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Evaluation of Different Plant Densities Effects on Grain Filling Rate and Duration, Yield and Its Components in Pinto Bean Varieties

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Abstract: In order to evaluate plant density and cultivar effects on grain filling rate and duration, yield and its components of 3 pinto bean cultivars a factorial experiment (using RCB design) was conducted in 2007 at agricultural and natural resources research institute in East Azerbaijan province (Tabriz/Iran). Three cultivars (Khomeyn, G -14088 and 11816) were planted at 4 densities (14, 20, 30 and 60 plants m^{-2}) in 3 replications. A 2-part linear model was used to quantifying the grain filling parameters. Interaction effect of cultivar and plant density affected Grain Filling Rate (GFR), Mass Maturity (MM), Maximum Grain Weight (MGW) and Effective grain Filling Period (EFP) significantly. Highest amount of these parameters observed at Khomeyn cultivar in 14 plants m^{-2}. These parameters decreased in Khomeyn and G-14088 cultivars with increasing in plant density significantly. Between cultivars and plant densities treatments of pinto bean was significant difference in yield and its components. But interaction effect of cultivar and plant density affected only days to maturity, number of pod per plant, 100 seed weight and grain yield parameters. These parameters (except grain yield) decreased with increasing in plant density. But increasing of plant density and number of pod in square meter compensated reduction of yield components. Therefore, grain yield increased with increasing in plant density. Khomeyn cultivar had maximum amount GFR, MGW, EFP, number of pod per plant, 100 seed weight and grain yield. Therefore, Khomeyn and 30 plants m^{-2} are best cultivar and plant density in pinto bean, respectively.

Key words: Cultivar, EFP, GFR, pinto bean, plant density

INTRODUCTION

Beans are from primitive crops of new world and also they contain half legumes used by mankind in the world (Broughton *et al*., 2003). Plant density is one of important and effective factors in determining of crop yield. Plant density isn't constant for one cultivar in different climatic conditions. In optimum plant density, inside and outside competition of shrubs should be minimal and enough space should exist for crop culture. The first studies were conducted by Kakiuchi and Kobata (2004), who observed that lower plant density increased the pod number per plant and higher plant density decreased the pod number per plant. Maddonni *et al*. (2006) observed that the highest 100 seed weight (41.13 g) is obtained in 30 plants m^{-2} and the lowest 100 seed weight (37.59 g) is obtained in 50 plants m^{-2} in kidney bean. Bruin and Pedersen (2008) observed that soybean planted in 38 cm row spacing yielded 248 kg ha^{-1} greater than soybean planted in 76 cm rows. Gan *et al*. (2007) have also shown increase of grain yield at higher plant density in chickpea. Wang *et al*. (1997) showed that in high plant density cultivars maturity occur earlier than low plant density so that plant maturity in 60 plants m^{-2} was 10.18 and 4.13 days earlier than 30 and 40 plants m^{-2}. Grain filling rate and grain filling duration are tow important traits in determining of grain yield that by means of them we can explain grain yield changes. Grain filling period from fertilization to grain maturity stage can be separated into 3 stages: in 1st stage, grain weight increase slowly in the course of lag phase, in 2nd stage, linear stage of grain filling starts and 90% of increasing of grain dry weight is in 2nd stage. The 2nd stage is named effective grain filling period. In 3rd stage that is named maturity stage,

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grain dry weight doesn't have noteworthy increase and the relation of mother plant with seed is interrupted at the end of 3rd stage. The growth and development of seed that harvested for commercial yield in grain crop contains 2 part: one part is grain filling rate and another part is effective grain filling period. GFR is collection of dry matter in ratio time (day) at linear stage of grain filling. Grain filling rate is estimated by linear regression that is obtained from grain dry weight at several times in the course of grain development and after omission of non-linear data. Determining of grain filling duration is very difficult because assignment of exact time of beginning and ending of grain filling is impossible.

We can use fertilization and grain formation for grain filling beginning and physiological maturity for ending of grain development (Royo *et al*., 2007). Effective grain filling period is obtained by ratio of grain yield to grain filling rate in the course of linear stage of grain filling (Broughton *et al*., 2003). Wang *et al*. (1997) reported grain filling rate and effective grain filling period decrease with increase in plant density significantly in wheat. Bruin and Pedersen (2008) have shown decreasing of grain filling rate, mass maturity, effective grain filling period and maximum grain weight in indeterminate cultivars of soybean but he reported that grain filling rate increase in determinate cultivar of soybean with increase in plant density. In this study, we tried to show effects of different cultivars and plant densities on grain filling parameters, yield and its components, explain of grain yield changes by grain filling parameters and also we will introduce the best cultivar and plant density of pinto bean that has the highest grain yield.

MATERIALS AND METHODS

A factorial experiment (using RCB design) was conducted at East Azerbaijan province (Tabriz/Iran). On 29th April, 2007 3 cultivars (Khomeyn, G -14088 and 11816) were planted at 4 densities (14, 20, 30 and 60 plants m^{-2}) in 3 replications. For assessment of increasing procedure of grain dry weight in the course of grain filling duration, sampling from seeds started 20 days after flowering and continued in 9 times in 6 days intervals. A linear regression model (2 parts) was used in order to estimate and analyze of grain filling parameters:

$$GW = \begin{cases} a + bt & t < t_{max} \\ a + bt_{max} & t \geq t_{max} \end{cases} \qquad (1)$$

In Eq. 1, GW is grain weight, a is width of beginning in line, t is degree days after pod formation or days after flowering and t_{max} is mass maturity time. This model separates grain weight changes in relation to time into two stages: In 1st stage (linear stage of grain filling), grain weight increase until arrive to maximum rate (mass maturity). The slope of regression line in this stage (a) indicates grain filling rate. In 2nd stage grain dry weight doesn't have any changes and its changes become constant. By means of this model, grain filling rate and mass maturity are obtained and then for estimate of maximum grain weight, the data of mass maturity was put in second part of Eq. 1. After calculation of grain filling parameters by means of DUD method and Proc NLIN order in SAS software that is applicable method of linear regression model (2 part) in computer, all data were analyzed using a factorial experiment (using R.C.B design) by means of SAS software. Treatment means were separated using Tukey's Test at 0.05 statically level.

RESULTS AND DISCUSSION

Application of Eq. 1 for grain dry weight data indicated same pattern for seed development in all of densities. Grain dry weight of cultivars had initially linear increase at 4 densities. Then increasing of grain dry weight arrived to maximum rate (mass maturity or physiological maturity). After this point grain dry weight didn't have any changes and its curved line became a horizontal and directive line. Cultivars had different grain filling rate in 4 densities (Table 1). Maximum rate of GFR was obtained at Khomeyn and 14 plants m^{-2} (least density) that its amount was 6.694 mg day^{-1}. GFR of G -14088 decreased with increase of plant density (Table 2). These cultivars have indeterminate growth therefore, they produce a lot of branches per plant and too much absorbed nutrient consume for vegetative growth in higher plant densities. Consequently the portion of seed from absorbed nutrients will be fewer and grain weight decrease. Because GFR is obtained by ratio of maximum grain weight to EFP therefore, GFR decreased with grain weight decreasing. The 11816 has determinate growth and produces few branches in main stem in lower plant densities in comparison with indeterminate cultivars. The amount of GFR in higher densities was obtained more than lower densities at 11816 (Table 2). The time of mass maturity was found to be significantly different for cultivars at all of plant densities (Table 1). Mass maturity time of cultivars ranged from 49.07-64.63 days. MM were 4 and 10 days later in lowest density of Khomeyn and G-14088, respectively in comparison with highest density (Table 2). Reason of MM reduction with plant density increasing can be fewer branch production per plant in high plant density and formation of pods at the top of plant that result in earlier maturity of grain and short time

Table 1: Mean squares from analysis of variance of grain filling parameters in pinto bean

SV	df	GFR	MM	MGW	EFP
Replication	2	0.038	0.206	0.484	10.308
Cultivar	2	41.665**	274.918**	77248.843**	102.954**
Plant density	3	0.86**	32.044**	5107.47**	53.491**
Cultivar×density	6	0.275*	32.413**	1665.938**	18.027*
Cv (%)		6.71	0.9	0.2	6.56

*, ** = significant at 0.05 and 0.01 statically levels, respectively

Table 2: Mean comparison of grain filling parameters in different densities of pinto bean cultivars

Treatment	GFR (mg day^{-1})	MM (day)	MGW (mg)	EFP (day)
(A_1 D_1)	6.694a	64.63a	297.6a	44.72a
(A_1 D_2)	6.346ab	64.11a	279.3b	44.03a
(A_1 D_3)	6.029ab	57.15b	226.9c	37.64abc
(A_1 D_4)	5.815b	54.24c	201d	34.64bc
(A_2 D_1)	4.541c	53.46c	167.7e	37.32abc
(A_2 D_2)	3.92cd	51.3d	138.5f	35.43bc
(A_2 D_3)	3.612d	50.24de	119.8g	33.47bc
(A_2 D_4)	3.198de	49.07e	101.9h	32.08c
(A_3 D_1)	2.473e	50.56d	97.55k	38.08abc
(A_3 D_2)	2.562e	53.01c	97.64k	39.5bc
(A_3 D_3)	2.58e	53.32c	98.97j	38.87abc
(A_3 D_4)	2.595e	54.02c	100.3i	34.14abc

Different characters in per column indicate significant difference at 0.05 statically levels. A_1 = Khomeyn; A_2 = G-14088, A_3 = 11816. D_1 = 14p/m^2, D_2 = 20 p m^{-2}, D_3 = 30 p m^{-2} and D_4 = 60 p m^{-2}

Table 3: Mean squares from analysis of variance of data for yield and yield component traits in pinto bean

SV	df	Days to maturity	No. pod/ plant	100 seed weight	Grain yield
Replication	2	0.045	0.653	0.173	9179.701
Cultivar	2	42.692**	39.034**	37.934**	48566.879**
Plant density	3	86.268**	41.663**	80.1**	485482.311**
Cultivar×density	6	9.745**	1.366	2.537**	24800.32**
CV (%)		0.93	3.03	2.16	3.54

** = significant at 0.05 and 0.01 statically levels, respectively

Table 4: Mean comparison of yield and yield components traits in pinto bean cultivars

Treatment	Days to maturity	No. pod/plant	100 seed weight (g)	Grain yield (kg ha^{-1})
(A_1 D_1)	99.37a	19.46b	42.55a	1212fg
(A_1 D_2)	95.56b	15.12ef	40.55a	1444bc
(A_1 D_3)	95.1b	14.53ef	36.5cde	1887a
(A_1 D_4)	87.43e	13.99efg	35.24de	1364cde
(A_2 D_1)	93.6bc	21.21a	40.31ab	1138g
(A_2 D_2)	91.74cd	18.1bc	38.05bc	1283defg
(A_2 D_3)	90.51d	17.72c	34.64ef	1752a
(A_2 D_4)	87.87e	15.31de	32.31f	1236efg
(A_3 D_1)	94.03bc	16.76cd	37.36cd	1231efg
(A_3 D_2)	91.86cd	14.71ef	36.22cde	1425bcd
(A_3 D_3)	89.99de	13.66fg	34.65ef	1566b
(A_3 D_4)	89.34de	13g	32.7f	1347cdef

Different characters in per row indicate significant difference at 0.05 statically levels. A_1 = Khomeyn, A_2 = G-14088, A_3 = 11816. D_1 = 14 p m^{-2}, D_2 = 20 p m^{-2}, D_3 = 30 p m^{-2} and D_4 = 60 p m^{-2}

for mass maturity. Highest amount of effective grain filling period was seen at Khomeyn and 14 plants m^{-2}. EFP was not affected by different plant densities in G-14088 and 11816 (Table 2). Because of flower formation at the lower parts of plant stem and being longer days to maturity (because of many pod per plant) in lower density, EFP lasted a long time. Wang *et al.* (1997) showed similar results in wheat. Greatest rate of maximum grain weight was obtained of Khomeyn in lowest density and least MGW was obtained of G-14088 in highest density. Maddonni *et al.* (2006) showed that an increase in plant population density reduced kernel weight. But in 11816 highest rate of MGW was obtained at highest density (Table 2). Bruin and Pedersen (2008) obtained similar results in determinate cultivar of soybean so that an increase in plant density from 30-40 and 50 plants m^{-2} resulted in MGW increase from 80.67-89 and 89.33 g. Lower densities of Khomeyn and G-14088 had higher GFR and EFP and because MGW is calculated of GFR and EFP by this formula: MGW = EFP×GFR consequently maximum rate of MGW was obtained in least density in these cultivars. But in 11816 maximum rate of GFR, EFP and MGW were obtained in highest density.

Between cultivars and plant densities of pinto bean was significant difference in yield and all of yield components. But interaction effect of them affected days to maturity, number of pod per plant, 100 seed weight and grain yield (Table 3).

Highest and lowest days to maturity were obtained at Khomeyn in 14 and 60 plants m^{-2}, respectively (Table 4). In higher plant density fewer branch per plant and appropriation of great photosynthetic materials for main stem result in reduction of days to flowering and maturity. Wang *et al.* (1997) showed similar results. Number of pod per plant decreased with increasing of plant density in three cultivars because of competition for nutrient, slight and space for growth (Table 4). Kakiuchi and Kobata (2004) observed similar results. Maximum rate of 100 seed weight was seen at Khomeyn and in lowest plant density. Minimum rate of 100 seed weight was seen at G-14088 and in highest plant density (Table 4). With due attention to decrease of GFR, EFP and particularly MGW in higher plant density reduction of this parameter was reasonable. Royo *et al.* (2007) indicated that highest 100 seed weight (160.7 g) was obtained in 30 plants m^{-2} and lowest 100 seed weight (102.2 g) was obtained in 50 plants m^{-2}. Although, all parameters decreased with increasing in plant density, not only grain yield didn't reduce with increase of plant density but also increased in all cultivars. But this increasing was continued to 30 plants m^{-2} (optimum plant density) and then grain yield decreased in 60 plants m^{-2} (Table 4). Reason of grain yield increase can be increasing of number of plant and pod number in square meter that compensated decreasing of yield components. Norsworthy and Shipe (2005) reported that seed yield was 211 g m^{-2} in narrow rows compared with 107 g m^{-2} in wide row.

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