
SE ± 0.05	0.005	0.006	0.018	0.006

Means followed by common letters are statistically similar to each other at 5% level of provability by DMRT

Effect of organic and inorganic sources of nitrogen on post harvest soil nutrient status in broccoli field

Soil N content

Variations among the initial soil N content were insignificant (0.073 to 0.09 %). The post harvest soil N was significantly affected by the treatment combinations (Table 5). The maximum N content (0.097 %) was recorded with the treatment combinations $USG_{180}\times CD_3$, $USG_{180}\times CD_5$, $PU_{180}\times OC_1$, $PU_{180}\times OC_2$, $USG_{140}\times PM_3$, $USG_{140}\times CD_5$, $USG_{160}\times OC_2$, $USG_{160}\times PM_3$, $USG_{160}\times CD_5$ and $USG_{180}\times OC_2$. For all the cases USG with 2 ton OC, 3 ton PM and 5 ton CD showed higher residual effect on post harvest soil. This indicated that the residual effect of N application in the form of USG combining with organic manure was higher than that of PU. This result was similar to the findings of Evaraats *et al.* (1999) who reported that the post harvest soil N content was increased with increasing amounts of N application. Nambiar (1991) observed that integrated use of organic manure with N, P and K fertilizers was quite promising providing greater stability in production as well as maintaining higher soil fertility status. Ali *et al.* (2009) reported that application of 3 t ha^{-1} PM once in a year with 70% NPKS can reduce 30% of NPKS fertilizers.

Table 5. Effect of different forms and levels of organic and inorganic sources of nitrogen on soil nitrogen, phosphorus and potassium status in broccoli field

Treatment	Initial soil N (%)	Post harvest soil N (%)	Initial soil P ($\mu g\ g^{-1}$)	Post harvest soil P ($\mu g\ g^{-1}$)	Initial soil K (meq $100g^{-1}$)	Post harvest soil K (meq $100g^{-1}$)
USG-$N_{140}\times$OC1	0.073	0.095b	19.5	20.8k	0.303	0.231e
USG-$N_{140}\times OC_2$	0.080	0.095b	12.6	26.6b	0.298	0.298a-d
USG-$N_{140}\times PM_2$	0.080	0.084bc	17.2	19.3l	0.303	0.270d
USG-$N_{140}\times PM_3$	0.080	0.097a	14.7	22.7hi	0.303	0.287a-d
USG-$N_{140}\times CD_3$	0.080	0.095b	13.2	23.2ghi	0.298	0.275cd
USG-$N_{140}\times CD_5$	0.080	0.097a	13.7	25.3cd	0.287	0.312ab
USG-$N_{160}\times OC_1$	0.087	0.095b	19.5	20.5k	0.298	0.287a-d
USG-$N_{160}\times OC_2$	0.090	0.097a	12.6	24.1fg	0.296	0.278bcd
USG-$N_{160}\times PM_2$	0.090	0.095b	17.2	24.6cde	0.303	0.287a-d
USG-$N_{160}\times PM_3$	0.083	0.097a	14.7	21.3jk	0.303	0.292a-d
USG-$N_{160}\times CD_3$	0.090	0.095b	13.2	22.2ij	0.298	0.298a-d
USG-$N_{160}\times CD_5$	0.090	0.097a	13.7	26.7b	0.287	0.312ab
USG-$N_{180}\times OC_1$	0.080	0.095b	19.5	21.1jk	0.298	0.278bcd
USG-$N_{180}\times OC_2$	0.090	0.097a	12.6	24.1de	0.298	0.298a-d
USG-$N_{180}\times PM_2$	0.087	0.095b	17.2	22.6i	0.303	0.289a-d
USG-$N_{180}\times PM_3$	0.080	0.095b	14.7	23.4ghi	0.303	0.287a-d
USG-$N_{180}\times CD_3$	0.083	0.097a	13.2	20.3kl	0.298	0.284a-d
USG-$N_{180}\times CD_5$	0.080	0.097a	13.7	27.6a	0.289	0.315a

Treatment	Initial soil N (%)	Post harvest soil N (%)	Initial soil P (µg g^{-1})	Post harvest soil P (µg g^{-1})	Initial soil K (meq $100g^{-1}$)	Post harvest soil K (meq $100g^{-1}$)
PU-N_{180}×OC_1	0.077	0.093b	19.5	25.1cd	0.298	0.298a-d
PU-N_{180}×OC_2	0.080	0.097a	12.6	23.9f-h	0.298	0.289a-d
PU-N_{180}×PM_2	0.080	0.084bc	17.2	26.3cd	0.301	0.270d
PU-N_{180}×PM_3	0.080	0.095b	14.7	24.0ef	0.303	0.303a-d
PU-N_{180}×CD_3	0.080	0.084bc	13.2	22.2ij	0.298	0.298a-d
PU-N_{180}×CD_5	0.080	0.095b	13.7	25.5c	0.287	0.306abc
CV (%)	0.69	6.42	2.53	5.05	4.25	3.50
SE ± 0.05	-	0.005	-	0.402	-	0.010

Means followed by common letters are statistically similar to each other at 5% level of probability by DMRT

Soil P content

Initial soil available P content varied insignificantly within the range of 12.6 to 19.5 µg g^{-1} (Table 5). However, post harvest soil P content was significantly affected by the different organic and inorganic treatment combinations (Table 5). Maximum P content (27.6 µg g^{-1}) was found with the treatment USG_{180} × CD_5 which was significantly higher than all other treatments. The lowest P content (19.3 µg g^{-1}) was recorded with USG_{140} × PM_2. Organic manures might have increased the microbial population and their solubilizing activities of insoluble phosphate. Sharma and Saxena (1985) explained that incorporation of poultry manure or FYM in to the soil increased maize yields through improving soil P indices which is also in accordance with the present study. Ali *et al*, (2009) reported that application of 3 t ha^{-1} PM once in a year with 70% NPKS can reduce the use of 30% NPKS as fertilizers.

Soil K content

Initial soil exchangeable K content was varied within the range of 0.287 to 0.303 meq $100g^{-1}$ soil (Table 5). The post harvest soil exchangeable K was significantly affected by the treatment combinations and the maximum K content (0.315 meq $100g^{-1}$ soil) was found from the treatment USG_{180} × CD_5 which was statistically identical with all other treatment combinations except USG_{140}×OC_1, USG_{140}×PM_2, USG_{140}×CD_3, USG_{160}×OC_2, USG_{180}×OC_1 and PU_{180}×PM_2. The lowest K content (0.231 meq $100g^{-1}$) was recorded in USG_{140} × OC_1 treatment. This indicated that the effect of N on K uptake varied irrespectively with treatment combination. This result was supported by the findings of Zhang *et al.* (1996) where they showed that the contents of soil organic matter and total N, P and K were raised, soil nutrients were activated and soil fertility level was enhanced by the combined application of organic and inorganic fertilizers. Ali *et al.*, (2009) reported that application of 3 t ha^{-1} PM once in a year with 70% NPKS can reduce the 30% use of NPKS as fertilizers.

Table 6. Effect of different forms and levels of organic and inorganic sources of nitrogen on soil sulphur and boron status in broccoli field

Treatment	Initial soil S ($\mu g\ g^{-1}$)	Post harvest soil S ($\mu g\ g^{-1}$)	Initial soil B ($\mu g\ g^{-1}$)	Post harvest soil B ($\mu g\ g^{-1}$)
USG-N_{140}×OC1	11.4	12.6e-h	0.228	0.171c
USG-N_{140}×OC_2	11.6	13.0d-g	0.124	0.171c
USG-N_{140}×PM_2	13.9	11.3h	0.228	0.285a
USG-N_{140}×PM_3	10.5	15.3a	0.124	0.228b
USG-N_{140}×CD_3	14.0	12.0gh	0.241	0.285a
USG-N_{140}×CD_5	10.6	15.3a	0.124	0.229b
USG-N_{160}×OC_1	10.8	13.1c-g	0.228	0.281a
USG-N_{160}×OC_2	10.8	13.1c-g	0.124	0.228b
USG-N_{160}×PM_2	13.5	12.0f-h	0.228	0.285a
USG-N_{160}×PM_3	10.8	14.7ab	0.124	0.285a
USG-N_{160}×CD_3	14.0	14.3a-d	0.241	0.228b
USG-N_{160}×CD_5	10.5	15.4a	0.124	0.171c
USG-N_{180}×OC_1	11.0	12.6e-h	0.228	0.171c
USG-N_{180}×OC_2	11.5	14.5abc	0.124	0.164d
USG-N_{180}×PM_2	13.9	12.7e-h	0.228	0.228b
USG-N_{180}×PM_3	10.8	15.1a	0.124	0.169c
USG-N_{180}×CD_3	14.0	11.4h	0.241	0.164d
USG-N_{180}×CD_5	10.5	15.0ab	0.124	0.164d
PU-N_{180}×OC_1	11.1	13.5b-f	0.228	0.285a
PU-N_{180}×OC_2	11.1	15.1a	0.124	0.229b
PU-N_{180}×PM_2	13.5	12.7e-h	0.228	0.285a
PU-N_{180}×PM_3	11.0	14.7ab	0.124	0.266a
PU-N_{180}×CD_3	13.6	13.9a-e	0.241	0.285a
PU-N_{180}×CD_5	10.6	14.8ab	0.124	0.228b
CV (%)	8.00	5.81	6.65	6.45
SE ±0.05	-	0.459	-	0.01

Means followed by common letters are statistically similar to each other at 5% level of provability by DMRT

Soil S content

Initial soil available S content ranged from 10.5 to 14.0 $\mu g\ g^{-1}$ (Table 6). But post harvest soil S was significantly affected by the treatment combinations (Table 6).

Maximum S content (15.4 µg g^{-1}) was recorded in the treatment combination of USG_{140} × CD_5 followed by USG_{140} × PM_3 (15.3 µg g^{-1}), $USG_{180}PM_3$, PU_{180}×OC_2, PU_{180}×CD_5, USG_{160}×CD_3, USG_{180}×OC_2, USG_{180}×CD_5, PU_{180}×PM_2, PU_{180}×CD_3 and USG_{160}×PM_3, respectively This indicated that the effect of N on the S uptake was irrespective to different treatment combination. This result was an accordance with the findings of Hoque *et al.* (2007) also found that the application of various organic manures significantly influenced the S uptake, soil pH, organic matter content, and the available S contents of the post-harvest soil.

Soil B content

Initial soil B content of the experimental units ranged from 0.124 to 0.241 µg g^{-1} (Table 6). The post harvest soil B content was significantly affected by the treatment combinations. Maximum B content (0.285 µg g^{-1}) was noted in the treatments USG_{140}×PM_2, USG_{140}×CD_3, USG_{160}×PM_2, USG_{160}×PM_3, PU_{180}×OC_1, PU_{180}×PM_2, PU_{180}×PM_3 and PU_{180}×CD_3 followed by PU_{180}×PM_3 and USG_{160}×OC_1. The lowest B content (0.164 µg g^{-1}) was noted in USG_{180}×OC_2, USG_{180}×CD_3 and USG_{180}×CD_5. This result is in agreement with the findings of Gaur and Verma (1991) and Rani Perumal *et al.* (1991) who depicted that combined application of organic manures and mineral fertilizers were promising in maintaining of lateral micronutrient like B for crop production stability and providing favorable physical, biological and soil ecological conditions.

Effect of organic and inorganic sources of nitrogen on nutrient uptake by the broccoli plant

Nitrogen uptake

The nitrogen uptake by the broccoli plants was significantly affected by different organic and inorganic sources of N (Table 7). Maximum N uptake was found with the treatment USG-N_{180}×OC_2 (208.3 kg N ha^{-1}) followed by USG-N_{160}×OC_2 (204.3 kg N ha^{-1}). However, USG-N_{180}×PM_3 (202.8 kg N ha^{-1}), PU-N_{180}×OC_2 (199.8 kg N ha^{-1}), USG-N_{180}×CD_5 (198.1 kg N ha^{-1}) and PU-N_{180}×PM_3 (193.3 kg N ha^{-1}) had higher levels of N uptake. Nitrogen uptake was increased with increasing levels of N applied and this amount was higher in the USG-applied plots with OC. This might be due to the high availability and uninterrupted supply of N with deep-placed USG in combination with OC. Here, organic manure might have acted as a slow-releasing N source which can supply N for a long period of time to the plant resulting higher N uptake. This finding was supported by Rickard (2008) as the plant N uptake was synergistically influenced by N application. Tremblay *et al*. (2001) also showed that the N uptake was approximately 260 kg ha^{-1} for an average yield of field vegetables.

Table 7. Effect of different forms and levels of organic and inorganic sources of nitrogen on nutrient uptake by broccoli plant

Treatment	N uptake (kg ha^{-1}±SE)	P uptake (kg ha^{-1}±SE)	K uptake (kg ha^{-1}±SE)	S uptake (kg ha^{-1}±SE)
$USG_{140}OC_1$	167.6±7.06hij	23.9±0.83cd	212.6±4.44a-e	2.38±0.10ef
$USG_{140}OC_2$	191.8±4.63b-e	30.8±1.45ab	238.3±6.82ab	3.02±0.14bcd
$USG_{140}PM_2$	139.4±2.36k	22.2±0.57d	187.2±3.91e	2.17±0.04f
$USG_{140}PM_3$	173.7±6.21f-i	25.1±1.09bcd	205.9±6.27b-e	2.68±0.19c-f
$USG_{140}CD_3$	143.3±7.33k	23.1±1.15d	206.1±3.25b-e	2.37±0.17ef
$USG_{140}CD_5$	173.7±4.79f-i	25.1±1.16bcd	216.0±2.76a-e	2.61±0.09c-f
$USG_{160}OC_1$	171.0±2.12g-j	25.7±0.90bc	215.5±3.38a-e	2.43±0.05ef
$USG_{160}OC_2$	204.3±4.17ab	33.0±2.15a	247.0±6.78a	3.24±0.21ab
$USG_{160}PM_2$	159.9±8.49ij	25.1±0.21bcd	193.9±5.63de	2.38±0.15ef
$USG_{160}PM_3$	188.8±8.59b-f	28.0±0.33ab	226.8±5.05a-d	2.73±0.13cde
$USG_{160}CD_3$	158.1±3.06j	24.8±0.23cd	200.5±6.04cde	2.45±0.11ef
$USG_{160}CD_5$	178.0±1.92d-h	26.4±1.70bc	212.9±3.87a-e	2.56±0.08def
$USG_{180}OC_1$	194.6±1.54abc	25.0±1.83bc	228.6±4.87a-d	3.00±0.15bcd
$USG_{180}OC_2$	208.3±7.39a	33.0±1.13a	247.3±8.05a	3.45±0.15a
$USG_{180}PM_2$	185.9±5.67c-g	28.3±0.82ab	214.9±5.52a-e	2.54±0.19def
$USG_{180}PM_3$	202.8±2.25ab	32.8±1.18a	238.3±7.36ab	3.10±0.16bcd
$USG_{180}CD_3$	185.2±6.86c-g	26.5±1.00bc	209.5±5.78b-e	2.45±0.15ef
$USG_{180}CD_5$	198.1±6.97abc	27.8±1.12bc	220.3±3.05a-e	2.60±0.09def
$PU_{180}OC_1$	168.6±6.12hij	24.3±1.30cd	202.5±5.65b-e	2.22±0.12ef
$PU_{180}OC_2$	199.8±4.56abc	28.5±0.87ab	234.9±5.90abc	2.66±0.12c-f
$PU_{180}PM_2$	172.7±2.31.g-j	22.7±0.79d	195.8±6.99de	2.30±0.17ef
$PU_{180}PM_3$	193.3±6.68a-d	26.1±1.29bc	211.1±4.07a-e	2.52±0.11def
$PU_{180}CD_3$	176.9±3.09-h	24.9±1.22cd	206.6±3.18b-e	2.46±0.09ef
$PU_{180}CD_5$	190.9±6.85b-e	26.5±1.03bc	219.1±4.58a-e	2.59±0.07def
CV (%)	5.33	7.61	3.95	9.31

Means followed by common letters are statistically similar to each other at 5% level of provability by DMRT

Phosphorus uptake

Application of nitrogenous fertilizer at higher rates significantly increased the P uptake and the highest value (33.0 kg ha^{-1}) was recorded with USG-N_{180}×OC_2 and USG-N_{160}×OC_2 being at par to USG-N_{180}×PM_3, PU-N_{180}×OC_2 and USG-N_{140}×OC_2. The lowest P uptake (22.2 kg ha^{-1}) was recorded with USG-N_{140}×PM_2. However, P uptake was found higher in the treatment where USG was applied with organic manure (Table 7). The major cause of variation in P uptake is due to the variation in yield of broccoli (Hussain *et al.* (2021). Similar result was found by Yoldas *et al*. (2008) as they reported that P concentration in broccoli heads were increased with increasing rates of N application. This higher P uptake might be the effect of N conversion to nitrate and subsequently this nitrate was absorbed by the root system creating a negative charge in root cells with charge equilibrium caused by cation absorption and consequently, P absorption by the plant increased (Moniruzzaman *et al*. (2007).

Potassium uptake

Potassium uptake increased with the increasing rates of nitrogenous fertilizer but similar K uptake (247.3 kg ha^{-1}) was recorded with USG-N_{180}×OC_2 followed by USG-N_{160}×OC_2 (247.0 kg).. The lowest K uptake (187.2 kg) was noted with USG-N_{140}×PM_2 treatment (Table 7). This was also due to the continuous supply and greater recovery percent of K fertilizer with USG-organic manure integration over PU. This result was supported by Yoldas *et al*. (2008) who reported that nitrogen application increased the K concentrations in broccoli heads. Similar results were also reported by Abdelrazzag (2002) and Magnusson (2002) with several vegetable crops. The possible reason for the higher K uptake was the conversion of N to nitrate in the soil solution and its absorption by the roots resulting a negative charge in root cells maintaining a charge equilibrium through cation absorption and consequently, K absorption by the plant increased (Moniruzzaman *et al*. (2007).

Sulfur uptake

It was observed that increasing levels of nitrogenous fertilizer significantly increased S uptake and the maximum S uptake (3.45 kg ha^{-1}) was recorded with USG-N_{180}× OC_2 followed by USG-N_{160}× OC_2 (3.24 kg). Here, the higher S uptake was found in the USG-treated plots rather than PU (Table 7) and S uptake was found greater with higher amount of organic manure. This might be due to the random supply and the greater recovery percent of S with the integrated application of USG-organic manure than PU. The higher N supply from USG synergistically induced a higher S uptake by the broccoli plant. Ali *et al.* (2009) reported that the total uptake of S ranged from 6 to 21 kg ha^{-1} with the application of dhaincha, mungbean residues, cowdung and poultry manure with 70% NPKS where higher uptake of nutrients by the crops was recorded compared to 70% NPKS application as fertilizer only.

Effect of organic and inorganic sources of nitrogen on **soil nutrient balance**

Nutrient balance has an important implication to maintain the total soil nutrients status for long-time and sustainable soil fertility (BARC, FRG'2005). The apparent nutrient balance in all the treated plots was found negative for N and K but a positive balance was observed in P and S. Zaman *et al.* (2008) found that the negative apparent NPKS balance in all the treatments composed of both organic and inorganic combination in rice.

Nitrogen balance

Nitrogen replenishment through chemical fertilizer and addition of organic manures either singly or in combination was not enough to balance N removal by crops because much of the applied N was lost from the soil. The N balance thus was very small but positive almost in all the treatment except treatment USG-N_{140} × OC_2 and USG-N_{160} × OC_2 which showed a little negative balance (Table 8). Nitrogen is subjected to loss through volatilization, denitrification, leaching and surface run-off during heavy rain; therefore, the theoretical balance of N in tropical soil may not be so useful, unless the subsequent crop utilizes the residual N of the previous crop. Non-symbiotic biological N fixation (BNF) was not taken under consideration. Without considering non-symbiotic BNF by the crop all treatments had more or less positive N balances except treatment USG-N_{140}×OC_2 and USG-N_{160} × OC_2 which showed a little negative balance. The negative N balances ranged between -3.8 to -11.8 kg ha^{-1} $season^{-1}$ (Table 8). The highest negative balance (-11.8 kg ha^{-1} $season^{-1}$) was obtained from USG-N_{140}×OC_2 with the higher initial crop growth followed by USG-N_{160} × OC_2 (-3.8 kg ha^{-1} $season^{-1}$). The results are also well accordance with Saha *et al.* (2003). Ali *et al.* (2009) reported a negative balance for N and K with the highest mining of K, while the balances for P and S were positive.

Table 8. Integrated effect of different forms and levels of organic and inorganic sources of nitrogen on apparent nitrogen balance on broccoli field (Nutrient input-output system)

Treatments	Input (N kg ha^{-1})			Output (N kg ha^{-1})			Apparent N balance (N kg ha^{-1})
	Inorganic source	Organic source	Total	Crop uptake	Loss	Total	
USG-N_{140}×OC1	114.5	25.5	180.0	167.6	-	167.6	12.4
USG-N_{140}×OC_2	89.0	51.0	180.0	191.8	-	191.8	-11.8
USG-N_{140}×PM_2	117.0	23.0	180.0	139.4	-	139.4	40.6
USG-N_{140}×PM_3	105.5	34.5	180.0	173.7	-	173.7	6.3
USG-N_{140}×CD_3	126.5	13.5	180.0	143.3	-	143.3	36.7
USG-N_{140}×CD_5	117.5	22.5	180.0	173.7	-	173.7	6.3
USG-N_{160}×OC_1	134.5	25.5	200.0	171.0	-	171.0	29.0
USG-N_{160}×OC_2	109.5	51.0	200.5	204.3	-	204.3	-3.8
USG-N_{160}×PM_2	137.0	23.0	200.0	159.9	-	159.9	40.1
USG-N_{160}×PM_3	125.5	34.5	200.0	188.8	-	188.8	11.2
USG-N_{160}×CD_3	146.5	13.5	200.0	158.1	-	158.1	41.9
USG-N_{160}×CD_5	137.5	22.5	200.0	178.0	-	178.0	22.0
USG-N_{180}×OC_1	154.5	25.5	220.0	194.2	-	194.2	25.9
USG-N_{180}×OC_2	129.0	51.0	220.0	208.3	-	208.3	11.7
USG-N_{180}×PM_2	157.0	23.0	220.0	185.9	-	185.9	34.1
USG-N_{180}×PM_3	145.5	34.5	220.0	202.8	-	202.8	17.2
USG-N_{180}×CD_3	166.5	13.5	220.0	185.9	-	185.2	34.8

Treatments	Input (N kg ha^{-1})			Output (N kg ha^{-1})			Apparent N balance (N kg ha^{-1})
	Inorganic source	Organic source	Total	Crop uptake	Loss	Total	
USG-N_{180}×CD_5	157.5	22.5	220.0	198.1	-	198.1	21.9
PU-N_{180}×OC_1	154.5	25.5	220.0	168.6	-	168.6	51.4
PU-N_{180}×OC_2	129.0	51.0	220.0	199.8	-	199.8	20.2
PU-N_{180}×PM_2	157.0	23.0	220.0	172.7	-	172.7	47.3
PU-N_{180}×PM_3	145.5	34.5	220.0	193.3	-	193.3	26.7
PU-N_{180}×CD_3	166.5	13.5	220.0	176.9	-	176.9	43.1
PU-N_{180}×CD_5	157.5	22.5	220.0	190.9	-	190.9	29.1

Note: Other sources of inputs (Biological N fixation, rain and irrigation water etc.) and output (Leaching loss, run-off, volatilization and denitrification loss etc.) were not considered here.

Phosphorus balance

The apparent P balance in soil resulting from different fertilizer management practices ranged from 20.0 to 30.8 kg ha^{-1} $season^{-1}$ in different treatments (Table 9). The apparent P balance was found positive in all treatments. The highest apparent P balance (30.8 kg ha^{-1} $season^{-1}$) was recorded in the treatment USG_{140}× PM_2 due to lower uptake of nutrients as compared to other treatments. Basak (2002) also observed similar trend of nutrient balance in the groundnut - rice cropping pattern under irrigated nutrient management system. Ali *et al*. (2009) reported a negative balance for N and K with the highest mining of K, while the balances for P and S were positive with anapplication of 3 t ha^{-1} PM once in a year.

Table 9. Integrated effect of different forms and levels of organic and inorganic sources of nitrogen on apparent phosphorus balance on broccoli (Nutrient input-output system)

Treatments	Inputs (P kg ha^{-1})			Outputs (P kg ha^{-1})		Apparent P balance (P kg ha^{-1})
	Inorganic source	Organic source	Total	Crop uptake	Total	
USG-N_{140}×OC1	49.0	4.0	53.0	23.9	23.9	29.1
USG-N_{140}×OC_2	45.0	8.0	53.0	30.8	30.8	22.2
USG-N_{140}×PM_2	32.0	21.0	53.0	22.2	22.2	30.8
USG-N_{140}×PM_3	21.5	31.5	53.0	25.1	25.1	27.9
USG-N_{140}×CD_3	48.5	4.5	53.0	23.1	23.1	29.9
USG-N_{140}×CD_5	45.5	7.5	53.0	25.1	25.1	27.9
USG-N_{160}×OC_1	49.0	4.0	53.0	25.7	25.7	27.3
USG-N_{160}×OC_2	45.0	8.0	53.0	33.0	33.0	20.0
USG-N_{160}×PM_2	32.0	21.0	53.0	25.1	25.1	27.9
USG-N_{160}×PM_3	21.5	31.5	53.0	28.0	28.0	25.0
USG-N_{160}×CD_3	48.5	4.5	53.0	24.8	24.8	28.2
USG-N_{160}×CD_5	45.5	7.5	53.0	26.4	26.4	26.6

Treatments	Inputs (P kg ha^{-1})			Outputs (P kg ha^{-1})		Apparent P balance (P kg ha^{-1})
	Inorganic source	Organic source	Total	Crop uptake	Total	
USG-N_{180}×OC_1	49.0	4.0	53.0	26.0	26.0	27.0
USG-N_{180}×OC_2	45.0	8.0	53.0	33.0	33.0	20.0
USG-N_{180}×PM_2	32.0	21.0	53.0	28.3	28.3	24.7
USG-N_{180}×PM_3	21.5	31.5	53.0	32.8	32.8	20.2
USG-N_{180}×CD_3	48.5	4.5	53.0	26.5	26.5	26.5
USG-N_{180}×CD_5	45.5	7.5	53.0	27.8	27.8	25.2
PU-N_{180}×OC_1	49.0	4.0	53.0	24.3	24.3	28.7
PU-N_{180}×OC_2	45.0	8.0	53.0	28.5	28.5	24.5
PU-N_{180}×PM_2	32.0	21.0	53.0	22.7	22.7	30.3
PU-N_{180}×PM_3	21.5	31.5	53.0	26.1	26.1	26.9
PU-N_{180}×CD_3	48.5	4.5	53.0	24.9	24.9	28.1
PU-N_{180}×CD_5	45.5	7.5	53.0	26.5	26.5	26.5

Potassium balance

Unlike P, the apparent balance of K in soil was highly negative as influenced by the treatment combinations. The magnitude of the negative K balance ranged from -104.2 to -164.3 kg ha^{-1} season^{-1} (Table 10). Potassium replenishment through application of inorganic fertilizer and organic manures either singly or in combination was not enough to balance K removal by crops since the crops used much of the applied K and some of the K leached from the soil. This may lead to K depletion in the long run. These results confirmed the reports by Hunag Li. and Xie (1990), Prasad (1993) and Saha *et al.* (2003) indicating negative K balances and ongoing K depletion in many irrigated rice systems. Ali *et al*. (2009) reported that application of 3 t ha^{-1} PM once in a year with 70% NPKS can reduce the use of 30% NPKS as fertilizers. There were negative balances for N and K with the highest mining of K, while the balances for P and S were positive. Ali *et al*. (2009) reported a negative balance for K with the highest mining of K with an application of 3 t ha^{-1} PM.

Table 10. Integrated effect of different forms and levels of organic and inorganic sources of nitrogen on apparent potassium balance on broccoli (Nutrient input-output system)

Treatments	Inputs (K kg ha^{-1})			Outputs (K kg ha^{-1})		Apparent K balance (K kg ha^{-1})
	Inorganic source	Organic source	Total	Crop uptake	Total	
USG-N_{140}×OC1	78.0	5.0	83.0	212.6	212.6	-129.6
USG-N_{140}×OC_2	73.0	10.0	83.0	238.3	238.3	-155.3
USG-N_{140}×PM_2	69.0	14.0	83.0	187.2	187.2	-104.2
USG-N_{140}×PM_3	62.0	21.0	83.0	205.9	205.9	-122.9
USG-N_{140}×CD_3	68.0	15.0	83.0	206.1	206.1	-123.1

Treatments	Inputs (K kg ha^{-1})			Outputs (K kg ha^{-1})		Apparent K balance (K kg ha^{-1})
	Inorganic source	Organic source	Total	Crop uptake	Total	
USG-N_{140}×CD_5	58.0	25.0	83.0	216.0	216.0	-133.0
USG-N_{160}×OC_1	78.0	5.0	83.0	215.5	215.5	-132.5
USG-N_{160}×OC_2	73.0	10.0	83.0	247.0	247.0	-164.0
USG-N_{160}×PM_2	69.0	14.0	83.0	193.9	193.9	-110.9
USG-N_{160}×PM_3	62.0	21.0	83.0	226.8	226.8	-143.8
USG-N_{160}×CD_3	68.0	15.0	83.0	200.5	200.5	-117.5
USG-N_{160}×CD_5	58.0	25.0	83.0	212.9	212.9	-129.9
USG-N_{180}×OC_1	78.0	5.0	83.0	228.6	228.6	-145.6
USG-N_{180}×OC_2	73.0	10.0	83.0	247.3	247.3	-164.3
USG-N_{180}×PM_2	69.0	14.0	83.0	214.9	214.9	-131.9
USG-N_{180}×PM_3	62.0	21.0	83.0	238.3	238.3	-155.3
USG-N_{180}×CD_3	68.0	15.0	83.0	209.5	209.5	-126.5
USG-N_{180}×CD_5	58.0	25.0	83.0	220.3	220.3	-137.3
PU-N_{180}×OC_1	78.0	5.0	83.0	202.5	202.5	-119.5
PU-N_{180}×OC_2	73.0	10.0	83.0	234.9	234.9	-151.9
PU-N_{180}×PM_2	69.0	14.0	83.0	195.8	195.8	-112.8
PU-N_{180}×PM_3	62.0	21.0	83.0	211.1	211.1	-128.1
PU-N_{180}×CD_3	68.0	15.0	83.0	206.6	206.6	-123.6
PU-N_{180}×CD_5	58.0	25.0	83.0	219.1	219.1	-136.1

Sulphur balance

The S balance was favorable as expected and considerable quantities of S were accumulated in the fertilized plots. The apparent positive S balance among the different treatments ranged from 16.5 to 17.8 kg ha^{-1} season^{-1} (Table 11). Treatments receiving both higher dose of organic manures and inorganic fertilizers showed higher nutrient uptake than that received lower organic and inorganic fertilizer. The highest positive S balance (17.83 kg ha^{-1} season^{-1}) was noted in treatment USG_{140}× PM_2. Basak *et al.* (2008) reported that S balance increased significantly in IPNS based treatment under Mustard - Boro rice - T. Aman rice cropping pattern. Ali *et al.* (2009) reported a positive balance for P and S with anapplication of 3 t ha^{-1} PM once in a year.

Table 11. Integrated effect of different forms and levels of organic and inorganic sources of nitrogen on apparent sulphur balance on broccoli field (Nutrient input-output system)

Treatments	Inputs (S kg ha^{-1})		Outputs (S kg ha^{-1})		Apparent S balance (S kg ha^{-1})
	Inorganic + organic source	Total	Crop uptake	Total	
USG-N_{140}×OC1	20.0	20.0	2.38	2.38	17.6
USG-N_{140}×OC_2	20.0	20.0	3.02	3.02	17.0

Treatments	Inputs (S kg ha^{-1})		Outputs (S kg ha^{-1})		Apparent S balance (S kg ha^{-1})
	Inorganic + organic source	Total	Crop uptake	Total	
USG-N_{140}×PM_2	20.0	20.0	2.17	2.17	17.8
USG-N_{140}×PM_3	20.0	20.0	2.68	2.68	17.3
USG-N_{140}×CD_3	20.0	20.0	2.37	2.37	17.6
USG-N_{140}×CD_5	20.0	20.0	2.61	2.61	17.4
USG-N_{160}×OC_1	20.0	20.0	2.43	2.43	17.6
USG-N_{160}×OC_2	20.0	20.0	3.24	3.24	16.8
USG-N_{160}×PM_2	20.0	20.0	2.38	2.38	17.6
USG-N_{160}×PM_3	20.0	20.0	2.73	2.73	17.3
USG-N_{160}×CD_3	20.0	20.0	2.45	2.45	17.6
USG-N_{160}×CD_5	20.0	20.0	2.56	2.56	17.4
USG-N_{180}×OC_1	20.0	20.0	3.00	3.00	17.0
USG-N_{180}×OC_2	20.0	20.0	3.45	3.45	16.6
USG-N_{180}×PM_2	20.0	20.0	2.54	2.54	17.5
USG-N_{180}×PM_3	20.0	20.0	3.10	3.10	16.9
USG-N_{180}×CD_3	20.0	20.0	2.45	2.45	17.6
USG-N_{180}×CD_5	20.0	20.0	2.60	2.60	17.4
PU-N_{180}×OC_1	20.0	20.0	2.22	2.22	17.8
PU-N_{180}×OC_2	20.0	20.0	2.66	2.66	17.3
PU-N_{180}×PM_2	20.0	20.0	2.30	2.30	17.7
PU-N_{180}×PM_3	20.0	20.0	2.52	2.52	17.5
PU-N_{180}×CD_3	20.0	20.0	2.46	2.46	17.5
PU-N_{180}×CD_5	20.0	20.0	2.59	2.59	17.4

Conclusion

From the above discussion it could be concluded that integration of organic and inorganic N sources have a little influence on soil physical and chemical properties of soil and its effects on soil nutrient balance. Post harvest soil organic carbon content was significantly influenced by the integration of organic-inorganic N management approach, but soil pH, bulk density and particle density were influenced a little. However, a significant influence was found on post harvest soil nutrient balance where K balance showed (-) ve but N (except a little), P, S and B showed (+) ve balance as affected by the integrated nitrogen management through organic-inorganic sources of N. Soil physical and chemical properties were slightly increased under higher rate of USG-organic manure as compared to PU-organic manure integration.

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STUDY ON COMBINING ABILITY AND HETEROSIS OF MAIZE INBRED LINES THROUGH LINE × TESTER METHOD

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Abstract

Eleven inbred lines were crossed with two testers in a Line × Tester mating design and the resulting twenty-two crosses along with the lines, testers and two checks BARI Hybrid Maize-9 (BHM-9) and 981 were evaluated during rabi season, 2013-14 in an alpha lattice design with two replications, for grain yield and its components to estimate the general combining ability (GCA) and specific combining ability (SCA) effects and heterosis. The analysis of variance (ANOVA) was found significant for most of the characters studied among the genotypes indicating greater diversity in the parental lines of the traits. Parents with good GCA for yield, E21 and BIL51(1), for 1000 grain weight, line E21 and for grains/ear, BIL72 and BIL51(1) could be used in hybridization program as donor. Heterosis was noticed - 44.92 to 13.02% among the cross combinations. However, three crosses BIL51(1) × BIL28, E21 × BIL95 and E04 × BIL95 were found promising considering SCA effect and could be utilized for enhancing hybrid production.

Keywords: Maize (*Zea mays* L.), line × tester, GCA (general combining ability), SCA (specific combining ability).

Introduction

Maize (*Zea mays* L is now cultivated worldwide, although it is grown mainly in wet and hot climates, that it is an extremely versatile crop (Fernandez, 2011). In 2020-21, maize was cultivated in 11.86 lac acre of land and production was 41.16 lac mtons (BBS, 2022) in Bangladesh. Due to its diversified use, increasing demand for poultry industry, higher nutritive value and also higher per acre yield, maize cultivation is increasing day by day in the country and it continues to increase speedily at an average rate of 20% per year (CIMMYT, 2008). Combining ability is an excellent tool which helps discern the goal and direction in a breeding programme (Manonmani and Khan, 2003). Exploitation of hybrid vigor and selection of parents based on combining ability has been used as an important breeding approach in crop improvement. In this context, Line × Tester (L × T)

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analysis (Kempthrone, 1957) has widely been used for evaluation of inbred lines by crossing them with testers. Breeder's objectives are to select hybrids on the basis of expected level of heterosis as well as specific combining ability. A combining ability is prerequisite for developing a good hybrid maize variety. It is one of the powerful tools in identifying the best combiner that may be used in crosses either to exploit heterosis or accumulate fixable genes. The present study involving a line × tester analysis aimed to determine the general combining ability (GCA) and specific combining ability (SCA) of crosses for different traits mostly on yield and evolving suitable hybrids locally.

Materials and Methods

Eleven inbred lines (as female parents) and two testers (as male parents) having good GCA were selected and crossed in line × tester fashion to generate 22 crosses were obtained from locally developed inbred lines in rabi 2012-13 at BARI, Gazipur. Seeds of all the parents and their F_1 hybrids were sown in Alpha lattice design with two replications in November 2013. Each entry was sown in 2 rows 5m long plot. Spacing was adopted 75 cm × 20 cm between rows and hills, respectively. One healthy seedling per hill was kept after proper thinning. Fertilizers were applied @ 250, 55, 110, 40, 5 and 1.5 kg/ha of N, P, K, S, Zn and B, respectively. Standard agronomic practices were followed (Quayyum, 1993). Two border rows were used at each end of the replication for minimize the border effect. Data on days to 50% pollen shedding and silking were recorded on whole plot basis. All the plants in 2 rows were considered for plot yield which was later converted to t/ha. Ten randomly selected plants were used for recording observations on plant ear height and grain yield (t/ha). Estimates of combining ability and their variance were made as suggested by Kempthorne (1957). Data were analyzed using R software (2017).

Results and Discussion

In the analysis of variance for combining ability (Table 1), the mean squares due to the parents, parents vs. crosses, crosses, lines, testers and lines × testers were found significant for several characters. It indicated the presence of genetic variability among the genotypes for those characters. Similar genotypic difference for ear length, grain weight, grain yield and other characters were reported by Sofi and Rathor (2006) and Narro *et al*. (2003). Significant variance was present in parents in respect of days to pollen shedding, days to silking and grains/ear. The variances for line were found significant only for days to silking and yield and the rest of the characters exhibited non-significant variances. Similarly, variances due to testers were found significant for grains/ear and yield and other traits were showed non-significant variances. Non-significant variances due to lines and testers for different traits suggested that these traits were predominantly controlled by non-additive type of gene action. Variances due to lines × testers were found

Table 1. Analysis of variance for grain yield and its component traits in line × tester analysis of Maize

Source of variation	DF	DP	DS	PH	EH	GR/EAR	TGW	YLD
Parents	12	79.73**	87.79**	550.21	242.92	10803.59**	1379.48	2.57
Parents vs. Crosses	1	247.95**	322.51**	50387.66**	18317.80**	850570.58**	89459.66**	758.62**
Crosses	21	6.02**	4.08	254.84	226.00	7708.46*	1679.22*	5.47**
Lines (L)	10	6.50	6.15*	323.54	231.26	6817.95	2316.36	8.96**
Testers (T)	1	4.45	1.11	10.02	87.36	35001.84*	81.81	0.10**
L×T	10	5.70**	2.31	210.62	234.61	5869.64	1201.88	2.52
Error	34	1.77	2.29	391.15	214.10	3106.97	814.70	1.62
Total	169							

*P=0.05, **P=0.01.

DP=Days to pollen shedding, DS = Days to silking, PH = Plant height (cm), EH = Ear height (cm).

GR/EAR= Grains per ear, TGW=1000- grainl weight (g), YLD= Grain yield (t/ha).

Table 2. Proportional contribution of lines, testers and their interactions to total variance in maize

Source	DP	DS	PH	EH	GR/EAR	TGW	YLD
Due to line	51.41	71.72	60.45	48.72	42.11	65.68	77.98
Due to tester	3.52	1.29	0.18	1.84	21.62	0.23	0.09
Due to L x T	45.07	26.98	39.35	49.32	36.26	34.08	21.92

DP=Days to pollen shedding, DS=Days to silking, PH =Plant height (cm), EH =Ear height (cm).

GR/EAR= Grains per ear, TGW=1000- grain weight (g), YLD= Grain yield (t/ha).

significant only in days to pollen shedding suggesting the presence of non-additive type of gene action in controlling the traits. In parents vs. crosses all the characters showed significant variances. Except ear height, all the traits mean sum of squares due to line were of a large magnitude than those due to line × tester. The variance due to GCA (line) being higher than the variance due to SCA (lines × testers) indicating preponderance of additive gene effects. Further it also revealed that the genetic advance for these characters could be made by simple breeding procedures involving selection based on progeny performance. The mean square due to testers were lower than lines × testers for all the characters studied suggested preponderance of non-additive gene effects.

The contribution of lines, testers and interactions to total variance are presented in Table 2. The proportional contribution of lines and interactions to the total variances was much higher than tester in all the traits. However, the contribution of lines was higher than the interactions to total variance for all the characters. This suggested female parent contributed the maximum to total variance in maize, which was followed by interaction and the estimate of variance due to general combining ability. Testers contributed the lowest to variance, which was in conformity with Rissi *et al*. (1991).

General combining ability

The GCA effects is shown in Table 3. Negative GCA value is desirable for days to pollen shedding, days to silking, plant height and ear height for short and earliness. None of the parents exhibited significant and negative GCA effects for days to pollen shedding, days to silking, plant height and ear height although some lines (E19, E05, E04, E34, E36, BIL72, E21, Lmly08 etc) showed negative values. Two parents BIL72 and BIL51(1) showed significant and positive GCA effects for these characters and expected to produce a greater number of grains/ear. For 1000-kernel weight, the GCA effect was found significant for two parents BIL51(1) and E21 and suppose to contribute for increasing the kernel size. Highly significant and positive GCA effects for 1000-kernel weight was observed by Uddin *et al*. (2006), Alam *et al*. (2008) and Abdel-Moneam *et al*. (2009). For grain yield, three parents showed significant and positive GCA effect. Significant and positive GCA for yield in maize was also reported by Paul and Duara (1991) and Ivy and Hawlader (2000). Parent BIL51(1) was also a good general combiner for grains/ear besides grain yield.

Specific combining ability effects (SCA)

None of the crosses showed significant and positive sca effect for yield. Five crosses (BIL19 × BIL28, E04 × BIL 95, BIL51(1) × BIL28, BIL51(1) × BIL95 and E21 × BIL95) involved average × average, high × average and low × average general combiners but exhibited non-significant SCA effects with high mean performance. Ivy and Hawlader (2000) reported that good general combining

Table 3. GCA effects and mean performance of parents for different yield contributing traits in Maize

	DP	DS	PH	EH	GR/EAR	TGW	YLD
Tester							
1. BIL 28	0.32	0.16	-0.48	-1.41	-28.20	-1.36	0.05
	(105)	(105)	(134)	(56.5)	(404)	(250)	(3.82)
2. BIL 95	-0.32	-0.16	0.48	1.41	28.20	1.36	-0.05
	(104)	(105)	(147.5)	(68)	(230)	(255)	(2.00)
SE ± (gi)	0.284	0.323	4.217	3.120	11.884	6.085	0.272
Line							
1. BIL72	0.82	0.75	-1.55	2.89	63.00*	-45.91**	-0.99
	(88)	(91)	((91)	(31.5)	(284.5)	(250)	(3.02)
2. E19	-0.43	0.25	5.20	3.64	-0.25	14.09	0.25
	(90)	(94)	(116.5)	(42.5)	(246)	(325)	(3.28)
3. E05	-1.43	-1.25	-2.30	-0.61	-9.75	4.09	-0.45
	(89)	(91)	(107)	(43)	(264)	(270)	(2.39)
4. BIL51(2)	1.82*	2.00*	-8.30	-7.11	-13.50	6.59	-0.10
	(88)	(90)	(87.5)	(34)	(163)	(300)	(1.92)
5. Lmly08	2.32*	2.00*	-10.05	-12.11	25.75	-28.41*	0.36
	(94)	(97)	(113)	(45)	(263)	(285)	(2.69)
6. E04	-1.43	-1.25	-11.80	-9.86	-0.25	16.59	1.26*
	(88)	(91)	(124)	(55)	(371)	(325)	(4.71)
7. BIL51(1)	0.57	0.75	15.95	8.64	47.75*	26.59*	2.23**
	(97)	(101)	(94)	(27)	(157.5)	(275)	(1.43)
8. BIL50(1)	0.32	-1.00	7.70	7.64	17.50	-25.91*	-1.02
	(90)	(92)	(112)	(42.5)	(306)	(300)	(3.48)
9. E34	-0.93	-1.00	2.95	6.89	-43.50*	9.09	-0.47
	(86)	(89)	(112)	(40.5)	(175.5)	(285)	(1.38)
10. E36	-0.68	-0.25	-7.70	-6.36	-87.50**	-5.91	-3.05**
	(88)	(92)	(115)	(39)	(246)	(295)	(1.91)
11. E21	-0.93	-1.00	9.45	6.39	0.75	29.09*	1.98**
	(88)	(91)	(112.5)	(39.5)	(232)	(315)	(3.34)
SE ± (gj)	0.667	0.758	9.998	7.316	27.870	14.272	0.637

DP=Days to pollen shedding, DS=Days to silking, PH =Plant height (cm), EH =Ear height (cm).
GR/EAR= Grains per ear, TGW=1000- grain weight (g), YLD= Grain yield (t/ha).

Table 4. SCA effects and mean performance of F_1 hybrids for yield and yield contributing traits in maize

Crosses	DP	DS	PH	EH	GR/EAR	TGW	YLD
1. BIL72 × BIL28	1.18	0.84	-14.27	-15.34	9.45	11.36	0.34
	(90)	(92)	(152)	(63)	(529)	(325)	(8.86)
2. BIL72 × BIL95	-1.18	-0.84	14.27	15.34	-9.45	-11.36	-0.34
	(87)	(90)	(181.5)	(96.5)	(567)	(305)	(8.07)
3. E19 × BIL28	0.43	0.34	3.98	6.41	-18.80	-13.64	1.43
	(88)	(91)	(177)	(85.5)	(438)	(360)	(11.19)
4. E19 × BIL95	-0.43	-0.34	-3.98	-6.41	18.80	13.64	-1.43
	(87)	(90)	(170)	(75.5)	(532)	(390)	(8.22)
5. E05 × BIL28	-0.57	-0.66	3.48	3.16	46.70	-13.64	1.14
	(86)	(89)	(169)	(78)	(494)	(350)	(10.19)
6. E05 × BIL95	0.57	0.66	-3.48	-3.16	-46.70	13.64	-1.14
	(87)	(90)	(163)	(74.5)	(457)	(380)	(7.81)
7. BIL51(2) × BIL28	-0.82	-0.41	-5.52	-3.84	1.45	13.86	0.04
	(89)	(92)	(154)	(64.5)	(445)	(380)	(9.45)
8. BIL51(2) × BIL95	0.82	0.41	5.52	3.84	-1.45	-13.86	-0.04
	(90)	(93)	(166)	(75)	(499)	(355)	(9.27)
9. Lmly08 × BIL28	-1.82*	-1.41	3.73	-0.34	44.20	33.86	-0.52
	(89)	(91)	(161.5)	(63)	(527)	(365)	(9.35)
10. Lmly08 × BIL95	1.82*	1.41	-3.73	0.34	-44.20	-33.86	0.52
	(92)	(94)	(155)	(66.5)	(495)	(300)	(10.29)
11. E04 × BIL28	0.43	0.84	7.98	5.91	-51.80*	-11.14	-1.19
	(87)	(90)	(164)	(71.5)	(405)	(365)	(9.58)
12. E04 × BIL95	-0.43	-0.84	-7.98	-5.91	51.80*	11.14	1.19
	(86)	(88)	(149)	(62.5)	(565)	(390)	(11.86)

Crosses	DP	DS	PH	EH	GR/EAR	TGW	YLD
13. BIL51(1) × BIL28	0.93	0.84	-0.77	2.41	8.20	13.86	0.23
	(90)	(92)	(183)	(86.5)	(513)	(400)	(11.97)
14. BIL51(1) × BIL95	-0.93	-0.84	0.77	-2.41	-8.20	-13.86	-0.23
	(87)	(90)	(185.5)	(84.5)	(553)	(375)	(11.40)
15. BIL50(1) × BIL28	1.68*	0.09	1.98	6.41	-77.55**	-13.64	-0.55
	(90)	(90)	(177.5)	(89.5)	(397)	(320)	(7.94)
16. BIL50(1) × BIL95	-1.68*	-0.09	-1.98	-6.41	77.55**	13.64	0.55
	(86)	(89)	(174.5)	(79.5)	(609)	(350)	(8.94)
17. E34 × BIL28	-0.57	-0.41	10.23	8.66	27.45	11.36	0.26
	(87)	(89)	(181)	(91)	(441)	(380)	(9.29)
18. E34 × BIL95	0.57	0.41	-10.23	-8.66	-27.45	-11.36	-0.26
	(86)	(90)	(161.5)	(76.5)	(443)	(360)	(8.68)
19. E36 × BIL28	-1.82*	-0.66	-8.52	-11.09	21.45	-18.64	-0.62
	(89)	(90)	(152)	(58)	(391)	(335)	(5.83)
20. E36 × BIL95	1.82*	0.66	8.52	11.09	-21.45	18.64	0.62
	(88)	(91)	(170)	(83)	(405)	(375)	(6.98)
21. E21 × BIL28	0.93	0.59	-2.27	-2.34	-10.80	-13.64	-0.57
	(86)	(90)	(175)	(79.5)	(447)	(375)	(10.91)
22. E21 × BIL95	-0.93	-0.59	2.27	2.34	10.80	13.64	0.57
	(86)	(89)	(180.5)	(87)	(525)	(405)	(11.95)
SE± (sij)	0.94	1.07	13.99	10.35	39.41	20.18	0.90

DP=Days to pollen shedding, DS=Days to silking, PH =Plant height (cm), EH =Ear height (cm).

GR/EAR= Grains per ear, TGW=1000- grain weight (g), YLD= Grain yield (t/ha).

Table 5. Heterosis over check variety (BHM-9) for different characters of F_1 crosses

SL	Crosses	DP	DS	PH(cm)	EH(cm)	Grains/ear	TGW(g)	Yield (t/ha)
1	BIL72×BIL28	-4.23**	-4.15**	-28.13**	-39.42**	9.18**	20.37**	-16.34**
2	BIL72×BIL95	-7.41**	-6.22**	-14.18**	-7.21**	16.91**	12.96**	-23.79**
3	E19×BIL28	-6.35**	-5.18**	-16.31**	-17.79**	-9.69**	33.33**	5.65*
4	E19×BIL95	-7.94**	-6.22**	-19.62**	-27.40**	9.69**	44.44**	-22.37**
5	E05×BIL28	-8.47**	-7.77**	-20.09**	-25.00**	1.86	29.63**	-3.75
6	E05×BIL95	-7.94**	-6.74**	-22.93**	-28.37**	-5.77**	40.74**	-26.24**
7	BIL51(2)×BIL28	-5.29**	-4.15**	-27.19**	-37.98**	-8.25**	40.74**	-10.77**
8	BIL51(2)×BIL95	-4.23**	-3.63**	-21.51**	-27.88**	2.78	31.48**	-12.50**
9	Lmly08×BIL28	-5.82**	-5.18**	-23.64**	-39.42**	8.66**	35.19**	-11.68**
10	lmly08×BIL95	-2.65**	-2.59**	-26.71**	-36.06**	2.06	11.11**	-2.85**
11	E04×BIL28	-7.41**	-6.22**	-22.46**	-31.25**	-16.49**	35.19**	-9.55**
12	E04×BIL95	-8.99**	-8.29**	-29.55**	-39.90**	16.49**	44.44**	11.97**
13	BIL51(1)×BIL28	-4.76**	-4.15**	-13.48**	-16.83**	5.77**	48.15**	13.02**
14	BIL51(1)×BIL95	-7.41**	-6.22**	-12.29**	-18.75**	14.02**	38.89**	7.68**
15	BIL50(1)×BIL28	-4.23**	-6.74**	-16.08**	-13.94**	-18.14**	18.52**	-25.04**
16	BIL50(1)×BIL95	-8.47**	-7.25**	-17.49**	-23.56**	25.46**	29.63**	-15.54**
17	E34×BIL28	-7.94**	-7.25**	-14.42**	-12.50**	-9.07**	40.74**	-12.25**
18	E34×BIL95	-7.41**	-6.74**	-23.64**	-26.44**	-8.76**	33.33**	-18.03**
19	E36×BIL28	-8.99**	-6.74**	-28.13**	-44.23**	-19.38**	24.07**	-44.92**
20	E36×BIL95	-5.82**	-5.70**	-19.62**	-20.19**	-16.60**	38.89**	-34.08**
21	E21×BIL28	-6.35**	-6.22**	-17.26**	-23.56**	-7.84**	38.89**	3.05
22	E21×BIL95	-8.99**	-7.77**	-14.66**	-16.35**	8.25**	50.00**	12.88**
	Mean	6.69	5.96	20.43	26.09	10.96	33.67	15.63
	Min	-8.88	-8.29	-29.55	-44.23	-19.38	11.11	-44.92
	Max	-2.65	-2.59	-12.29	-7.21	25.46	50.00	13.02
	SD ±	1.84	1.48	5.34	10.22	6.16	10.73	10.39
	CD (5%)	0.81	0.66	2.37	4.53	2.73	4.76	4.61
	CD (1%)	1.12	0.91	3.21	6.22	3.91	6.56	6.61

DP= Days to pollen shedding, DS= Days to silking, PH = Plant height (cm), EH = Ear height (cm).
GR/EAR = Grains per ear, TGW = 1000- grain weight (g), YLD= Grain yield (t/ha).

parents did not show high SCA effects in their hybrid combinations. On the contrary, Paul and Duara (1991) reported that the parents with high GCA always produced hybrids with high estimates of SCA. Thus, the SCA effect of the crosses was not reflected through the GCA effects of the parents. Roy *et al.* (1998) and Ivy and Hawlader (2000) also found the similar result. Significant and negative SCA effects for days to pollen shedding and silking are desirable for selection of early maturing hybrids. Three crosses showed significant and negative SCA effects for pollen shedding. None of the crosses exhibited significant and negative SCA effects for days to silking. Although only three crosses (Lmly08 × BIL28, BIL50(1) × BIL95 and E36 × BIL28) in days to pollen shedding and none of the crosses in days to silking exhibited significant and negative SCA effects but all the crosses showed significant and negative heterosis. Negative SCA effects for plant and ear height indicating short stature plant. None of the parents showed significant and negative SCA effects but exhibited significant and negative heterosis for all the crosses. In case of number of grains per ear, two crosses (E04 × BIL95 and BIL50(1) × BIL95) expressed significant and positive SCA effect. A positive SCA effect is desirable for 1000- grain weight. No significant and positive SCA was observed among the crosses but all the crosses showed significant and positive heterosis for this character.

Heterosis

Percent heterosis over BHM-9 was calculated for grain yield and other six different yield contributing characters are presented in Table 5. The degree of heterosis varied from cross to cross and from character to character. Negative heterosis is desirable for days to pollen shedding, days to silking, plant height and ear height. All the crosses in respect to days to pollen shedding, days to silking, plant height and ear height exhibited significant and negative heterosis. Positive heterosis is desirable for grains/ear, 1000- grains weight and yield. Regarding grains/ear, nine crosses showed significant and positive heterosis. All the crosses in respect of 1000- grains wt showed significant and positive which is desirable. For grain yield, five crosses showed significant and positive heterosis in the range - 44.92 to13.02% although none of the crosses exhibited significant and positive SCA effect (Table 4). Karim *et al.* (2021) and Talukder *et al.* (2016) reported -23.39 to 4.6% and -51.39 to 12.53% heterosis for grain yield in their study, respectively.

Conclusion

Good general combining ability effects for yield and important yield contributing characters were observed in the lines E21 and BIL51(1) for yield, E21 and BIL51(1) for 1000 - grain weight and BIL72 and BIL51(1) for grains /ear could be used in hybridization program as donor. These parents could result in the production of superior single crosses. Better performing three crosses BIL51(1) × BIL28, E21 × BIL95 and E04 × BIL95 could be used for commercial variety development after verifying the performance across locations.

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WATER PRODUCTIVITY AND ECONOMIC RETURN OF BOTTLE GOURD AT DIFFERENT IRRIGATION AND FERTIGATION DOSES

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Abstract

Bottle gourd needs frequent watering with fertilization to get a potential yield. The experiment was conducted in the Irrigation and Water Management Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, during the *Rabi* season (2017–2020) to determine fruit yield, water productivity, and net return. There were five irrigation treatments such as ring basin irrigation at 7 days interval (T_1) with recommended fertilizer, drip-fertigation at an alternate day with 0, 20, 35, and 50% (T_2-T_5) less nitrogen (N) potassium (K) than the recommended doses. T_4 gave the significantly highest fruit yield (39.30 t ha^{-1}). Drip-fertigation system saved 50% of seasonal water than the ring basin method. Treatment T_4 gave the highest water productivity (17 kg m^{-3}) and benefit-cost ratio (BCR) (3.16). Therefore, it can be concluded that bottle gourd can be irrigated every alternate day through a drip-fertigation system using 35% less NK than the recommended doses to get a higher yield, water productivity, and net return.

Keywords: Drip fertigation, Yield, Water productivity, Net return, BCR.

Introduction

Global vegetable production has increased from 646 million tons in 2000 to 1.13 billion tons in 2019 (FAO, 2021). Among them, Bangladesh ranked third (16 million tons/annum), while China and India ranked first and second (Islam, 2021).

One of the prospective vegetable crops is bottle gourd (*Lagenaria siceraria* L.), which belongs to the Cucurbitaceae family. It is a very popular vegetable in Bangladesh and is widely cultivated throughout the country mostly during the winter season. Its production is highly profitable and yield per hectare of land is highly dependent on the proper use of fertilizer and pesticides (Akter 2014; Hasan *et al.*, 2014; 2017). Its production has increased from 1.5% (2013-14) to 1.7% (2020-21) of yearly total vegetable production (BBS, 2021).

Crop cultivar, soil, and local climate are important characteristics that regulate the fruit yield and water requirement of the crop. For high-yielding varieties, it is suggested to irrigate at 5 to 6-day intervals depending on soil, location, and temperature to produce a better fruit yield in terms of quality and quantity (Bosh *et al.*, 1980). Another study in Hathazari, Chattogram, Bangladesh on BARI Lau-4

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gave higher fruit yield, water productivity, and economic return by irrigating 3-day intervals using the ring basin irrigation method (Haque and Faisal, 2021). Another study in Rampur, Chitwan, Nepal on bottle gourd with different varieties gave the significantly highest number of nodes plant^{-1} using daily irrigation with 75% of Pan Evaporation. This highest number of nodes plant^{-1} creates the possibility of higher brunch and consequently, higher bearing of fruit (Adhikari *et al.,* 2008).

Along with irrigation and proper use of fertilizer is also necessary for maintaining plant growth and fruit yield (Ananda Murthy *et al.,* 2020; Kumar *et al.,* 2022; Meena and Bhati, 2017; Tan *et al.,* 2009). A field study in Akola, India gave the significantly highest yield of bottle gourd (27 t ha^{-1}) using drip fertigation with 200:100:100 kg NPK ha^{-1} at 7-day intervals (Kumar *et al.*, 2022). However, a study on the effect of irrigation and fertilizer on bottle gourd in Bangladesh is not found.

Drip fertigation is a modern technique and is widely used in many developed countries for horticultural crops. The concept of drip fertigation is to create a continuous method strip along the lines of the plants. It increases the irrigation water and fertilizer use efficiency to a considerable extent and is recommended for high-value horticultural crops. This technology saves both water and fertilizer and gives a higher fruit yield than any other method (Bar-Yosef, 2020; Bresler, 1977; Dasberg and Or, 1999). Several studies have been reported on drip-fertigation method is a more water-saving irrigation method for increasing fruit yield, water productivity, and irrigation water productivity of bottle gourd. (El-Seifi *et al.*, 2015; Mubarak and Janat, 2021; Suresh and Kumar, 2007; Tan *et al.*, 2009). However, information regarding drip-fertigation of bottle gourd in the context of Loamy soil in Bangladesh (AEZ 28) is not known. Hence, the present study was undertaken to determine the performance of bottle gourd under drip-fertigation systems at different irrigation intervals and fertigation doses. Therefore, the objective was to determine fruit yield, water productivity (or water use efficiency), and net return of bottle gourd for the drip-fertigation system.

Materials and Methods

The experiment was conducted on bottle gourd (var. BARI Lau-3) during three consecutive *Rabi* seasons from 2017 to 2020 in the experimental field of Irrigation and Water Management Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur. In 2018–19, the plants were damaged after two harvests due to heavy rainfall and wind speed. The soil was silty clay loam with an average bulk density of 1.50 g cc^{-1} and a field capacity of 28 % (by dry weight basis). Cumulative evaporation and rainfall during the study period were 414.60 mm and 179.00 mm (2017–18 in Figure 1a), and 627.50 mm and 123.00 mm (2019–20 in Figure 1c). The mean evaporation during the day was 2.76 mm and 3.69 mm (Figures 1a and c). The temperature during the day and night varied from 17.20–35.60°C and 5.50–30.00°C (2017–18 in Figure 1b), and 15.30–37.00°C and 9.00–24.60°C (2019–20 in Figure 1d), respectively.

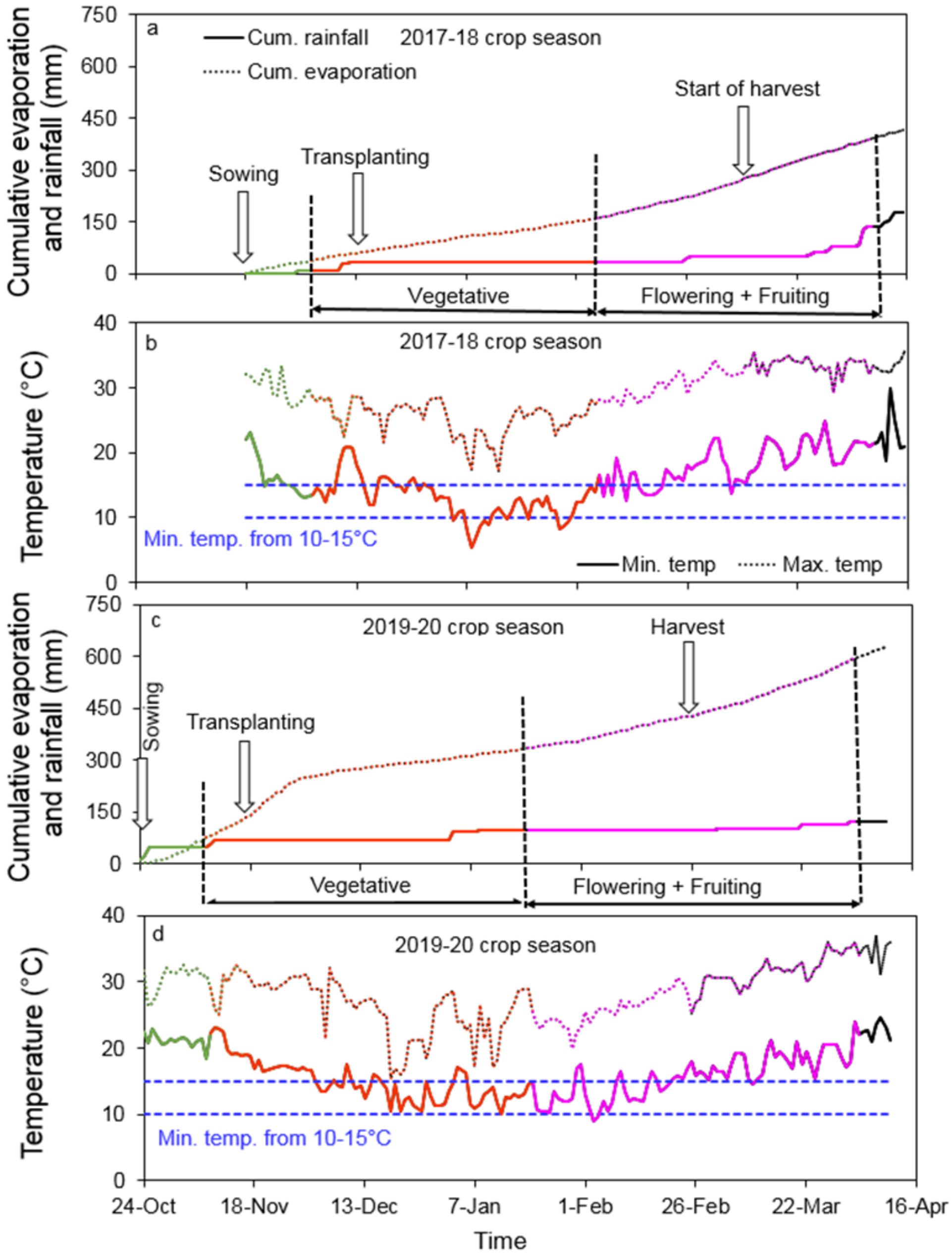

Fig. 1. Weather parameters of cumulative evaporation and rainfall (a, c), and minimum and maximum temperature (b, d) during the 2017–18 and 2019–20 crop seasons. The downward arrows in a and c present the time of sowing, transplanting, and the start of fruit harvest. The vegetative stage is highlighted in red, while the flowering and fruiting stages are highlighted in purple colour.

The experiment was laid out in a randomized complete block design with five treatments and three replications. The treatments were: T_1 = Ring basin irrigation at 7-day intervals with recommended fertilizer doses (RFD) (control) , T_2 = Drip-fertigation at an alternate day with 0% less NK than RFD (or 150:150 kg NK ha^{-1}), T_3 = Drip-fertigation at an alternate day with 20% less NK than RFD (or 120:120 kg NK ha^{-1}), T_4 = Drip-fertigation at an alternate day with 35% less NK than RFD (or 98:98 kg NK ha^{-1}) and T_5 = Drip-fertigation at an alternate day with 50% less NK than RFD (or 75:75 kg NK ha^{-1}).

The seeds of the bottle gourd were sown on 18 November 2017 and 24 October 2019 to produce seedlings. The seedlings were transplanted in the experimental plots on 13 December 2017 and 16 November 2019. The unit plot size was 4 m × 4 m with a 1.5 m buffer. The N and K in the form of urea and muriate of potash (MP) were applied with irrigation water as per the design of the treatments. The total phosphorus (P) in the form of triple super phosphate (TSP), gypsum, borax, zinc (Zn), and magnesium was applied as a basal dose in the pit. Cow dung was applied at the rate of 10 kg pit^{-1}. A total fertilizer of 150, 175, 150, 100, 12, 10, and 40 kg ha^{-1} urea, TSP, MP, gypsum, zinc, boric acid, and magnesium sulphate was used (BARI Agricultural Technology Handbook, 2020). However, irrigation was applied based on the treatments. The intercultural operations, insecticides and pesticides were applied as and when necessary. Fruits were harvested from 11 March to 16 April 2018 in 2017–18 crop season and from 25 February to 10 April 2020 in 2019–20 crop season.

In this experiment, irrigation was applied using two irrigation methods (ring basin method as a control and drip-fertigation method as an efficient and smart irrigation method). For the ring basin method, the amount of irrigation water was calculated based on soil moisture deficit up to field capacity and applied using a hose pipe based on time to reach the volume. Soil moisture was determined before each irrigation by gravimetric method. The same formula was used for irrigating other winter crops in the same study area (Mila *et al.*, 2015; 2017). For the drip-fertigation system, irrigation was applied every alternate day meeting the demand for crop evapotranspiration. The average dripper discharge was 3.8 litres hr^{-1}. Common irrigation of a total of 12 mm and 5 mm was applied from sowing to plant establishment for the 2017–18 and 2019–20 crop seasons. The irrigation treatments were started 7 days after transplanting. Drip irrigation time was varied from 25 minutes (initial stage) to 60 minutes (flowering + fruiting stages), depending on crop evapotranspiration (ET). The initial stage included the vegetative stage spanned from 3 Dec (or 15 days after transplanting) –5 Feb (or 79 DAT) in 2017–18 and 8 Nov (or 15 DAT)–19 Jan (or 87 DAT) in 2019–20 and flowering and fruiting stages after the end of vegetative to 7 days before the last harvest is shown in Figures 1a and c.

Drip-fertigation system

Four tanks were installed for four fertigation treatments (T_2–T_5) and placed at a height of 1 m from the ground surface supported by either a bamboo structure or iron frame on one side of the treatments. The tank had a capacity of 215 litres. A water tap was attached to one side of the bottom part of each tank to which the fertigation system was connected. The drippers were set according to the plant spacing in the treatments. Each plant received an emitter through which, water was applied to the plant in drips.

Water productivity and irrigation water productivity

Water productivity (WP) and irrigation water productivity (IWP) were calculated using the following formula:

$$\text{WP (kg/m}^3\text{)} = \text{Fruit yield (t ha}^{-1}\text{)} \times 100/\text{seasonal water use (mm)} \quad (1)$$

$$\text{IWP (kg/m}^3\text{)} = \text{Fruit yield (t ha}^{-1}\text{)} \times 100/\text{Irrigation water use (mm)} \quad (2)$$

Where, seasonal water use is the water used by irrigation, effective rainfall, and soil water change (Mila, 2021).

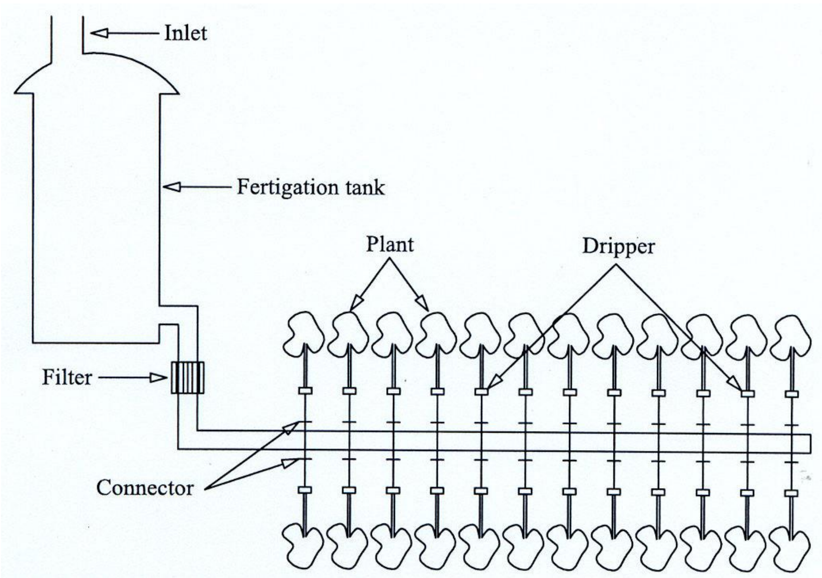

Fig. 2. Schematic diagram of the drip-fertigation system.

After harvest, the data on yield attributes of fruit length, fruit diameter, number of fruits plant^{-1}, unit fruit weight, and weight of fruit plot^{-1} were recorded. Finally, fruit yield (t ha^{-1}) was calculated from the weight of the fruit plot^{-1}.

Economic analysis was done for the five irrigation treatments using a drip-fertigation and ring basin irrigation systems (with a 7-day interval). Among the drip-fertigation treatments, the fixed cost was the same but the variable cost varied due to the variation in the amount of fertilizer (especially NK), irrigation, and labour. The items included in calculating the fixed cost for the drip-fertigation system were the fertigation tank, GI fittings with a supporting platform, PVC pipe, and micro tube (Table 3a). The expected life for the drip-fertigation system was considered to be 4 years. The fixed cost per year was calculated by dividing the total fixed cost for the installation of the system by the expected life of the system. However, no installation cost was required for the ring basin irrigation method. The variable cost for both methods included the cost of seedlings, pit making, fertilizer, trial, irrigation, and labour (Table 3b). The current market price was used for calculating the variable costs. The total cost year^{-1} was calculated by the summation of the total fixed cost and the total variable cost year^{-1} (Table 3c). Net return was calculated by subtracting total cost from gross return year^{-1} (Table 3c). Finally, the benefit-cost ratio year^{-1} was calculated by the ratio of gross return and net return year^{-1} (Table 3c). Data on fruit yield and yield attributes were analysed by using R software (R Core Team, 2013). The correlation and regression analysis between fruit yield and yield attributes or water productivity or irrigation water productivity was done using Jamovi and Excel software.

Results and Discussion

Effect of ring basin and drip-fertigation irrigation method on fruit yield and yield attributes

The effect of drip-fertigation on fruit yield and yield attributes of bottle gourd for 2017–18 and 2019–20 are shown in Table 1. In both the years, fruits plot^{-1}, fruits plant^{-1}, the weight of fruit plot^{-1}, and yield were significant, while in the 2nd-year unit weight and diameter of fruit were significant. The maximum t yields of 37.2 and 41.4 t ha^{-1} were obtained from treatment T_4 followed by treatment T_5 (33.0 and 36.4 t ha^{-1}) By contrast, the significantly lowest yields of 25.0 and 24.3 t ha^{-1} were found by applying irrigation in the ring basin method at 7-day intervals with recommended fertilizer doses (control in Table 1). However, the highest yield treatment was 21–29% lower than that of the potential yield of this variety.

A study on bottle gourd produced a yield of 27 t ha^{-1} using 200:100:100 kg NPK ha^{-1} at 7-day intervals through drip fertigation (Kumar *et al.*, 2022). Another study on bottle gourd gave a higher yield of 36.2 t ha^{-1} using irrigation at 4-6 days intervals with 110:70 kg NP ha^{-1} (Meena and Bhati, 2017). However, this study obtained the highest yield in irrigating on every alternate day with 35% less NK than recommended (98:98 kg NK ha^{-1}). The reason might be frequent watering based on crop evapotranspiration with 35% less NK can make a better solution for plant water uptake and consequently higher yield. On the other hand, the use of NK with 20 or 50% less amount might create a solution of lower or higher density that makes plants a situation of fertilizer deficient condition in a way of uptaking less fertilizer (for low density) or no fertilizer (for high density). Therefore, in the future, it would be important to determine the scientific reason behind this yield increase with the use of 35% less amount of NK fertilizer.

Table 1. Fruit yield and yield attributes of bottle gourd used in ring basin and drip fertigation methods at different frequencies during 2017–18 and 2019–20.

Treatment	Fruit length (cm)	Diameter of fruit (cm)	Fruits $plot^{-1}$ (no.)	Fruits $plant^{-1}$ (no.)	Unit weight of fruit (kg)	Weight of fruits $plot^{-1}$ (kg)	Fruit yield (t ha^{-1})
2017-18 crop season							
T_1	32.79	9.86	23.00	5.75	1.74	39.95	24.97
T_2	32.55	10.26	30.67	7.67	1.57	47.97	29.83
T_3	32.16	9.74	26.67	6.67	1.79	47.86	29.91
T_4	32.73	10.87	33.33	8.33	1.76	59.52	37.20
T_5	33.52	10.17	30.00	7.5	1.76	52.84	33.02
CV (%)	2.43	8.12	8.72	8.72	5.66	10.33	10.30
$LSD_{(0.05)}$	NS	NS	4.72	1.18	NS	9.65	6.00
2019-20 crop season							
T_1	32.77	9.86	25.66	6.41	1.74	38.80	24.25
T_2	32.34	10.32	31.66	7.91	1.58	52.74	32.96
T_3	32.40	9.75	29.33	7.33	1.70	52.91	33.07
T_4	33.00	10.52	37	9.25	1.87	66.22	41.39
T_5	33.34	10.25	33.4	8.33	1.74	58.30	36.44
CV (%)	2.95	3.15	10.78	10.7	4.63	5.50	5.54
LSD $_{(0.05)}$	NS	0.26	2.76	0.68	0.06	5.10	1.52

Here, T_1 = Ring basin irrigation at 7 days interval with recommended fertilizer doses (RFD) (control); T_2, T_3, T_4, and T_5 = Drip-fertigation at an alternate day with 0%, 20%, 35% and 50% less NK than RFD.

Effect of ring basin and drip-fertigation irrigation method on water use, water productivity, and irrigation water productivity

Irrigation, water use, and water productivity of bottle gourd for ring basin and drip-fertigation irrigation method are shown in Table 2. Overall, the ring basin method used 482 mm and 448 mm of water over the season in 2017–18 and 2019–20, respectively. While, the drip-fertigation method used only 255 mm and 226 mm of water, respectively during same season. The drip-fertigation system saved 47 and 50% of seasonal water than that of the ring basin method. Previous studies on bottle gourd using drip irrigation at various frequencies and amounts or compared with other irrigation methods (Mubarak and Janat, 2021; Tan *et al.,* 2009). Another study in Nepal found that daily, 2-day, and 4-day irrigation intervals using drip fertigation with 75% and 50% of ET saved an average of 30% and 57% of water than that of 100% of ET (Tan *et al.*, 2009).

The effective rainfall during the growing season was 160 mm and 117 mm during 2017–18 and 2019–20, respectively. The maximum water productivity (WP) of 15 and 18 kg m^{-3} (or a mean of 17 kg m^{-3}) was recorded for treatment T_4 followed by T_5 and the lowest was estimated for treatment T_1. A similar result was found for irrigation water productivity (IWP). Compared with the ring basin method, treatment T_4 gave 3 and 5 times WP and IWP. A study on bottle gourd using 75 to 50% crop ET) gave an average of 1 to 2 times more IWP than that of 100% ET (Tan *et al.*, 2009).

Table 2. Water use and water productivity of bottle gourd in ring basin and drip-fertigation methods at different frequencies during 2017–18 and 2019–20.

Treatments	Irrigation applied (no.)	Water for plant establishment (mm)	Irrigation applied (mm)	Effective rainfall (mm)	Water use (mm)	Water productivity (kg m^{-3})	Irrigation water productivity (kg m^{-3})
2017–18 crop season							
T_1	12	12	310	160	482	5	8
T_2	22	12	83	160	255	12	36
T_3	22	12	83	160	255	12	36
T_4	22	12	83	160	255	15	45
T_5	22	12	83	160	255	13	40
2019–20 crop season							
T_1	11	5	326	117	448	5	7
T_2	28	5	104	117	226	15	32
T_3	28	5	104	117	226	15	32
T_4	28	5	104	117	226	18	40
T_5	28	5	104	117	226	16	35

Dripper discharge was 3.75 litres hr^{-1} for both years.

Here, T_1 = Ring basin irrigation at 7 days interval with recommended fertilizer doses (RFD) (control); T_2, T_3, T_4, and T_5 = Drip-fertigation at an alternate day with 0%, 20%, 35% and 50% less NK than RFD.

Economic analysis between furrow and drip-fertigation method

Economic analysis for the drip-fertigation system over the traditional system for bottle gourd cultivation was done based on the mean of two years of data (2017-18 and 2019-20) in Table 3. The economic analysis reveals that the maximum benefit-cost ratio (BCR) 3.16 was obtained from treatment T_4 by applying 35% less NK than recommended doses through the drip-fertigation system followed by treatment T_5 (BCR 2.82) by applying 50% less NK than recommended doses through the drip-fertigation system. The lowest BCR of 1.92 was found by applying irrigation in a ring basin method at 7-day intervals with recommended fertilizer doses (control). The higher BCR in the drip fertigation method over ring basin methods was due to comparatively higher yield using less amount of irrigation and fertilizer which compensated with the higher cost incurred due to the installation cost, fertilizer, irrigation, and labour cost. Similarly, a higher return of

Taka 403137/ha was found in the drip-fertigation (T_4) system.. The findings agreed with the advantages of using the drip-fertigation method for growing high-value horticultural crops (Akanda *et al.,* 2004; Bar-Yosef, 2020; Biswas *et al.,* 2016; Bresler, 1977; Dasberg and Or, 1999). This is economic in terms of getting higher fruit yield, quality fruit, water savings, and judicious use of fertilizers but the initial installation cost was higher. However, this drip irrigation system can be used for more than one season if stored properly for the next season. Therefore, in the future, it needs further research on the improvement of this drip irrigation system for more functional and sustainable with minimum cost.

Table 3. Economic analysis for drip-fertigation over traditional system for bottle gourd cultivation .

(a). Fixed cost for two irrigation methods

Name of the items	Quantity	Rate (Tk.)	Cost (Tk./ha)	
			Ring basin	Drip-fertigation
Fertigation tank	40 nos.	1000	-	40000
GI fittings and supporting platform	-	-	-	10000
PVC pipe (0.0125 m diameter)	3000 m	4	-	12000
Micro-tube (0.32 m diameter)	7500 m	2.50	-	18750
Total fixed cost, Tk.				80750
Expected life of the system	4 years			
Total fixed cost year^{-1}				20188

b). Variable cost

Name of the items	Cost (Tk./ha)				
	T_1	T_2	T_3	T_4	T_5
Seedlings	1600	1600	1600	1600	1600
Pit making	2500	2500	2500	2500	2500
Fertilizer	19150	19150	16135	16000	14650
Trail	125000	125000	125000	125000	125000
Irrigation	20000	5000	5000	5000	5000
Labour	24000	16000	16000	16000	16000
Total variable cost (Tk.)	192250	192250	192250	166100	164750

(c). Net Return and benefit-cost ratio

Name of the items	Net return (Tk/ha.)				
	T_1	T_2	T_3	T_4	T_5
Average fruit yield ha^{-1} (ton)	24.61	31.40	31.49	39.30	34.73
Selling rate (Tk. ton^{-1})	15000	15000	15000	15000	15000
Gross return (Tk.)	369150	470925	472350	589425	520950
Total cost year^{-1} (Tk.)	192250	189438	187638	186288	184938
Net return year^{-1} (Tk. ha^{-1})	176900	281487	284712	403137	336012
Benefit-cost ratio		2.49	2.52	3.16	2.82

Here, T_1 = Ring basin irrigation at 7 days interval with recommended fertilizer doses (RFD) (control); T_2, T_3, T_4, and T_5 = Drip-fertigation at an alternate day with 0%, 20%, 35% and 50% less NK than RFD.

Conclusion

The highest fruit yield of bottle gourd 39.30 t ha^{-1} was obtained from treatment T_4 by applying 35% less NK than recommended doses through a drip-fertigation system followed by T_5 (34.73 t ha^{-1}) by applying 50% less NK than recommended doses through the same system. The ring basin and drip irrigation method required 241 mm and 465 mm of seasonal water. The drip fertigation system also saved 50% of seasonal water than that of the ring basin method. Treatment T_4 also gave 3, 6, and 2.5 times higher water productivity, irrigation water productivity, and net return than that of the ring basin method. Therefore, it can be concluded that the drip-fertigation system was more profitable than the ring basin irrigation system in cultivating bottle gourd.

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IMPACT OF TEXTILE DYEING EFFLUENTS ON GERMINATION, GROWTH, YIELD AND NUTRITIONAL QUALITY OF TOMATO (*Solanum lycopersicum* L.)

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Abstract

An experiment was conducted at the experimental field of the Soil Science Division, Bangladesh Agricultural Research Institute (BARI) during 2017-18 to find out the impact of textile dyeing effluents on germination and seedling stage for the production of Tomato. There were six treatments comprising five concentrations of textile dyeing effluents along with ground water as control treatment for irrigation purposes and tomato (var. BARI tomato-15) was used as plant material. In most of the cases 100% ground water irrigation (T_6 treatment) treated plant showed the best result regarding plant characteristics such as germination percentage (100%), fresh weight of fruit (70.00 g), yield/plant (1867g) which were statistically identical to waste water 20% + 80% of pure water treatment (T_5). On the other, waste water 100% + pure water 0% (T_1 treatment) showed the lowest result were germination percentage (66.67%), fresh weight of fruit (59.21g) and yield/plant (553 g). T_6 treatment showed the highest amount of ascorbic acid (1.34 mg/100 g) and β-carotene (0.08 mg/100 g) and the lowest amount (0.65 mg/100 g and 0.02 mg/100 g, respectively). The accumulation of heavy metals such as Zn, Fe, Cu, Pb accumulated in fruits at the rate of 3.95-9.73, 3.34-9.42, 4.43-11.31 and 2.79-6.19 ppm, respectively. Among these T_1, T_2, T_3 and T_4 treated samples, those containing Zn, Fe, Cu and Pb exceed the WHO recommended permissible limit. So, it can be suggested that, selected wastewater of a dyeing factory should be applied as irrigation water for the purpose of crop production as well as tomato cultivation.

Keywords: Textile, effluents, tomato, germination, growth, nutritional quality.

Introduction

Bangladesh is an agricultural country, where industrialization is taking place in a gradually increasing phase. The important industries are textiles, leather tanning, fertilizer, sugar, chemical, pharmaceutical, oil refining etc. Among these, textile industry is rapidly expanding day by day. There are 2030 small and large knit dyeing industries in Bangladesh (BKMEA, 2015). These industries are major source of effluents due to the nature of their operations, which require a high volume of water that eventually results in high waste water generation. The most common textile wet processing set up consists of desizning, scouring, bleaching,

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mercerizing, dyeing as well as finishing processes. Among these dyeing is the process of adding color to the fibers, which normally requires a large volume of water and reported that to dye 1 kg of cotton materials with reactive dyes requires an average of 70-150 L water, 0.6 kg NaCl and 40 g reactive dyes, alkalis and others pretreatment and dyeing auxiliaries (Allegre *et al.,* 2006). After the completion of dyeing, the used water is discharged as wastewater or effluents.

The wastewater from textile processing contains huge residues of dyestuff, which are major sources of heavy metals, salt, organic halogens (AOX), acid, alkalis, carcinogenic aromatic amines and color (Reife, 2003 & Smith, 2006). Dyeing effluents are characterized by high bio-chemical oxygen demand (BOD), Chemical oxygen demand (COD), sodium and other dissolved solids as well as micro nutrients and heavy metals (Garg & Kaushik, 2007). Considering these facts, textile industries are considered harmful for our natural environment such as soil, plants, aquatic life and human being as well.

Industrial wastes are the major source of heavy metals in the surface water, ground water and soils (Correia, 1998). On the other hand, heavy metals such as Cadmium, Copper, Plumbum, Nickel and Mercury may be present in soil from the parent materials during soil formation. Soil is a supporting layer for all organisms in the world. The most important one is that soil acts as a medium for plant growth and can recycle the nutrient and resources needed by plant. Soil will absorb heavy metals from the polluted wastewater as well as ground water and these will cause side effects for vegetable growth. As root grows in the soil, it will absorb water and nutrients from the solution. Heavy metals that are attached to soil water and soil particles will be absorbed by plant roots and accumulate in vegetables (Ross, 2007).

Higher concentrations of heavy metals in human bodies may induce tumors and mutations and are capable of causing genetic damage to germ cells (Dianne *et al.,* 1999). It is seen that several research studies were done on the above mentioned issue in different parts of the world. Regarding the issue, only a few research studies have been done in Bangladesh with leafy vegetables. However, no research has been conducted with fruit crops, specifically tomato. This is very popular vegetable in Bangladesh and has good nutritional value and taste. This vegetable is possible to cultivate in the effluent discharge areas. The present study was undertaken to observe the toxic effect of textile dyeing effluents on growth and yield of tomato and to find out the suitable stages of textile effluents for safe reutilization as irrigation.

Material and Methods

Collection of Textile Effluents

A pot experiment was conducted at the experimental field of Soil Science Division, Bangladesh Agricultural Research Institute (BARI) during 2017-18. Different concentrations of textile dying effluents were collected in pre cleaned plastic bottles from Tex Euro Bd. Ltd, a 20 tons dyeing capacity knit composite factory that is situated near Gazipur, Bangladesh. The effluents were stored at 25^0C temperature to avoid changes in their physiochemical properties. Various physio-chemical characteristics were analyzed at the laboratory of Soil Science Division, BARI, Joydebpur, Gazipur to assess the effects of textile dyeing effluents on germination, growth, yield and nutritional quality of tomato A germination test of tomato seed under different concentrations of textile dying effluents was conducted in soil Physics lab. In case of field growth observation, three tomato plants were planted in each pot. After being planted, all plants were irrigated by textile dyeing effluents according to treatments. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. A treatment detail of the treatments is given below.

T_1 =Waste water 100% + pure water 0%
T_2 = Waste water 80% + pure water 20%
T_3 = Waste water 60% + pure water 40%
T_4 = Waste water 40% + pure water 60%
T_5 = Waste water 20% + 80% of pure water
T_6 = Waste water 0% + pure water 100% (control)

Laboratory analysis of textile dyeing effluent

The physico-chemical parameters such as pH, temperature, electrical conductivity, dissolved oxygen (DO), total suspended solids (TSS), total dissolved solids (TDS), and nitrate (NO_3^-), phosphate (PO_4^{-3}), sulphate (SO_4^{-2}), chloride (Cl^-) and some heavy metals were determined in the soil science laboratory at the BARI, Gazipur. The pH and temperature of waste water were determined using portable HACH pH meter. Determination of other parameters such as nitrate (NO_3^-), sulphate (SO_4^{-2}), phosphate (PO_4^{-3}) was carried out in the laboratory using DR-2800™ portable Spectrophotometer. Electrical conductivity was determined by conductivity meter (EC150, HACH). Biochemical oxygen demand (BOD) was measured by dilution method (APHA, AWWA and WEF, 1998). Keeping samples 5 days in an incubator at 20°C after measuring initial DO of samples. Dissolved oxygen (DO) was measured by chemical method. Chemical oxygen demand (COD) was determined by dichromate digestion method. Chloride was determined by Mohr's silver-nitrate method. Suspended solids (SS) were measured gravimetrically while total solid was obtained by the sum of SS and TDS. Heavy metals (nickel, zinc, copper, chromium, lead, and cadmium) determination was carried out using Atomic Absorption Spectrophotometer (SPECTRA A.A-55B, VARIAN, and Australia) as per standard methods.

The experiment was laid out following the randomized complete block design (RCBD) with three replication. The values were subjected to one-way analysis of variance (ANOVA) and DMRT for comparison of means to determine statistical significance by using open source R program.

Results and Discussion

Physiochemical properties of wastewater and groundwater

The pH of different wastewater treatments varied between 7.2 and 9.5 while T_1 and T_2 exceeded the recommended value (6.5 to 8.5) of DOE for irrigation water quality standard and the values were 9.5 and 9.1, respectively. The concentration of total dissolved solids (TDS) was found to be well above in sample T_1 (3320 mg L^{-1}) than the irrigation standard (2100 mg L^{-1}) suggested by DOE. The concentration of total suspended solids (TSS) in T_1 was 310 mg L^{-1} which was much higher than the prescribed value (200 mg L^{-1}) of DOE for irrigation. The value of electrical conductivity (EC) highest in T_1 wastewater samples was 3450 µs cm^{-1} which exceeded the standard limit (1200 µs cm^{-1}). T_2, T_3 and T_4 treatments also exceeded the standard limit. Dissolved oxygen (DO) is very important for aquatic life. The DO of different studied samples was in this range except for T_1 T_2 & T_3 which contained the lowest DO (0.58, 2.85, 3.58 mg L^{-1}, respectively). Moreover, other element contents such as sulphate, nitrate, phosphate, lead, copper, nickel, cobalt, chromium and zinc were within the standard limit for irrigation purposes (table 1).

Table 1. Physio-chemical parameters of textile dying effluent

Parameters	Irrigation standard (DOE)	Treatments					
		T_1	T_2	T_3	T_4	T_5	T_6
pH	6.5-8.5	9.5	9.1	8.2	7.4	7.3	7.2
TDS (mg/l)	2100	3320	2790	2070	1380	690	300
TSS (mg/l)	200	310	260	195	142	78	30
EC (µs cm^{-1})	1200	3450	2690	1950	1355	660	350
DO (mg/l)	4.5-8	0.58	2.85	3.58	4.8	5.77	6.5
Cl^- (mg/l)	1000	2700	8	2500	64	42	31
$NO3^-$ (mg/l)	10	0.8	1.0	1.2	1.3	1.4	1.5
PO_4^- (mg/l)	15	0.19	0.23	0.32	0.38	0.48	0.52
SO_4^{-2} (mg/l)	1000	65	48	35	21	10	0
Copper (ppm)	3	0.1110	0.0890	0.0275	0.0050	0.0002	BDR
Zinc (Zn) ppm	10	0.9140	0.7940	0.5660	0.4154	0.3240	BDR
Iron (Fe) ppm	1.0	0.7306	0.3406	0.0870	0.0326	0.0078	BDR
Lead (Pb) ppm	0.1	0.0262	0.0050	BDR	BDR	BDR	BDR

Note: DOE= Department of Environment, Bangladesh, BDR= below the detectable range

T_1 = waste water 100% + pure water 0%), T_2 = waste water 80% + pure water 20%), T_3 = waste water 600% + pure water 40%), T_4 = waste water 400% + pure water 60%), T_5 = waste water 20% + pure water 80%), T_6 = waste water 00% + pure water 100% (control).

Germination percentage

Germination percentage varied significantly among the treatments at 2 DAS and 5 DAS (Days After Seeding) but there was no significant variation among the treatments at 3 and 4 DAS. In case of 2 DAS the germination percentage ranged between 0 to 33.33% where the maximum germination percentage observed in treatment T_6 (33.33%) and the lowest in the T_1 (0.00%) which was statistically similar to T_2 (6.67%) and T_3 (6.67%). In case of 3 DAS and 4 DAS there was no significant variation among the treatments. In case of 5 DAS treatments T_5 and T_6 showed the highest result of (100%) germination. However, T_1 showed the lowest result of (0.00%) germination. The other treatments showed a moderate germination percentage which ranged from 33.33%-83.33%. From the above findings it is assumed that the germination rate is almost inhibited with increasing concentrations of effluents. It may also occur due to high pH and high temperature of the effluent. Ramana, *et al.*, (2002) showed the effect of different concentrations (0%, 5%, 10%, 15%, 20%, 25%, 50%, 75% and 100%) of distillery effluent (raw spent wash) on seed germination in some vegetable crops viz., tomato, chili, bottle gourd, cucumber and okra and stated that higher the concentration, the lower the germination percentage.

Fresh and dry weight of plant at 3rd leaf stage

The fresh weight of plant at 3rd leaf stage was found to be the highest in T_6 treatment (6.72 g) and the lowest in T_1 treatment (4.30 g) (Figure 2).The other treatments varied from 5.64 g - 6.18 g. In case of dry weight of plant at 3rd leaf stage, the highest was found in T_6 treatment (0.729 g) and the lowest was in T_1 treatment (0.383 g). There was no significant difference among the other treatments. Khan *et al.*, (2009) showed that plant growth promoting factors largely depend on the irrigation water, which determines the external and internal characteristics of plant. The application of textile dyeing wastewater into soil for irrigation purposes raises the soil pH, EC and SAR values which reduce nutrient uptake by vegetative growth of plant. Since among the different stages of textile effluents used in the present study T_1 treated samples contained several constituents that had a negative impact on plant growth habit and provided the lowest fresh and dry weight as well.

Table 2. Effect of textile dyeing effluent on fresh and dry weight of plant

Treatments	Fresh Weight (g)	Dry Weight (g)
T_1 =Waste water 100% + pure water 0%	4.30	0.383
T_2 –=Waste water 80% + pure water 20%	5.64	0.519
T_3 =Waste water 60% + pure water 40%	5.87	0.608
T_4 =Waste water 40%+ pure water 60%	6.11	0.558
T_5 =Waste water 20% + 80% of pure water	6.18	0.613
T_6 =Waste water 0% + pure water 100% (control)	6.72	0.729
CV (%)	7.91	8.49

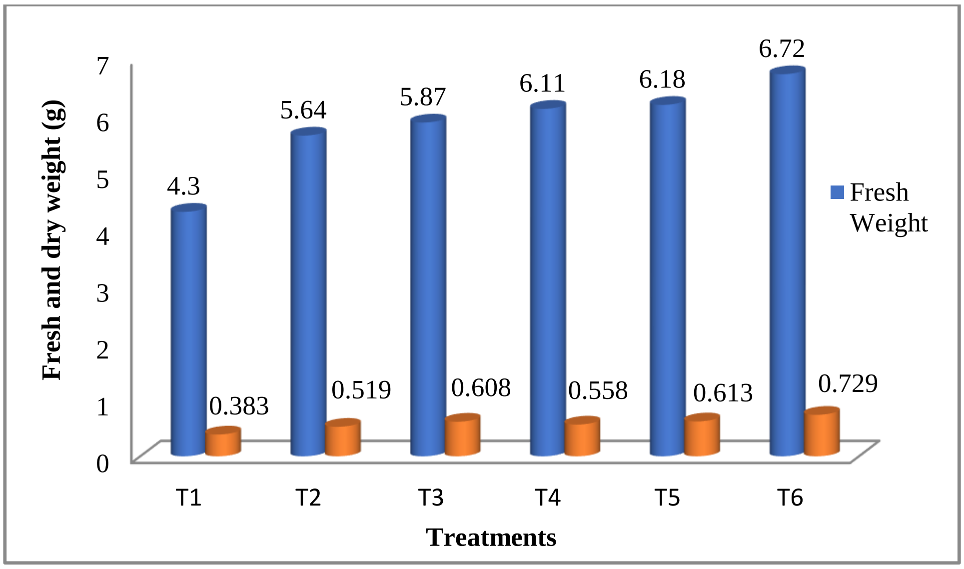

Fig. 2. Effect of textile dyeing effluent on fresh and dry weight of plant.

T_1 = waste water 100% + pure water 0%), T_2 = waste water 80% + pure water 20%), T_3 = waste water 600% + pure water 40%), T_4 = waste water 400% + pure water 60%), T_5 = waste water 20% + pure water 80%), T_6 = waste water 00% + pure water 100% (control)

Table 3. Effect of textile dyeing effluent on fruit characteristics and yield

Treatment	Plant height (cm)	No of fruit/plant	fruit Length (cm)	fruits diameter (cm)	Fresh weight/fruit (g)	Yield/ plant (g)
T_1	54.56	9.33	3.87	3.52	59.21	553
T_2	59.31	14.00	3.91	3.56	62.32	873
T_3	62.89	18.33	3.93	3.59	63.47	1164
T_4	67.39	19.67	3.96	3.61	65.35	1286
T_5	68.32	23.33	4.09	3.64	67.50	1575
T_6	71.13	26.67	4.33	3.67	70.00	1867
CV (%)	8.88	9.79	3.90	1.37	5.42	15.38
LSD (0.05)	2.81	3.34	0.24	0.03	2.50	292

T_1 = waste water 100% + pure water 0%) , T_2 = waste water 80% + pure water 20%), T_3 = waste water 600% + pure water 40%), T_4 = waste water 400% + pure water 60%), T_5 = waste water 20% + pure water 80%), T_6 = waste water 00% + pure water 100% (control)

Fruit characteristics and yield

The highest plant height was observed in T_6 treatment (71.13 cm), while the shortest plant in T_1 treatment (54.56 cm) (Table 3). The highest number of fruits was counted in T_6 treatment (26.67), while the lowest in T_1 treatment (9.33) (Table 3). The other treatments provided 14.00-23.33 fruits. Fruit length was the highest in T_6 treatment (4.33 cm) and the lowest in T_1 treatment (3.87 cm). Other treatments varied from 3.91-4.09 cm. In case of fruit diameter the highest was found at 3.67 cm in T_6 treatment, and the lowest in T_1 treatment (3.52 cm). The highest fresh weight of fruit was found in T_6 treatment (70.00 g), while the lowest in T_1 treatment (59.21 g). Yield /plant was found to be the highest in T_6 treatment (1867 g) and the lowest in T_1 treatment (553 g). The result showed a great variation in case of yield/ plant. Ahmed *et al.*, (2011) also reported that higher concentrations of heavy metals in waste water creating adverse effects on growth and yield of crops.

Concentration of ascorbic acid and β-carotene

The highest amount of ascorbic acid was found in T_6 treatment (1.34 mg/ 100 g) and the lowest was found in T_1 treatment (0.65 mg/ 100 g). Other treatments ranged from 0.79 -1.02mg/ 100 g (Fig. 2). In case of β-carotene T_6 treatment gave the highest amount (0.08 mg/100 g), while T_1 treatment gave the lowest amount of β-carotene (0.02 mg/100 g). Other treatments ranged between 0.03-0.07 mg/ 100 g. Hussain *et al.*, (2010) stated that textile effluents with heavy metals caused a reduction in parameters like chlorophyll content, protein, carbohydrate, ascorbic acid and β-carotene. Hence, plants treated with mixed effluent from equalization tank (T_1 treatment) showed lower levels of ascorbic acid and β-carotene than those treated with groundwater and other effluents.

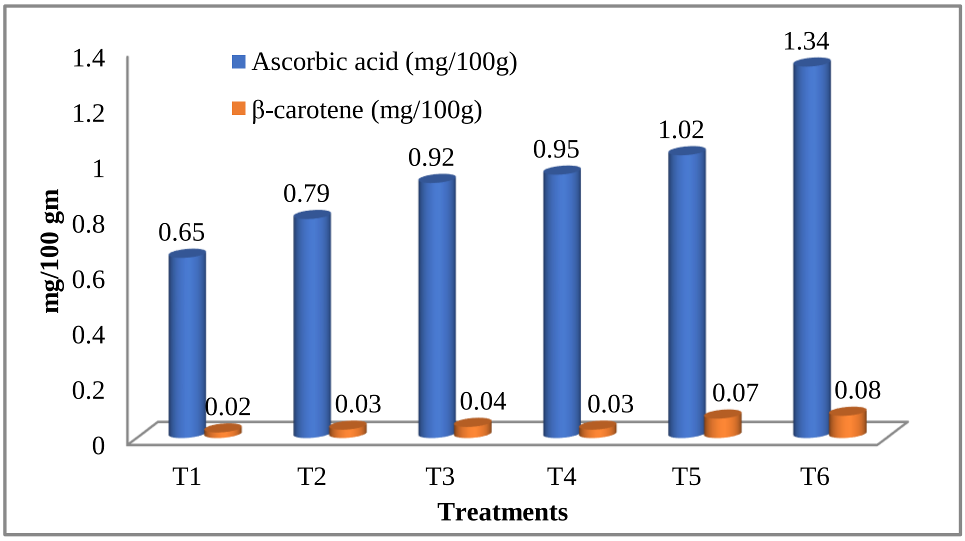

Fig. 2. Effect of textile dyeing effluent on ascorbic acid and β-carotene of tomato

T_1 = waste water 100% + pure water 0%) , T_2 = waste water 80% + pure water 20%), T_3 = waste water 600% + pure water 40%), T_4 = waste water 400% + pure water 60%), T_5 = waste water 20% + pure water 80%), T_6 = waste water 00% + pure water 100% (control

Heavy metals accumulation in edible part after harvest

Zinc concentration was found to be the highest in T_1 treated tomato (9.73 ppm) and the lowest in T_6 treatment (3.95 ppm) (Table 4). According to WHO/FAO (2007) critical level of zinc ions in edible portion of different vegetables is 5.00 ppm. Fruits of $T_{1,}$ $T_{2,}$ T_3 and T_4 treatments exceed this level, so these may cause harm to the health if intake these fruits. Fe was found to be the highest in fruit for T_1 treatment (9.42 ppm) and the lowest in T_6 treatment (3.34 ppm). Cu was found to be the highest in fruit of T_1 treatment (11.31 ppm) and the lowest in T_6 treatment (4.43 ppm). According to WHO/FAO (2007) critical level of Cu ions in edible portion of different vegetables is 8.00 ppm. Fruits of $T_{1,}$ $T_{2,}$ T_3 and T_4 treatments exceed this level, so these may cause harm to the health if intake them. Lead concentration was found to be the highest in okra of T_1 treatment 6.19 ppm and T_6 gave the lowest of 2.79 ppm. According to WHO/FAO (2007) critical level of Pb ions in edible portion of different vegetables is 4.00 ppm. In the present research work it was observed that fruits of $T_{5,}$ and T_6 treatments didn't exceed this level. Fruits from other treatments exceed this level, so these may cause harm to the health if intake them.

Table 4. Accumulation of heavy metal (ppm) in fruit of tomato

Treatment	Zinc (Zn) ppm	Iron (Fe) ppm	Copper (Cu) ppm	Lead (Pb) ppm
T_1	9.73 a	9.42 a	11.31 a	6.19 b
T_2	7.85 ab	9.61 a	10.33 ab	8.72 a
T_3	7.52 ab	5.03 c	8.67 bc	8.23 a
T_4	6.57 bc	7.66 b	8.39 bc	4.20 c
T_5	4.11 d	3.40 d	5.51 d	3.73 c
T_6	3.95 d	3.34 d	4.43 d	2.79 d
CV (%)	12.55	6.92	13.11	13.87

Conclusion

It is concluded that Textile dye industrial untreated effluent significantly influence growth parameters of tomato crop due to toxic effects of chemicals and heavy metals. Growth and yield performance of tomato was the best in 100% groundwater. Furthermore, accounting for the effect of textile dyeing effluents revealed thatwaste water 20% + 80% pure water (T_5) performed better than the others in terms of tomato growth and yield. Nutritional qualities of tomato varied remarkably, and observed that the maximum amount of ascorbic acid and β-carotene were found in 100% groundwater (T_6) treated sample which was statistically identical to waste water 20% + 80% of pure water (T_5). So, it can said that 20% mixed textile dyeing effluents in irrigation water should be tolerated in agricultural crop production to ensure the accumulation of heavy metals in different plant parts within the safe limit set by WHO standard. Mixture of less polluted dyeing wastewater can be used in vegetables cultivation to observe the growth, yield, food value and heavy metals accumulation to provide cost effective wastewater neutralization technique. As uptake of heavy metals by plant depend on many factors therefore, further research is needed to precisely identify the suitable steps of dyeing wastewater discharge for the betterment of human, agriculture as well as textile industry owners.

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STABILITY ANALYSIS OF KENAF (*Hibiscus cannabinus* L.) FIBER YIELDS USING GGE BI-PLOTS

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Abstract

High yield and stability are prerequisites for crop improvement and adaptation. Genotype + genotype × environment has been used to study G × E interaction in multi-environments, thus, this trial addressed selection for bast and core fibres yields and yield stability of kenaf. Fourteen kenaf genotypes were assessed in six diverse locations in Nigeria in a randomized complete block design with three replications for two years. Fibres weight data were pooled across the two years and subjected to GGE bi-plot analysis. Significant differences existed among the bast and core fibre yields of the genotypes in the locations. Genotype SAU75-441 produced the highest mean bast fibre yield (2.80 t ha^{-1}) while GS14-52 and AEHC-3 were also promising with respect to bast fibre production across locations. Core fibre yields of SAU75-441, GS14-52, AEHC-3, AU75-452 and AU 24524 were greater 4.00 t ha^{-1}. Hence, SAU75-441, GS14-52 and AEHC-3 are identified for further consideration for their yield potentials. Orin Ekiti and Ikenne had higher bast yields (2.55 t ha^{-1}) and (2.52 t ha^{-1}), respectively with core fibre yields (4.48 t ha^{-1}) and (4.29 t ha^{-1}), respectively. The bi-plot identified Ikenne, Ilora, Iwo and Orin Ekiti as a mega-environment where genotype SAU75-441 was the vertex for both bast and core fibres. Genotype GS14-52 was the vertex genotype in the Kaduna and Kisi mega-environment for the fibres. Genotypes SAU75-441, GS14-52 and AEHC-3 were therefore considered most suitable for the respective environments. Genotypes SAU75-414 and GS14-52 were highest bast and core fibres yields, and most stable with broadest adaptation in the two fibre types, hence, they are best recommended for future crop improvement programme.

Keywords: Bast fibre, Core fibre, GGE bi-plot, G × E interaction, *Hisbiscus*, Kenaf.

Introduction

Kenaf (*Hibiscus cannabinus* L.), the third largest fibre crop of economic importance after cotton and jute, belongs to the family Malvaceae. The crop has the potential to serve the dual purposes of cash and food crops. It is currently attracting the interest of both farmers and industrialists in Nigeria because of its food, environmental, industrial and economic benefits (Balogun *et al.*, 2009). Two types of fibres, namely bast and core fibres, exit for different uses. The bast fibre is obtained from the bark while the core fibre is from the inner (pith) core of the plants. Despite the greater adaptability and easy of cultivation and handling of

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kenaf than other fibre crops (Lemahieu *et al*. 2003), fitness into farming systems of the tropics especially intercropping; its multipurpose food potentials, economic and environmental benefits as well as increasing farmers' awareness, cultivation and productivity of the crop is still limited in sub-Saharan Africa and Nigeria in particular (Keshk *et al.*, 2006). The potential dry matter yield averages of about 6 to 10 t ha^{-1} of the crop is realizable in Africa (Masnira *et al*., 2015; Ogunniyan *et al.,* 2016).

Multi-environment yield trials are used to select favourable genotypes based on the mean yield and performance stability. Same genotype responds differently to different environments thus displaying the diverse phenotypic expression in all environments. The variation in the genotypic response to a specific environment is attributed to genotype × environment (G × E) which constitutes difficulty in selecting varieties based on the mean performance alone. The G × E is important in crop improvement through plant breeding programmes and introduction of new improved cultivars (Neacşu, 2011; Mulugeta *et al.,* 2013). Numerous statistical methods have been employed to explain G × E and its relationship with adaptability and stability in crops. However, Genotype + Genotype × Environment (GGE) models have been emphasized for multi environment trial data. The GGE bi-plot for mega environment analysis, genotype evaluation and test environment evaluation has been useful to visualize the pattern of G × E in multi environment genotype evaluation of different crops (Yan *et al*., 2000; Yan *et al*., 2007; Brar *et al*., 2010).

The fibre yield of kenaf in the sub-Sahara Africa is low, with a mean combined bast and core fibre yield of 5.5 t ha^{-1} in Nigeria. A strategy to increase production and productivity in a crop is to select for higher yielding varieties that have broad adaptability. This will widen the production base in terms of time and locations. There is the need to improve the crop's yield in relation to agro-ecological conditions. Therefore, the aims of this study were to evaluate 14 advanced kenaf genotypes for bast and core fibres yield and yield stability across locations with the intention to select promising and suitable for recommendation to farmers.

Materials and Methods

A total of 14 selected genotypes of kenaf were evaluated in six locations (Kisi, Kaduna, Orin, Ekiti, Ikenne, Ilora and Iwo) in Nigeria for bast and core fibres yields during the rainy season in 2017 and 2018. The 14 genotypes consisted of 12 accessions and two existing commercial varieties of the crop in Nigeria. The test locations cut across Rain Forest, Derived savannah and Guinea Savannah agro-ecologies of the country (Table 1). The trial was laid out in randomized complete block design with three replications in each location. Plants of each genotype were established in a four-row plot, 5 m each, at a spacing of 20 cm within row and 50 cm between rows in each location.

Table 1. Description of the six locations where the kenaf genotypes were evaluated

Location	Latitude (° N)	Longitude (° E)	Altitude (m asl)	Agro-ecology
Kisi	08.59	003.56	364	Guinea Savanna
Kaduna	09. 29	007. 22	252	Guinea Savanna
Orin Ekiti	07 50	005.14	456	Rainforest
Ikenne	06. 52	003.04	061	Rainforest
Ilora	07.49	003.49	269	Derived Savanna
Iwo	07.63	004.18	231	Derived Savanna

Four seeds were sowed per hill and thinned to two plants per stand to adjust the population density to 80,000 plants ha^{-1} at 3 weeks after planting. About 60 kg ha^{-1} NPK fertilizer was applied at four weeks after planting (IAR & T, 2015). The plots were kept weed free throughout the study by hoeing twice and slashing one. The hoeing was done with hoe during the vegetative growth stage while cutlass was used to slash during the flowering stage.

Forty randomly selected plants from each plot were cut at 5 cm above ground when the crops were 80 days old. The freshly cut kenaf bundles were sorted by plot, tagged and soaked in a running stream for 14 days after which the bast fibres were stripped from core manually. Both the bast and core fibres were washed in clean water to ensure fibre quality. The fibre was dried by direct sunshine for five days. The fibre dryness was taken by hand feeling. The bast and core fibres were weighed separately for each genotype. Data collected were pooled across 2017 and 2018 and means were tested by using Least Significant Difference before GGE bi-plots were used. The GGE bi-plot was also used to identify high yielding and adapted kenaf genotypes.

Relative magnitude and direction of genotypes along the abscissa and ordinate axes in a biplot were used to understand the response pattern of genotypes across environments according to Yan and Kang (2003). Best genotypes were those which combined high fibre yield with stable performance across locations. An ideal genotype was taken according to Mitrovic *et al*. (2012) as the highest yielding across test environments that was absolutely stable in performance. Concentric circles were used to visualize the distance between each environment and the ideal environment. The centre of concentric circles was regarded an ideal test environment for being the most representative of the overall environments and the most powerful to discriminate genotypes (Yan and Rajcan, 2002). In the "mean vs. stability" of the GGE bi-plot view, the average yields of the genotypes were determined by the projections from the positions of the genotypes onto the average tester ordinate (ATC ordinate) while the stability of genotypes was measured by their projections from the average tester coordinate abscissa (ATC abscissa) or the horizontal line. The further the genotype from the ATC ordinate, the higher the bast fibre yield. In addition, the shorter the length of the projection to the ATC abscissa, the more stable the genotype.

Results and Discussion

Significant differences existed among the bast fibre yields of the kenaf genotypes evaluated in six locations in Nigeria in 2017 and 2018 (Table 2). The effect of the Genotype × year interaction on the bast fibre yield was also significantly different ($p \leq 0.05$). Genotype SAU75-441 (G11) produced the highest mean bast fibre yield (2.80 t ha^{-1}) across the locations while the least mean bast fibre yield of 1.74 t ha^{-1} was recorded in SLE 14-1 (G12). It was also found that mean bast fibre yields of genotypes SAU75-441 (G11), GS14-52 (G8), AEHC-3 (G3) and IFEKEN DI-400 (G10) were significantly higher than the mean across the locations. IFEKEN 400 (G9) had bast yield that was statistically similar to the mean grand bast fibre yields. Each of the five genotypes produced greater than 2.5 t ha^{-1} bast fibre. Yields of bast fibre in Orin Ekiti (2.55 t ha^{-1}) and Ikenne (2.52 t ha^{-1}), had highest than those of other four locations. The mean bast fibre yields of the genotypes in Ilora and Iwo locations were close to the overall mean (2.27 t ha^{-1}) for the six locations while the least yield was obtained in Kisi with 2.00 t ha^{-1}.

Table 2. Bast fibre yield of kenaf genotypes evaluated in six locations in Nigeria over 2017 and 2018

Entry	Genotype	Bast fibre yield (t ha^{-1})						
		Kisi	Kaduna	Orin Ekiti	Ikenne	Ilora	Iwo	Mean
G1	2GQQ 13	1.72	1.85	2.53	2.48	2.13	2.03	2.12
G2	ACG33-293	1.89	1.84	2.23	2.32	1.80	2.06	2.02
G3	AEHC-3	2.35	2.49	3.07	3.09	2.69	2.76	2.74
G4	AU 24524	2.33	2.13	2.44	2.57	2.44	2.46	2.40
G5	AU2452-43	1.88	2.22	2.57	2.36	2.31	2.17	2.25
G6	AU75-192	1.87	2.16	2.35	2.25	2.12	2.15	2.15
G7	AU75-452	1.75	2.06	2.65	2.69	2.58	2.50	2.37
G8	GS14-52	2.45	2.58	3.14	3.14	2.59	2.74	2.77
G9	IFEKEN 400	2.40	2.40	2.97	2.80	2.49	2.42	2.58
G10	IFEKEN DI-400	2.32	2.47	2.97	2.96	2.46	2.53	2.62
G11	SAU75-441	2.25	2.67	3.21	3.11	2.71	2.82	2.80
G12	SLE14-1	1.70	1.45	1.95	2.05	1.81	1.50	1.74
G13	SLE14-13	1.75	1.41	2.11	2.13	2.02	1.90	1.89
G14	SLE14-2	1.76	1.64	2.14	2.00	1.81	1.58	1.82
	Mean	2.00	2.06	2.55	2.52	2.26	2.22	2.27
	LSD (0.05)	0.39	0.30	0.34	0.30	0.32	0.42	
	MS Genotype	3.55	4.04	4.17	4.17	4.13	3.60	
	MS Year	29.07	32.41	32.22	32.83	32.53	31.49	
	MS Genotype × Year	1.25*	1.37*	1.50*	1.29*	1.20*	1.19*	
	CV (%)	22.7	24.6	23.2	23.8	24.0	23.4	

The GGE bi-plot analysis revealed that the first and second principal component axes explained 95% of the total variation in bast fibre yield of kenaf (Figure 1). The polygon revealed AU75-452 (G7), SAU75-441 (G11), GS14-52 (G8), IFEKEN 400 (G9), SLE14-2 (G14), SLE14-1 (G12) and SLE14-13 (G13) as the vertex genotypes. The "which-won-where" view of the GGE bi-plot identified four mega-environments. Ikenne, Ilora, Iwo and Orin Ekiti formed a mega-environment where genotype SAU75-441 (G11) was the vertex. On the other hand, Kaduna and Kisi fell in a sector where GS14-52 (G8) and IFEKEN 400 (G9) were at the vertexes. However, AU75-452 (G7), SLE14-1 (G12), SLE14-13 (G13) and SLE14-2 (G14) were at the vertex in other sectors that were not identified with any of the environments.

The "mean vs. stability" of the GGE bi-plot view showed genotypes SAU75-441 (G11), GS14-52 (G8) and AEHC-3 (G3) occurred on the innermost circle of the GGE bi-plot (Figure 2). The three genotypes were also at the most distant end in the direction of the projection of the AEA, while SLE14-1 (G12), SLE14-13 (G13) and SLE14-2 (G14) were prominent among those that occurred at the farthest end against the AEA projection. According to the Figure 2, genotypes GS14-52 (G8), AEHC-3 (G3), IFEKEN DI-400 (G10), AU2452-43 (5), AU75-192 (G6) and SLE14-13 (G13) had least projections from the AEA on the bi-plot. However, genotypes AU2452-43 (5), AU75-192 (G6) and SLE14-13 (G13) had low PC 1. The core fibre yields of the kenaf genotypes evaluated in six locations in Nigeria in 2017 and 2018 were presented in Table 3. The effect of the Genotype × Year interaction on the core fibre yield was also significantly different ($p \leq 0.05$). The least core fibre yield (2.92 t ha^{-1}) was recorded on SLE14-2 (G14) followed by SLE14-1 (G12) (2.93 t ha^{-1}) while SAU75-441 (G11) had the highest core fibre yield of 4.96 t ha^{-1}. The core fibre yields of SAU75-441 (G11), GS14-52 (G8), AEHC-3 (G3), IFEKEN 400 (G9) and IFEKEN DI-400 (G10), AU75-452 (G7) and AU 24524 (G4) were greater than 4.0 t ha^{-1}. The results also showed that 3.52 t ha^{-1} which was the lowest average by location was obtained in Kisi while Orin Ekiti had the highest average core fibre yield of 4.48 t ha^{-1} among other test locations. Only Orin Ekiti and Ikenne had core fibre yields that were higher than the grand mean.

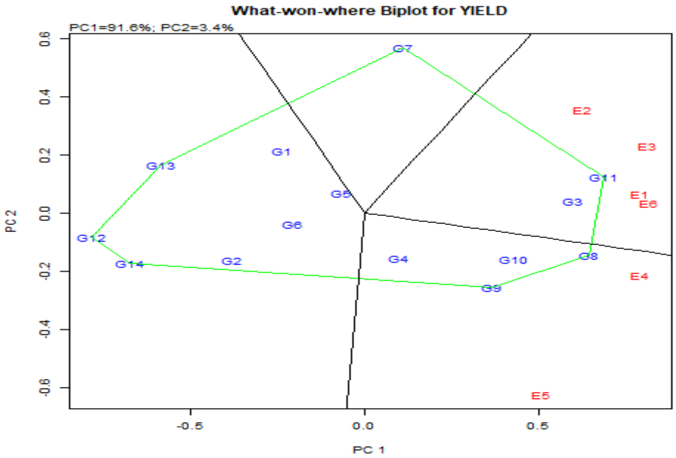

Fig. 1. The GGE bi-plot showing the ‘which won where’ for bast fibre yield of kenaf genotypes, 2GQQ 13 (G1), ACG33-293 (G2), AEHC 3 (G3), AU 24524 (G4), AU2452-43 (G5), AU75-192 (G6), AU75-452 (G7), GS14-52 (G8), IFEKEN 400 (G9), IFEKEN DI-400 (G10), SAU75-441 (G11), SLE14-1 (G12), SLE14-13 (G13) and SLE14-2 (G14), evaluated in six locations, Ikenne (E1), Ilora (E2), Iwo (E3), Kaduna (E4), Kisi (E5) and Orin Ekiti (E6), in Nigeria over 2017 and 2018.

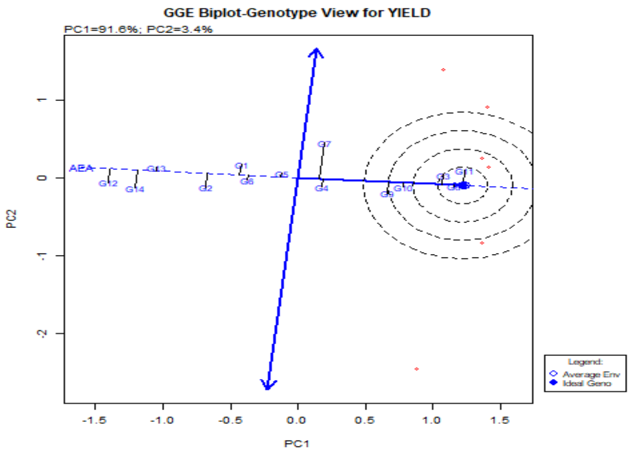

Fig. 2. The GGE bi-plot showing the mean versus stability for bast fibre yield of kenaf genotypes, 2GQQ 13 (G1), ACG33-293 (G2), AEHC 3 (G3), AU 24524 (G4), AU2452-43 (G5), AU75-192 (G6), AU75-452 (G7), GS14-52 (G8), IFEKEN 400 (G9), IFEKEN DI-400 (G10), SAU75-441 (G11), SLE14-1 (G12), SLE14-13 (G13) and SLE14-2 (G14), evaluated in six locations, Ikenne (E1), Ilora (E2), Iwo (E3), Kaduna (E4), Kisi (E5) and Orin Ekiti (E6), in Nigeria over 2017 and 2018.

Table 3. Core fibre yield of kenaf genotypes evaluated across six locations in Nigeria over 2017 and 2018

Entry	Genotype	Core fibre yield (t ha^{-1})						
		Kisi	Kaduna	Orin Ekiti	Ikenne	Ilora	Iwo	Mean
G1	2GQQ 13	2.99	2.92	4.04	3.85	3.63	3.26	3.45
G2	ACG33-293	2.73	3.01	3.74	3.82	3.51	3.57	3.40
G3	AEHC-3	4.00	4.43	5.53	5.51	4.81	4.40	4.78
G4	AU 24524	3.65	3.99	4.67	4.35	3.99	3.86	4.08
G5	AU2452-43	3.41	3.71	3.90	4.06	3.41	3.18	3.61
G6	AU75-192	3.14	3.98	4.02	4.00	3.23	3.06	3.57
G7	AU75-452	3.13	3.82	4.91	4.81	3.98	4.44	4.18
G8	GS14-52	4.75	4.38	5.62	5.55	4.95	4.25	4.92
G9	IFEKEN 400	4.25	4.22	5.12	5.14	4.41	4.19	4.55
G10	IFEKEN DI-400	3.98	4.10	5.18	5.04	3.85	4.54	4.45
G11	SAU75-441	4.48	4.46	5.57	5.43	5.28	4.58	4.96
G12	SLE14-1	2.96	2.45	3.37	2.65	3.04	3.12	2.93
G13	SLE14-13	2.91	3.03	3.85	3.13	3.23	3.03	3.20
G14	SLE14-2	2.83	3.18	3.17	2.75	2.61	3.01	2.92
	Mean	3.52	3.69	4.48*	4.29*	3.85	3.75	3.93
	LSD	0.51	0.41	0.50	0.42	0.60	0.67	
	MS Genotype	5.32	4.85	7.14	5.76	5.10	5.46	
	MS Year	62.39	61.36	84.09	71.56	62.23	65.89	
	MS Genotype × Year	2.46*	2.72*	3.63**	3.80**	2.60*	2.40*	
	CV (%)	22.21	23.00	24.09	25.25	23.01	22.56	

The 'which-won-where' for the core fibre yield of kenaf was presented in Figure 3. The first and second principal component axes explained 94.7% of the total variation in core fibre yield. The polygon had five sectors, out of which only two identified with the test environments Genotype GS14-52 (G8) was the vertex in the sector where Kaduna and Kisi were identified, and GS14-52 (G8) and IFEKEN 400 (G9) and AU 24524 (G4) as adaptable genotypes. Other genotypes in the mega-environment included AEHC-3 (G3) and IFEKEN DI-400 (G10) while AU75-452 (G7)

(2.55 t ha^{-1}) and Ikenne (2.52 t ha^{-1}), had highest than those of other four locations. The mean bast fibre yields of the genotypes in Ilora and Iwo locations were close to the overall mean (2.27 t ha^{-1}) for the six locations while the least yield was obtained in Kisi with 2.00 t ha^{-1}. The SAU75-441 (G11) was the vertex genotype in a sector where Ikenne, Ilora, Iwo and Orin Ekiti were identified as a mega-environment. The SLE14-2 (G14), ACG33-293 (G2), SLE14-1(G12) and AU75-192 (G6) were the vertex genotypes in other sectors where no environment was identified.

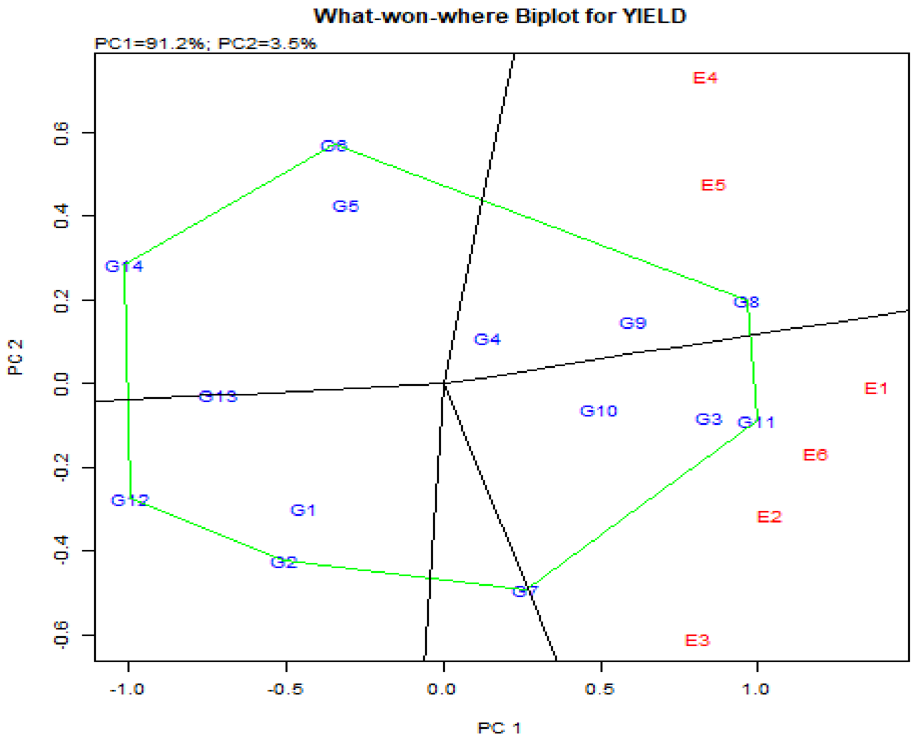

Figure 3. The GGE bi-plot showing the 'which won where' for core fibre yield of kenaf genotypes, 2GQQ 13 (G1), ACG33-293 (G2), AEHC 3 (G3), AU 24524 (G4), AU2452-43 (G5), AU75-192 (G6), AU75-452 (G7), GS14-52 (G8), IFEKEN 400 (G9), IFEKEN DI-400 (G10), SAU75-441 (G11), SLE14-1 (G12), SLE14-13 (G13) and SLE14-2 (G14), evaluated in six locations, Ikenne (E1), Ilora (E2), Iwo (E3), Kaduna (E4), Kisi (E5) and Orin Ekiti (E6), in Nigeria over 2017 and 2018.

The GGE bi-plot showing the genotype view for core fibre of the kenaf genotypes in 2017 and 2018 was presented in Figure 4. Genotypes SLE14-13 (G13), AU 24524 (G4), IFEKEN400 (G9) and GS14-52 (G8) were closer to the AEA than the remaining genotypes, especially the AU75-452 (G7) and AU75-192 (G6) which were projected farther from the axis. Genotypes SAU75-441 (G11) and GS14-52 (G8) had the highest PC1 values while SLE14-2 (G14) and SLE14-1 (G12) had the least. Genotype GS14-52 (G8) was closest to the ideal environment.

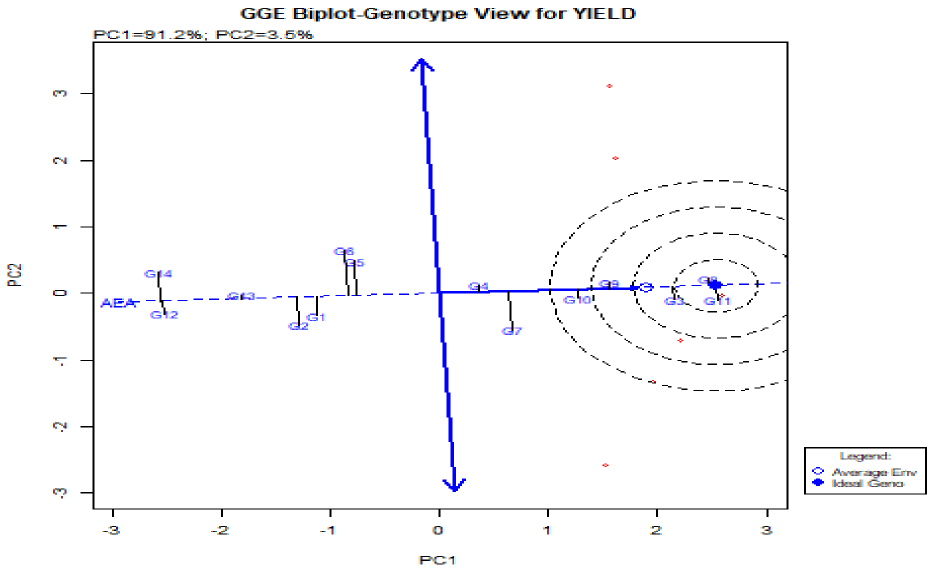

Figure 4. The GGE bi-plot showing the mean versus stability for core fibre yield of kenaf genotypes, 2GQQ 13 (G1), ACG33-293 (G2), AEHC 3 (G3), AU 24524 (G4), AU2452-43 (G5), AU75-192 (G6), AU75-452 (G7), GS14-52 (G8), IFEKEN 400 (G9), IFEKEN DI-400 (G10), SAU75-441 (G11), SLE14-1 (G12), SLE14-13 (G13) and SLE14-2 (G14), evaluated in six locations, Ikenne (E1), Ilora (E2), Iwo (E3), Kaduna (E4), Kisi (E5) and Orin Ekiti (E6), in Nigeria in 2017 and 2018.

There were significant variation in the plant heights of the crop in various locations due to the effect of genotype and G × Y interaction except Ikenne where the effect of the G × Y was not significantly different (Table 4). The stem diameters differed due to genotypic effect in Kaduna only. The effect of year was significant on the plant height of the crop in Kaduna, Ilora and Iwo. The coefficient of variation of the two parameters were low (less than 15 %) in all the locations. Genotypes SAU75-441 (G11), GS14-52 (G8), IFEKEN 400 (G9), IFEKEN DI-400 (G10) and AEHC-3 (G3) were prominent among those with highest plant heights and stem diameters.

Discussion

Significant differences that existed in both the bast and core fibre yields of the kenaf genotypes in the six locations in Nigeria across the two years indicates variation in the response of the crop to the various environments in accordance with the genetic potential of each genotype (Table 1). Wide variation has been observed in agronomic characteristics, and in the fibre yields kenaf genotypes (Ogunniyan, 2016). Yield is greatly influenced by environmental factors such as time of planting, climate or soil status and micro-environment created by the cultural practices applied. Crop genotypes respond differently to the environment factors in each location, and this is the reason the reason for stability analysis to select genotypes that have wide adaptability (Lotan *et al.,* 2012; Hassan *et al.,* 2013; Mulugeta *et al.,* 2013; Ogunniyan *et al.,* 2017).Genotypes SAU75-441 (G11), AEHC-3 (G3), IFEKEN DI-400 (G10) and GS14-52 (G8) were promising with respect to production bast fibre. This is evident in their yields which were higher than the grand mean across the locations. Hence, genotypes SAU75-441 (G11), GS14-52 (G8) and AEHC-3 (G3) are identified for further consideration for recommending for use by farmers. The core fibre yields followed the trend in the performance of the genotypes. Genotypes SAU75-441(G11), GS14-52 (G8), AEHC-3 (G3), IFEKEN 400 (G9) and IFEKEN DI-400 (G10), AU75-452(G7) and AU 24524 (G4) were high core fibre yielders. They had yield potentials greater than the yields of the two existing varieties namely IFEKEN DI-400 (G10) and IFEKEN 400 (G9) in the two fibre types. Highest mean fibre yield obtained in Orin-Ekiti, closely followed by Ikenne suggests the two locations as suitable for production of the crop. Orin Ekiti has been found to be a suitable for kenaf production (Ogunniyan *et al.,* 2017). This may be due to the prevailing weather condition with moderate amount of rainfall and solar radiation required for the growth of the crop as observed by Shukor *et al.* (2009).

Only two of the four mega-environments are congruent to test environments identified by the “which-won-where” view of the GGE bi-plot. Genotypes AU75-452 (G7), SAU75-441 (G11), GS14-52 (G8), IFEKEN 400 (G9), SLE14-2 (G14), SLE14-1 (G12) and SLE14-13 (G13) led in adaptation to the various mega-environments without recourse to their yield because they were at the as the vertices. This reason portrays SAU75-441 (G11), GS14-52 (G8) and IFEKEN 400 (G9) as champions in their various mega-environments. Genotype SAU75-441 (G11) can be nominated for the mega-environment involving Ikenne, Ilora, Iwo and Orin Ekiti. On the other hand, GS14-52 (G8) and IFEKEN 400 (G9) were most promising in Kaduna and Kisi mega-environment. These genotypes were therefore considered most suitable and promising in the respective environments. The remaining vertex genotypes in other sectors that did not identify with any of the environments can be useful in some other environments.

The least projections of genotypes GS14-52 (G8), AEHC-3 (G3), IFEKEN DI-400 (G10), AU2452-43 (5), AU75-192 (G6) and SLE14-13 (G13) from the AEA on the bi-plot means they are stable genotypes. Their locations on the bi-plot which correspond with the direction of the AEA projection show the genotypes are high yielding. They are also closely related to the ideal genotype due to the occurrence in the innermost concentric circle. Therefore, SAU75-441(G11), GS14-52 (G8) and AEHC-3 (G3) have identified as most suitable with respect to bast fibre yield and stability across locations with respect to bast fibre yield.

Table 4. Variation in plant height and stem diameter of kenaf genotypes evaluated across six locations in Nigeria over 2017 and 2018

Entry	Genotype	Kisi		Kaduna		Orin Ekiti		Ikenne		Ilora		Iwo		Mean	
		Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)
G1	2GQQ 13	264.31	1.82	224.4	2.24	272.47	2.17	279.87	1.73	184.16	1.63	222.55	2.02	241.29	1.94
G2	ACG33-293	263.85	1.74	229.2	2.30	272.32	1.74	264.18	1.64	202.25	1.59	239.99	2.12	245.30	1.86
G3	AEHC-3	257.78	1.85	213.5	2.21	284.00	2.17	273.67	1.79	228.72	1.79	248.87	2.15	251.09	1.99
G4	AU 24524	259.22	1.75	229.0	2.23	288.00	2.01	262.20	1.59	202.67	1.22	231.20	2.07	245.38	1.81
G5	AU2452-43	262.40	1.86	222.9	2.15	267.65	1.96	275.18	1.52	186.70	1.34	245.42	2.04	243.38	1.81
G6	AU75-192	257.46	1.79	223.5	2.22	288.53	2.01	246.83	1.80	211.62	1.73	239.45	2.06	244.57	1.94
G7	AU75-452	264.11	1.90	231.2	2.13	293.33	2.06	290.77	1.62	220.89	1.76	227.43	2.16	254.62	1.94
G8	GS14-52	271.91	2.02	248.2	2.45	293.20	2.21	271.37	1.86	226.73	1.81	246.41	2.29	259.64	2.11
G9	IFEKEN 400	270.90	1.87	230.5	2.24	288.11	2.23	281.32	1.86	221.78	1.81	238.00	2.20	255.10	2.04
G10	IFEKEN DI-400	270.65	1.90	237.7	2.40	288.47	2.16	277.30	1.90	231.61	2.00	243.49	2.15	258.20	2.09
G11	SAU75-441	273.17	2.01	249.4	2.52	305.21	2.32	281.46	1.81	230.70	2.20	248.29	2.28	264.71	2.19
G12	SLE14-1	264.13	1.85	215.4	2.17	269.82	1.92	270.22	1.60	220.68	1.70	250.66	1.97	248.49	1.87
G13	SLE14-13	263.44	1.75	229.6	2.23	273.00	2.05	268.97	1.58	209.78	1.89	232.60	1.82	246.23	1.89
G14	SLE14-2	255.38	1.80	215.1	2.25	277.01	2.15	253.79	1.65	225.97	1.87	231.14	1.78	243.07	1.92
	Mean	264.19	1.85	228.54	2.27	282.94	2.08	271.22	1.71	214.59	1.74	238.96	2.08	250.08	1.95
	LSD (0.05)	24.50	0.29	20.15	0.31	43.14	0.43	26.49	0.36	36.02	0.53	20.87	0.37		
	MS Genotype	445.72*	0.02	540.04*	0.06*	464.89*	0.08	454.52*	0.05	744.91*	0.15	412.33*	0.10		
	MS Year	173.25	0.04	459.50*	0.01	521.62	0.08	126.66	0.02	477.15*	0.27	556.32*	0.11		
	MS Genotype × Year	285.78*	0.05	288.72*	0.05	457.40*	0.08	96.58	0.05	176.33*	0.05	163.15*	0.02		
	CV (%)	5.93	9.89	5.54	8.36	9.35	12.18	6.19	13.10	9.86	18.02	5.49	10.82		

LSD, MS and CV were Least Significant Difference, mean square and Coefficient of Variation, respectively.

Genotypes AU75-452 is high yielding but not stable while AU 24524 (G4) is stable, but had yield not different from the grand mean. Therefore, the two genotype were ranked as not favourable. Unlike for the bast fibre yield, genotypes SLE14-13 (G13), AU 24524 (G4), IFEKEN 400 (G9) and GS14-52 (G8) were closer to the AEA than the remaining genotypes signifying they are stable genotypes but genotypes SLE14-13 (G13) is low core fibre yield. Hence, SLE14-13 (G13) is discarded with AU 24524 (G4). Genotypes SAU75-441 (G11), GS14-52 (G8) and AEHC-3 (G3) which were most desirable had the highest PC1 values and closest to the ideal environment showing that they combined high core fibre yield with stability relative to other genotypes evaluated. They are also associated with the ideal genotypes. According to Yan and Kang, (2003); Mitrovic *et al*., (2012), reported most desirable is highest yielding across test environments and absolutely stable in its performance.

The plant height and stem diameter contributed to the fibre yields of the crop because both the bast and core fibres were derived from the stem. The bark of the crop was processed into bast fibre while the pith was the core fibre. Total fibre yield, therefore, increases with increase in plant height and stem diameter. The plant height and stem diameter have also been reported as major contributors to the fibres yield of kenaf (Ogunniyan *et al*., 2016). The significant variation in the plant height of the genotypes is indicative of the differences in the potential of each genotype. Similarly, the significant differences in the G × Y interaction effects show that each genotype responded differently to change in the environments created by location variables. This finding further supports the identification of genotypes SAU75-441, GS14-52 G8), IFEKEN 400 (G9), IFEKEN DI-400 (G10) and AEHC-3 (G3) with the highest plant heights and stem diameters as most promising owing to their fibre yields.

Conclusion

Genotypes SAU75-414 (G11), GS14-52 (G8) and AEHC-3 (G3) were highest yielding and most stable with respect to the two types of fibres. They were most closely related to the ideal genotypes and perfomed better than existing commercial genotypes. It can therefore be concluded that the genotypes had broadest adaptation, high yield and more stability for both bast and core fibres production, and therefore selected as the most desirable.

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COMBINING ABILITY AND HETEROSIS IN DIALLEL CROSSES OF MAIZE (*Zea mays* L.) FOR YIELD AND YIELD CONTRIBUTING CHARACTERS

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Abstract

A field research was carried out durig 2014-15and 2015-16, using eight white maize inbred lines (CML154, VL109196, CML491, VL05590, CML502, CLRCWQ10, CLRCWQ26 and CML511) designated as P1, P2, P3, P4, P5, P6, P7 and P8 respectively, to estimate the combining ability effects and heterosis of 28 crosses produced following half diallel mating design at Bangladesh Agricultural Research Institute, Gazipur, Bangladesh. Assessment was done for eight characters viz. days to pollen shedding, days to silking, plant height, ear height, ear length, number of grains/ear, 1000 -grain weight and yield. Considering overall performance of GCA effects observed that parent P_6 was the best general combiner for both yield and earliness while parent P_2 and P_8 for dwarfness. Two hybrids namely, $P_3 \times P_5$ and $P_6 \times P_8$ exhibited significant positive SCA effects and significant positive heterosis for grain yield. These two hybrids were selected for future trial.

Introduction

Maize is considered as a major cereal crop in the world because of its high yield, abundant diversity and for essential nutrient element. In Bangladesh, maize emanates as a second most important cereal crop after rice and gaining popularity among the farmers because of its high yield.The maize area in Bangladesh is increasing to 0.444 million hectare during 2017-18 (DAE, 2018Plant breeder plays a vital role to make better cross combinations through selection of desirable inbreds. In the time of inbred selection plant breeder should have combining ability information of all inbred used in the experiment (Burt *et al.* 2011). Combining ability also provides information about the nature of the crosses. The average performance of an inbred line in its cross combination is defined as general combining ability (GCA) and specific combining ability (SCA) clarify that based on average performance some cross combinations showed superior or inferior performance than expected (Sprague and Tatum 1942). Diallel mating designs works well for getting genetic information of desired trait from fixed or random

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selected parental lines (Griffing 1956). The presence of additive variance is very important for the development of crop through selection because only this variance shows reaction for selection. Additive gene effect is quantified through general combining ability of a parent that means important for parent selection and dominance and/or non-additive genetic is quantified through specific combining ability and is important for hybrid development (Nadaranjan *et al.*, 2005). Both additive and non-additive variances played a vital role in genetic control of different agronomic traits in maize (Estakhr *et al.*, 2012). In Bangladesh farmers are more interested in high yielding hybrid with short plant height. The main objective of the study was to develop high yielding hybrid having with short plant height. So, best parents with desirable characters and crosses showing heterosis could be find out for fulfilling the objectives.

Material and methods

Eight white maize inbred lines, namely CML154, VL109196, CML491, VL05590, CML502, CLRCWQ10, CLRCWQ26 and CML511 were received from CIMMYT and selected based on their agronomic performances for making half diallel (8×8) crosses (Table 1). All inbred lines were mated by hand pollination and 28 crosses were produced during rabi season of 2014-15 at Bangladesh Agricultural Research Institute (BARI), Gazipur and in the next rabi season of 2015-16, all the cross combinations were evaluated along with four commercial checks. The soil of the experiment sites were homogenous so randomized complete block design were followed with three replications. All evaluating materials were grown in two rows of 4m long. Row to row spacing was 60cm and plant to plant spacing was 25 cm. Each row consisted of 17 plants after thinning and all standard agronomic practices were followed for quick growing of plants. Data were recorded on plant height, ear height, ear length, grains per ear and 1000 -grain weight from five randomly selected plants from each treatment. Grain yield were finally converted in ton/ha.

Table 1. Parents used in diallel crosses and their important features

Parents	Origin	Source
P_1	CML154	CIMMYT
P_2	VL109196	CIMMYT
P_3	CML491	CIMMYT
P_4	VL05590	CIMMYT
P_5	CML502	CIMMYT
P_6	CLRCWQ10	CIMMYT
P_7	CLRCWQ26 and	CIMMYT
P_8	CML511	CIMMYT

The ANOVA and combining ability was analyzed using PB Tools software following Model I (fixed effect) method IV (without reciprocals and parents) following Griffing (1956). Heterosis percentages of crosses for different characters were calculated using standard checks described by Mather and Jinks (1971) as follows:

$$\text{Standard heterosis (\%)} = [(F_1 - SC)/ SC] \times 100$$

Where, F_1 is the mean performance of the cross and SC is the mean of the Standard check varieties. The significance test for heterosis was done by using standard error of the value of check variety.

Results and Discussion

Combining ability analysis

Primary analysis of variance disclosed that highly significant to significant variation were observed for some of the characters indicating existence of noticeable amount of genetic variability among the parents and their hybrids (Table 2). So there is a scope of improvement by using these characters of maize. This results is in concurrence with Amiruzzaman *et al.,* (2013). In keeping with above mentioned result comprehensive analysis of combining ability and type of gene action was therefore suitable for guessing the characters investigated through this research. ANOVA for combining ability (Table 2) of parents and crosses showed significant GCA and SCA variances, respectively. As reported by Griffing (1956), GCA variance contains additive epistasis effect, while SCA variance contains non-additive epistasis effect. So, significant GCA and SCA variance suggested that there is an importance of both additive and non-additive gene effects for governing these characters in maize. These results agree with the findings by Estakhr *et al.,* (2012). However, GCA/SCA ratio of mean squares for all characters except yield in this study was higher than unity. That is variances due to GCA was higher than SCA for all characters except yield indicating additive gene action plays significant role for controlling these characters. Selection would be useful for improvement of these characters. But in grain yield SCA variances showed higher value than GCA variances indicating grain yield is controlled by non-additive gene effects. Khotyleva *et al.* (1986) reported dominant gene effects are more responsible for controlling grain yield than additive gene effects. Dass *et al.* (1997) also noted that supremacy of non-additive gene action for governing the grain yield of maize. Recently Archana *et al.,* (2018) reported non-additive gene action for heat stress conditions.

Estimate of general combining ability (GCA) effects of eight parents for different characters are presented in Table 3. GCA analysis revealed that, three parents (P_1, P_6 and P_8) showed highly significant and negative GCA effect for days to pollen shedding and silking indicating good combiner for earliness. Similar findings reported by Archana *et al.*, (2018) in their studies and they identified parental lines having good general combiner for days to 50% anthesis, days to 50% silking. Earliness of the hybrid depends on days to pollen shedding and silking, so significant negative value is desirable. The parents P_2 (-7.29), P_8 (-11.01) and P_5 (-6.82), P_8 (-8.93) exhibited highly significant negative value for plant height and ear height, respectively. These parents proved to be a good general combiner for developing dwarf hybrid because plant height and ear height ~~is~~ are the indicator of dwarfness. Ear length, no of grain/ear, 1000 grain weight are the yield contributing characters and significant positive value is desirable. Among the parents $P_{6,}$ P_7 showed highly significant positive value for ear length and P_8 possess significant positive value for no. of grain/ear. Therefore, these parents considered to be a good combiner for improving yield. But none of the parents exhibited significant positive value for 1000 grain weight. Only two parents P_3 and P_6 had significant positive value for yield. Hence P_3 and P_6 parents could be treated as good general combiner for improving maize yield. Therefore, it may be concluded that for development of high yielding hybrid and desirable traits these parental genotype could be productively used in future breeding program. Archana *et al.*, (2018) identified two parents ZL 11953 and VL128 in their study having significant *GCA* effects for grain yield. Dinesh *et al.* (2016) reported that three inbreds *viz.*, L78, L73, and L37 as good general combiners for grain yield among 145 inbred lines.

Specific combining ability effects of 28 crosses for studied characters are presented in Table ~~3~~ 4. Among the crosses, none showed significant value for days to pollen shedding. For days to silking only one cross $P_4 \times P_6$ (-1.00) showed desirable significant negative value and considered as a good specific combiner for improving this character. Two crosses namely $P_4 \times P_5$ and $P_6 \times P_7$ exhibited highly significant negative value for plant height (-16.54, -15.43) and ear height (-21.33, -15.77), respectively may be treated as good specific combiner for improving this traits. Therefore, these crosses can be effectively used in hybrid breeding program for developing dwarf hybrid. Regarding no. of grain/ear none of the parent showed significant positive effect but two crosses $P_2 \times P_5$ and $P_4 \times P_7$ had significant positive value for 1000 grain weight. The crosses $P_3 \times P_5$ and $P_6 \times P_8$ was the best specific combiner for grain yield because of significant positive SCA value. Begum *et al.* (2018), Jodage *et al.* (2018) also drew similar conclusion for grain yield. Grain yield is the reflection of high yielding hybrid development. Again GCA effects helps to bring out effective parent for developing desired profitable hybrid and SCA effects associated with heterosis. Result of in this study revealed that, there is a relation between GCA effects and SCA value of their resembling crosses, hence two parents P_3(0.62) and P_6 (0.69) having positive GCA value for grain yield, and therefore, some crosses of these two parents, namely $P_3 \times P_5$ (1.69) and $P_6 \times P_8$ (1.23) produced significant positive SCA effect.

Table 2. Analysis of variance for combining ability for eight characters in maize

Source of variation	df	DPS	DS	PH (cm)	EH (cm)	EL (cm)	NG/E	TGW (g)	Y (t/ha)
Genotype	27	9.08**	8.36**	428**	474**	1.53*	12062**	2028**	2.80*
GCA	7	9.90**	9.14**	314.91**	384.03**	1.00*	4367	1195	0.82
SCA	20	0.62	0.56	82.17*	91.53	0.34	3900	495**	3.86**
Error	54	1.31	1.1	142.72	188.29	0.86	1918	146	1.49
GCA:SCA	83	15.97	16.32	3.83	4.19	2.94	1.12	2.41	0.21

*, ** indicated at 5% and 1% level of significance; DPH (Days to pollen shed), DS (Days to silk), PH (Plant height), EH (Ear height), EL (Ear length), NG/E (No. of grain/ear), TGW (1000 grain weight), Y (Yield).

Table 3. Estimate of general combining ability (GCA) effects of parents for different characters in maize crosses

Parents	DPS	DS	PH (cm)	EH (cm)	EL (cm)	NG/E	TGW (g)	Y (t/ha)
P_1	-1.42**	-1.35**	0.1	1.29	0.24	-48	0.75	-0.48
P_2	0.25	0.32	-7.29**	-2.6	-0.76*	29	-50.75	0.01
P_3	2.3**	1.89**	12.25**	14.07**	0.35	-54	27.53	0.62*
P_4	0.47	0.49**	3.99	-2.32	-0.71	35	31.53	0.03
P_5	0.92**	0.93**	-3.46	-6.82**	-0.38	-66	1.69	-0.62*
P_6	-1.58**	-1.74**	2.71	-2.54	0.43*	34	0.14	0.69**
P_7	-0.19	0.14	2.71	7.85**	0.51*	24	16.75	0.15
P_8	-0.75**	-0.68**	-11.01**	-8.93**	0.32	46*	-27.64	-0.4
SE (gi)	0.25	0.23	2.63	3.02	0.21	18	16.72	0.27
LSD (5%)	0.49	0.45	5.15	5.92	0.41	39.33	31.60	0.49
LSD (1%)	0.65	0.59	6.79	7.79	0.54	58.20	48.79	0.65

*, ** indicated at 5% and 1% level of significance; DPH (Days to pollen shed), DS (Days to silk), PH (Plant height), EH (Ear height), EL (Ear length), NG/E (No. of grain/ear), TGW (1000 grain weight), Y (Yield).

Table 4. Estimate of specific combining ability effects of crosses for different characters in maize.

Cross	DPS	DS	PH (cm)	EH (cm)	EL (cm)	NG/E	TGW (g)	Y (t/ha)
$P_1 \times P_2$	-0.52	-0.56	-4.48	-8.49	0.3	-0.46	30.86	0.08
$P_1 \times P_3$	0.42	0.39	-5.71	-3.49	-0.14	41.54	11.41	0.09
$P_1 \times P_4$	0.59	0.61	6.57	4.9	-1.09*	-49.13	-6.59	-0.02
$P_1 \times P_5$	-0.86	-0.83	-10.98	-7.6	0.25	-9.46	17.3	-0.76
$P_1 \times P_6$	-0.36	-0.17	4.85	10.45	-0.53	-34.68	-131.59**	-0.46
$P_1 \times P_7$	0.92	0.78	3.52	1.73	1.02*	38.1	31.52	0.79
$P_1 \times P_8$	-0.19	-0.22	6.24	2.51	0.19	14.1	32.08	0.28
$P_2 \times P_3$	0.09	0.06	-8.65	-1.94	0.19	-67.46	-36.92	-0.06
$P_2 \times P_4$	1.25*	1.28*	-9.71	-2.88	0.58	28.54	-23.58	-0.58
$P_2 \times P_5$	-0.86	-0.83	16.07**	19.95**	-0.75	-21.79	96.96*	0.14
$P_2 \times P_6$	-0.02	0.17	1.57	-4.66	0.47	-21.02	24.08	0.26
$P_2 \times P_7$	-0.08	0.11	11.57	2.29	-0.98*	6.43	-122.14**	-0.41
$P_2 \times P_8$	0.14	-0.22	-11.37	-4.27	0.19	75.76	15.75	0.58
$P_3 \times P_4$	-0.8	-0.78	4.74	2.45	-0.2	-15.46	1.3	0.54
$P_3 \times P_5$	-0.25	-0.22	7.85	7.95	0.47	39.54	13.86	1.69**
$P_3 \times P_6$	-0.08	-0.22	4.68	0.01	0.02	-25.68	31.3	-0.75
$P_3 \times P_7$	0.53	0.72	-3.32	3.95	0.25	51.1	-15.92	0.23
$P_3 \times P_8$	0.09	0.06	3.4	-8.94	-0.59	-23.57	-20.03	-1.74**
$P_4 \times P_5$	0.92	0.65	-16.54**	-21.33**	-0.48	-24.46	-50.81	-1.06

Cross	DPS	DS	PH (cm)	EH (cm)	EL (cm)	NG/E	TGW (g)	Y (t/ha)
$P_4 \times P_6$	-0.91	-1.00*	-0.71	-0.6	0.41	72.32	-1.03	0.7
$P_4 \times P_7$	0.03	-0.06	6.63	10.01	0.3	33.1	122.76**	-0.35
$P_4 \times P_8$	-1.08	-0.72	4.02	7.45	0.47	-44.9	-42.03	0.76
$P_5 \times P_6$	1.31*	1.22*	5.07	5.56	0.08	-28.02	18.47	-0.69
$P_5 \times P_7$	-0.41	-0.5	0.4	-2.49	-0.03	-32.57	-52.03	0.9
$P_5 \times P_8$	0.14	0.5	-1.87	-2.05	0.47	76.76	-6.81	-0.23
$P_6 \times P_7$	-0.91	-0.83	-15.43**	-15.77**	-0.14	19.54	47.74	-0.3
$P_6 \times P_8$	0.98	0.83	2.96	5.01	-0.31	17.51	26.01	1.23*
$P_7 \times P_8$	-0.08	-0.22	-3.37	0.29	-0.42	-115.68**	-11.92	-0.86
SE (ij)	0.56	0.51	5.83	6.70	0.45	39.75	37.01	0.60
LSD (5%)	1.10	1.00	11.43	13.13	0.88	77.91	69.94	1.10
LSD (1%)	1.44	1.32	15.04	17.29	1.16	102.56	110.66	1.44

*, ** indicated at 5% and 1% level of significance; DPH (Days to pollen shed), DS (Days to silk), PH (Plant height), EH (Ear height), EL (Ear length), NG/E (No. of grain/ear), TGW (1000grain weight), Y (Yield).

Using BHM9 as a standard check the percent standard heterosis was calculated and presented in table 4 5. The hybrid $P_1 \times P_6$ (-2.25), $P_1 \times P_8$ (1.12), $P_4 \times P_6$ (0.75) and $P_6 \times P_7$ (-1.50) had desirable significant negative heterosis for days to pollen shedding. Morphologically earliness is measured by days to pollen shedding and silking, hence, negative heterosis value is desirable. Since, these four hybrids exhibited significant negative heterosis, they can be used for short duration hybrid development. Depending on calculated value of heterosis, negative heterosis produced in eight crosses for plant height and sixteen crosses for ear height, respectively. These crosses can be extensively used for developing dwarf hybrid. Significant positive heterosis is desirable for yield contributing characters i.e ear length, no. of grain/ear and1000 grain weight. Considering ear length maximum crosses had significant positive (22 crosses) heterosis. Meanwhile, no. of grain/ear and 1000 grain weight of maximum crosses had significant negative value of heterosis. Only one crosses ($P_3 \times P_6$) and three crosses ($P_1 \times P_{3,}$ $P_1 \times P_{7,}$ $P_2 \times P_6$) showed significant positive value for no. of grain/ear and1000 grain weight, respectively. Significant positive heterosis is desirable for grain yield, and in this study among 28 crosses, two crosses namely $P_3 \times P_5$ (6.25%) and $P_6 \times P_8$ (11.29%) showed significant positive heterosis for grain yield. Debnath (1992) and Roy *et al.* (1998) found appreciable percentage of heterosis for grain yield in maize. Similar kind of results were also reported by Kumar *et al.*, (2016), Amiruzzaman *et al.*, (2013), Begum *et al.*, (2018) in their study.

Table 5. Percent heterosis over the check variety BHM9 for different characters in 8×8 diallel crosses of maize

Parents	DPS	DS	PH (cm)	EH (cm)	EL (cm)	NG/E	TGW (g)	Y (t/ha)
$P_1 \times P_2$	0.00	1.49**	-4.74**	-12.93**	4.44**	-8.83**	-3.68*	-32.14**
$P_1 \times P_3$	3.00**	4.48**	3.67**	5.75**	6.67**	-0.71	5.76**	-26.23**
$P_1 \times P_4$	1.12**	2.99**	5.50**	-1.15	-4.44**	-3.42	-11.24**	-32.93**
$P_1 \times P_5$	0.00	1.87**	-5.96**	-15.80**	4.44**	-5.22*	-7.46**	-31.72**
$P_1 \times P_6$	-2.25**	-0.37	4.13**	3.45	4.44**	-33.72**	-13.13**	-30.84**
$P_1 \times P_7$	0.75*	2.61**	3.52**	4.89*	15.56**	1.10	8.59**	-24.12**
$P_1 \times P_8$	-1.12**	0.75**	-1.53	-8.91**	4.44**	-7.03**	-9.35**	-34.20**
$P_2 \times P_3$	4.49**	5.97**	-1.07	3.74	4.44**	-19.66**	-1.79	-23.05**
$P_2 \times P_4$	3.75**	5.60**	-3.06**	-11.21**	2.22**	-16.31**	-13.13**	-33.46**
$P_2 \times P_5$	1.87**	3.73**	3.06**	4.60*	-6.67**	0.58	-7.46**	-32.76**
$P_2 \times P_6$	0.00	1.87**	-0.76	-12.93**	6.67**	-13.22**	9.54**	-19.29**
$P_2 \times P_7$	1.50**	3.73**	3.82**	2.01	-2.22*	-38.23**	-6.52**	-30.75**
$P_2 \times P_8$	1.12**	2.61**	-13.00**	-18.10**	0.00	-19.79**	-6.52**	-26.75**
$P_3 \times P_4$	3.75**	5.22**	10.24**	7.76**	2.22*	3.29	-9.35**	-17.21**
$P_3 \times P_5$	4.87**	6.34**	8.26**	8.62**	6.67**	-0.71	-9.35**	6.25**
$P_3 \times P_6$	2.25**	3.36**	8.26**	5.46**	8.89**	5.87*	-11.24**	-23.13**

Parents	DPS	DS	PH (cm)	EH (cm)	EL (cm)	NG/E	TGW (g)	Y (t/ha)
$P_3×P_7$	4.49**	6.34**	5.96**	17.82**	11.11**	-2.90	-2.74	-18.91**
$P_3×P_8$	3.37**	4.85**	2.75*	-7.76**	0.00	-11.93**	-15.01**	-42.81**
$P_4×P_5$	4.12**	5.60**	-6.73**	-30.75**	-4.44**	-12.44**	-22.57**	-39.25**
$P_4×P_6$	-0.75*	0.75**	3.36**	-9.20**	6.67**	-2.51	-1.79	-15.02**
$P_4×P_7$	1.87**	3.73**	6.73**	8.91**	6.67**	24.69**	-13.13**	-30.04**
$P_4×P_8$	0.00	2.24**	-0.76	-7.76**	2.22*	-15.41**	-9.35**	-24.78**
$P_5×P_6$	2.25**	3.73**	2.60*	-7.76**	4.44**	-12.31**	-5.57**	-34.24**
$P_5×P_7$	1.87**	3.73**	0.46	-5.75*	4.44**	-15.54**	-9.35**	-24.29**
$P_5×P_8$	1.87**	4.10**	-6.88**	-19.83**	2.22*	-15.02**	-15.01**	-40.25**
$P_6×P_7$	-1.50**	0.37**	-3.98**	-13.51**	8.89**	4.06	2.93	-23.26**
$P_6×P_8$	0.00	1.49**	-1.83	-10.06**	2.22*	-7.03**	0.09	11.29**
$P_7×P_8$	0.37	2.24**	-4.74**	-5.17*	2.22*	-12.44**	-3.68*	-38.93**
Mean	1.54	3.27	0.62	-4.48	3.73	-8.39	-6.48	-26.17
SE	0.37	0.35	1.03	2.05	0.90	2.32	1.39	2.30
LSD (5%)	0.75	0.72	2.12	4.20	1.85	4.76	2.86	4.72
LSD (1%)	1.02	0.98	2.87	5.68	2.49	6.42	3.86	6.37

*, ** indicated at 5% and 1% level of significance; DPH (Days to pollen shed), DS (Days to silk), PH (Plant height), EH (Ear height), EL (Ear length), NG/E (No. of grain/ear), TGW (1000 grain weight), Y (Yield).

Conclusion

The results of the study revealed that parents P_3 and P_6 having good combining ability for yield, also P_6 showed desirable value for days to pollen shedding and days to silking. Whereas P_8 showed good combining ability for days to pollen shedding, days to silking number of grain per ear, plant height and ear height. Besides P_2 also having good combining ability for plant height and ear height. These parents could be used as a donor parent for transferring desirable gene in hybrid breeding program. Two cross combinations P3× P5 and P6× P8 were identified as the best on their performance for specific combining ability and heterosis value. So, these promising crosses can be used in maize hybrid development program.

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INCREASING OILSEED PRODUCTIVITY THROUGH INCLUSION OF MUSTARD IN T. AMAN- FALLOW-BORO RICE CROPPING PATTERN IN JASHORE

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Abstract

The field experiment was conducted at Mahmudkati, Monirampur under Regional Agricultural Research Station, Bangladesh Agricultural Research Institute, Jashore for two consecutive years of 2021-22 and 2022-23 through inclusion of mustard var. BARI Sarisha-14 in the fallow period and to study the comparative agronomic performance economic return, increasing cropping intensity, productivity and land use efficiency. The experiment was laid out in a randomized complete block design (RCBD) with ten dispersed replications. Three crops pattern (*T. Aman rice –Mustard - Boro rice*) and farmers' existing pattern (*T.Aman- fallow- Boro*) as control were tested.Two years mean data showed that the improved management practices provided higher yield in improved pattern. Average higher rice equivalent yield (REY), (20.22 t ha-1) production efficiency (59.92 kg ha-1 day-1) and 92.88% land utilization indexwas found in the improved cropping pattern in both years. Gross return of the improved pattern was Tk..711010 ha-1 which was more than 68.24% higher than farmer's pattern of Tk. 422615 ha-1. Gross margin (Tk. 483610 ha-^{1}) and MBCR (2.13) were also higher in improved cropping pattern in both years than existing pattern.

Keywords: Oilseed productivity, **l**and use efficiency, cropping intensity, mustard and economic return

Introduction

Bangladesh needs to produce more food on less land to assure future food security for millions of people every year. Horizontal expansion is very limited, but increase in crop production could be possible with vertical expansion through increasing cropping intensity and Land Use Efficiency. In order to produce more food within a limited area, two most important options to be adopted are i) to increase the cropping intensity by producing three or more crops from the same piece of land in a year and ii) to increase the production efficiency of the individual crop by using optimum management practices (Dobermann *et al*., 2013; Ladha *et al*., 2016). The present cropping intensity of the country is 198%. Food requirement is estimated to be doubled in the next 25 years. Under such situation; it is very important to improve the existing cropping pattern. There are some scopes of increasing cropping intensity by improving the existing cropping patterns through inclusion of short duration crops viz., mustard, potato, mungbean and transplant aus rice in the rice based cropping systems following the modern

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variety and improved technologies. The main challenge of the new millennium is to increase yield of per unit area by at least 50 % through manipulating the limited land resource. The major cropping pattern of agriculture in Bangladesh mostly consists of rice based crops (Haque, 1998). More than 60% of the total cropped areas covered by *Boro-Fallow-T. Aman* rice cropping pattern in Bangladesh. As a result, the vast area remains fallow for 75 days after T. *Aman* harvest. About 2.4 mha crop land is occupying by this cropping pattern in Bangladesh (Ladha *et al.,* 2003; Dawe *et al.,* 2004; Bhuiyan *et al.,* 2004). The areas of oilseed and pulse in Rabi season are decreasing because of increasing cultivation of Boro rice. But the farmers harvest poor yield from local var. Tori7 that can be increased manifold by introducing high yielding varieties (Alam and Rahman, 2006; Basak *et al.,* 2007). Recently, BARI has developed high yielding yellow seeded mustard (*Brassica campestris*) varieties viz., BARI Sarisha- 14 and BARI Sarisha-15 whose yield potential is higher than Tori-7 and can easily be cultivated during fallow period. Most areas of Bangladesh at present under two crops based cropping pattern, but there prerequisite to increase crop number to meet up the demand. A number of reports on different cropping pattern are available in Bangladesh (Ahmed *et al*. 2017) where an additional crop could be introduced without much changes or replacing the existing ones for considerable increase of the overall productivity as well as profitability of the farmers. Keeping these views in mind, the present study was designed to evaluate the feasibility of increasing cropping intensity and productivity by growing three crops in a year in a same piece of land by introduce mustard var. BARI Sarisha-14 in the fallow period.

Materials and Methods

The experiment was laid out in a randomized complete block design with ten dispersed replications. The trial was conducted to increase cropping intensity, productivity and land use efficiency by incorporating mustard var. BARI Sarisha-14 in the existing cropping pattern: *T. Aman- fallow- Boro* at the farmers' field condition in Mahmudkati, Monirampur, Jashore (Latitude: 23.163401 N, Longitude: 89.218166 E) during two consecutive years 2021-22 and 2022-23.Two cropping patterns viz., T_1= Existing cropping pattern: *T. Aman rice – Fallow - Boro rice*, and T_2 = Improved cropping pattern: *T. Aman rice – Mustard - Boro rice* were the treatments variables. The unit plot size was 1340 Sq. m. with 10 dispersed replications. T. *Aman* rice was the first crop of the sequence. Seedlings of rice were grown in adjacent plot and transplanting was done with 25-30 days old seedlings. *T. Aman rice* var. BRRI dhan 75 were transplanted with 20 cm × 15 cm during 25July - 05 Aug, 2021 and 2022 in both years. Fertilizer management and intercultural operations like weeding, mulching, irrigation and pest management were done according to BRRI (2013). *T. Aman* rice was harvested during 22October, 2021 and 2022 in two consecutive years. *T. Aman* rice plant was harvested at 15 cm from soil surface and remaining parts of the plants was incorporated in soil. Mustard was grown during rabi season and it was the second crop of the sequence. Fertilizer management and intercultural operations like weeding, mulching, irrigation and pest management were done according to FRG, 2018. Mustard var. BARI sarisha-14 was seeded as broadcast method with seed rate of 7 kg ha-[1]. The crop was sown during 05 November, 2021 and 2022 and harvested during 23 January, 2022 and 2023, respectively. Boro rice was the third crop of the sequence. Seedlings of rice were grown in adjacent plot and transplanting was done with 35-40 days old seedlings of rice var. BRRI dhan 28 and BRRI dhan63 at a spacing of 20 cm × 15 cm during 26 to 27 January, 2022 and 2023. Fertilizer management and intercultural operations like weeding, mulching, irrigation and pest management were done according to BRRI (2013). Boro rice was harvested during 26 April to 06 May, 2022 and 2023 in two consecutive years. Rice plant was harvested at 30 cm height from soil surface and remaining parts of the plants was incorporated in soil. Crop nutrient uptake was estimated following the standard value of FRG, 2018. The area mostly falls undermedium-high land and high land areas of High Ganges River Flood Plain of Agro Ecological Zone (AEZ) 11. Organic matter content is low in higher parts, but moderate in lower parts. The general fertility level is low including N, P, S and B although CEC medium and K- bearing minerals are medium to high but the Zn status is low to medium (FRG2018). The area receives an annual rainfall of around 1035 mm with relatively early onset and late cessation and the mean annual high temperature is 32.1ºC (89.78ºF), annual low temperature is 22.95ºC (73.31ºF).The initial soil status of the experimental sites was presented in Table1.

Table 1. Initial status of soils of the experimental plots at Mahmudkati, Monirampur, Jashore

Soil characteristics				Mahmudkati, Monirampur, Jashore				
Land type and soil texture				Medium-high land and high land area and loamy soil				
Soil depth	pH	Organic Matter (%)	Total N (%)	Available nutrients				
				K (meq /100g soil)	P (µg/g soil)	S (µg/g soil)	Zn (µg/g soil)	B (µg/g soil)
0-15 cm	7.7 Slightly alkaline	1.71 low	0.09 Low	009 (High)	14.99 (Low)	16.05 (Optimum)	1.85 (Medium)	0.26 Low
15-30 cm	7.8 Slightly alkaline	0.82 Very low	0.04 Very low	0.04 Medium	7.62 Very low	18.38 Optimum	0.83 low	0.14 Very low

After physiological maturity, yield for each crop was determined plot-wise and converted into yield on an area basis (kg/ha). Data on yield was statistically analyzed using statistics 10. Marginal benefit-cost analysis was done to estimate the economic feasibility of Transplant Aman rice, Mustard and Boro rice crop. The production costs of these crops included the cost of field preparation, seed, planting, irrigation, fertilizers, crop protection measures and harvesting.

Table 2. Crop management practices in farmer's existing and improved cropping pattern at Mahmudkati, Monirampur, Jashore

Observation	Existing cropping pattern			Improved cropping pattern		
Crop	T. aman rice	Fallow	Boro rice	T. aman rice	Mustard	Boro rice
Variety	Swarna	-	BRRI dhan 28	BRRI dhan 75	BARI Sarisha-14	BRRI dhan 63
Spacing	20 cm × 15 cm		20 cm × 15 cm	20 cm× 15 cm	Broadcast	20cm ×15cm
Unit plot size	1340 m^2			1340 m^2		
Fertilizer dose (Urea-TSP-MoP- Gyps.-Zn -B Kg/ha)	102-62-20-08-0-0	-	200-75-92-60-7.5-0	150-90-112.5-90-10-0	262-150-05-160-10 + 1.5	225-112-150-90-10-0
Date of sowing for seed	1July	-	17 December	1July	05 November	18 December
Date of transplanting	29 July-15 Aug	-	26 January	25 July- 05 Aug	-	27 January
Seedling age (days)	25-30	-	35-40	25-30	-	35-40
Harvesting date	15November	-	26 April	22 October	23 January	06 May
Total crop duration (days)	138	-	131	114	79	139

Agronomic performance like field duration, rice equivalent yield (REY), production efficiency and land utilization index of cropping patterns were calculated. The details of crop management practices followed for each crop is provided in Table 2.

Rice equivalent yield (REY): For comparison between crop sequences, the yield of all crops was converted into rice equivalent on the basis of prevailing market prices of individual crop (Lal *et al*., 2017). Rice equivalent yield (REY) was computed as yield of individual crop multiplied by market price of that crop divided by market price of rice.

$$\text{Rice equivalent yield (t ha/yr)} = \frac{\text{Yield of individual crop} \times \text{market price of that crop}}{\text{Market price of rice}}$$

Production efficiency

Production efficiency value in terms of kg ha-1day-1 was calculated by total main product in a cropping pattern divided by total duration of crops in that pattern ((Lal *et al*., 2017; Tomar and Tiwari, 1990).

$$\text{Production Efficiency (kg/ha//day)} = \frac{\sum Y_i}{\sum d_i}$$

Where, Yi= Yield (kg) of ith crop, di= Duration (day) of ith crop of the pattern and i= 1, 2, 3, 4

Land utilization index (LUI)

It was worked-out by taking total duration of crops in an individual cropping pattern divided by 365 days (Rahman *et al*., 1989). It was calculated by the following formula:

$$\text{Land Utilization Index (\%)} = \frac{d_1 + d_2 + d_3}{365} \times 100$$

Where, d_1, d_2 and d_3 the duration of 1st, 2nd and 3rd crop of the pattern. The gross income was estimated using the prevailing average market prices for the yield of these crops in Bangladesh. Net income was calculated by subtracting total expenditure from the gross income which was computed by dividing the gross income with total expenditure (Mahmood *et al*., 2016). Economic analysis was done on the basis of prevailing market price of the commodities. The inputs used included seed, fertilizer, labour and insecticides. The MBCR of the farmer's prevalent pattern and any replacement for it can be computed as the marginal value product ((MVP) over the marginal value cost (MVC). The Marginal of prevalent pattern (F) and any potential replacement (E) which was computed as (CIMMYT, 1988).

$$\text{Marginal Benefit Cost Ratio (MBCR)} = \frac{\text{Gross return (E) - Gross return (F)}}{\text{TVC(E)-TVC(F)}} = \frac{MVC}{MVP}$$

Results and Discussion

Yield of the cropping patterns: Results of three crops pattern (*T. Aman - Mustard - Boro*) and farmer's existing pattern (*T.Aman - fallow Boro*) have been presented in Table 3. It was revealed that the entire component crops of *Transplant Aman rice – Mustard - Boro rice* cropping pattern under improved practices (IP) gave higher grain and seed yield as well as by-product yield in two consecutive years. The yield of improved pattern was higher due to inclusion of mustard with improved production technologies for the component crops. Similar results were also obtained by Anwar *et al*., 2017, Khatun *et al*., (2016), Kamrozzaman *et al.,* (2015) and Nazrul *et al*. (2013). Inclusion of mustard with improved variety in *T. Aman rice - Mustard-Boro* rice cropping pattern practice increased the total yield over the farmers existing cropping pattern practice. Grain yields of T. aman rice in case of improved cropping pattern grain yields were 5.80 and straw yields 7.65 t/ha. Grain yield of 5.90 t ha-1 and straw yield of 7.53 t/ha in 1st and 2nd year and mean grain and straw yields of T. aman rice were 5.85 and 7.59 t/ha, respectively. Seed yield of mustard were 1.75 and 1.80 t ha-1 and stover yields were 3.42 and 3.53 t ha-1 in two successive years, respectively where mean seed yield of mustard was 1.78 t ha-1 .Grain yield of Boro rice were 7.05 t/ha and straw yield of 6.94 t/ha in first year and 7.10 t/ha and straw yields 6.85 t/ha in second year. Mean grain and straw yields of Boro rice were 7.08 and 6.90 t/ha , respectively. T. Aman rice in three crops pattern produced 39.62% higher grain yield over farmers' practice due to change of variety with improved production technologies. Similar results were also obtained by (Nazrul *et al.*, 2013; Khan et al., 2006). Farmers' pattern gave lower yield due to imbalance use of fertilizers and poor management practices. Three crops pattern produced higher by-product yield (17.96 t ha-1) over farmers' practice (13.07 t ha-1). Mean by-product yield of three crops pattern was 37.41 % higher over farmer's pattern due to change of variety with improved technologies and inclusion of one crop in the existing pattern.

Rice equivalent yield: Total productivity of a cropping system was evaluated in terms of rice equivalent yield (REY) and it was calculated from yield of component crops. Average higher rice equivalent yield (20.22 t ha-1) was recorded with the improved pattern, *Transplant aman - Mustard- Boro* over farmer's existing cropping pattern (12.07 t/ha.), *Transplant aman - Fallow -Boro* (Table 4). REY increased 8.15 t ha-1 by inclusion of mustard with improved production technologies for the component crops. Inclusion of mustard in rabi season in existing cropping pattern increased total productivity by 67.56 % compared to farmers' practice. These results are in agreement with Mondal *et al*. (2015). They reported that total productivity increased by 67 % over farmers' practice. It is noted that inclusion of additional crop during the fallow period produced higher rice equivalent yield than farmer's practice, Transplant *aman* -Fallow -Boro. Similar results were also obtained by Khatun *et al*.,2016; Kamrozzaman *et al.*, 2015; Ferdous *et al*. 2011, Anowar *et al*. 2012, Nazrul *et al*., 2013.

Table 3. Productivity of farmer's existing and improved cropping pattern at Mahmudkati, Monirampur, Jashore

Year	Cropping pattern	Crop	Variety	Field duration (days)	Total field duration (days)	Grain or seed yield (t ha-1)	Straw or stover yield (t ha-1)
2021-22	Existing cropping pattern	T. aman	Swarna	112	250	4.23 ±0.17	7.05 ±0.21
		Fallow	-	-		-	-
		Boro	BRRI dhan 28	138		5.7 ±0.21	6.05±0.24
	Improved cropping pattern	T. aman	BRRI dhan 75	113	338	5.8 ±0.15	7.65±0.29
		Mustard	BARI Sarisha-14	79		1.75 ±0.22	3.42±0.18
		Boro	BRRI dhan 63	146		7.05±0.11	6.94±0.29
2022-23	Existing cropping pattern	T. aman	Swarna	113	250	4.15±0.21	6.38±0.23
		Fallow	-	-		-	-
		Boro	BRRI dhan 28	137		5.59±0.15	6.65±0.18
	Improved cropping pattern	T. aman	BRRI dhan 75	114	340	5.9±0.16	7.53±0.12
		Mustard	BARI Sarisha-14	81		1.8±0.24	3.53±0.19
		Boro	BRRI dhan 63	145		7.1±0.23	6.85±0.27

Price: Mustard = Tk. 85 kg-1, Rice = Tk. 35 kg-1, Rice straw = Tk. 6 kg-1 and Mustard Stover = Tk. 5 kg-1
Price (Tk. kg-1): Urea-22, TSP-22, MoP-15, Gypsum-30, Zinc Sulphate-200, Boric acid-160,
REY: Rice Equivalent Yield, GM: Gross Margin.

Field duration: Field duration of a cropping pattern comprises on the individual crop duration. Farmers' cropping pattern Boro-fallow-T. Aman has needed 250 and 250 days field duration in 1st and 2nd year. The newly introduced one crop in the farmer's existing pattern was mustard var. BARI Sarisha-14. A short duration T. Aman rice var. BRRI dhan 75 was also introduced to minimize the field duration of the crop. Total field duration of three crops pattern, T. Aman-Mustard - Boro has needed 338 and 340 days including seedling age of rice to complete the cycle in 1st and 2nd year (Table 3). Thus, long turn around period of 115 days in the farmer's existing pattern was utilized. Result indicated that mustard could be easily fitted in T. Amon rice- Mustard – Boro rice cropping pattern with an average of 26 days turnaround time in a year. Similar trend was also observed by Mondal *et al.* (2015) who reported that all the tested four crops pattern can be grown successfully one after another in sequence

Production efficiency: Mean maximum production efficiency (59.92) in terms of kg ha-1 day-1 was obtained from three crops improved cropping pattern, *Transplant aman- Mustard –Boro* and minimum (48.30 kg ha-1 day-1) in farmers' existing practice, Transplant *aman* -Fallow - Boro (Table 4). The higher production efficiency in improved cropping pattern Transplant *aman*- Mustard - Boro might be due to inclusion of high yielding mustard varieties and improved management practices. Similar trend was noted by Nazrul *et al*. (2013) and Khan *et al*. (2006).

Land utilization index: Land utilization index is the effective use of land in a cropping year, which mostly depends on crop duration. Results of the study have been presented in Table 4.Mean land utilization index (LUI) indicated that improved cropping pattern used the land for 92.88% period of the year, whereas existing cropping pattern used the land for 68.49% period of the year. The improved cropping pattern leads to higher land use efficiency due to longer period field occupied by the crops (339 days), whereas the farmers practice occupied the field for 250 days of the year. Similar results were also obtained by Khatun *et al*., 2016.

Table 4. REY, PE and LUI of farmer's existing and improved cropping pattern at Mahmudkati, Monirampur, Jashore during 2021-22 and 2022-23.

Items	Farmers' existing cropping pattern			Improved cropping pattern		
	2021-22	2022-23	Average	2021-22	2022-23	Average
REY(t ha-1)	12.17	11.97	12.07	20.17	20.26	20.22
PE (kg ha-1day-1)	48.70	47.89	48.30	59.73	60.12	59.92
LUI (%)	68.49	68.49	68.49	92.60	93.15	92.88

REY= Rice Equivalent Yield, PE = Production Efficiency and LUI= Land Utilization Index

Table 5. Cost and return analysis of farmer's existing and improved cropping pattern at Mahmudkati, Monirampur, Jashore during 2021-22 and 2022-23

Parameters	Gross return (Tk. ha-1)			Total variable cost (Tk. ha-1)			Gross margin (Tk. ha-1)			MBCR		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Farmers' existing cropping pattern	426150	419080	422615	191654	190665	191160	234496	228415	231456	1.22	1.20	1.21
Improved cropping pattern	706560	715460	711010	221080	233720	227400	485480	481740	483610	2.20	2.06	2.13

Price: Mustard Tk. 85 kg-1, Rice =Tk. 35 kg-1, Rice straw = Tk. 6 kg-1and Mustard stover = Tk. 5 kg-1

Price (Tk. kg-1): Urea-22, TSP-22, MP-15, Gypsum-30, Zinc Sulphate-200, Boric acid-160,

MBCR= Marginal Benefit Cost Ratio

Cost and return analysis

Cost and return analysis were done based on prevailing market price during the crop season. Improved cropping pattern showed its superiority over farmer's pattern during two consecutive years (Table 5) .From the economic point of view; improved cropping pattern (T. Aman- Mustard- Boro rice) showed its superiority over farmer's existing cropping pattern (T. Aman- Boro rice). Mean gross return of improved cropping pattern *(T. Aman- Mustard- Boro rice*) was found Tk. 711010 ha-1 and farmers' pattern was Tk. 422615 ha-1 which was more than 68.24 % higher over farmers' existing pattern. Two rice crop patterns (Farmers' existing pattern) gave the lower gross return Tk. 422615 ha-1. Mean variable cost was higher in improved cropping pattern (Tk. 227400 ha-1) might be due to inclusion of new component crops (mustard) in the pattern while the farmer's existing pattern (Tk. 191160 ha-1) . The mean gross margin was higher in improved cropping pattern (Tk. 483610 ha-1) than farmer's existing cropping pattern (Tk. 231456 ha-1). Three crops pattern achieved higher gross margin mainly due to higher yield advantages of the new component crops. The mean marginal benefit cost ratio (MBCR) was found 2.13 which indicated the superiority of the improved cropping pattern over the farmer's existing cropping pattern. The marginal benefit cost ratio (MBCR) also showed that inclusion of mustard in the existing pattern might be profitable and acceptable to the farmers. Inclusion of new crop (mustard) as well as improvement of management practices in the improved cropping pattern increased the economic return. These results are supported by Mondal *et al.* (2015) and Khatun *et al.*, 2016. They reported that inclusion of T. Aus, potato, mustard and mungbean in the existing pattern were profitable and acceptable to the farmers and grown successfully one after another in sequence of one year cycle.

Conclusion

From the above results it showed that improved cropping pattern was more profitable compared to existing pattern. Considering higher rice- equivalent yield, monetary return and more sustainability of the improved cropping pattern, viz., *T. Aman rice (var. BRRI dhan75) – Mustard (var. BARI Sarisha14) - Boro rice (var. BRRI dhan63) showed* higher over farmer's pattern of T. Aman (var. Sarna)-Fallow-Boro (var. BRRIdhan28). As such change of variety with additional crop mustard could be suggested for cultivation in medium-high land and high land areas of the High Ganges River Floodplain Agro Ecological Zone (AEZ) 11 of Bangladesh.

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