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Effect of different planting density on thermal time use efficiencies and productivity of guar genotypes under southern transition zone of Karnataka

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Abstract
A field experiment was conducted during *Kharif* seasons of 2014 at University Agricultural and Horticultural Sciences, College of Agriculture, Shivamogga, Karnataka, to study the dry matter accumulation, and various thermal time use efficiencies *viz.*, accumulated growing degree days (GDD), heat use efficiency, helio thermal use efficiency (HTU), photo thermal use efficiency (PTU) of guar cultivars grown under different Planting Density. The guar varieties RGC-1003, HG 365 and RGC 936 were sown with four different planting density *viz.*, 45 cm x 15 cm, 30 cm x 15 cm, 45 cm x 10 cm and 30 cm x 10 cm. the experiment was laid out in RCBD with factorial concept and replicated thrice. The experimental results indicated a high degree of linear relationship between GDD and dry matter accumulation of guar with all the genotype across planting density. among different planting density significantly higher thermal time use efficiencies *viz.*, heat use efficiency (1.82 $x10^{-2}$), helio thermal use efficiency (3.47 $x10^{-3}$), photo thermal use efficiency (3.73 $x10^{-2}$) was recorded with the crop grown in 30 cm x 10 cm of spacing also recorded significantly higher grain yield (898.18 kg ha^{-1}) and stover yield (1931.39 kg ha^{-1}) as compared to other spacing. Among genotypes RGC 1003 recorded significantly thermal time use efficiencies *viz.*, heat use efficiency (1.91 $x10^{-2}$), helio thermal use efficiency (3.64 $x10^{-3}$), photo thermal use efficiency (3.90 $x10^{-2}$) and grain yield (743.89 kg ha^{-1}), stover yield (1629.94 kg ha^{-1}) as compared to HG 365 and RGC 936.

Keywords: Guar, genotypes, planting density and thermal time use efficiencies

Introduction
Clusterbean (*Cyamopsis tetragonoloba* L. Taub.), commonly known as guar, has come to be recognized as one of the most important commercial crop of arid and semi-arid region. It is a drought hardy leguminous crop because of its deep tap rooting system and has high capacity to recover from water stress. The seed of clusterbean contains about 30-33% gum in the endosperm. The discovery of the galactomannan gum in the endosperm during 1948, led to this hitherto insignificant plant gaining importance as an industrial crop. The gum is utilized for many food items like ice creams, baked and dairy products etc. Moreover, its gum also used in many other industries like pharmaceuticals, cosmetics, mining, textile, paper, oil drilling, explosive industry etc. Traditionally, pods of the clusterbean are used for vegetable purpose. Its plant, seed and stover are good source of nutritive fodder and feed for livestock. Clusterbean is also raised as a green manure and cover crop. Being a leguminous crop, it enriches the soil fertility by fixing the atmospheric nitrogen. The crop is mainly grown during rainy season, but it can also be grown successfully during summer season under irrigated condition. However, the average yield of cluster bean in arid and semiarid region is very low as compared to its potential. The productivity can be significantly increased with the use of improved production technologies. Guar being a rainfed crop thrives best in hot sunny areas where temperature, light and moisture are the principal factors that influence the crop yield. Three important climatic parameters *viz.*, temperature, rainfall and light are most important for optimum crop growth and development there by exploits the potentiality of a crop. Among these, temperature plays a vital role in almost all biological processes of crop plants. It is one of the most important climatic factors affecting the growth, development and yield of crops and dry matter production and its accumulation in different parts. Higher productivity of crop can be achieved by proper combinations such as variety, plant population. Plant population is one of the major factors, which leads to higher crop yield. Kalyani *et al.* (2012) [7] in cluster bean found that grain and stover yield increased significantly with every increase in plant population.

The response of genotypes under guar condition is more pronounced with wider planting geometry than closer planting geometry, which helps in better exploitation of nutrients through its profuse root system. Even though closer planting geometry is more congenial to get higher yield under rainfed condition, because of its drought tolerance and root morphology. In drylands, one of the major factor responsible for low productivity is reduced seed germination and maintenance of optimum plant population and to attain higher leaf area and population through increased plant density. Guar is the crop which can tolerate high plant density and produces higher grain yield (Singh and Singh 1989) [14] in guar. Arrangement of plants in a unit area is more influencing on grain yield with the more or less population per unit area. In the present study also, plant population per unit area and planting geometry had significant influence on grain yield of guar.

Material and Methods

The field experiment was conducted during kharif 2014 at ZAHRS, College of Agriculture, University of Agricultural and Horticultural Sciences (UAHS), Navile, Shivamogga which is situated at 130 58 North latitude and 750 34 East latitude with an altitude of 650 meters above mean sea level. The soil of experimental site was red clay texture with acidic pH of 5.6 and low available nitrogen (241 kg ha^{-1}), high in available P_2O_5 (87 kg ha^{-1}), low in available K_2O (131.72 kg ha^{-1}). The total rainfall received during the crop growth period was more (494 mm) against the normal (307 mm). Mean minimum and maximum temperature were 30.5^0C and 13.5^0C, respectively during the crop growth period. The experiment was laid out in RCBD with factorial concept and it comprising of Twelve treatments combinations involving four spacing *viz*., 45 cm x 15 cm, 30 cm x 15 cm, 45 cm x 10 cm and 30 cm x 10 cm and three varieties *viz*., RGC1003, RGC 936 and HG 365 with replicated thrice. A common cultivation practices have followed for all genotypes as per the recommended package of practices for the Agro-climatic Zone. Sowing of guar was done by maintaining spacing as per the treatments. The land was prepared by ploughing followed by harrowing and levelling. Farm yard manures was applied 15 days before sowing and incorporated in to the soil. Recommended dose of fertilizers N, P, K kg ha^{-1} were applied in the form of Urea, SSP and MOP. After ten to fifteen days of sowing thinning was done by retaining one healthy seedling $hill^{-1}$ and thereby optimum plant population was maintained. All the agronomic practices were carried out uniformly to raise the crop. For taking data on growth, yield and yield components on cluster bean, five plants were selected randomly in each plot. Yield obtained from each plot was converted to kg/ ha. The data obtained on yield during the study was statistically analyzed by following the analysis of variance for Randomized Block Design with factorial concept as suggested by Gomez and Gomez (1984) [4].

Growing degree days (GDD)

Cumulative growing degree days were determined by summing the daily mean temperature above base temperature, expressed in degree day. For millets, T base is considered as 10 °C (Lucas *et al.* 2016). This was determined by using the following formula as per (Nuttonson, 1995) [11]:

$$\mathrm{GDD}(^{\circ}\mathrm{C}) = \frac{(\mathrm{T_{max}} + \mathrm{T_{min}})}{2} - \mathrm{T_{base}}$$

Where,
Tmax = Daily maximum temperature (°C)
Tmin = Daily minimum temperature (°C)
Tbase = Minimum threshold/base temperature (°C)

Heat use efficiency (HUE)

Heat use efficiency is also represented by thermal time use efficiency (TTUE), which indicates the amount of dry matter produced per unit of growing degree days or thermal time. This was computed by using the following formula:

$$\mathrm{HUE} = \frac{\text{Total dry matter (g hill}^{-1})}{\Sigma\mathrm{GDD}}$$

Helio thermal units (HTU)

The product of the growing degree day and the corresponding actual bright sunshine hours had been termed as Helio thermal units (HTU) and expressed as g ºC $days^{-1}$ hrs^{-1} (Chakravarthy and Sastry, 1985).
Helio thermal units (HTU) = GDD × actual bright sunshine hours

Helio thermal use efficiency (HTUE)

Helio thermal use efficiency was calculated by dividing the total dry matter recorded at respective days by the accumulated helio thermal units and expressed as g ºC $days^{-1}$ hrs^{-1}.
Helio thermal use efficiency was calculated as:

$$\mathrm{HTUE} = \frac{\text{Total dry matter (g hill}^{-1})}{\Sigma\mathrm{HTU}}$$

Where,
Σ HTU = cumulative helio thermal units

Photo thermal units (PTU)

The product of the growing degree-days and the length of the day in hours accumulated over a given period is the photo thermal units (PTU) and expressed as ºC $days^{-1}$ hrs^{-1} (Chakravarthy and Sastry, 1985).
Photo thermal units (PTU) = GDD × day length

Photo thermal use efficiency (PTUE)

Photo thermal use efficiency was calculated by dividing the total dry matter recorded at respective days by the accumulated photo thermal units and expressed as g ºC $days^{-1}$ hrs^{-1}. Photo thermal use efficiency was calculated as:

$$\mathrm{PTUE} = \frac{\text{Total dry matter (g hill}^{-1})}{\Sigma\mathrm{PTU}}$$

Where,
Σ PTU = cumulative photo thermal units

Statistical analysis

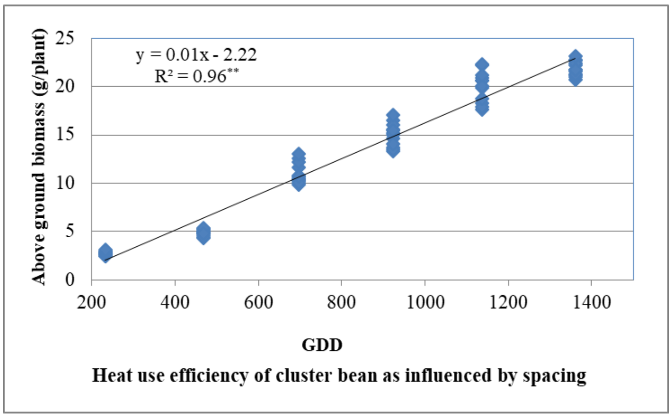
The data collected from the experiment at different growth stages were subjected to statistical analysis by adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984) [4].

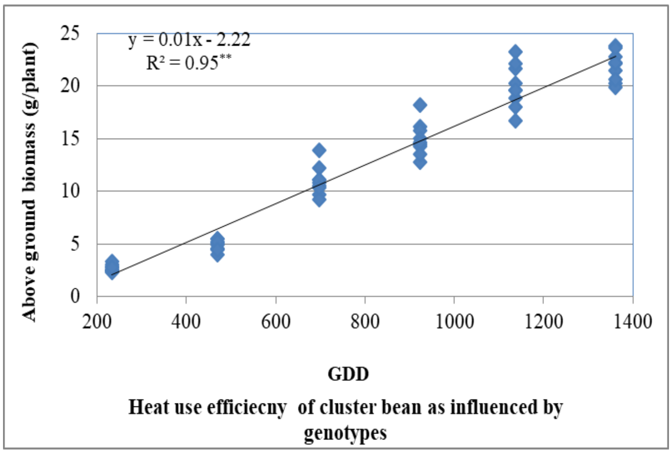
Results and Discussion

Effect of different planting density, genotypes and their interactions on thermal time efficiencies

Table 1: Thermal time use efficiency of guar as influenced by spacing and genotypes

Treatments	Thermal time use efficiency		
Spacing (S)	HUE (^{0} C day x10^{-2})	HTUE (^{0} C hrs x10^{-3})	PTUE (^{0} C hrs x10^{-2})
45x15 cm	1.70	3.19	3.48
30x15 cm	1.79	3.37	3.66
45x10 cm	1.72	3.28	3.53
30x10 cm	1.82	3.47	3.73
F-test	*	*	*
S.Em ±	0.01	0.04	0.02
C.D. at 5%	0.04	0.13	0.07
Genotypes (G)			
RGC-1003	1.91	3.64	3.90
RGC-936	1.62	3.00	3.31
HG-365	1.76	3.34	3.60
F-test	*	*	*
S.Em ±	0.01	0.04	0.02
C.D. at 5%	0.03	0.11	0.06
Interaction (S X G)			
45x15 cm + RGC-1003	1.85	3.49	3.78
45x15 cm + RGC-936	1.54	2.85	3.16
45x15 cm + HG-365	1.71	3.22	3.50
30x15 cm + RGC-1003	1.92	3.69	3.92
30x15 cm + RGC-936	1.68	3.04	3.42
30x15 cm + HG-365	1.79	3.40	3.65
45x10 cm + RGC-1003	1.87	3.56	3.83
45x10 cm + RGC-936	1.58	2.97	3.23
45x10 cm + HG-365	1.72	3.31	3.53
30x10 cm + RGC-1003	1.99	3.81	4.08
30x10 cm + RGC-936	1.67	3.15	3.41
30x10 cm + HG-365	1.81	3.45	3.70
F-test	NS	NS	NS
S.Em ±	0.02	0.07	0.04
C.D. at 5%	-	-	-





Genotype RGC-1003 was found more efficient in utilizing Heat use efficiency (1.91x10^{-2}), photo thermal use efficiency (3.90 x10^{-2}) and Helio thermal use efficiency (3.64x10^{-3}). This higher use efficiency shows the efficient dry matter portioning to various plant parts. The relation between net biomass accumulation and intercepted radiation was linear throughout most of the growth, till the end of pod filling. The decrease thermal time efficiencies prior to maturity were due to leaf shedding Kiran and Roy (2006) [8] in urd bean. RGC-1003 required comparatively more heliothermal units to complete different phenological stages during all the stages of crop growth (Table 1). The HUE (0.01), PTUE (0.03) and HTUE (0.002) of different genotypes of cluster bean are shown in the figures 1, 2 and 3. Plants grown at 30 cm x 10 cm recorded higher Heat use efficiency (1.82x10^{-2}), photo thermal use efficiency (3.73x10^{-2}) and Helio thermal use efficiency (3.47x10^{-3}) (Table 1). The HUE (0.01), PTUE (0.03) and HTUE (0.002) of cluster bean grown at different spacing are shown in the figures 1, 2 and 3. Highest plant density had consistently greater fractional interception of heat units during the entire growing period and reached full interception during earlier growing stages. At later stages it decreases due to leaf senescence. With respect to interaction effects 30 cm x 10 cm with RGC-1003 recorded higher heat use efficiencies (1.99x10^{-2}), photo thermal use efficiency (4.08x10^{-2}) and helio thermal use efficiency (3.81x10^{-3}). The HUE (0.01), PTUE (0.03) and HTUE (0.002) of guar genotypes grown at different spacing are shown in the figures 1, 2 and 3.

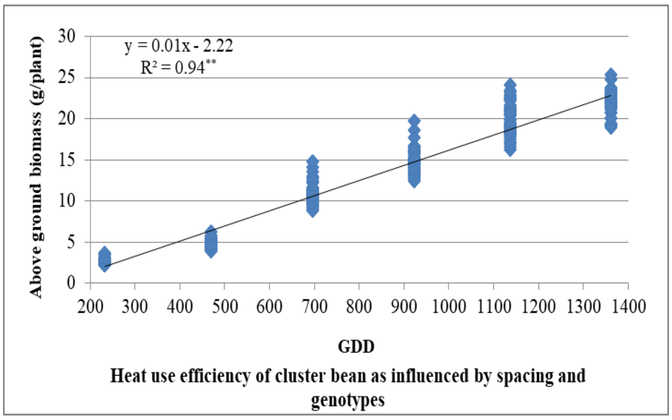
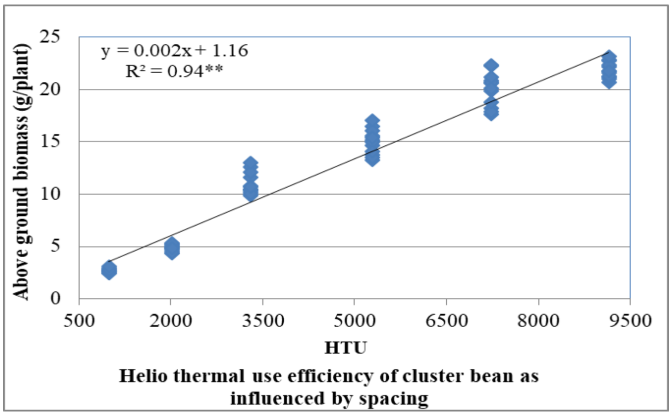


Fig 1: Heat use efficiency of cluster bean as influenced by spacing, genotypes and their interactions.



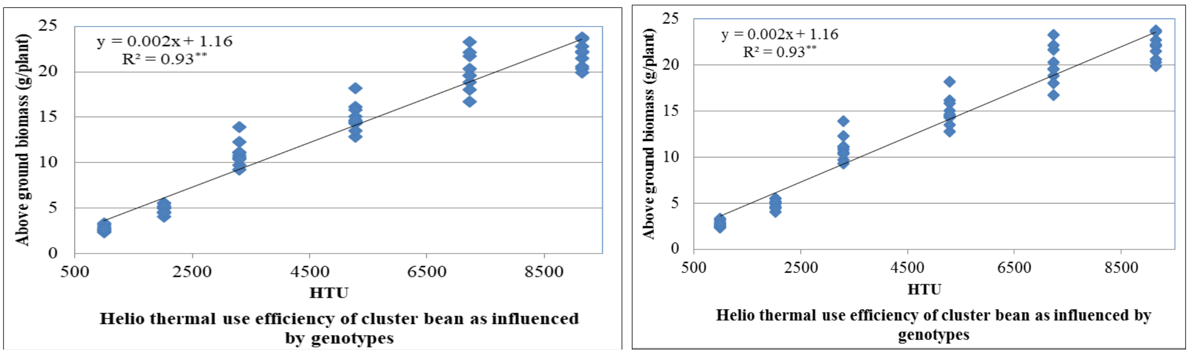


Fig 2: Helio thermal use efficiency of cluster bean as influenced by spacing, genotypes and their interactions

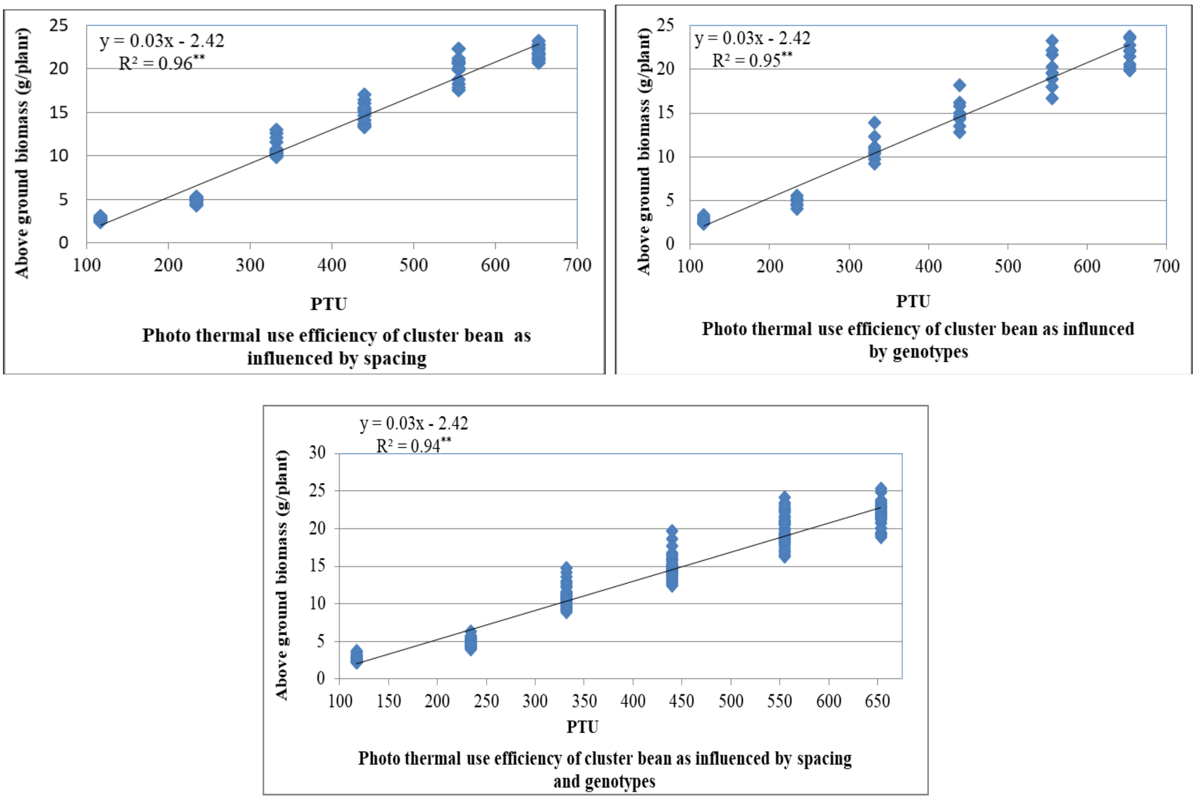


Fig 3: Photo thermal use efficiency of cluster bean as influenced by spacing, genotypes and their interactions.

Table 2: Yield components as influenced by spacing and genotypes of guar

Treatments					
Spacing (S)	**Number of pods**	**Number of clusters**	**Number of seeds**	**Pod length (cm)**	**100 seed weight (g)**
45x15 cm	16.33	5.26	5.99	3.97	3.04
30x15 cm	21.15	5.82	6.66	4.27	3.17
45x10 cm	19.22	5.63	6.50	4.21	3.10
30x10 cm	23.48	7.18	6.76	4.47	3.22
F-test	*	*	*	*	*
S.Em ±	0.73	0.32	0.08	0.05	0.03
C.D. at 5%	2.15	0.95	0.25	0.15	0.08
Genotypes (G)					
RGC-1003	29.31	7.94	7.07	4.62	3.33
RGC-936	11.36	4.36	5.82	3.83	2.91
HG-365	19.47	5.61	6.55	4.23	3.17
F-test	*	*	*	*	*
S.Em ±	0.63	0.28	0.07	0.04	0.02
C.D. at 5%	1.87	0.82	0.21	0.13	0.07
Interaction (S X G)					
45 x 15 cm + RGC-1003	25.44	6.33	6.87	4.40	3.27
45 x 15 cm + RGC-936	7.11	4.55	4.93	3.41	2.73
45 x 15 cm + HG-365	16.44	4.89	6.18	4.09	3.13
30 x 15 cm + RGC-1003	30.67	7.45	7.13	4.55	3.37

30 x 15 cm + RGC-936	12.11	4.22	6.13	3.99	2.97
30 x 15 cm + HG-365	20.67	5.78	6.71	4.26	3.17
45 x 10 cm + RGC-1003	27.34	7.44	6.96	4.50	3.27
45 x 10 cm + RGC-936	11.11	3.89	6.05	3.88	2.90
45 x 10 cm + HG-365	19.22	5.55	6.51	4.24	3.13
30 x 10 cm + RGC-1003	33.78	10.55	7.31	5.04	3.40
30 x 10 cm + RGC-936	15.11	4.78	6.18	4.04	3.03
30 x 10 cm + HG-365	21.56	6.22	6.80	4.34	3.23
F-test	NS	NS	NS	NS	NS
S.Em ±	1.26	2.08	0.82	0.56	0.05
C.D. at 5%	-	-	-	-	-

Table 3: Grain yield (kg ha^{-1}), Stover yield (kg ha^{-1}) and Harvest index of guar as influenced by spacing, genotypes and their interactions.

Treatments			
Spacing (S)	**Grain yield (kg ha^{-1})**	**Stover yield (kg ha^{-1})**	**Harvest index**
45x15 cm	524.50	1299.31	0.28
30x15 cm	721.24	1496.50	0.32
45x10 cm	652.77	1413.84	0.31
30x10 cm	743.89	1629.94	0.34
F-test	*	*	*
S.Em ±	25.78	54.94	0.01
C.D. at 5%	76.10	162.18	0.03
Genotypes (G)			
RGC-1003	898.18	1931.39	0.32
RGC-936	448.36	980.54	0.30
HG-365	635.26	1467.77	0.31
F-test	*	*	NS
S.Em ±	22.33	47.58	0.01
C.D. at 5%	65.90	140.45	-
Interaction (S X G)			
45 x 15 cm + RGC-1003	778.85	1755.79	0.31
45 x 15 cm + RGC-936	290.21	769.52	0.28
45 x 15 cm + HG-365	504.44	1372.61	0.27
30 x 15 cm + RGC-1003	933.69	1979.17	0.32
30 x 15 cm + RGC-936	625.43	1001.85	0.39
30 x 15 cm + HG-365	672.55	1508.49	0.31
45 x 10 cm + RGC-1003	874.87	1901.00	0.31
45 x 10 cm + RGC-936	433.45	924.61	0.32
45 x 10 cm + HG-365	649.99	1415.90	0.32
30 x 10 cm + RGC-1003	1005.31	2089.58	0.32
30 x 10 cm + RGC-936	444.36	1226.16	0.28
30 x 10 cm + HG-365	714.05	1574.07	0.31
F-test	NS	NS	NS
S.Em ±	44.65	95.16	0.016
C.D. at 5%	-	-	-

The grain yield of a crop is the integrated results of a number of physiological processes. In the present study genotypes significantly influenced the grain yield of guar. RGC-1003 recorded significantly higher grain yield (898.18 kg ha^{-1}) as compared to HG-365 (635.26 kg ha^{-1}) and RGC-936 (448.36 kg ha^{-1}) (Table. 3). The increase in grain yield of RGC1003 may be due to increase in yield parameters *viz.*, number pods $plant^{-1}$ (29.31), number of clusters $plant^{-1}$ (7.94), number of seeds pod^{-1} (7.07), pod length (4.62 cm) and 100 seed weight (3.33 g) (Table. 2). The results of this present investigation are in conformation with the findings of Jain *et al.* (1987) [5] in cluster bean. The low yield in other varieties is due to decreased yield attributes. Among the planting density 30 cm x 10 cm spacing recorded significantly higher grain yield (743.89 kg ha^{-1}) as compared to 30 cm x 15 cm (721.24 kg ha^{-1}) and 45 cm x 10 cm (652.77 kg ha^{-1}). Significantly lower grain yield was observed in 45 cm x 15 cm (524.50 kg ha^{-1}) (Table. 3). The higher grain yield may be attributed to higher yield components *viz.*, pod number (23.48), number of clusters $plant^{-1}$ (7.18), number of seeds pod-1 (6.76), pod length (4.47 cm), 100 seed weight (3.22 g) (Table 2) and results were in conformity with the findings of Akhtare *et al.* (2012) [1]. He also reported a functional relationship in grain yield with various yield attributes of cluster bean. The interaction effect did not differed significantly between the genotype and spacing levels with respect to grain yield. Significantly higher stover yield (1931.39 kg ha^{-1}) was recorded with RGC1003 as compared to HG-365 (1467.77 kg ha^{-1}) and RGC-936 (980.54 kg ha^{-1}). This higher stover yield of RGC-1003 may be attributed to higher dry matter accumulation in vegetative parts. Lower stover yield may be due to reduced size of photosynthesising surface which might have caused reduction in growth. These results are in confirmatory with the work of Sanghi and Sharma (1964) in guar. The closer spacing of 30 cmx 10 cm produced significantly higher stover yield (1629.94 kg ha^{-1}) compared to other planting density. The increase in stover yield with closer spacing was mainly due to vertically expansion of plants with higher growth and dry matter production resulted in higher stover yield. Harvest index is a measure of physiological productivity potential of a crop. The significant differences in harvest index were observed due to spacing and genotype levels are presented in Table.3. In the present study RGC-1003 has recorded higher (0.32) harvesting index as compared to HG-365 (0.31) and RGC-936 (0.30). This may be due higher partitioning and translocation of photosynthates from source to sink because of higher vegetative growth and higher interception and utilisation of solar radiation this may produce higher above ground dry matter. Similar results were also reported by Daulay and Henry (1997) as well as Siddaraju *et al.* (2010) in cluster bean. Plants grown at spacing of 30 cm x 10 cm recorded significantly higher HI (0.34) as compared to wider spacing of 30 cm x 15 cm (0.32), 45 cm x 10 cm (0.31) and low HI was observed in 45 cm x 15 cm (0.28) (Table. 3). Higher HI at closer spacing due to higher economic yield contributing from the higher plant population per unit area as compared with lesser population per unit area of wider spacing. These findings are in agreement with those recorded by Malik *et al.* (1981) [10], Taleei *et al.* (1999) [15] and also Jan *et al*. (2000).

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