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ARTICLE

Improvement of Early Maturing and Climate Resilient Chickpea (*Cicer arietinum* L.) Cultivars Suitable for Multiple Environments in Bangladesh

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ABSTRACT

Ensuring food security for the rapidly increasing population and changing climatic scenarios are requisites for exploiting the genetic divergence of food crops. A study was undertaken to sort out an early maturing chickpea variety for fitting easily between rice-rice cropping systems in the Eastern Indo-Gangetic Plain of Bangladesh. The trial was comprised of eight elite lines of chickpea and executed at various localities in Bangladesh from 2014–15 to 2017–18. The result explored the chickpea genotype, BARI Chola-11 remained superior to the rest of the elite genotypes for having a short maturity period (100–106 days), and lesser days to 50% flowering (47–55 days). The same genotype was recorded to have robust vegetative and reproductive yield attributes including plant height (49–57 cm), podsplant^{-1} (37–50), and optimum 100 seed weight (19.5–20.6 g). Owing to better yield attributes, BARI Chola-11 resulted in the maximum seed yield (1200–1500 kg ha^{-1}) of chickpea and might be recommended for general adoption in the region for boosting nutritional security status through improved productivity under changing climate.

KEYWORDS

Short-duration variety; multi-location yield trial; high yielding variety; GGE biplot analysis; preliminary yield trial; super early type

1 Introduction

Globally, leguminous crops especially chickpea (*Cicer arietinum* L.) contribute vital contributions to ensure the nutritional security of skyrocketing population [1,2]. The crop finds multiple utilizations such as the provision of nutritional food to humans and protein-rich feed (pod walls and seed coats) for livestock. It is a reliable source of protein, lipids, carbohydrates, fibres, minerals and amino acids [3]. Sprouted chickpea is rich in phosphorus, magnesium, iron, calcium, zinc, fibre, fatty acids and carotenoids, cryptoxanthin, lutein and zeaxanthin in amounts than golden rice [4]. Globally, chickpea was cultivated in more than 50 countries and acreage of 12.0 million ha with a production of 11.0 million metric tons where the average yield was 913 kg ha^{-1} [5]. However, chickpea is a popular pulse crop in

Bangladesh due to its nutritional value as well as preferential demand in the holy Ramadan for the Muslim community. So, traditionally this crop was grown throughout the country. But it is widely cultivated in Jashore, Jhenaidah, Meherpur, Kustia, Faridpur, Pabna and Barind Rajshahi [6] and about 85% of chickpea is grown in these areas. Its acreage and production are decreasing day by day due to its long life cycle as compared to other rabi crops and different biotic and abiotic stresses [7]. Farmers are therefore reluctant to chickpea cultivation for its long-duration growth habit although it has huge demand in Bangladesh and the world market. However, there is a dire need to develop a short maturing genotype of chickpea to be integrated into the rice-rice cropping system that will reduce pulses import bill. In spite of the huge demand for chickpea, its acreage is only 6,100 hectares and production is 7,700 metric tons and the average yield is 1,260 kg/ha in Bangladesh [6]. Whereas we have huge potential areas and about 7,770 sq km of Barind Tract (24°20′N and 25°35′N and longitudes 88°20′E and 89°30′E). In these Barind areas, rice mono-cropping is a traditional age-old practice where lands remain fallow for about six months (November-May/June) after T-aman harvesting. Introducing suitable short-duration pulse crops during the fallow period may increase the cropping intensity, provide household nutritional security and generate extra income for farmers as well as mitigation of water scarcity. In addition, there is no way to increase our cultivable area, by fitting the chickpea in existing cropping patterns in Barind Tract. Fitting the chickpea rice-rice cropping pattern, the crop duration must be within three months. Moreover, chickpea has been established as a proven technology in the limited residual soil moisture and hard-setting nature of the soils in the north and western parts of Rajshahi under the High Barind areas of Bangladesh. Keeping this in mind, an attempt has been taken to sort out one of the most superior chickpea genotypes from the pool of elite genotypes for growing in the Eastern Indo-Gangetic Plain of Bangladesh eastern India and Nepal.

2 Materials and Methods

2.1 Selection Method

Initially, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has improved twenty-three super early genotypes through their regular crossing program at the ICRISAT research farm, Hyderabad, India. From these super early genotypes Pulses Research Centre (PRC), Bangladesh Agricultural Research Institute (BARI), Ishurdi, Pabna received eight chickpea genotypes during 2014–15 to evaluate their earliness and agronomic traits (yield and yield attributes) under Bangladesh weather conditions. During rabi season (cool dry season) of 2015–16 eight genotypes were sown on 17 November 2014 at Pulses Research Centre, Ishurdi, Pabna consisting of two commercial varieties viz.; BARI Chola-5 and BARI Chola-9 as check entitled on ‘Chickpea International Screening Nursery (Super Early type)’ as a first trial.

2.2 Experimental Treatments and Design

Initially, four advance lines collected from ICRISAT viz., ICCV-060157-15, ICCV-0601557-3, ICCV-060157-11 and ICCV-060157-12 were selected based on their earliness at the first trial, and ICCV-0601557-3 was included for the regular yield performance trial of PRC entitled on ‘Observation Trial (OT) of Chieckpea’ during rabi of 2015–16 consisting of other 21 PRC and ICRISAT chickpea breeding materials with BARI Chola-5 and BARI Chola-9 as check varieties. The trial entitled ‘Observation Trial (OT) of Chickpea’ was sown on 19 November 2015 at PRC, BARI, Ishurdi, Pabna followed by RCB design with two replications and spacing of 50 cm between rows. Each entry was sown in 2 rows of 4 m long plot, whereby crop was sown in 50 cm at a row to row and plant to plant spacing was 10 cm. From OT five genotypes viz., BCX 01008-8, BCX 01008-4, BCX 01008-3, ICCV 07105 and ICCV 060157-3 were selected to evaluate the yield and earliness in the multi-locations of chickpea growing areas of Bangladesh entitled on Preliminary Yield Trial (PYT) including two commercial varieties, e.g., BARI Chola-5 and BARI Chola-9 in 2016–17 at six chickpea growing regions like Ishurdi, Gazipur, Jashore, Madaripur, Barishal and Jamalpur. The multi-locational trial entitled on PYT of chickpea was established from 14 to 23 November 2016 at different locations and the trial was assigned in a RCBD with three replications. From the first multi-locational trial PYT, three genotypes BCX 01008-3, BCX 01008-4 and ICCV 060157-3 were selected for further evaluation in the second multi-locational trial entitled Regional Yield Trial (RYT) of chickpea including with two commercial varieties BARI Chola-5 and BARI Chola-9 as checks during 2017–18 at six different locations viz., Ishurdi, Gazipur, Jashore, Jamalpur, Madaripur, Barishal and Rajshahi. The crop was completely damaged at Madaripur due to heavy rainfall just after establishing. The trial was laid out in an RCBD with three replications where row to row distance was 50 cm. Each line was sown in 8 rows of a 4 m long plot and seeds were sown from late November to the first week of December 2017 at different locations.

2.3 Experimental Sites

Among the four experiments, the experiment entitled 'International Screening Nursery' and 'Observation Trial' was carried out at Pulses Research Centre, BARI, Ishurdi, Pabna. Another two multi-location yield trials 'Preliminary Yield Trial' and 'Regional Yield Trial' were conducted at different chickpea growing areas and different Agro-Ecological Zones of Bangladesh like Gazipur, Barisal, Madaripur, Jashore, Jamalpur, and Barind Rajshahi (Fig. 1).

The experimental sites were significantly varied from each other based on the geographical position, soil texture and climatic condition (Tables 1 and 2).

2.4 Agronomic Management and Crop Harvesting

In all trials, seeds were sown at 3 cm depth followed by covered with soils by laddering. Then irrigation is applied for confirmation of germination. Recommended fertilizers viz.; 20-20-20-10.8-1.0 kg NPKSB ha^{-1} were used at the final land preparation [8] for better crop establishment. Each of the lines was monitored from seed sowing to harvesting and compared with both checks. The best individual lines were selected based on earliness, disease reaction and higher yield capacity at the mature stage. The crops were harvested from the entire plots and grain yield was recorded.

2.5 Breeding of the Advance Line ICCV 060157-3 and Disease Scoring

The advance ICCV 060157-3 was developed from a crossing program made between (ICCV 96029 X ICC 16644) X ICCV 93954 at ICRISAT, Hyderabad, India. The crop was infested by Botrytis Grey Mold (BGM) disease and this disease was graded according to a scoring scale (1−9) as described by Alam et al. [9].

2.6 Statistical Analysis

In the case of the International Screening Nursery and Observation Trial, the yield and yield components were analyzed following PLABSTAT computer-based statistical software [10]. But in the case of multi-location trials viz., PYT and RYT all data were analyzed using R software [11] and only the yield data were subjected to analysis of variance of Finlay-Wilkinson regressions and GGE biplot model of stability analysis using PB Tools. Each genotype was defined by three categories: (1) mean yield overall environments, (2) the linear regression (b values) of genotype mean yield in each environment and (3) the mean square deviation from the regression for each genotype.

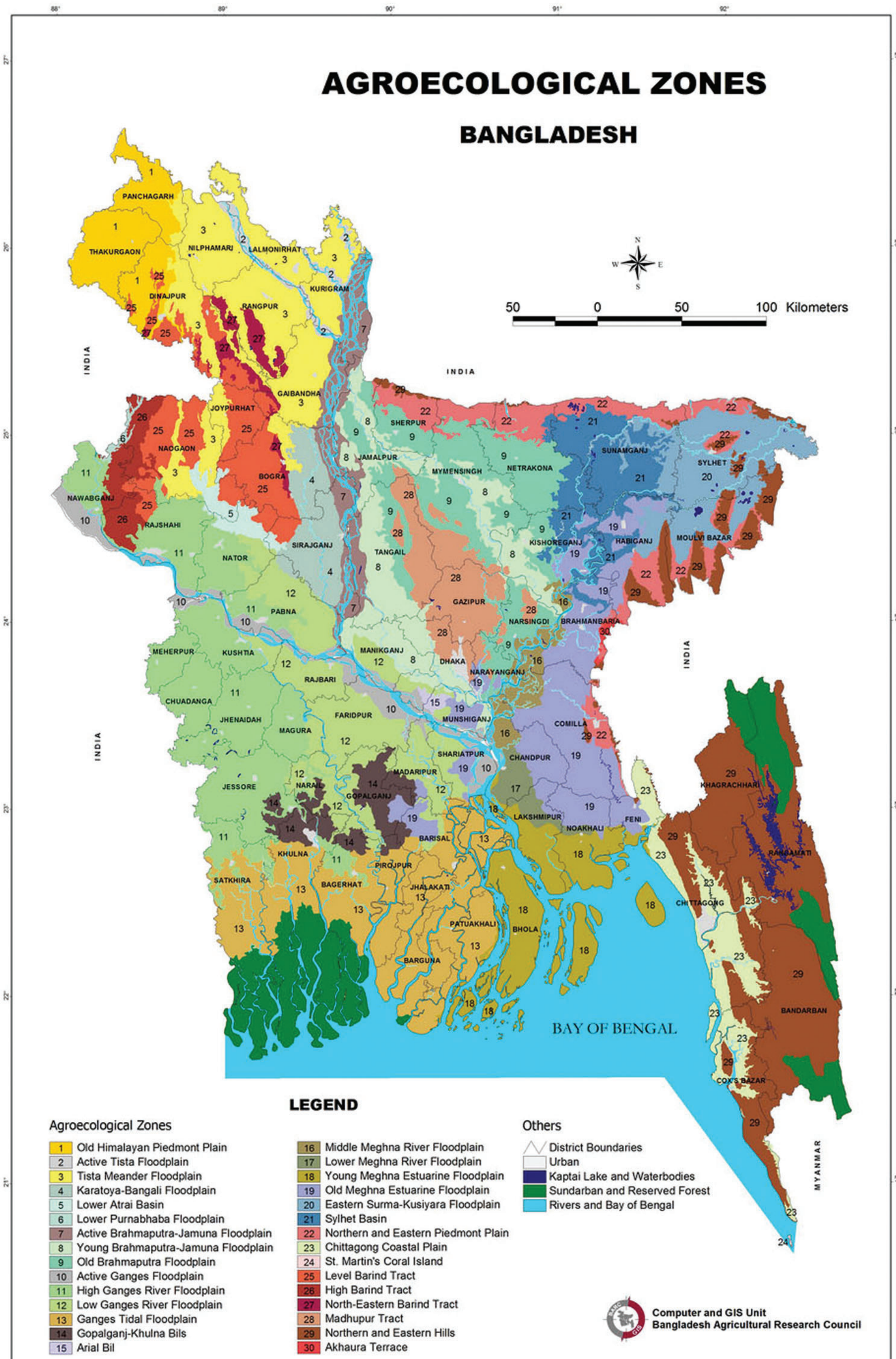

Figure 1: The agro-ecological position of the multi-location experimental sites (within the red triangle) in Bangladesh

Table 1: Silent features of the experimental sites along with climatic conditions (monthly total rainfall data) during 2016–17 and 2017–18

Locations	Variable															
	AEZ	Altitude (m)	Geographical position	Soil texture	Monthly total rainfall (mm)											
					November		December		January		February		March		April	
					2016	2017	2016	2017	2017	2018	2017	2018	2017	2018	2017	2018
Ishurdi	11	16.00	24°030 N 89°050 E	CL	0.00	0.00	0.00	35.00	0.00	0.00	0.00	0.00	0.00	15.90	0.00	212.25
Jashore	11	6.10	23°170 N 89°210 E	CL	0.00	0.00	0.00	20.40	0.00	0.00	0.00	0.60	07.90	0.80	106.70	168.40
Barishal	13	2.10	22°480 N 90°370 E	SC	09.82	10.00	0.00	27.0	0.00	30.00	0.00	0.00	06.82	10.00	70.40	220.00
Madaripur	14	7.00	23°10 N 90°120 E	SL	08.00	09.50	0.00	24.0	0.00	27.50	0.00	0.00	04.58	08.95	72.80	223.0
Jamalpur	9	18.00	24.940° N 89.930° E	S	79.79	95.00	81.58	250.0	7.00	81.51	6.50	83.82	125.3	60.95	290.0	219.8
Gazipur	28	14.00	22°460°N 90°390° E	SCL	1.57	0.00	0.00	34.00	0.00	0.00	0.00	18.00	7.75	30.00	24.38	324.0
Barind, Rajshahi	11	16.00	24.170° N 89.140° E	VCL, terrace	0.00	0.00	0.00	19.60	02.20	0.00	0.00	12.60	43.6	08.60	102.00	142.50

Note: CL = Clay loam; SC = Silty clay; SL = Silty loam; SCL = Silty clay loam; VCL = Very clay loam.

Table 2: The monthly mean temperature of the experimental sites during 2016–17 and 2017–18

Locations		Monthly average temperature (°C)											
		November		December		January		February		March		April	
		2016	**2017**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Ishurdi	Tmax	24.7	26.0	19.4	19.9	18.0	17.7	26.8	30.0	30.9	32.9	30.8	31.8
	Tmin	16.6	19.9	14.3	16.5	11.3	12.4	13.8	18.4	17.9	19.9	20.8	20.9
Jashore	Tmax	25.7	28.7	22.5	28.0	26.7	25.3	27.9	31.8	32.5	37.0	33.5	36.0
	Tmin	15.5	14.9	12.8	14.8	9.4	8.7	10.7	15.7	14.7	20.2	16.0	21.3
Barishal	Tmax	28.7	23.4	26.4	20.0	25.7	16.3	27.0	22.5	32.3	31.7	32.8	33.8
	Tmin	19.2	22.9	14.9	19.5	12.1	15.7	14.4	19.9	19.7	22.6	24.1	26.9
Madaripur	Tmax	26.8	21.6	25.4	19.5	23.7	15.9	25.9	19.8	30.5	30.9	31.9	32.7
	Tmin	18.5	19.5	13.9	15.5	13.0	11.0	12.8	16.8	18.5	21.8	23.6	25.9
Jamalpur	Tmax	23.9	30.0	27.7	27.2	24.9	21.5	28.5	28.3	29.7	32.9	31.9	33.5
	Tmin	12.4	18.9	14.7	15.6	11.9	10.0	14.5	14.4	18.4	18.5	21.1	21.3
Gazipur	Tmax	30.3	30.9	28.6	26.5	21.0	23.8	19.9	29.1	25.7	33.1	29.9	32.6
	Tmin	18.4	18.3	15.1	15.2	17.6	10.6	23.5	15.3	22.8	19.4	26.8	21.4
Barind, Rajshahi	Tmax	29.9	29.4	26.2	26.2	25.2	22.5	28.7	28.9	31.3	34.0	35.1	34.1
	Tmin	17.5	17.4	13.7	14.7	11.0	08.5	13.5	14.2	18.5	19.1	23.2	22.2

Note: Tmax = Maximum temperature; Tmin = Minimum temperature.

3 Results

3.1 International Screening Nursery

Data on yield and yield attributes have been presented in Table 3. All the lines flowered three to four weeks earlier as compared to BARI Chola-5 and BARI Chola-9. But only four genotypes including ICCV-060157-15, ICCV-0601557-3, ICCV-060157-11 and ICCV-060157-12 matured two weeks earlier than the checks. Most of them were semi-erect types.

Table 3: Performance of eight genotypes of chickpea entries in Chickpea International Screening Nursery (Super Early type) received from ICRISAT

Advanced lines	PP at harvest	Days to flower	Days to maturity	Plant height (cm)	Pods plant^{-1}	100-seed wt (g)	Yield (kg ha^{-1})	BGM score (1–9)
ICCV-060157-15	84	45	106	46	17	21.1	1254	3
ICCV-0601557-3	96	43	107	49	19	20.8	1205	3
ICCV-060157-11	115	45	105	47	24	23.1	1295	3
ICCV-060157-12	125	43	106	49	19	22.3	1380	3
ICCV-060154-40	76	52	119	56	24	35.8	1243	3
ICCV-060155-12	55	47	121	50	23	34.1	503	4
ICCV-060156-30	88	50	123	58	39	29.4	1483	4
ICCV-060156-33	58	49	124	58	18	38.4	695	4
BARI Chola-5	127	75	122	48	48	15.5	1993	3
BARI Chola-9	115	76	121	51	42	24.6	2185	3
$LSD_{0.05}$	39.0*	2.3**	2.2**	7.7*	10.9**	2.4**	759.5*	0.5**

Note: Legend: PP = Plant population; BGM = Botrytis grey mold. LSD = The least significant difference (LSD) at $P \leq 0.05$, NS = Not significant, *significant at $P \leq 0.05$, and **significant at $P \leq 0.01$.

The genotype ICCV-060156-33 was the tallest one followed by ICCV-060156-30 and ICCV-060157-15 were the recorded dwarf ones. Almost all of them have been recorded in poor biomass (short plant canopy with few branches), the fewer pods compared with checks. Most of them were recorded as bold seeded. The 100 seed weight of ICCV-060156-3338 g remained unmatched compared to the rest of the genotypes. There are no advanced lines that can out yield the check varieties BARI Chola-5 and BARI Chola-9. ICCV-060157-15, ICCV-0601557-3, ICCV-060157-11 and ICCV-060157-12.

3.2 Observation Trial

Selected early genotypes from chickpea International Screening Nursery were included with the breeding lines of PRC for evaluation of their yield performance and other yield contributing traits in replicated field trial entitled on OT. The crop performance in OT was presented in Table 4.

Table 4: The yield and yield components of different genotypes in observation trial of chickpea in 2015–16 at Pulses Research Centre, BARI, Ishurdi, Pabna

Entries	PP m^{-2}	Days to flower	Days to maturity	Plant height (cm)	Pods $plant^{-1}$	100 Seed weight (g)	Yield (kg ha^{-1})	BGM score (1–9)	% Yield over	
									Check 1	Check 2
BARI Chola-5	33	86	126	54.3	42	12.1	1210	4.0	–	−6.8
BCX 01005-1	35	92	133	79.2	36	17.0	1125	3.0	−7.0	−13.3
BCX 01005-6	30	93	134	78.2	32	16.4	1038	2.5	−14.3	−20.1
BCX 01005-7	37	91	133	72.9	36	22.3	955	2.0	−21.1	−26.4
BCX 01006-2	25	91	131	70.9	45	16.0	1235	2.0	2.1	−4.9
BCX 01006-4	31	87	131	69.2	32	16.6	811	2.3	−33.0	−37.5
BCX 01007-3	24	84	126	62.9	43	22.0	1326	2.3	9.6	2.2
BCX 01007-7	29	84	129	64.4	29	14.8	1110	3.8	−8.3	−14.5
BCX 01007-9	25	85	130	56.9	33	18.3	1211	2.8	0.1	−6.7
BCX 01007-11	33	81	126	63.0	36	14.6	1138	3.5	−6.0	−12.4
BCX 01007-12	30	81	130	61.6	31	17.2	1070	3.3	−11.6	−17.6
BCX 01008-3	24	83	131	73.7	37	19.5	1313	2.3	8.8	1.1
BCX 01008-4	26	84	130	74.5	30	20.4	1435	2.0	18.6	10.6
BCX 01008-8	29	84	130	77.9	32	20.3	1543	2.0	27.5	18.8
BCX 01008-10	19	84	131	73.4	38	18.8	1283	2.8	6.0	−1.2
BCX 01008-11	21	87	132	58.6	49	22.1	1225	3.0	1.2	−5.6
ICCV 98801	22	86	133	67.3	31	20.9	1210	2.5	0.0	−6.8
ICCV 93706	21	87	131	66.2	29	24.6	1063	2.0	−12.2	−18.1
ICCV 12116	24	81	132	63.9	40	24.1	1155	2.3	−4.6	−11.0
ICCV 060157-3	24	53	113	64.7	39	19.8	1230	2.0	1.7	−5.2
ICCV 07105	22	88	132	65.4	42	17.6	1276	2.0	5.5	−1.7
ICCV 94954	20	79	129	64.8	43	24.7	1093	2.5	−9.7	−15.4
ICCMABCA-41	14	80	131	69.4	32	35.2	741	2.3	−38.7	−42.9
BARI Chola-9	22	83	126	61.5	46	23.50	1298	3.3	7.3	–
$LSD_{0.05}$	9.3**	1.9**	2.0**	12.4*	ns	2.1**	396.4*	–	–	–

Note: Legend: PP = Plant population; BGM = Botrytis grey mold; LSD = Least significant difference at $P \le 0.05$, ns = Not significant, *significant at $P \le 0.05$, and **significant at $P \le 0.01$.

All traits except pods plant^{-1} were significantly different among tested genotypes. The entry ICCV 060157-3 was flowered earlier (53 days) and BCX 01005-6 flowered late (93 days) among the tested genotypes. Similarly, in case of days to maturity, ICCV 060157-3 took minimum days (113 days) to mature and the entry BCX 01005-6 matured at late (134 days). BCX 01005-1 was the tallest followed by BCX 01005-6 and BARI Chola-5 was the dwarf followed by BCX 01007-9. The maximum 49 pods plant^{-1} was counted in BCX 01008-11 followed by BARI Chola-9 and a minimum of 29 in BCX 01007-7 and ICCV 93706. The 100-seeds weight of ICCMABCA-41 was 35.2 g (bold size) while the small size seeds (12.07 g) from BARI Chola-5. The yield of BCX 01008-8 was higher (1543 kg ha^{-1}) followed by BCX 01008-4 and BCX 01007-3, and the yield of ICCMABCA-41was lower (741 kg ha^{-1}) followed by BCX 01006-4 and BCX 01005-7. In the case of BGM disease infestation, almost all of the entries possess moderate resistance whereas early entry ICCX 060157-3 escaped the convenient environment for BGM infestation due to their earliness. A heavy hail storm occurred on 6 March and 5–6 days of continuous rainfall occurred in the last week of March which led to water-logging and resulted in lower yield than in previous years.

3.3 Preliminary Yield Trial

Variation of all the parameters was observed in different genotypes of chickpea across all the environments except in Jashore where all the genotypes were significantly different among all the parameters (Tables 5 and 6).

The advance line ICCV 060157-3 flowered earlier (65 days) considering the mean values of six locations whereas BARI Chola-9 took a maximum of 72 days to flower. Among the locations, most of the genotypes flowered earlier (Range: 49–58 days) in Barishal and Jamalpur were late (70–82 days). ICCV 060157-3 was matured earlier (in 108 days) considering the mean values.

In the case of locations, all the genotypes comparatively matured earlier in Jashore and Barishal. Mean plant height was maximum in BCX 01008-8 (61.7 cm) and minimum in BARI Chola-5 (50.0 cm). Comparatively the tallest plant height was observed in Ishurdi and shorter in Madaripur. The mean highest 47 pods plant^{-1} was counted from genotype BARI Chola-5 and the lowest was 37, which was counted from genotype ICCV 060157-3. The number of pods varied from location to location as at Ishurdi, it was maximum (54–86) whereas the corresponding range was 19–30 in Madaripur. The seed weight of all genotypes was lowest at Madaripur and the highest mean of 100-seed weight was counted from BARI Chola-9 (22.77 g) and the lowest was obtained from BARI Chola-5 (13.14 g). The seed yield was higher in BCX 01008-4 (1126 kg ha^{-1}) followed by BCX 01008-3 and the yield of ICCV 060157-3 was lower (852 kg ha^{-1}) across the locations. Compared to six locations, almost all the genotypes produced a higher yield (1242–1575 kg ha^{-1}) in Jashore, and a lower yield (592–813 kg ha^{-1}) in Gazipur may be due to environmental variation.

Regression coefficient ranged was 0.49 (for genotype BCX 01008-4) to 1.18 (for genotype ICCV 07105) (Table 7). The regression coefficients of the five genotypes were higher than 1.0 indicating their sensitivity to environmental changes. However, two genotypes (BCX 01008-4 and BCX 01008-8) had a regression coefficient of less than 1.0 (Table 7).

Table 5: Days to flowering, days to maturity and plant height of different chickpea entries were varied in preliminary multi-location trials in the winter season of 2016–17

Entries	Days to flowering							Days to maturity							Plant height (cm)						
	Isd	Gaz	Jes	Mad	Bar	Jam	Mean	Isd	Gaz	Jes	Mad	Bar	Jam	Mean	Isd	Gaz	Jes	Mad	Bar	Jam	Mean
BARI Chola-5	76	65	64	69	49	79	67	121	115	107	132	109	138	120	77.1	39.9	42.7	33.3	58.9	48.1	50.0
BCX 01008-8	74	66	63	70	56	80	68	109	117	107	131	111	136	118	76.0	66.5	56.7	34.3	77.0	59.9	61.7
BCX 01008-4	74	63	64	70	58	77	68	109	117	107	129	111	133	118	76.1	63.9	57.3	30.7	71.1	58.7	59.6
BCX 01008-3	74	64	63	71	54	78	67	112	117	106	130	108	135	118	75.6	57.9	55.7	31.0	66.3	63.7	58.4
ICCV 07105	77	66	63	70	56	82	69	120	124	109	131	108	141	122	73.8	51.9	52.3	35.3	58.5	48.1	53.3
ICCV 060157-3	67	63	53	65	45	65	51	101	100	91	125	90	130	106	77.1	53.0	47.1	36.3	67.7	65.9	57.9
BARI Chola-9	80	68	72	74	58	78	72	121	122	112	130	109	138	122	72.5	43.5	51.9	38.7	62.8	39.3	51.4
$LSD_{0.05}$	ns	ns	1.3**	ns	ns	4.5**	–	4.1**	6.9**	1.9**	Ns	4.3**	ns	–	ns	7.3**	4.4**	ns	ns	1.9**	–

Note: Legend: Isd = Ishurdi, Gaz = Gazipur, Jes = Jashore, Mad = Madaripur, Bar = Barishal, Jam = Jamalpur. LSD = The least significant difference at $P \leq 0.05$, ns = not significant, *significant at $P \leq 0.05$, and **significant at $P \leq 0.01$.

Table 6: Podsplant^{-1}, 100-seed weight (g) and plant BGM of different chickpea genotypes were varied in a preliminary yield trial in the winter season of 2016–17

Entries	Pods plant^{-1}							100 seed weight (g)							BGM	
	Isd	Gaz	Jes	Mad	Bar	Jam	Mean	Isd	Gaz	Jes	Mad	Bar	Jam	Mean	Mad	Bar
BARI Chola-5	78	42	55	25	53	28	47	13.3	14.7	15.00	10.7	11.1	14.1	13.1	7	5
BCX 01008-8	82	38	32	22	39	31	41	19.5	20.7	20.00	11.7	17.3	18.4	17.9	6	5
BCX 01008-4	71	35	39	23	38	32	40	20.8	22.0	19.00	12.0	17.8	20.7	18.7	6	5
BCX 01008-3	58	33	43	27	38	34	39	19.9	19.7	20.17	11.7	16.8	20.6	18.1	5	5
ICCV 07105	74	35	59	27	30	22	41	19.2	17.8	22.17	11.0	13.9	16.7	16.8	6	4
ICCV 060157-3	54	25	60	19	39	26	37	21.3	18.9	21.17	10.7	18.1	19.5	18.3	6	4
BARI Chola-9	86	28	60	30	35	21	43	23.4	24.1	25.67	22.4	18.0	23.1	22.8	6	6
$LSD_{0.05}$	ns	ns	4.9**	ns	ns	1.5**	–	1.8**	ns	0.8**	2.0**	1.7**	2.3**	–	–	–

Note: Legend: BGM = Botrytis grey mold; Isd = Ishurdi, Gaz = Gazipur, Jes = Jashore, Mad = Madaripur, Bar = Barishal, Jam = Jamalpur. LSD = The least significant difference at $P \leq 0.05$, ns = not significant, *significant at $P \leq 0.05$, and **significant at $P \leq 0.01$.

Table 7: Yield performance and stability of the six genotypes of chickpea in diverse environments during 2016–17 cool dry seasons

Entries	Yield (kg ha^{-1})							Regression co-efficient (bi)	Mean square deviation
	Isd	Gaz	Jes	Mad	Bar	Jam	Mean		
BARI Chola-5	1458	729	1395	854	986	655	1013	1.08	9605
BCX 01008-8	1258	604	1335	840	883	791	952	0.90	6494
BCX 01008-4	1476	813	1242	807	1008	1410	1126	0.49	56076
BCX 01008-3	1319	646	1498	751	1171	803	1031	1.04	6947
ICCV 07105	936	738	1532	764	913	260	857	1.18	25378
ICCV 060157-3	1260	1200	1575	1100	1067	691	1149	1.13	47823
BARI Chola-9	1235	625	1472	957	925	440	942	1.17	8283
$LSD_{0.05}$	394**	Ns	115**	ns	ns	23**	–	–	–

Note: Legend: Isd = Ishurdi, Gaz = Gazipur, Jes = Jashore, Mad = Madaripur, Bar = Barishal, Jam =Jamalpur. LSD = The least significant difference at $P \leq 0.05$, ns = not significant, *significant at $P \leq 0.05$, and **significant at $P \leq 0.01$.

These genotypes were relatively better adapted to the suboptimal environment and were insensitive to environmental changes regardless of seed yield. Such genotypes could be recommended only for cultivation in unfavourable conditions. However, one of the promising genotypes BCX 01008-3 was found with regression co-efficient closer to unity (1.04) with higher yield than the check varieties suggesting that this advanced line could be recommended for cultivation in diverse environments for higher yield. Therefore, this genotype can be selected as stable over the environments. Regarding Mean Square Deviation also the genotype BCX 01008-3 possessed minimum values therefore; this genotype is more stable across the environment.

The multi-locational trial is an important selection procedure for the selection of location-specific genotypes based on yield and stability performance. It is included the additive main effects, multiplicative interaction (AMMI), stability variance, coefficient of variability, GGE biplot analysis. Among these commonly used analyses, GGE biplot analysis was used to select stable genotypes among locations (Fig. 2). The yield performance of a cultivar in a tested environment is a result of the genotypic main effect (G), environmental main effect (E) and genotype × environment (GE) interaction. GGE biplot technique also separates two principal components, PC1 and PC2. In this experiment, the first two PCs of the GGE model explained 92.5% of the variation in GGE. The polygon view of the GGE-biplot analysis helps to detect genotype-by-environment interaction and possible mega environments in multi-locational yield trials. Here, seven genotypes represented a polygon and the vertex genotypes corner of the polygon were BCX 01008-4, BARI Chola-5 and ICCV 060157-3. They are best in the environment lying within their respective sector in the polygon view of the GGE-biplot; thus these genotypes are considered specifically adapted and the most responsive genotypes. The environments fall into three quadrants, and the genotypes on the other hand into four quadrants.

In all locations, Jamalpur and Ishurdi had larger environmental vectors reflecting a high capacity to discriminate the genotypes therefore these should be regarded as the most appropriate to select widely adapted genotypes. Vertex genotype BARI Chola-5 performed well in Ishurdi whereas genotype BCX 01008-4 was best adapted to Jamalpur. Genotypes BCX 01008-3 and BCX 01008-8 were close to the origin of axes and had wider adaptation, i.e., most stable genotypes. In the GGE biplot, genotypes with high PC1 scores have a high mean yield, and those with low PC2 scores have stable yield across environments. Considering these, the genotypes BCX 01008-4 and BCX 01008-3 yielded higher but only

BCX 01008-3 demonstrated the best stable performance suggesting its adaptation to a wide range of environments with a higher yield. Based on the stability parameters, higher yield, and disease reaction, BCX 01008-3 demonstrated better performance but it was in 2nd position out of seven genotypes for yield. Again BCX 01008-4 with the highest mean yield was also suited for unfavourable environments and the genotype ICCV 060157-3 was found as the shortest duration type. Therefore, the genotypes BCX 01008-3, BCX 01008-4 and ICCV 060157-3 have been identified to assess in the next cool dry season for further evaluation of their performance under another. The Multi-locational Yield Trial (MYT) is entitled 'Regional Yield Trial' during rabi season 2017–18.

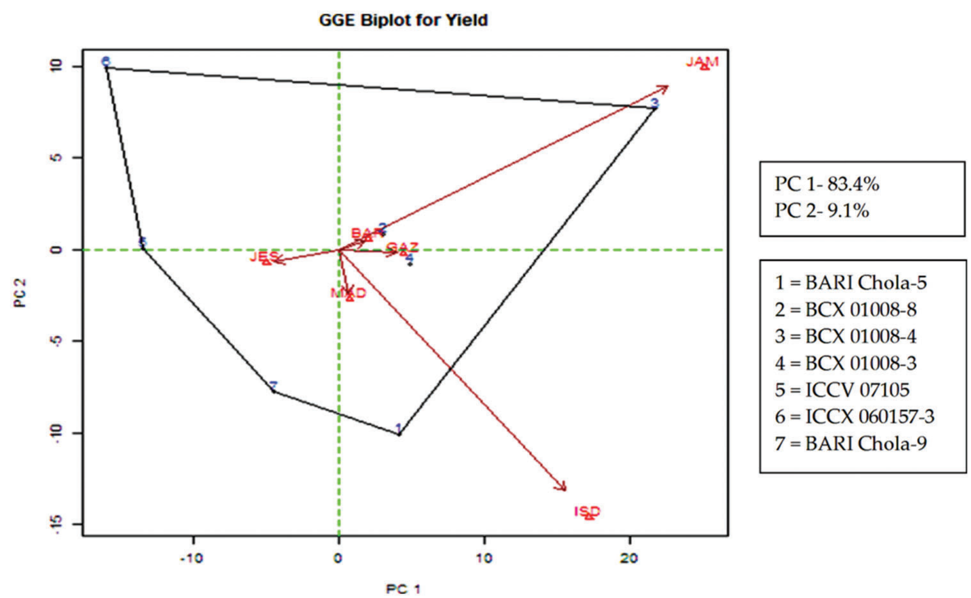

Figure 2: GGE biplot based on yield (kg ha^{-1}) different cultivars of chickpea (Isd = Ishurdi, Gaz = Gazipur, Jes = Jashore, Mad = Madaripur, Bar = Barishal, Jam = Jamalpur)

3.4 Regional Yield Trial

Results of the regional yield trial were presented in Tables 8–10. Results from this experiment revealed significant or non-significant variation among all the parameters over the locations. The genotype ICCV 060157-3 flowered earlier (56 days) considering the mean values of five locations. Among the locations, most of the genotypes flowered earlier (Range: 39–55 days) in Barishal and late (68–85 days) in Rajshahi. ICCV 060157-3 was matured earlier (101 days) considering the mean values.

In the case of locations, all the genotypes comparatively matured earlier in Jashore and Barishal. Mean plant height was maximum (68.8 cm) in BCX 01008-3 and minimum (51.5 cm) in BARI Chola-5. The comparatively taller plant was observed in Rajshahi and shorter in Gazipur. The mean maximum (64) pods plant^{-1} was counted from genotype BARI Chola-5 and the lowest (53) from genotype ICCV 060157-3. The number of pods varied from location to location. At Ishurdi, it was a maximum ranging 61–124 whereas in Gazipur it was a minimum with a range of 20–36. The maximum 100-seed weight (20.6 g) was recorded from BARI Chola-9 and the lowest (14.13 g) from BARI Chickpea-5. The seed yield (1431 kg ha^{-1}) of BARI Chola-9 was higher followed by BCX 01008-4 and ICCV 060157-3 across the locations. Compared to six locations, almost all the genotypes produced a higher yield (1363–1777 kg ha^{-1}) in Rajshahi and most importantly short duration genotype ICCV 060157-3 produced a maximum of 1777 kg ha^{-1} in Barind, Rajshahi.

Table 8: Plant population (m^{-2}), days to flowering and days to maturity of selected chickpea genotypes were varied in regional multiplication trials during the winter season in 2017–18

Entries	Plant population m^{-2}						Days to flowering						Days to maturity					
	Isd	Gaz	Jas	Bar	Raj	Mean	Isd	Gaz	Jas	Bar	Raj	Mean	Isd	Gaz	Jas	Bar	Raj	Mean
BARI Chola-5	18	–	34	–	25	26	77	68	65	48	84	68	117	123	105	90	135	114
BCX-01008-3	15	–	33	–	24	24	79	73	64	54	79	70	116	119	104	92	132	113
BCX-01008-4	22	–	30	–	25	26	77	67	64	55	80	69	115	121	104	92	131	113
ICCV-060157-3	29	–	28	–	24	27	64	60	51	39	68	56	106	107	92	85	114	101
BARI Chola-9	17	–	28	–	24	23	78	68	66	54	85	70	109	122	104	88	135	112
$LSD_{0.05}$	7.0*	–	NS	–	NS	–	3.5**	5.8*	1.4**	3.0**	2.5**	–	1.8**	0.8**	1.0**	3.2**	4.6**	–

Note: Legend: Isd = Ishurdi, Gaz = Gazipur, Jes = Jashore, Mad = Madaripur, Bar = Barishal, Jam = Jamalpur. LSD = The least significant difference at $P \leq 0.05$, ns = not significant, *significant at $P \leq 0.05$, and **significant at $P \leq 0.01$.

Table 9: Plant height, pods $plant^{-1}$ and 100-seed weight of selected chickpea entries were varied in the regional multi-location trial during the winter season of 2017–18

Entries	Plant height (cm)						Pods $plant^{-1}$						100-seed weight (g)					
	Isd	Gaz	Jas	Bar	Raj	Mean	Isd	Gaz	Jas	Bar	Raj	Mean	Isd	Gaz	Jas	Bar	Raj	Mean
BARI Chola-5	61.27	41.1	46.6	59.1	49.3	51.5	124	22	60	48	64	64	13.58	13.81	13.05	16.40	13.83	14.13
BCX-01008-3	68.47	61.0	66.6	70.7	77.4	68.8	86	28	55	56	62	57	20.71	19.78	19.20	19.07	18.50	19.45
BCX-01008-4	64.93	53.2	64.0	71.1	77.3	66.1	88	24	49	53	71	57	20.86	20.22	18.25	21.17	19.73	20.04
ICCV-060157-3	64.27	47.3	50.0	66.0	67.1	58.9	61	36	46	47	76	53	20.05	17.13	20.77	17.50	20.77	19.24
BARI Chola-9	50.73	43.8	54.1	59.1	60.9	53.7	86	20	51	53	64	55	22.66	21.41	18.61	20.63	19.87	20.63
$LSD_{0.05}$	7.2**	6.1**	12.2**	8.7*	7.3**	–	NS	NS	8.9*	NS	NS	–	2.1**	0.1**	0.5**	NS	1.6**	–

Note: Legend: Isd = Ishurdi, Gaz = Gazipur, Jes = Jashore, Mad = Madaripur, Bar = Barishal, Jam = Jamalpur. LSD = The least significant difference at $P \leq 0.05$, ns = not significant, *significant at $P \leq 0.05$, and **significant at $P \leq 0.01$.

Table 10: Yield performance and stability of the five genotypes of chickpea in RYT over environments during Rabi 2017–18

Entries	Yield (kg ha^{-1})						BGM score
	Isd	Gaz	Jas	Bar	Raj	Mean	Bar
BARI Chola-5	1005	1181	1361	1206	1363	1223	3
BCX-01008-3	928	1025	1597	1045	1527	1224	3
BCX-01008-4	1018	1094	1590	1517	1700	1384	2
ICCV-060157-3	1085	1038	1474	1223	1777	1319	4
BARI Chola-9	1341	1125	1580	1484	1623	14 31	4
LSD $_{0.05}$	374.7	284.6	148.0*	833.4	63.0**	–	1.0**

Note: Legend: BGM = Botrytis Grey Mold; Isd = Ishurdi, Gaz = Gazipur, Jas = Jashore, Bar = Barishal, Raj = Rajshahi (Barind). LSD = The least significant difference (LSD) at $P \leq 0.05$, ns = not significant, *significant at $P \leq 0.05$, and **significant at $P \leq 0.01$.

GGE biplot analysis was performed for the selection of genotypes based on yield and stability performance over the locations (Fig. 3). In this experiment, the first two PCs of the GGE model explained 82.61% of the difference in GGE. The polygon view of the GGEbiplot analysis helps to detect genotype by environment interaction and possible mega environments in multi-location yield trials. Here, five advance lines represented a polygon and all the lines were the vertex lines, in corner of the polygon. They are best in the environment in the polygon view of the GGEbiplot; thus these genotypes are considered specifically adapted, i.e., most responsive genotypes.

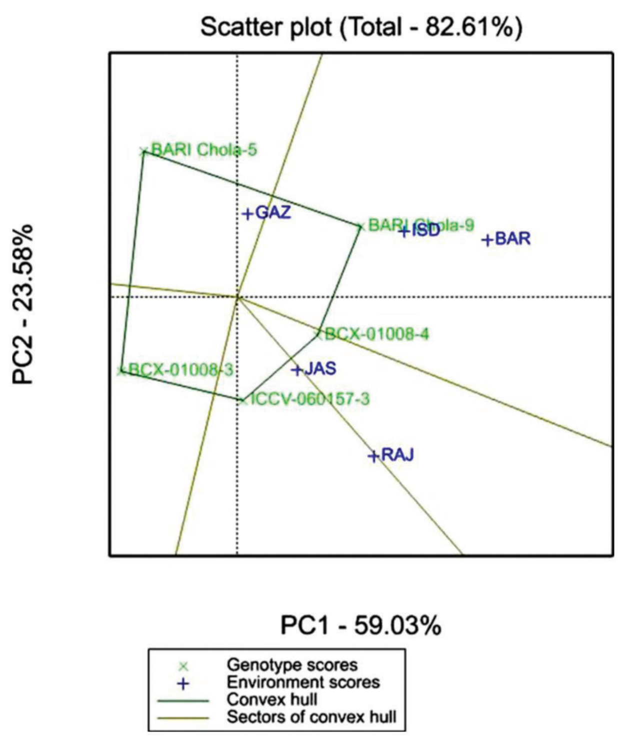

Figure 3: GGE biplot based on yield (kg ha^{-1}) of chickpea genotypes (ISD = Ishurdi; GAZ = Gazipur; JAS = Jashore; BAR = Barishal)

The genotypes fall into four and the environments into two quadrats. Out of the tested locations, Barishal and Rajshahi had larger environmental vectors reflecting a high capacity to discriminate the genotypes therefore these should be regarded as the most suitable to select widely adapted genotypes. Vertex genotype BARI Chola-9 performed well in Ishurdi and Barishal where short duration genotype ICCV 060157-3 was best adapted to Jashore and Rajshahi. Genotype BCX 01008-4 was close to the origin of axes. Considering these, the genotypes BARI Chola-9, BCX 01008-4 and ICCV 060157-3 yielded higher but only BCX 01008-4 had the best stable performances suggesting its adaptation to a wide range of environments with a higher yield. Among these genotypes, the genotype ICCV 060157-3 has been finally selected for proposal as a short-duration variety of chickpea BARI Chola-11 with stable yield performance over locations.

4 Discussion

Although chickpea is an important pulse crop, the yield is declining in Bangladesh. One of the major constraints for declining chickpea production in Bangladesh is the long duration. In addition, it cannot fit in the cropping pattern against others crop competition during the cool dry season. Therefore, an attempt has been taken to the development of a short-duration chickpea cultivar with a multi-breeding procedure. Among the different experiments titled on “International Screening Nursery” was the first experiment. Eight imported early elite lines from ICRISAT were included, and among the eight elite short duration genotypes, four genotypes, e.g., ICCV-060157-15, ICCV-0601557-3, ICCV-060157-11 and ICCV-060157-12 were identified as early maturing genotypes if their yield performance was lower compared to the checks varieties. Similar results were reported by Koinain [12] in her Master of Science experiment. These four genotypes also have shown a high degree of resistance against BGM, which is a serious disease of chickpea.

These selected four genotypes were included in the regular breeding program of PRC titled “Observation Trial” for evaluation of the yield performance with other PRC breeding lines, from this trial only five advance lines, e.g., BCX 01008-8, BCX 01008-4, BCX 01008-3, ICCV 07105 and ICCV 060157-3 were identified as better yield performer, and these advance lines were selected for first multi-location trial titled on “Preliminary Yield Trial” during the 2016–17 crop growing season. All yield contributing traits like days to flowering, days to maturity, plant height, pods plant^{-1}, 100 seed weight, and yield (kg ha^{-1}) was recorded in the observation trials with BGM disease scoring, and considering yield performance, higher pods plant^{-1}, the lowest days to maturity and less BGM reaction, five advance lines, e.g., BCX 01008-8, BCX 01008-4, BCX 01008-3, ICCV 07105 and ICCV 060157-3 were identified for a multi-locational trial like PYT and RYT in the next two consecutive winter seasons.

The Multi-locational Yield Trial is a vital experiment for the selection of a specific genotype based on yield and stability performance [13,14]. The additive main effects of multiplicative interaction (AMMI) [13,15,16], stability variance [17], coefficient of variability [18] and computer software based on GGE biplot analysis are the statistical model which was commonly used to describe GE interaction and facilitate genotype recommendations in MYT. Biplot analysis is the most commonly used for the selection of stable genotypes among different locations. The yield of each cultivar in a tested environment is a result of the genotypic main effect (G), environmental main effect (E) and genotype X environment (GE) interaction in biplot analysis [13]. GGE biplot technique separates two principal components, PC1 and PC2 which are derived from subjecting environment-centred yield data (the yield variation due to GGE) to singular value decomposition where the horizontal axis (PC1) indicates the main effect of genotype while the vertical axis (PC2) shows the interaction of genotype and environment which is the basic criterion for judging genotypic stability [19]. In this experiment, 92.5% of the variation was estimated based on the first two PCs of the GGE model. In the GGE biplot, genotypes with high PC1 scores have a high mean yield, and those with low PC2 scores have stable yield across environments

[20]. In the case of all locations, Jamalpur and Ishurdi were identified as the most adapted environmental locations for the selection of wider adapted genotypes. The genotype BARI Chola-5 performed well in Ishurdi, the genotype BCX 01008-4 was best adapted to Jamalpur. But the genotypes BCX 01008-3 and BCX 01008-8 were identified as wider adapted, and the most stable genotypes over tested locations. On the other hand, the genotype BCX 01008-4 was identified as suited for unfavourable environments with the highest mean yield. The genotype ICCV 060157-3 was found as an early maturing genotype. Considering the mean yield performance, yield stability, and earliness over the locations the genotypes BCX 01008-3, BCX 01008-4, and ICCV 060157-3 have been selected for the further MYT entitled on "Regional Yield Trial of Chickpea" over chickpea growing regions of Bangladesh during the cool season 2017–18 as the continuation of variety release program.

Among the multi-locational trials, the regional yield trial was used for assessing the genotype performance in the final stage (s) of a breeding program [21,22]. In the present study, 82.61% variation was explained in GGE from the two PCs using the GGE biplot analysis based on the yield and stability performance. The genotypes BARI Chola-9, BCX 01008-4, and ICCV 060157-3 were selected as higher yielders, and the genotype BCX 01008-4 had the best stable performances suggesting its adaptation to a wide range of environments with a higher yield. From this experiment, the genotype ICCV 060157-3 has been finally selected as a short-duration genotype and proposed as a short-duration chickpea variety as BARI Chola-11 with stable performance over locations.

5 Registration of a Variety

Based on four experimental data the advance line ICCV 060157-3 has been selected as an early maturing genotype with stable yield performance over locations. The main characteristic of this advanced line ICCV 060157-3 has been finalized based on the average data of four experiments. The details of varietal characteristics are given as follows. The genotype requires 47–55 days to 50% flowering. The plant height of the selected line is about 49–57 cm. It requires 100–106 days to harvest (seed to seed). The average pods plant^{-1} is about 37–50, and the 100 seed weight was 19.5–20.6 g with medium seed size. The potential yield of this genotype was about 1.2–1.5 ton ha^{-1}.

The details varietal characteristics and breeding procedure report of the advanced line ICCV 060157-3 has been submitted to National Seed Board (NSB), Dhaka through Director General, Bangladesh Agricultural Research Institute to propose an early maturing chickpea variety as 'BARI Chola-11'. Then the evaluation committee of NSB approved, and released the advanced line ICCV 060157-3 as an early maturing variety BARI Chola-11 in August 2018 for commercially cultivated at farmer's fields all over the chickpea growing regions of Bangladesh.

The Breeder Seed of BARI Chola-11 will be preserved by Pulses Research Centre, BARI, Ishurdi, Pabna, Bangladesh. A small amount of breeder seed will be provided to Bangladesh Agricultural Development Corporation (BADC) to produce and maintained foundation seed. A seed sample of BARI Chola-11 has been placed in the National Plant Genetic Resource Centre, BARI. The seeds of this variety will be available upon request from the date of this publication for distribution immediately. Small amounts of seed may be obtained for research purposes from the lead researcher for at least 5 years from the date of this publication.

6 Conclusion

The area and production of chickpea have declined over the last two decades due to competition with irrigated rice. From our research, the high-yielding and short-duration cultivar BARI Chola-11 was obtained from several multi-locational trials in different climatic environments in Bangladesh. Initially, the genotypes ICCV-060157-15, ICCV-0601557-3, ICCV-060157-11 and ICCV-060157-12 were selected for early maturing lines compared with existing commercial varieties of Bangladesh. Then these four lines/cultivars were included in the PRC regular breeding trial with other breeding materials. From this trial, the genotype ICCV-0601557-3 was selected as an early maturing advance line. Two multi-location yield trials were then conducted for evaluation of yield stability, earliness, and other agronomical traits of this early line ICCV-0601557-3 with another advanced line and two commercial varieties as checks at six different locations. The advance line ICCV-0601557-3 has been selected as an early matured genotype and this was submitted to National Seed Board, Dhaka, Bangladesh as a proposed variety of BARI Chola-11 with all experimental data. Finally, the proposed advance line ICCV-0601557-3 was released as a variety BARI Chola-11, which might be recommended for commercial cultivation on a larger scale in Bangladesh.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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