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RESPONSE OF TWO YEMENI SORGHUM VARIETIES TO PLANT DENSITY

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ABSTRACT: Two field experiments were conducted during 1999 and 2000 summer seasons in the Experimental Station, Faculty of Agriculture, Sana'a University, Yemen. Each experiment included 6 treatments which were the combinations of two sorghum Yemeni varieties, i.e. Tagareb (V1) and Safra'a (V2), and three plant densities: 83,333 (D1, low), 111,111 (D2, medium) and 166,666 (D3, high) plants/ha. The treatments were arranged in a split plot design with 4 replicates, where varieties were allocated in the main plots while the sub plots were devoted to plant densities. This investigation aimed to evaluate the two mentioned varieties under the three plant densities, and to detect plant traits contributing by the major shares in grain variation of sorghum plant.

Data indicated that V1variety gave higher values of head weight, grain weight/head (plant) and surpassed V2 variety in grain yield by 25.9%. But, V2 exerted superiority in straw weight/plant, 1000-grain weight and produced more biological and straw yields amounted to 52.0 and 112.2%, respectively, over V1.

The studied plant densities showed that each increase in plant density caused reduction in LA, straw weight/plant, head weight, grain weight/head and 1000-grain weight. However, as plant density increased up to the high level (D3), significant increments were obtained in each of biological, straw and grain yields/ha, amounted to 54.2, 55.1 and 52.1%, respectively, comparing to the low level (D1).

With respect to the interaction between the two studied factors, data indicated superiority of V2 at all studied densities in biological as well as straw yields with higher values for both varieties as plant density increased. As for grain yield, results showed, also, higher values of both examined varieties as plant density increased, but V1 surpassed V2 at any density. The most productive combination, which could be recommended

for achieving maximum sorghum grain yield under Sana'a conditions, was planting Tagareb variety (V1) at 166,666 plants/ha (D3). This superior combination (V1xD3) surpassed the most lowest one (i.e. V2xD1) by 88.8% in grain yield/ha.

In the second order, leaf area /plant (LA), straw weight/plant, head weight, grain weight/head (plant) as well as 1000-grain weight for each variety were involved in a simple correlation study. There were positive and high significant correlation coefficients between all pairs of the forenamed traits. Thereafter, head weight, 1000-grain weight and LA were chosen for path analysis study to identify their relative importance in grain weight per sorghum plant for both varieties. The maximum values of the direct effects, i.e. 0.545 and 0.398, were gained by head weight of V1 and V2, respectively. 1000-grain weight recorded the next values in importance. The highest indirect effects were exerted by 1000-grain weight via head weight. Regarding the relative importance, the major individual shares were obtained by head weight but values were higher for V1 than with V2. The next important trait was 1000-grain weight. The total summation share of these two traits together accounted to 64.8 and 47.0 % in the variation of grain weight/plant. So, sorghum breeder must select plants which characterized with high values of head weight followed by 1000-grain weight as the prime traits for the improvement of sorghum varieties.

INTRODUCTION

Sorghum [*Sorghum bicolor*, (L.) Moench] is the fourth most important cereal crop after wheat, rice and maize (Gibbon and Pain, 1985). In the Republic of Yemen, sorghum comes the first, in importance, among cereal crops, being recorded 57.7% and 54.6% of total cereal areas and production, respectively, in the year 2001. However, there is a need to maximize sorghum production to face the local demands where Yemen imported >500 tons of sorghum with cost >6.5 million Yemeni Rials, in the year 2001 (Agricultural Statistics Year Book, 2001). To achieve this aim, sorghum fields must planted by high yielding and well-adapted varieties under the optimum plant density.

Variations have been reported among sorghum varieties in growth, yield and yield components (El-Rassas *et al*, 1986). On the other hand, there were contradictory results as for the response of sorghum to plant density. In this connection, grain yield was improved by decreasing plant density as showed by Ismail and Ali (1996), while Eweis *et al* (1992) reported that increasing plant density produced more grain yield. Furthermore, sorghum grain yield did not change significantly between the applied densities, i.e. 125,000-435,000 plants/ha (Rodriquez *et al*, (1994).

In the second order, plant traits contributing by the major share in the variation of sorghum grain weight/plant must be well detected for gaining high productivity.

So, the present investigation aimed to:

1- Evaluate two Yemeni sorghum varieties under three plant densities, and
2- Detect plant traits contributing by the major shares in grain variation of sorghum plant.

MATERIALS AND METHODS

Two field experiments were conducted during 1999 and 2000 summer seasons in the Experimental Station, Faculty of Agriculture, Sana'a University, Yemen. Each experiment included 6 treatments which were the combinations of:

1-Two Yemeni varieties, i.e. Tagareb (V1) and Safra'a (V2), and
2-Three plant densities: 83,333 (D1, low), 111,111 (D2, medium) and 166,666 (D3, high) plants/ha. These densities were resulted due to planting sorghum at 60 cm between ridges and the distance between hills was either 20 cm (one plant/hill), 30 cm (two plants/hill) or 20 cm (two plants/hill), respectively. A split plot design with 4 replicates was used where varieties were allocated in the main plots while plant densities were arranged in the sub plots. The experimental unit area was $9m^2$, contained 5 ridges each of 3 m long. Sorghum [*Sorghum bicolor* (L.) Moench] grains were planted on 26 April in both seasons. No. of plants/hill were thinned, according to the treatment, before the 2^{nd} irrigation. Irrigation was applied as needed and started immediately after sowing. Other agricultural practices such as weeding, fertilization,., etc were performed as usual for sorghum.

Data recorded

1- Sorghum criteria:

During growth period, leaf area (LA)/plant using the disc borer method and leaf area index (LAI) were estimated at 80 days after sowing (DAS). Plant height was recorded immediately before harvest. At harvest, one middle ridge was harvested from each experimental unit and the following data were determined: head weight, grain weight/head (plant), 1000-grain weight, straw weight/plant, and biological, head, straw as well as grain yields.

2- Simple correlation and yield analysis:

Leaf area /plant (LA), straw weight/plant, head weight, grain weight/head (plant) as well as 1000-grain weight were involved in a simple correlation study. Thereafter, LA, head weight and 1000-grain weight were chosen for path analysis to identify their relative importance in grain weight/plant for both examined varieties, according to the method described by Snedecor and Cochran (1967).

Statistical analysis

The collected data were subjected to the proper statistical analysis of variance according to Snedecor and Cochran (1967) using the Computer. L.S.D at 0.05 level of significance was used for comparing between means.

RESULTS AND DISCUSSION

1- Sorghum criteria:

Data presented in Tables (1, 2 & 3) show sorghum plant height, leaf area (LA)/plant, leaf area index (LAI), straw weight/plant, head weight, grain weight/head (plant), 1000-grain weight, biological, straw and grain yields as affected by the grown varieties, plant densities and their interactions

Varietal differences:

Data indicated that plants of V2 (Safra'a) variety were taller than those of Tagareb (V1) variety by 73 cm (Table, 1). It is well known that plant height is mainly genetically-controlled. Varietal differences in plant height of sorghum were reported by El-Rassas *et al* (1986). Leaf area (LA) and leaf area index (LAI) of sorghum plant were not different between the examined varieties, however V2 exerted superiority in straw weight/plant. The increase in straw weight may be due to the associated increment in plant height.

There were significant differences between the two evaluated varieties in head weight, grain weight/head (plant) and 1000-grain weight (Table, 2). V1 variety gave higher values of head weight and grain weight/head (plant), but V2 produced higher 1000-grain weight than that of V1. The differences in head weight and 1000-grain weight may be due to the genetic makeup of the variety. Increasing grain weight/head (plant) of V1 may be a result of the increment in head weight. Variations among sorghum varieties were detected in grain weight/head, head weight and 1000-grain weight (El-Rassas *et al* 1986 and El-Shazly and El-Rassas, 1990).

On the other hand, V2 variety produced more biological and straw yields amounted to 52.0 and 112.2%, respectively, than V1 (Table, 3). This observation may be attributed to the increase in straw yield/plant of V2. However, V1 variety surpassed V2 in grain yield by 25.9%. The increments gained by V1 in head weight and grain weight/head may explain this finding. Differences were observed among sorghum varieties in grain yield per unit area (El-Rassas *et al* 1986 and Moharram *et al*, 2001) as well as dry matter yield (Fernandez, 1988).

Effect of plant density:

Results of the applied plant densities, i.e. D1 (low), D2 (medium) and D3 (high), in affecting plant height, leaf area (LA)/plant, leaf area index (LAI) and straw weight/plant of sorghum (Table, 1) showed that widening the distance between hills from 20 cm (D1 or D3) to 30 cm (D2) resulted in increasing plant height which indicates more importance of hill distance irrespective of No. of plants per each for utilization of environmental growth resources to elongate plant stem, in wider hill spacing. In this connection, Eweis *et al* (1992) planted sorghum in hills spaced 20, 15 and 10 cm and found that plants were taller with widening the distance between hills.

Each increase in plant density caused reduction in LA and straw weight/plant but had no marked effect on LAI. As planting was dense, the competition between plants for light, water, nutrients, …,etc, is expected to be more, that means less available growth resources. This could interpret the low associated values of LA which resulted in reducing straw weight/plant. Increasing plant density decreased LA of sorghum plant (Eweis *et al*, 1992). Two sowing rates of sorghum (8 and 16 kg/ha) were used by Hamed and Mohamed (1987). They mentioned that plants were heavier at 8 kg/ha than with 16 kg/ha. When sorghum was sown at intra-row spacing of 3.4 and 6.7 inches, Jones and Johnson (1991) showed that doubling the intra-row spacing did not affect LAI.

Marked reductions in head weight, grain weight/head and 1000-grain weight were recorded with any increase in plant density (Table, 2). This result may be attributed to the decrease in plant LA that means reducing the metabolites synthesized per plant. Decreasing plant density caused increments in sorghum grain weight/head, 1000-grain weight (Eweis *et al* 1992) and head weight (Rodriquez *et al*, 1994).

As plant density increased up to the high level (D3), significant increments were obtained in each of biological, straw and grain yields/ha, amounted to 54.2, 55.1 and 52.1%, respectively, in the comparison with the low level (D1) (Table, 3). The increase in No. of plants per unit area with dense planting may responsible for the obtained increments in sorghum productivity. These results are in agreement with those recorded by Eweis *et al* (1992) in grain yield and Amano and Salazar (1989) in DM yield.

Interaction effects:

All studied sorghum traits, except LAI, were significantly affected by the interaction between varieties and plant densities.

Plants of V2 were taller and produced, as a result, more straw weight/plant than those of V1 at each density (Table, 1). Moreover, straw weight/plant, of both varieties, tend to decrease with increasing plant density. Both varieties gave LA/plant significantly equal at any plant density but their values were more as plant density decreased.

Values of head weight and grain weight/head were significantly higher for both varieties with thin planting, although V2 values were markedly less than those of V1 at any density (Table, 2). In spite of higher values of 1000-grain weight were recorded by V2 than V1 at the three studied densities, the obtained varietal values decreased with each reduction in plant density. In this respect, three sorghum varieties were sown at three plant densities as indicated by Ogunlela and Okoh (1989). They showed that head weight, grain weight/head and 1000-grain weight of the examined varieties responded different to plant densities.

Regarding sorghum yields, data in Table (3) indicate superiority of V2 at all applied densities in biological as well as straw yields with higher values for both varieties as plant density increased. So, the maximum values were gained by V2 x D3 combination which exceeded the lowest one (i.e. V1 xD1) by 130.4 and 214.3% in biological and straw yields, respectively. The increases in straw weight/plant of V2 and the highest No. of plants per unit area at D3 density may be responsible for this observation.

With respect to grain yield, results show also higher values of both examined varieties as plant density increased, but V1 surpassed V2 at any density. The most productive combination, which could be recommended for achieving maximum sorghum grain yield under Sana'a conditions, was planting Tagareb variety (V1) at 166,666 plants/ha (D3). The highest values in grain weight/head recorded by V1and the increment in No. of plants per unit area as plant density increased up to D3 may explain this finding. This superior combination (V1xD3) surpassed the most lowest one (i.e. V2xD1) by 88.8% in grain yield. Variations among sorghum varieties in response to plant density were studied by Wade *et al* (1993) who planted eight sorghum varieties under four densities, i.e. 10,000, 50,000, 90,000 and 130,000 plants/ha. They reported that variety differed in plant density which maximized grain yield.

2- Simple correlation and yield analysis:

The traits involved in the simple correlation study were leaf area /plant (LA), straw weight/plant, head weight, grain weight/head (plant) as well as 1000-grain weight for both examined varieties, i.e. Tagareb (V1) and Safra'a (V2).

Perusaling results in Table (4) indicate that there were high significant positive correlation coefficients between all pairs of the involved traits (Table, 4). This is true for both evaluated varieties. The highest values regarding grain weight/plant were in it's associations with head weight or 1000-grain weight, being 0.892 and 0.870 for V1 and 0.848 ad 0.824 for V2, respectively. In the literature review, head weight, grain weight/plant as well as 1000-grain weight were positively and highly significant correlated with each other (Abd El-Samie and El-Bially, 1995).

The next aim in this part of study was to determine which traits are the main sources and detecting the contribution of each in the variation of grain weight per sorghum plant for both tested varieties. For this, three traits, i.e. head weight, 1000-grain weight and leaf area/plant (LA) were chosen and the correlation coefficient of each in association with grain weight/plant was partitioned to its direct (path coefficient) and indirect effects as illustrated in Table (5). Results demonstrated that all involved traits exerted positive direct effects. In this respect, the maximum values, i.e. 0.545 and 0.398, were gained by head weight of V1 and V2, respectively. 1000-grain weight recorded the next values in importance. Moreover, the highest indirect effects were exerted by 1000-grain weight via head weight, being 0.444 and 0.336 for the two forenamed varieties, respectively. Abd El-Samie and El-Bially (1995) showed that head weight recorded the highest direct effect (0.555) on grain weight of sorghum plant. They added that the indirect effect of this trait, i.e. 1000-grain weight, was obtained via head weight, being 0.494.

Regarding the relative contributions of the above traits to the variation of grain weight per sorghum plant, results (Table, 6) revealed that the major individual share was obtained by head weight, being 29.7% for V1. This is true also for V2 but with relatively less value (15.8%). The highest relative importance of head weight for sorghum plant grain weight was reported also by Abd El-Samie and El-Bially (1995) who illustrated that head weight contributed by 22.2% to the variation of grain weight per sorghum plant. Here, the next important trait was 1000-grain weight. The total summation share of these two aforementioned traits together accounted to 64.8 and 47.0 % in the variation of grain weight/plant for V1 and V2, respectively.. However, the three involved traits, in this connection, contributed by 87.3 and 81.0% for the variation of V1 and V2, respectively. So, sorghum breeder must select plants which characterized with high values of

Table 1: Plant height, leaf area (LA), leaf area index (LAI) and straw weight/plant of sorghum as affected by the grown varieties, plant densities and their interactions (Combined analysis).

Variable	Plant ht., cm			LA, dm^2/plant			LAI			Straw wt., g/plant		
	V1	V2	Mean	V1	V2	Mean	V1	V2	Mean	V1	V2	Mean
D1	189.4	258.7	**224.1**	49.19	50.14	**49.66**	4.75	4.92	**4.84**	137.7	275.4	**206.6**
D2	194.6	275.2	**234.9**	43.99	45.06	**44.53**	5.03	5.14	**5.09**	108.4	259.6	**184.0**
D3	193.6	262.6	**228.1**	35.63	36.54	**36.09**	5.31	5.26	**5.38**	102.1	223.5	**162.8**
Mean	**192.5**	**265.4**		**42.94**	**43.91**		**5.03**	**5.11**		**116.1**	**252.8**	

LSD, 0.05, for :	Plant ht.	LA	LAI	Straw wt.
V:	5.6	N.S	N.S	8.2
D:	6.8	2.45	N.S	5.3
VxD:	9.6	3.46	N.S	7.5

Table 2: Head weight, grain weight per head (plant) and 1000-grain weight of sorghum as affected by the grown varieties, plant densities and their interactions (Combined analysis).

Variables	Head wt., g			Grain wt. , g /plant (head)			1000-grain wt. (g)		
	V1	**V2**	Mean	**V1**	**V2**	Mean	**V1**	**V2**	Mean
D1	150.3	111.1	**130.7**	107.4	87.1	**97.2**	52.40	60.25	**56.33**
D2	132.1	100.3	**116.2**	98.7	81.4	**90.0**	49.53	58.54	**54.04**
D3	120.5	82.7	**101.6**	81.7	68.0	**74.8**	46.40	57.20	**51.80**
Mean	**134.3**	**98.0**		**96.0**	**78.8**		**49.44**	**58.67**	

LSD, 0.05, for :	Head wt.	Grain wt.	1000-grain wt.
V	2.9	2.0	1.79
D:	6.8	3.2	0.92
V x D:	9.6	4.5	1.30

Table 3: Biological, straw and grain yields of sorghum as affected by the grown varieties, plant densities and their interactions (Combined analysis).

Variables	Biological yield, t/ha			Straw yield, t/ha			Grain yield, t/ha		
	V1	V2	Mean	V1	V2	Mean	V1	V2	Mean
D1	12.928	18.876	**15.902**	7.266	14.346	**10.806**	5.662	4.530	**5.096**
D2	15.353	23.588	**19.470**	8.029	17.956	**12.992**	7.324	5.632	**6.478**
D3	19.249	29.787	**24.518**	10.694	22.839	**16.766**	8.555	6.948	**7.751**
Mean	**15.843**	**24.084**		**8.663**	**18.380**		**7.180**	**5.703**	

LSD, 0.05, for :	Biological yield	Straw yield	Grain yield
V	0.516	0.456	0.149
D:	0.644	0.408	0.313
V x D:	0.911	0.577	0.446

Table 4: The simple correlation coefficients between some traits of the two sorghum varieties (above diagonal values for V1, and the below diagonal for V2) over the two years of experimentation.

Variables	LA (1)	Straw wt. /plant (2)	Head wt. (3)	1000-grain wt. (4)	Grain wt. /plant (5)
(1)		**0.657****	**0.578****	**0.711****	**0.708****
(2)	0.692**		**0.773****	**0.758****	**0.791****
(3)	0.627**	0.825**		**0.814****	**0.892****
(4)	0.590**	0.684**	0.844**		**0.870****
(5)	0.728**	0.803**	0.848**	0.824**	

**: significant at 0.01 level of probability.

Table 5: Partitioning of the simple correlation coefficients between sorghum grain wt./plant with other involving traits for both Tagareb (V1) and Safra'a (V2) varieties.

Sources	Values for (V1)	Values for (V2)
1- **Head wt.** :		
Direct effect	0.545	0.398
Indirect effect via (2)	0.241	0.267
Indirect effect via (3)	0.106	0.183
Correlation coefficient	0.892**	0.848**
2- **1000-grain wt.**:		
Direct effect	0.296	0.316
Indirect effect via (1)	0.444	0.336
Indirect effect via (3)	0.130	0.172
Correlation coefficient	0.870**	0.824**
3- **Leaf area/plant (LA)**:		
Direct effect	0.183	0.292
Indirect effect via (1)	0.315	0.250
Indirect effect via (2)	0.210	0.186
Correlation coefficient	0.708**	0.728**

**: significant at 0.01 level of probability.

Table 6: The contribution percentage of some sorghum traits in the variation of grain wt./plant for both Tagareb (V1) and Safra'a (V2) varieties.

Source of Variation	(V1)		(V2)	
	Coefficient of determination	Contribution %	Coefficient of determination	Contribution %
Head wt. (A)	0.297	29.7	0.158	15.8
1000-grain wt. (B)	0.088	08.8	0.100	10.0
LA (C)	0.033	03.3	0.085	08.5
(A) x (B)	0.263	26.3	0.212	21.2
(A) x (C)	0.115	11.5	0.146	14.6
(B) x (C)	0.077	07.7	0.109	10.9
Residual factors	0.127	12.7	0.190	19.0
Total	1.000	100.0	1.000	100.0

these forenamed traits (i.e. head weight, 1000-grain weight, and leaf area/plant) especially head weight followed by 1000-grain weight as the prime traits for the improvement of sorghum varieties

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استجابة صنفين من الذرة الرفيعة اليمنية للكثافة النباتية

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أقيمت تجربتين حقليتين في مزرعة محطة البحوث بكلية الزراعة، جامعة صنعاء، باليمن، خلال الموسمين الصيفيين لعامى ١٩٩٩ و ٢٠٠٠. تضمنت كل تجربة ستة معاملات عبارة عن التوافقات بين صنفين من الذرة الرفيعة اليمنية [هما: تجارب (V1) وصفراء (V2)] مع ثلاث كثافات نباتية : ٨٣،٣٣٣ (D1 ، منخفضة). ١١١،١١١ (D2، متوسطة) و ١٦٦،٦٦٦ (D3، مرتفعة) نبات/هكتار. نظمت هذه العاملات في تصميم القطع المنشقة بأربعة مكررات، حيث

وضعت الأصناف في القطع الرئيسية بينما خصصت القطع الفرعية للكثافات النباتية . كان الهدف من هـذا البحث هو تقييم الصنفين المذكورين تحت ظروف الثلاث كثافات نباتية وأيضا تحديد الصفات النباتية المساهمة بأكبر قدر فى تباينات محصول حبوب نبات الذرة الرفيعة.

أوضـحت النتائج أن الصنف تجارب (V1) أعطى أعلى قيم في وزن الرأس ووزن الحبوب في الرأس (النبات) عن الصنف صفراء (V2) والذى أظهر تفوقاً في وزن القش/نبات ووزن الألف حبة كمـا أعطى إنتاجية من المحصول البيولوجي ومحصول قش وصلت إلي ٥٢,٠ و ١١٢,٢%، علي التوالي، أعلى من الصنف V1 . فى حين كان الصنف V1 هو المتفوق في محصول الحبوب بمقدار ٢٥,٩%.

أحدثـت كـل زيادة في الكثافة النباتية انخفاضا في مساحة الأوراق/نبات، وزن القش في النبات، وزن الـرأس، وزن الحـبوب في الرأس، ووزن الألف حبة. ولكن كلما زادت الكثافة النباتية وحتى أعلـي مستوى (D3) امكن الحصول علي زيادة معنوية في كل من المحصول البيولوجي ومحصول القش ومحصول الحبوب قدرها ٥٤,٢ ، ٥٥,١، و ٥٢,١%، علي التوالي، وذلك بالمقارنة مع الكثافة النباتية المنخفضة (D1).

تشـير نتائج التداخل بين عاملي الدراسة إلي تفوق الصنف V2 تحت كل الكثافات المدروسة في محصـولي البيولوجي والقش مع زيادة قيم كلا الصنفين كلما زادت الكثافة النباتية. بالنسبة لمحصول الحـبوب، إتضح أيضا زيادة إنتاجية كلا الصنفين كلما زادت الكثافة النباتية، مع تفوق الصنفV1 علي الصنف V2 في كل الكثافات.

مـن جهة أخرى، فقد تم دراسة كلا من الإرتباط البسيط ومعامل المرور فى صنفى الدراسة. وقد وجـد إرتـباط موجـب وعالى المعنوية بين صفتى كل زوج من الصفات التالية (التى شملتها دراسة الإرتـباط البسـيط): مساحة أوراق النبات، وزن القش/نبات، وزن الرأس، ووزن الألف حبة، وزن حـبوب النبات (الرأس) ووزن الألف حبة، وذلك لكل من صنفى الدراسة. وفى دراسة تحليل معامل المـرور، تم إختيار ثلاث صفات هى: وزن الرأس، ووزن الألف حبة ومساحة أوراق النبات لتحديد المسـاهمة النسـبية لكل منها فى تباين وزن حبوب النبات (الرأس) فى الصنفين تحت الدراسة. ولقد أظهر التحليل أن صفة وزن الرأس كان لها أكبر تأثير مباشر(0.545 و ٠,٣٩٨ على الصنفين V1 وV2 ، علـى الترتيـب)، يليها التأثير المباشر لصفة وزن الألف حبة والتى سجلت أعلى تأثير غير مباشر من خلال صفة وزن الرأس. كما إتضح أن صفة وزن الرأس كان لها أكبر مساهمة نسبية فى تباين محصول الجبوب/نبات ولو أن مساهمتها فى الصنف V1 كانت أعلى مما فى حالة الصنف V2 ، يليها مساهمة صفة وزن الألف حبة. كان مجموع مساهمات هاتين الصفتين معا ٦٤,٨ و ٤٧,٠ % فـى تبايـن وزن الحبوب/نبات للصنفين السابقين، على التوالى.وعلى هذا، وطبقا لهذه الدراسة، فعلى مـربى النبات إنتخاب النباتات التى تتصف بأعلى قيم أساسا لوزن الرأس يليها وزن الألف حبة كأهم صفات من أجل تحسين أصناف الذرة الرفيعة للحبوب.