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Genotypic variation of adaptive and yield component traits of introduced grain oats (*Avena sativa* L.) grown in Bangladesh

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Abstract

Oat (*Avena sativa* L.) is considered a nutritious cereal. Its demand has surged across the globe steadily for half a decade, including in Bangladesh. Because there is no local variety, the current supply in Bangladesh solely relies on imports. This study aimed to introduce grain oats from the United States of America (U.S.A.) to Bangladesh and determine the extent of their adaptability and yield in this new environment. One hundred oat accessions were introduced in collaboration between North South University, Bangladesh and the University of Florida, U.S.A. They were evaluated in field conditions from November 2019 to April 2020 in the Dinajpur district, Bangladesh in two replicated measurements of 13 morphological traits with RCBD design. The broad-sense heritability ranged from 11.7% to 90.0% for the measured traits. The yield-related trait, spikelet numbers, was positively correlated with height (0.30), dry weight (0.46), and harvest index (0.42) but negatively correlated with heading (-0.05), flowering date (-0.05), and tiller numbers (-0.16). Growth habit was negatively correlated with height (-0.07) and dry weight (-0.25). Principal components 1 and 2 explained 43.01% of the variability and were strongly influenced by heading and flowering date. Cluster analysis assigned the genotypes into six main clusters, and the analysis showed that spikelet numbers, growth habit, height, harvest index, and heading date were key yield-contributing and adaptive traits. Identifying traits highly correlated with oat yield could be useful for developing new varieties adapted to Bangladesh environments. This study is a pioneer; it paved the way to breed new high-yielding grain oat varieties for Bangladesh.

Keywords: Oats, Heritability, trait evaluation, yield component traits.
Abbreviations: H^2_Broad sense heritability, CV_Coefficient of variation, SE_Standard error, LSD_Least significant differences, HD-heading date, FD_Flowering date, GD_Germination date,TL_Total length, GH_Growth habit, PL_Panicle length, HI_Harvest index, EV_Early vigor, TW_Total weight, PW_Panicle weight , TSN_Total spikelet numbers, TN_Tiller number, UTN_Unproductive tiller numbers, RCBD_Randomized complete block design, SRDI_Soil resources and development institute, DAS_Days after sowing.

Introduction

Oat (*Avena sativa* L.) is unique among cereals due to its richness in nutritional components and multifunctional characteristics. Numerous advanced research studies have revealed the nutritional importance of oat. Oat has gained considerable attention for its high content of phytochemicals, dietary fibres, and nutritional value (Butt et al*.,* 2008; Rasane et al*.,* 2015; Leisova-Svobodova et al*.,* 2019). It contains a high number of proteins, lipids, minerals and *β*-glucan and a mixed linkage polysaccharide, which constitutes an important part of oat dietary fibres (Anttila et al*.,* 2004). It also contains a high number of phytochemicals such as flavonoids, venethramides, flavonolignans, saponins, sterols, triterpenoids and tocols. Oat possesses different pharmacological activities including antioxidant, anti-inflammatory, wound healing, immune-modulatory, anti-diabetic and anti-cholesterolaemic (Rasane et al., 2015). All these biological activities indicate that oat is a therapeutic agent (Singh et al., 2013). It is a major source of functional food ingredients with high health benefits. This is supported by adequate scientific authentication and can serve as an important constituent of functional foods for promoting a healthy lifestyle in society (Kumar et al., 2017). Including oat bran and grains in food products improves their nutrition and acts as a therapy against different lifestyle diseases such as diabetes (Butt et al., 2008). Pure oats are gluten-free and are used to treat celiac disease, which is prevalent in Bangladesh (Rukunuzzaman et al*.,* 2013). It has the potential to address micronutrient deficiencies or hidden hunger at a minimal cost in many countries including Bangladesh by improving bio-fortification opportunities. Oats are not only healthy for consumers but also healthy for the environment. It is valuable in environmentally-sustainable crop rotation systems, helping to ensure sound cropping and soil conservation practices (Rucki, 2020).

Previously, oat was mostly used as animal feed; recently, human consumption has increased around the world due to increased awareness about the potential benefits of oats for human health (Ahmad et al., 2010). In Bangladesh, the demand for oats and their byproducts has been increasing day by day, but the supply is very limited as the country is mostly dependent on imports. The high prices (10-12 times higher than rice) of the available brands are an important concern because many consumers cannot afford this as a regular food. Surprisingly, there is no variety of grain oats for human consumption currently available in Bangladesh and the related research is also limited. Only two varieties of oats (Oat-Kent and Oat Swan) were studied for the forage production for ruminant animals (Islam et al., 2010). Breeding grain oat varieties for Bangladeshi consumers would benefit their health and increase their nutritional diversity and food security. Sourcing grain oats accessions is an important concern for Bangladeshi breeders. Therefore, this study aimed to communicate and introduce oats in Bangladesh by performing adaptability trials and selecting high-yielding, short-duration, and nutritious accessions. This was the first effort to breed grain oats in Bangladesh.

Results

Descriptive statistics including broad sense heritability (H^2)

A wide range of variations for different traits was observed among the accessions grown in the field. The descriptive statistics including broad sense heritability (δ^2, %), genotypic variance (δ^2_G), coefficient of variation (CV, %), standard error (SE), and least significant differences (LSD) for the 13 agronomic traits are reported in Table 1. The field photos in supplementary Fig 1 and the histogram in supplementary Fig 2 depict the successful growth and variation of the morphological traits in the environmental conditions of Bangladesh.

High heritability was observed in three adaptive traits: HD (83.5%), FD (83.8%) and GD (90%); there was moderate heritability in TL (65.1%), GH (53.4%), PL (51.7%), HI (44.2%), EV (42.7%), TW (36.9%), PW (47.4%) and TSN/P (41.8%); moreover, there was relatively low heritability in TN (14.2%) and UTN (11.6%). Higher genotypic variances were found in TSN (433.4) and TW (356.0); moderate variances were found in TL (78.4), PW (67.3), HI (21.3), HD (21.1), FD (21.2) and PL (16.9). GD, EV, GH, TN, and UTN showed very little genotypic variances.

The highest CV was found for UTN (78.4) followed by PW (28.9), TSN/P (24.8), and TW (24.2). The FD (5.4) and HD (5.6) showed the lowest CV followed by TL (6.8). Other traits such as EV, TN, PL, and HI showed medium levels of CV (Table 1).

Trait correlation

The yield-related trait TSN/P showed a significant positive correlation with TL (0.30), PL (0.46), TW (0.36), PW (0.50), and HI (0.41) but a non-significant negative correlation with HD (-0.05), FD (-0.05), TN (-0.16), and UTN (-0.25) (Table 3). GH showed a significant negative correlation with TW (-0.27) and PW (-0.29) and a positive correlation with HD (0.26) and FD (0.27). TN was significantly correlated with PW (0.47) and TW (0.45) while UTN was negatively correlated with PW (-0.49). Unique correlations were found among the traits; for example, negative correlations occurred between GH and PW, EV, and HD (Table 3). Moreover, TL and TSN showed positive correlations; these unique correlations were highlighted with bold font.

Principal component analysis

Principal components analysis (PCA) was performed using all the 13 adaptive and yield-related traits of the oats germplasm based on the correlation matrix (Table 2 Fig 2, and Supplemental Table 2 and Fig 3). Nine PCs exhibited more than 0.5 eigen values; a total variability of approximately 94.96% was shown among the characteristics that were studied. PC1 showed the largest variation (26.23%) while PC2, PC3, PC4, PC5 and PC6 exhibited variabilities of 16.77%, 11.96%, 9.43%, 8.43%, 7.37%, respectively. The rest of the PCs from PC7 to PC13 contributed less variability, ranging from 5.12% to 0.006%. (Table 2 and Supplemental Table 2). A scree plot in the supplemental Fig 3 shows the eigenvalue of each PC.

The component matrix values of HD and FD were -0.475 and 0.777 for PC1 and 0.478 and 0.777 for PC2 (Table 2). Fig 2 shows the loading plots of PC1 and PC2; the HD and FT traits strongly influenced both PCs while EV, LS, TN and UTN had very little influence (low values) and contribution. PW, TW, HI, and TSN/P had a strong influence on PC1.

Cluster analysis

To find the most promising, high-yielding, and adaptive lines, we employed Ward's (1963) cluster analysis method and classified all the accessions into six groups (I to VI), as shown in Fig 3. We characterized them based on their performance (Table 4). Group III was the lowest-yielding group with lowest the PW (13.8g), HI (21.1), TSN/P (61.4), late HD, and the highest UTN. In turn, group V was the highest yielding and had all desirable characteristics of intermediate GH (the mean was 5.9, which is in between erect and spread type), low LS (2.8), early HD, higher HI and TSN. Group VI is average in its trait values. Groups I and II have the highest TSN but a late HD, a high UTN, and a low HI (Table 4). The highest data values among the groups were highlighted based on these observations and statistical analysis of the agronomic field data.

Discussion

The field evaluation of newly-introduced oat germplasm demonstrated the potential adaptability in the local environment and paved the way for the selection of better-suited lines for variety development. Our result showed the high heritability of HD, FD and GD; these were comparable to the study conducted by Singh et al*.,* (2019) in Kanpur, India and Ihsan et al., (2021) in Khyber Pakhtunkhwa, Pakistan.

Table 1. Variations of 13 agronomic traits of 100 Oats accessions grown in Bangladesh in the Winter season of 2019-20.

Variability parameter	GD	EV (1-5)	GH (1-9)	TN	UTN	TL (cm)	PL (cm)	TW(g)	PW (g)	HI (%)	HD	FD	TSN/P
Minimum	7.0	1.5	1.5	7.2	0.0	123.1	24.7	47.6	7.2	11.9	74.5	76.5	52.4
Maximum	11.0	5.0	8.8	22.2	5.2	172.3	63.2	210.7	63.5	47.3	100.5	102.5	185.2
Mean	8.3	3.7	6.0	12.4	1.2	146.3	32.7	105.2	35.0	33.3	85.7	87.7	108.3
SE	0.21	0.41	0.53	2.0	0.81	4.58	2.74	17.44	6.10	3.66	1.43	1.43	17.38
LSD (5%)	0.38	0.21	0.31	0.86	0.34	3.08	1.56	8.73	3.34	1.95	1.40	1.40	9.05
CV (%)	16.3	19.0	17.4	18.5	78.4	6.8	14.7	24.2	28.9	17.6	5.6	5.4	24.8
σ^2_G	1.75	0.26	0.66	1.33	0.17	78.5	16.09	356.0	67.3	21.3	21.1	21.2	433.4
H^2 (%)	90.0	42.7	53.4	14.2	11.7	65.1	51.7	36.9	47.4	44.2	83.5	83.8	41.8

GD, Days to Germination; EV, Early vigour score (1 to 5); GH, Growth habit (1 to 9), TN, Tiller number; UTN, Unproductive tiller number; TL, Total length; PL, Panicle length; TW, Total weight; PW, Panicle weight; HI, Harvest index (PW/TW); HD, Heading date; FD, Flowering date; TSN/P, Total spikelet number per panicle. LSD, least significant difference, SE, standard error, H^2, Broad sense heritability in %; δ^2_G, genotypic variance

Table 2. Principal components analysis showing the contributions of 13 characters among the oat accessions.

Traits	PC1	PC2	PC3
HD	-0.475	0.777	0.102
FD	-0.478	0.777	0.101
LS	-0.031	0.179	0.326
EV (1-5)	0.510	-.060	-0.081
GH (1-9)	-0.434	0.183	-0.248
TN	0.355	0.009	0.764
UTN	-0.448	0.156	0.537
TL (cm)	0.402	0.428	-0.050
PL (cm)	0.245	0.646	-0.368
TSN/P	0.560	0.433	-0.289
TW (g)	0.736	0.222	0.372
PW (g)	0.898	0.201	0.191
HI	0.545	0.013	-0.302
Eigenvalue	3.411	2.181	1.555
% Variance	26.23	16.778	11.96
Cumulative % variance	26.236	43.014	54.977

GD, Days to Germination; EV, Early vigour score (1 to 5); GH, Growth habit (1 to 9), TN, Tiller number; UTN, Unproductive tiller number; TL, Total length; PL, Panicle length; TW, Total weight; PW, Panicle weight; HI, Harvest index (PW/TW); HD, Heading date; FD, Flowering date; TSN/P, Total spikelet number per panicle

Table 3. Correlations among the 13 agronomic traits of 100 Oats accessions grown in Dinajpur, Bangladesh.

	GD	*EV (1-5)*	*GH (1-9)*	*TN*	*UTN*	*TL (cm)*	*PL (cm)*	*TW(g)*	*PW (g)*	*HI (%)*	*HD*	*FD*	*TSN/P*
GD	1.0***												
EV (1-5)	0.093	1.0***											
GH (1-9)	-0.165	-0.317*	1.0***										
TN	0.221	0.130	-0.175	1.0***									
UTN	-0.013	-0.230	0.238	0.007	1.0***								
TL (cm)	-0.061	0.289*	-0.068	-0.201	-0.009	1.0***							
PL (cm)	-0.247	0.062	0.150	-0.196	-0.105	0.443***	1.0***						
TW(g)	0.139	0.457***	-0.246*	0.470***	-0.357	0.325***	0.109	1.0***					
PW (g)	0.165	0.474***	-0.297***	0.455***	-0.488***	0.310***	0.164	0.820***	1.0***				
HI (%)	0.079	0.185	-0.153	0.141	-0.476***	0.090	0.174	0.103	0.633***	1.0***			
HD	-0.148	-0.245*	0.263	-0.123	0.306*	-0.032	0.232	-0.171	-0.254*	-0.253*	1.0***		
FD	-0.146	-0.249*	0.269	-0.122	0.310*	-0.031	0.233	-0.177	-0.257*	-0.251*	0.99***	1.0***	
TSN/P	0.069	0.280*	-0.090	-0.161	-0.250*	0.294***	0.456***	0.360***	0.495***	0.418***	-0.05	-0.05	1.0***

GD, Days to Germination; EV, Early vigour score (1 to 5); GH, Growth habit (1 to 9), TN, Tiller number; UTN, Unproductive tiller number; TL, Total length; PL, Panicle length; TW, Total weight; PW, Panicle weight; HI, Harvest index (PW/TW); HD, Heading date; FD, Flowering date; TSN/P, Total spikelet number per panicle.

*&*** indicate signifcant association at P <0.05, P <0.01, and P <0.001 levels, respectively.

GD, Days to Germination; EV, Early vigour score (1 to 5); GH, Growth habit (1 to 9), TN, Tiller number; UTN, Unproductive tiller number; TL, Total length; PL, Panicle length; TW, Total weight; PW, Panicle weight; HI, Harvest index (PW/TW); HD, Heading date; FD, Flowering date; TSN/P, Total spikelet number per panicle

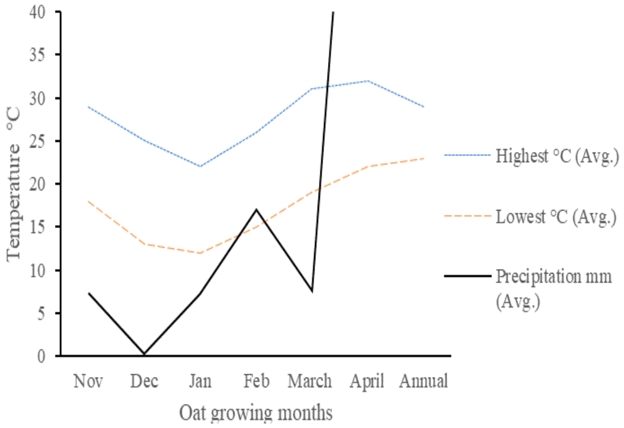

Fig 1. Line graph showing the average highest and lowest temperature (°C) and the precipitation (mm) data during the growing period of Bochaganj Upazila in the Dinajpur district of Bangladesh. (https://www.timeanddate.com/weather/bangladesh/dinajpur/climate)

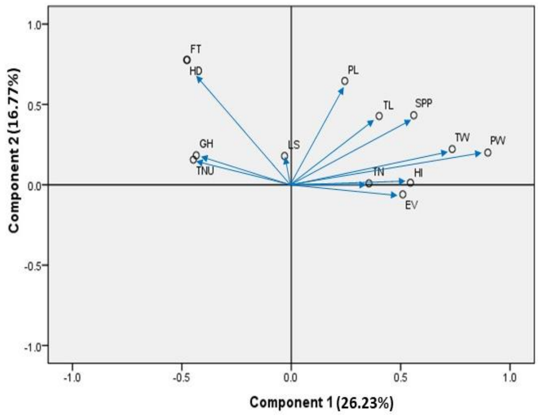

Fig 2. Loading plot of principal component 1 and component 2, which explain 43.01% of the variance in the 13 quantitative traits of Oat (*Avena Sativa* L.) germplasm grown in Bangladesh in the winter season of 2019-20. Vectors of the traits are shown in blue.

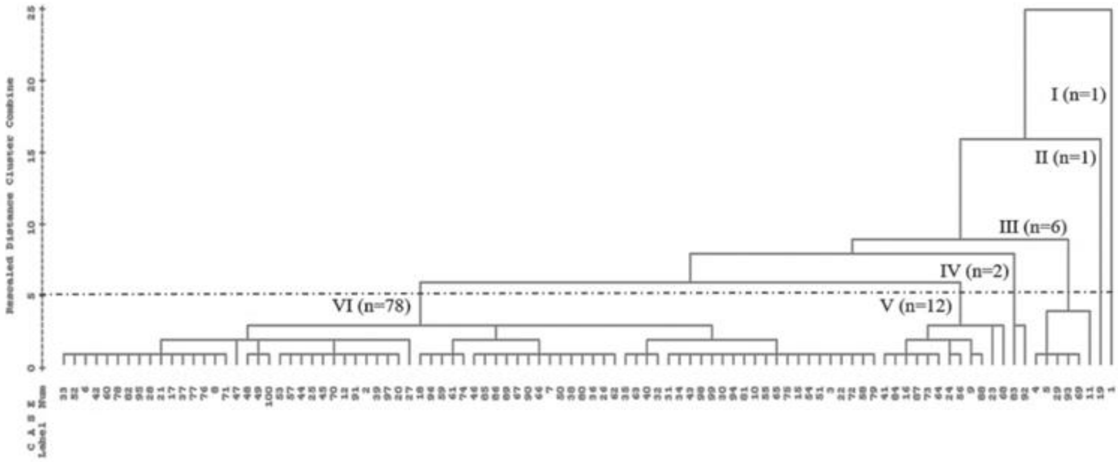

Fig 3. Classification of 100 Oats accessions grown in Bangladesh in the winter season of 2019-20. A cluster analysis was conducted using data from 13 agronomic traits using Ward's hierarchical analysis (Ward 1963) using SPSS v.16.

Table 4. Variations of the yield potential traits among the cluster groups.

Group	GD	EV (1-5)	GH (1-9)	TN	UTN	TL (cm)	PL (cm)	TW(g)	PW (g)	HI (%)	HD	FD	TSN/P
I	10.0	4.5	6.5	16.6	0.9	141.2	35.3	210.7	63.5	31.6	90.0	92.0	178.9
II	7.0	3.0	6.8	7.2	1.2	125.6	38.6	47.6	15.2	31.9	91.5	93.5	185.2
III	8.2	3.2	6.5	10.5	3.2	141.3	29.5	66.0	13.8	21.1	90.8	92.8	61.4
IV	7.0	4.8	4.8	12.6	0.5	151.5	30.9	166.5	48.4	29.4	78.8	80.3	117.3
V	8.8	4.2	5.9	12.0	1.0	156.7	36.7	122.9	43.6	35.6	84.8	86.8	149.5
VI	8.2	3.7	6.0	12.6	1.0	145.2	32.3	103.2	34.9	34.0	85.5	87.5	103.3
Whole mean	8.3	3.7	6.0	12.4	1.2	146.3	32.7	105.2	35.0	33.3	85.7	87.7	108.3

This demonstrates the larger genetic effects and lower genotype and environment interaction present in our introduced oat accessions especially of these traits. The heritability of PL was lower; moreover, TN was higher with a similar HD and FD compared to the study of Leisova-Svobodova et al. (2019) evaluated in Czech Republic and Estonia where the climate is characterized by long winter with low temperature. This indicates that the traits PL and TN were affected by the short winter and high temperature at the reproductive stage in Bangladeshi conditions (Fig 1). Compared to the study of Singh et al., (2019), oat accessions in this study were 8 days early in HD, 26 cm taller in TL, and nearly double in TN. Because HD and TL had high and moderate heritability, this might indicate that our introduced varieties are short-heading but tall type. In contrast, a higher TN with a very low heritability may be due to the high temperature and humidity of Bangladesh. In rice, Ata-Ul-Karim et al., (2022) explained that the selection of traits with moderate to high heritability is effective in breeding. The negative correlation between TSN/P and HD and the positive correlation between TSN/P and PL in the present study was supported by the similar findings of Ihsan et al*.,* (2021). This reflects that the total spikelet number was less affected by the HD and the genotype of long PL contributed the higher TSN/P. Ihsan et al., (2021) reported a positive correlation between TSN/P and TN. In contrast, we found that they were negatively correlated. A strong positive correlation between TSN/P and PW was observed in this study, while Singh et al., (2019) reported nearly no correlation between them and indicated that plant stature had a positive effect on biomass and grain yield. GH was positively correlated with TW which means that GH contribute the biomass yield in these accessions and important for the selection. A PC analysis revealed that the heading and flowering (HD and FD) traits influenced both components for variation and are important for the adaptation to the environmental conditions in Bangladesh as well as for higher biomass and grain yield.

The accessions in group V were high yielding because they had all desirable characters of intermediate GH (5.9, which is a semi-prostate type of growth habit), low LS (2.8), early HD, and high HI and TSN/P, which yielded higher than the released popular varieties "FL720" and "Horizon 201" in the southern US. This indicates that the oat yields in Bangladesh may potentially be higher compared to those in the southern US. The dual-purpose facultative variety 'FLLA11019-8' reported by (Babar et al., 2023) belonged to group VI. The high genetic variability of the traits (Table 2) indicated that these 100 oats accessions collected from the US have successfully incorporated diverse germplasm to create a variety of plant phenotypes in Bangladeshi conditions. The broad-sense heritability indicates the repeatability of the trait measurement. The moderate-to-high heritability of traits (other than TN and UTN) indicated that the selection for these traits should be effective (Ata-Ul-Karim et al., 2022). TN is an important yield-related trait; thus, this suggests that additional sampling or replication could be needed to increase heritability. Moreover, this report is based on single-year data. Multi-year studies together with other physiological and nutritional traits are necessary. Nonetheless, our findings provided overall insights into the extent of the phenotypic variation of grain oats and trait-based selection for high-yield potential accession for Bangladeshi breeding programs to ensure food security and nutritional security for Bangladesh and others worldwide.

Materials and Methods

Plant materials

100 grain oat accessions including advanced breeding lines and cultivated varieties were collected from the University of Florida (UF) and the Louisiana State University (LSU) in the USA (Supplementary Table 1). Subsequently, they were evaluated in Dinajpur, Bangladesh from December 2019 to April 2020 for yield potential and adaptation.

Field condition and experimental design

Oat is a winter crop and grows well in a cool and dry environment. We evaluated oat accessions in the field condition in Bochaganj Upazila in the Dinajpur district (25°48′N 88°27.7′E), which is in the most northern area of Bangladesh. The experimental crops were planted under field conditions using a randomized complete block design (RCBD) and there were two replications. The row-to-row and plant-to-plant distances were 30 cm and 25 cm, respectively. Sowing was done on December 21, 2019, and the harvest started on April 12, 2020. Subsequently, we evaluated their adaptability and estimated yield component traits. During the entire cropping cycle, the average highest and lowest temperatures were 27.5 and 16.5 ^{0}C, respectively (Timeanddate, 2020). The average precipitation was 22.11 mm. Fig 1 shows the detailed climate data of the growing period. The soil of the experimental location is a non-calcareous light textured with a low level of fertility (Shirazy et al., 2017). Therefore, the recommended doses per hectare for wheat cultivation (according to the fertilizer recommendation software developed by the Soil Resource Development Institute, SRDI- FSR, 2019) in this area were 120 Kg of Urea, 45 Kg of Triple super phosphate (TSP), 60 Kg of muriate of potash (MP), 35 Kg of Gypsum, and 4.5 Kg of Boric acid. Other standard agricultural practices including weeding, irrigation, etc. were applied according to the necessity to ensure strong plant growth. Pest and disease infestations were very low. Only once, at the late vegetative stage, the presence of a green bug was found; it was controlled by a cypermethrin 10 EC application.

Trait measurements

We evaluated fourteen traits related to phenology and agronomic performance following the guidelines of the International Board of Plant Genetic Resources (IBPGR, 1985) as well as Babar et al., (2016) for Oats. The germination date (GD), early vigour (EV), growth habit (GH), tiller number (TN), plant height (PH), panicle length (PL), total biomass or weight (TW), panicle weight (PW), heading date (HD), flowering date (FD), and total spikelet number (TSN) were measured. We observed the lodging behaviour of each line during harvest. To estimate the genetic variation and select candidate lines with high yield, 18 plants were randomly selected from 30 in each line (accession) and their average values were statistically analysed.

The GD was defined as the number of days after sowing (DAS) after the coleoptile appeared above the soil. The EV score ranged from 1 to 5 range based on the visual observation; a score of 1 was given for poor early growth and 5 for strong early growth at 50 DAS. The GH score was collected using a scale from 1 to 9, where a score of 1 to 4 was assigned for the long upward spring type, 5 for a moderate cone shape, and 6 to 9 for a prostate winter type (Nava et al., 2010). HD was defined as the time from sowing to the panicle exertion of half the plants in each line. Moreover, FD was counted as the time from sowing to flowering of half the plants in each line. At around 25 days after heading, whole plants were harvested and dried in a well-ventilated room to measure the yield components and dry matter production. TN was counted as the number of productive tillers. PH was measured from the base to the panicle neck. PL was measured from the neck to the tip of the longer panicle. TW was measured as the culm plus leaf weight. PW was measured as the panicle (including spikelet and rachis branch) weight. TSN was the number of fertile and non-fertile spikelets in the main culm of a representative plant in each line.

Data analysis

The descriptive statistics of the measured traits among the germplasms and data frequency distribution were calculated using Microsoft Excel statistics (Redmond, WA, USA). The analysis of variance (ANOVA) with significance tests, correlation analysis, and cluster analysis were performed using statistical packages for social sciences (SPSS) version 19.0. The standard error (SE), least significant difference (LSD), broad sense heritability (H^2), and genotypic variance (δ^2_g) were calculated using the R software (R-project 2016) version 4.2.1 and the package 'variability' and 'agricolae' by Propat et al., 2020 and Mendiburu and Yaseen, 2020, respectively.

Conclusions

Evaluating the accessions for yield and adaptation-related traits is fundamental before initiating any successful breeding program. Based on this characterization of these accessions, the plants belong to group V as high-yielding, well-adapted accessions for Bangladesh; as such, they can be selected for further research for varietal development. The key limitation of this study was that to grow the plants in the country, there is only one season; moreover, there is a lack of 1000-grain weight data. For the grain quality and nutritional analysis in future research, we suggest having a better selection that can contribute to the health improvement of the people and help resolve the issue of hunger, especially for children. This study is the pioneer report as it introduced and conducted research on grain oats in Bangladesh. Selecting suitable accessions that are adaptive to the local environment and breeding new grain oat varieties for local consumers will lead to more affordable prices. In turn, over time, this will contribute to the improvement of the health and nutrition of the people of Bangladesh by ensuring better nutritional diversity.

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Declaration of competing interest

Authors declare no conflict of interest.

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