academicJournals

Vol. 11(32), pp. 3020-3026, 11 August, 2016
DOI: 10.5897/AJAR2015.10467
Article Number: AEFA3CB59962
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Evaluation of morphological aspects of common bean (*Phaseolus vulgaris* L.) genotypes for post-flowering drought resistance in Rift Valley of Ethiopia

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Received 30 September, 2015; Accepted 17 February, 2016

The development of bean varieties adapted to drought situations is a key strategy to minimize crop failure and improve food security. In this study, 25 genotypes of common beans (*Phaseolus vulgaris* L.) were grown under post flowering drought stress and non-stress conditions to evaluate their performance at Melkassa Agricultural Research Center during the off-season months (from December to May) in 2011/2012. The treatments were laid out on a triple lattice design with three replications. A number of plant attributes were measured at mid-pod fill and harvesting stages. Under drought stress, the highest seed yield (125.3 gm^{-2}) was recorded for a Dimtu variety, while the lowest (72.5 gm^{-2}) for SB-15945-17. Therefore, Dimtu was the most drought tolerant genotype under drought stress. On the contrary, SB-15945-17 had the lowest seed yield under drought stress and drought-induced seed yield reduction of 50.8%. Seed yield showed significant and positive correlation with number of pods per plant (r =0. 39), number of seeds per pod (r =0. 32) and hundred seed weight (r =0. 41) under drought stress. The study demonstrated the existence of genetic variability among the common bean genotypes when subjected to post-flowering drought stress and such variability could be utilized in the development of common bean genotypes suitable for drought prone-areas.

Key words: Common beans, correlation, drought stress, genotype, *Phaseolus vulgaris*.

INTRODUCTION

Drought is the most important limiting factor for crop production and it is becoming an increasingly severe problem in many regions of the world. In addition to the complexity of drought itself (Passioura, 2007), plant responses to drought are complex and different mechanisms are adopted by plants when they encounter drought (Hinkossa et al., 2013). Drought can be defined as a state where a dry soil (due to lack of rain or delayed irrigation) causes a substantial reduction in crop performance in terms of plant survival, economic yield or crop quality (Muñoz-Perea et al., 2007). Common bean (*Phaseolus vulgaris* L.) performance is severely constrained by periodic water deficits in most production areas (Beebe et al., 2013; Hinkossa et al., 2013; Yaqoob et al., 2013). Frequency of occurrence of water deficits, severity of stress, timing of stress relative to plant age,

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and sensitivity of the plant at different stages of growth interact to determine yield loss associated with water deficits (Beebe et al., 2013; Hinkossa et al., 2013).

Post-flowering drought responses have been identified in common bean (Hinkossa et al., 2013). Post-flowering response is observed when water limitation occurs during the grain-filling stage (Subbarao et al., 1995). The most sensitive stages to grain filling in common bean were at flowering and ten days prior to flowering (Hinkossa et al., 2013; Yaqoob et al., 2013). It was noted that post-flowering heat stress caused yield losses up to 50% due to reduced seed filling duration (Bernier et al., 2007).

Common bean is probably native to the tropical parts of South America (Onwueme and Sinha, 1991), from where it was perhaps introduced to Africa and other continents (Baudoin et al., 2001; Beebe et al., 2013). After its dissemination, it is grown extensively in five major continental areas: Africa, North and Central America, South America, Eastern Asia and Western and Southeastern Europe (Adams et al., 1985; Beebe et al., 2013). Moreover, common bean is a non-centric crop, with multiple domestication sites throughout the distribution range. Even though the exact time of its introduction is controversial, it is generally believed that common bean was probably brought to Ethiopia in the 16^{th} century (Gepts, 1990).

In common bean, four different drought scenarios have been identified in the growing region (Subbarao et al., 1995; Tilahun et al., 2004). The first scenario represents terminal drought where there could be enough moisture for early establishment and growth, but later phonological stages are exposed to moisture deficit (Beebe et al., 2013). The second scenario represents intermittent drought where dry spells happen any time during the growing period and, the third scenario represents predictable drought where common bean plants could be exposed to stress at an early stage of growth but could receive enough water at later stages. The last scenario represents dry, semi-arid climate where the amount of rainfall is relatively low to cover the physiological demand of the crop at any stage of growth (Bernier et al., 2007; Beebe et al., 2013).

Even though the previous research efforts made by the national program in Ethiopia and by other international research institutions have resulted in a release of a number of improved common bean varieties with resistance to drought, the evaluation of the morpho-physiological attributes to drought tolerance in these varieties still remain the subject of investigation. Information on genetic progress achieved over time from breeding efforts for drought tolerance attributes since the early inception of common bean breeding and the morpho-physiological factors of genetic improvement achieved so far from the same efforts have also not been systematically studied. The study was to evaluate genotypic differences in growth, physiological response and yield of the bean genotypes when subjected to post-flowering drought stress.

MATERIALS AND METHODS

Description of the study area

The study was carried out at Melkassa Agricultural Research Center located in Central Rift Valley of Ethiopia. The elevation of the center is 1550 m above sea level at 8” '24’ "N latitude and of 39” '21’ "E longitude. Loam and clay loam soil textures are the dominant soil types in the area.

Experimental materials, procedure and design

The genotypes used for the study were obtained from National Bean Research Project of Melkassa Agricultural Research Center, which consisted of 21 released varieties and 4 inbred lines. The study was conducted from December to May in 2011/2012 at the Research Station. Twenty-five genotypes were laid out in triple lattice design under drought stress and non-stress conditions in three replications. The crop was planted on 10^{th} February, 2012. Each genotypes was grown in two rows of 3 m length kept at 0.6 m apart. The distance between plants within a row was 0.1 m. Plants of both stressed and non-stressed treatments received full irrigation from planting to flowering stage. Drought stress was initiated at late flowering stage (up to 10 days after flowering). The drought stressed plots received irrigation at an interval of 12 to 14 days. The non-stressed plots received irrigations every 6 days until physiological maturity. Other cultural practices used were similar for both growth conditions.

Parameters measured

Five plants were randomly sampled from the useful area of each split plot, and the following parameters were assessed:

(1) Above ground biomass weight: was determined by adding up various plant part
(2) Leaf area (cm^2): was estimated by measuring the maximum length (ML) and width (MW) of leaves and multiplying these by a correction factor of 0.6 derived from the actual leaf area determined by leaf area meter (Setegn, 2006).
(3) Days to 50% flowering (DFF): number of days was taken by each genotype from the day of planting for the day on which 50% of the plants in a plot opened at least one flower per plant.
(4) Days to 90% maturity (DM): Determined as the number of days from date of planting to the date when 90% of the plants in each plot attained physiological maturity.
(5) Pod Harvest Index (PHI %) = [pod weight] / [leaf weight + stem weight +pod weight] x 100
(6) NPPP: Number of pods per plant
(7) NSPP: Number of seeds per pod
(8) 100-seed weight (HSW) (g): weight of hundred randomly sampled seeds from all plants harvested per plot.
(10) Seed yield (gm^{-2}): Seed yield was determined as: Seed yield (gm^{-2}) = (Seed weight/plot area)
(11) Harvest Index (%): the ratio of seed yield to the above ground dry weight (stem + leaves + pods + seed) at harvest.
(12) Drought susceptibility index (DSI) for seed yield: DSI = (1-Yds/Yns)/DII, where Yds and Yns mean yields of a given genotype in drought stress and non-stress, respectively (Fisher and Maurer, 1978).
(13) Geometric mean (GM): the GM was determined for seed yield

as GM = $(ns \times ds)^{1/2}$ where ns and ds are mean of a given genotype in drought stress and non-stress, respectively.

Statistical analysis

The analysis of variance was computed for all parameters considered using SAS (v 9.1.3) GLM procedure (SAS Institute, 2004) software to demonstrate the existence of differences among the genotypes under the two growth conditions. Means of the parameters that exhibited significant differences were separated using Duncan's Multiple Range Test (DMRT). The nature and magnitude of associations among the quantitative traits were analyzed using simple correlation test at 5 and 1% probability.

RESULTS AND DISCUSSION

Effect of drought stress on biomass production

The effect of drought stress was highly significant for above ground fresh and dry biomass weights at mid pod-fill and harvesting stages (Table 1). The water regime x genotypes interactions term was also significant for both fresh and dry weights at both mid-pod fill and harvesting stages. Relative to non-stress, drought stress caused significant reductions in above ground biomass weight in the range of 12.0 (Gofta) to 41.4% (IBADO) for fresh weight, 7.3 (SB-15945-19) to 58.6% (IBADO) for dry weight at mid pod- fill stage. Higher biomass accumulation in legumes is positively correlated with higher seed yield, while negatively with drought tolerance since genotypes that are water saving are commonly low-yielding. This implies that above ground biomass determines sink establishment and economic yield. These results are in agreement with those obtained by Setegn (2006); Subbarao et al. (1995); Tilahun et al. (2004) and Hinkossa et al. (2013). In addition, common bean genotypes under drought stress responded to drought by leaf movement, leaf shedding, reducing leaf area and inhibition of the expansion of younger leaves (Acosta-Gallegos and Adams, 1991).

Effect of drought stress on growth

Effect of drought stress on leaf area and days to 90% maturity were highly significant, whereas differences among genotypes were significant for all the four traits (Table 2). Drought induced reduction in leaf area and days to 90% maturity ranged from 7.9% (IBADO) to 54.7% (Atndaba), and 3.5% (Mexican-142) to 9.4% (Dinknesh), respectively. The highest leaf area (790.3 cm^2) was recorded for Cranscope, while the lowest (350.0 cm^2) for SB-15945-17 under drought stress. The highest number of days to maturity was recorded by Zebra and the lowest by Argene under both growth conditions. Adams et al. (1985) and Hinkossa et al. (2013) similarly reported that under drought stress common bean genotypes respond to drought by leaf movement, leaf shedding, reducing leaf area and inhibition of the expansion of younger leave.

Effect of drought stress on seed yield and yield components

Although genotypic differences were significant only for harvest index, effect of drought stress was significant on seed yield, as well as harvest index (Table 3). Seed yield of all twenty five genotypes under drought stress were significantly lower than their corresponding non-stress growth conditions. Drought stress caused a significant reduction in seed yield that ranged from 22.6 (Dimtu) to 56.3% (Gofta) (Table 4). Under drought stress, the highest seed yield(125.3 g m^{-2}) was recorded for Dimtu, while the lowest (72.5 g m^{-2}) for SB-15945-17. Drought events during the seed filling stage can cause major reduction in yield by reducing starch accumulation as a result of limited assimilate partitioning to the developing grain (Hinkossa et al., 2013). Gofta had the highest (1.13) DSI for seed yield, whereas Dimtu had smallest (0.45) DSI for seed yield. Geometric mean (GM) was the highest for Dinknesh (147.5) followed by Dimtu (142.4) and the least was for SB-15945-17 (103.4) (Table 4). These results were similar with those reported by Setegn (2006), Tilahun et al. (2004), Hinkossa et al. (2013) and Yaqoob et al. (2013).

Differences between the watering regimes, among the genotypes and the water regime x genotypes interactions were significant for all seed yield components (Table 5). Drought stress induced reduction in number of pods per plant ranged from 2.4% (Cranscope) to 41.8% (Beshbesh) and number of seeds per pod within a range of 6.0 (Melka dima) to 40.6% (Mexican-142) (Table 6). Drought stress also caused a reduction in hundred seed weight that ranged from 3.3 % (Nazareth-2) to 36.5% (Argene) (Table 6). The amount of yield reduction depends not only on the timing of stress, but also on the severity of the stress (Passioura, 2007). Number of pods per plant is the most variable trait to affect yield in common beans. The studies shown that terminal drought could reduce pod formation, seed setting and seed filling by affecting the source-sink relationships. Tilahun et al. (2004) observed that pods per plant, seeds per pod and hundred seed weight are crucial for producing economic yield, and vary in time scale. Similar results were reported by Hinkossa et al. (2013) and Yaqoob et al. (2013).

Correlation coefficient analysis

The correlation coefficient among most of the quantitative characters was highly significant under both growth conditions (Table 7). Seed yield was significantly and positively correlated number of pods per plant (r = 0.39), number of seeds per pod (r = 0.32) and hundred seed

Table 1. Analysis of variance of above ground dry and fresh weights of common bean genotypes grown under two water regimes and harvested at two developmental stages.

Source of variation	df	Mid pod-fill stage		Harvesting stage	
		Fresh weight	Dry weight	Fresh weight	Dry weight
Replication	2	47302.85 *	2747.84* *	430.64 *	22.66
Block	4	1943.03	32.10	97.04	45.38*
Water regime (WR)	1	188009.40**	15708.17**	22448.17 **	1854.34 **
Genotype (G)	24	6997.74	276.18	302.92**	44.45**
WR x G	24	1235.99*	100.34 *	225.01*	12.29*
Error	98	5600.48	200.17	127.43	13.42

*, ** Significant at P ≤ 0.05 and P ≤ 0.01, respectively.

Table 2. Analysis of variance for growth and phenological parameters of 25 common bean genotypes grown under two watering regimes.

Source of variation	df	Leaf area	Days to 50% flowering	Days to 90% maturity
Replication	2	35321.58*	0.83	2.67**
Block	4	145965.09**	6.09**	1.09**
Water regime (WR)	1	1123375.74**	0.81	826.03**
Genotype (G)	24	78059.28**	15.47**	17.38**
WR x G	24	20724.28**	0.35	2.46**
Error	98	10337.65	1.06	0.44

*, ** Significant at P ≤ 0.05 and P ≤ 0.01, respectively.

Table 3. Mean square of yield and harvest index of 25 common bean genotypes grown under two water regimes harvested at maturity stage.

Source Of variation	Df	Seed yield	Harvest index
Replication	2	229.81	308.24 **
Block	4	532.64	24.82
Water regime (WR)	1	229790.94**	4895.18**
Genotype (G)	24	395.81	111.54**
WR × G	24	607.26**	71.77**
Error	98	638.05	36.68

**significant at P ≤ 0.01.

weight (r = 0.41) under stressed condition, while seed yield was positively correlated with days to 90% maturity (r = 0.19), under non-stressed condition (Table 7). Similarly, Szilagyi (2003) reported that correlation coefficients between the non-stress and drought stress were positive and highly significant for seed yield, number of pods per plant, 100-seed weight, and days to maturity. This indicated that number of pods per plant, number of seeds per pod, hundred seed weight and days to maturity have positive effect on seed yield.

Conclusion

Accurate identification and detection of drought tolerance common beans genotype is the cornerstone for drought-prone areas. The study demonstrated that Dimtu was the most drought resistant genotype, produced the highest seed yield under drought stress. In contrast, SB-15945-17 had the lowest seed yield under drought stress, and this genotype can be considered the most drought-susceptible of all the genotypes. Although evaluation of drought resistance in common bean using the qualitative and quantitative traits remains an effective method, morphological comparisons have some limitations, including the influence of environment, subjectivity in the character evaluation and management practice. Therefore, complementary evaluation using appropriate molecular markers such as Amplified Fragment Length Polymorphism (AFLP) and Simple Sequence Repeat

Table 4. Effect of drought stress on seed yield and harvest index and seed yield based DSI and GM in 25 common bean genotypes grown at Melkassa.

Genotype	Seed yield (g m^{-2})					Harvest Index (%)		
	Non-stress	Drought stress	% reduction	DSI	GM	Non-stress	Drought stress	% Reduction
Argene	165.7^{c-e}	101.6^{a-d}	38.7	0.78	129.6	51.1^{cd}	42.9^{c-f}	16.0
Atndaba	171.7^{d}	79.1^{d}	53.9	1.08	116.5	74.1^{a}	46.9^{b-e}	36.7
Awash melka	183.0^{bc}	110.5^{a-d}	39.6	0.80	142.2	49.0^{d}	43.6^{b-f}	11.0
Awash-1	170.1^{cd}	96.9^{a-d}	43.0	0.88	128.4	51.9^{cd}	42.3^{c-f}	18.5
Beshbesh	191.1^{b}	85.7^{cd}	55.2	1.10	127.9	55.1^{b-d}	46.0^{b-e}	16.5
Chercher	166.8^{c-e}	117.8^{a-c}	29.4	0.58	140.2	65.9^{b}	46.3^{b-e}	29.7
Chore	193.8^{a}	88.2^{b-d}	54.5	1.08	130.7	49.8^{d}	39.1^{c-f}	21.5
Cranscope	190.2^{ab}	85.9^{cd}	54.8	1.10	127.8	54.1^{b-d}	47.6^{b-e}	12.0
Dimtu	161.9^{de}	125.3^{a}	22.6	0.45	142.4	62.0^{a-d}	47.7^{b-e}	23.1
Dinknesh	194.7^{a}	111.8^{a-d}	42.6	0.86	147.5	58.6^{b-d}	45.4^{b-f}	22.5
Gofta	188.8^{a-c}	82.5^{cd}	56.3	1.13	124.8	50.2^{d}	45.4^{b-f}	9.6
IBADO	164.9^{c-e}	88.5^{b-d}	46.3	0.92	120.8	49.8^{d}	44.4^{b-f}	10.8
Melka dima	181.7^{bc}	79.7^{d}	56.2	1.12	120.3	66.2^{b}	37.2^{ef}	43.8
Melkie	167.9^{c-e}	99.2^{a-d}	40.9	0.82	129.1	60.8^{a-d}	47.0^{b-e}	22.7
Mexican-142	187.3^{a-c}	93.3^{a-d}	50.2	1.02	132.2	56.5^{b-d}	35.6^{f}	36.9
Nasir	170.3^{cd}	99.6^{a-d}	41.5	0.84	130.2	61.3^{a-d}	57.9^{a}	5.5
Nazareth-2	175.8^{b-d}	100.7^{a-d}	42.7	0.86	133.1	57.2^{b-d}	43.6^{b-f}	23.8
Red wolayita	160.5^{de}	124.1^{ab}	22.7	0.46	141.1	60.1^{a-d}	49.1^{a-c}	18.3
Roba-1	166.6^{c-e}	75.3^{d}	54.8	1.10	112.0	53.6^{b-d}	44.4^{b-f}	17.2
Tabor	167.7^{c-e}	94.6^{a-d}	43.6	0.88	125.9	54.4^{b-d}	46.6^{b-e}	14.3
Zebra	175.3^{b-d}	100.9^{a-d}	42.4	0.84	132.9	52.3^{b-d}	45.9^{b-f}	12.2
SB-15945-14	190.7^{ab}	98.6^{a-d}	48.3	0.96	137.1	56.9^{b-d}	38.3^{d-f}	32.7
SB-15945-15	172.3^{d}	91.3^{a-d}	47.0	0.94	125.4	50.4^{d}	44.4^{b-f}	11.9
SB-15945-17	147.5^{e}	72.5^{e}	50.8	1.02	103.4	52.6^{b-d}	38.0^{b-d}	27.8
SB-15945-19	165.9^{c-e}	91.2^{a-d}	45.0	0.90	123.0	61.2^{a-d}	54.0^{ab}	11.8
Means	174.9	96.6	44.8	0.90	129.9	56.6	45.2	20.1
LSD ($P \leq 0.05$)	2.2	1.2				2.1	0.4	
CV (%)	7.8	6.4				4.35	9.41	

Means within the same column followed by similar letters are not significantly different according to DMRT at 5% level of probability, DSI = drought susceptibility index, GM =geometric mean.

Table 5. Mean squares of seed yield components of 25 common bean genotypes grown under two water regimes at Melkassa.

Source of variation	df	Number of pods per plant	Number of seeds per pod	100-seed weight
Replication	2	25.89	1.28 *	0.18
Block	4	84.28 *	0.61	422.89**
Water regime (WR)	1	2884.67**	100.21**	424.37**
Genotype (G)	24	87.81 **	0.87**	265.71 **
WR x G	24	16.48 *	0.63 *	13.63**
Error	98	28.21	0.36	4.69

*, ** Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

(SSR) markers is needed to identify better varieties suitable for drought-prone areas. Understanding the genetics of drought tolerance, and having DNA markers linked to drought tolerance genes will help plant breeders to combine drought tolerance with other traits desired by farmers.

Table 6. Effect of drought stress on seed yield components of common bean genotypes grown at Melkassa.

Genotype	Number of pods per plant			Number of seeds per pod			100-seed weight (g)		
	Non-stress	Drought stress	% reduction	Non-stress	Drought stress	% reduction	Non-stress	Drought stress	% reduction
GX-1175-3	27.7^{cd}	18.9^{d}	31.8	5.4^{c-f}	4.7^{a-c}	12.9	27.3^{e}	24.1^{e-g}	11.7
STTT-165-92	31.5^{a-d}	23.0^{a-d}	26.9	6.1^{a-e}	4.7^{a-c}	22.9	19.9^{i-k}	18.1^{j-m}	9.0
AR04GY	39.6^{ab}	30.9^{a}	21.9	6.1^{a-e}	4.2^{a-c}	31.1	23.0^{f-i}	14.6^{m}	36.5
TA04JI	37.6^{a-c}	30.3^{ab}	19.4	6.2^{a-d}	4.4^{a-c}	29.0	19.0^{jk}	18.4^{j-m}	3.2
AFR-722	26.7^{cd}	23.1^{a-d}	13.5	5.2^{d-f}	4.3^{a-c}	17.3	47.2^{a}	44.4^{a}	5.9
DOR-554	25.3^{d}	22.3^{a-d}	11.9	5.6^{b-f}	4.1^{a-c}	26.8	23.3^{f-i}	22.2^{f-j}	4.7
Red wolayita	30.9^{a-d}	23.1^{a-d}	25.2	6.4^{a-d}	3.9^{c}	39.1	22.2^{f-j}	20.3^{g-l}	8.6
G-11239	33.9^{a-d}	26.0^{a-d}	23.3	6.4^{a-d}	3.8^{c}	40.6	17.7^{k}	16.3^{lm}	7.9
SB-15945-15	28.9^{b-d}	18.4^{d}	36.3	6.9^{ab}	4.1^{a-c}	40.6	21.8^{f-j}	21.2^{f-k}	2.8
SB-15945-17	32.7^{a-d}	20.2^{b-d}	38.2	6.5^{a-d}	4.3^{a-c}	33.8	18.9^{jk}	17.6^{k-m}	6.9
SB-15945-19	28.1^{cd}	18.1^{d}	35.6	6.7^{a-c}	5.1^{a}	23.9	19.4^{i-k}	17.8^{j-m}	8.2
Cross 5	37.6^{a-c}	21.9^{a-d}	41.8	5.9$^{a.f}$	4.8^{a-c}	18.6	20.9^{h-k}	19.3^{i-l}	7.7
Mean	30.8	22.1	28.2	5.9	4.3	27.1	26.1	22.7	13.0
LSD ($P \leq 0.05$)	1.9	1.5		2.4	1.4		4.9	2.7	
CV (%)	6.17	9.16		3.50	4.03		2.6	5.08	

Means within the same column followed by similar letters are not significantly different according to DMRT at 5% level of probability.

Table 7. Correlation coefficient among eight quantitative traits of common bean genotypes grown under non-stress (above the diagonal) and drought stress (below the diagonal) conditions at Melkassa Agricultural Research Center.

Variables	DFF	DM	PHI	NPPP	NSPP	HSW	SY	HI
DFF	0.00	0.45**	-0.00	0.05	0.17	-0.31	0.09	-0.04
DM	0.43**	0.00	-0.05	-0.06	0.06	-0.05	0.19*	-0.11
PHI	-0.02	-0.10	0.00	-0.01	-0.06	0.08	-0.22*	0.55**
NPPP	0.11	-0.07	-0.08	0.00	0.19*	0.33**	0.06	0.05
NSPP	0.29*	0.25*	-0.12	-0.05	0.00	-0.47	-0.11	-0.05
HSW	-0.23*	0.05	0.03	-0.15	-0.22**	0.00	0.08	0.07
SY	0.04	-0.08	-0.13	0.39*	0.32*	0.41*	0.00	-0.18
HI	-0.08	-0.04	0.18	0.54	0.29*	0.20*	0.15	0.00

* Significant at $P \leq 0.05$, ** Significant at $P \leq 0.01$. DFF = Days to 50% flowering, DM = Days to 90% maturity, PHI = Pod harvest index, NPPP = Number of pods per plant, NSPP = Number of seeds per pod, HSW =100-seed weight, SY =Seed yield, HI = Harvest index.

Conflict of interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The author wishes to sincerely thank Adama Science and Technology University, for funding of this research and Melkassa Agricultural Research Center for providing plant materials, services acquisition and creation of congenial working environment during the research work.

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