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Genetic analysis of head inclination and its components in selected sunflower hybrids

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ABSTRACT

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To provide information about genetic control of head inclination in sunflower, 12 selected hybrids developed by crossing four lines and three testers were evaluated as a line × tester mating design using randomized complete block design with three replications in Karaj, Iran. The results showed that the parental lines contributed, more than other sources, in variation of head weight (62.4%) of hybrids while contribution of the testers was more for head diameter (62.8%), plant height (48.6%), head height (70.5%), achene yield (41.7%) and head inclination (54.5%). We found that the two hybrids; RGK33 × AGK370 (23.7%) and RGK33 × AGK356 (24.0%) had the lowest head inclination, respectively, while among the parental lines only RGK33 and AGK356 were in suitable range (25-35%) indicating that crossing the parental lines with undesirable head inclination may lead to the production of hybrids with suitable head inclination. We also found that head weight and head inclination are controlled mainly by additive gene action that suggests the crucial role of parental lines in development of hybrids with desirable head inclination. Both additive and non-additive gene action were significant for head diameter, plant height, head height and achene yield. Over-dominant gene action observed for plant height, achene yield and inclined length, and partial dominance for head diameter, weight, height and inclination. Higher broad sense heritability for plant height (0.86), head weight (0.72), head height (0.73) and head diameter (0.71), and lower heritability for head inclination, indicated that heritability of head inclination is independent from these components. All hybrids developed by crossing of restorer lines RGK21 and RGK33 had suitable head inclination as compared with the progenies of RGK15. This information is valuable for improvement of head inclination and developing ideo-types in sunflower breeding programs.

Keywords: sunflower, gene action, dominance, heritability, ideo-type, line × tester

INTRODUCTION

Sunflower with an annual world area of cultivation of 26.5 million hectare and production of 47.9 million tons (FAO, 2018) is the third major source of edible oil in the world following soybean and rapeseed. Development of hybrids with high genetic potential for seed yield and optimum plant architecture is among the main objectives in sunflower breeding programs (Hladni *et al.*, 2011). Breeding for desirable plant characteristics requires information about the nature of gene action and the mode of inheritance of quantitative traits as well as general and specific combining abilities of parental inbred lines.

Morphological characteristics as plant height and head size and weight are more related traits to head inclination in sunflower. Many researchers have studied genetic control of these traits, although there are inconsistency in reports about the nature of gene action on expression of these traits. Different types of head inclination are observed in sunflower considering the percentage of curved area; severe bending, without bending, and bending about 15-65% of stem length, however, 15-35% head inclination is desirable (Knowles, 1994).

Combination of different traits as head size, head weight, plant height and achene yield of a single head affects head inclination of sunflower. Head size, measured as head diameter, involves two main components of achene yield; achene number and weight as heavy part of plant product and are positively associated with achene yield of sunflower (Singh *et al.,* 1998; Chikkadevaiah and Nandini, 2002). It seems that environmental conditions has more effect on morphological characteristics of sunflower such as head diameter (Fick and Miller, 1997), however, there are different reports concerning genetic control of these characteristics in sunflower.

To select for head inclination an understanding of the nature of gene action in controlling of head inclination related traits is required. Machikowa *et al*. (2011) and Tabrizi *et al.* (2012) reported that additive gene action is more important in inheritance of head diameter, however Hladni *et al.* (2007) and Karasu *et al.* (2010) reported that non-additive gene action in inheritance of these traits was significant.

Plant height is an important feature of plant architecture and yield formation in sunflower (Skoric *et al.,* 2012). Ghaffari *et al.* (2011), Nooryazdan *et al*. (2011), Machikowa *et al*. (2011) and Tabrizi *et al.* (2012) showed that additive gene action was more important in inheritance of plant height. Karasu *et al.* (2010), however, reported predominance of non-additive gene action in inheritance of plant height. Farrokhi *et al.* (2008) reported that plant height is under control of both additive and non-additive gene action and over dominance has a major role in inheritance of this trait. Over dominance gene action is reported for head diameter and other characteristics as plant height, 100 seed weight and seed yield (Gangappa *et al.*, 1997).

Achene yield is a portion of head weight and constitute the major part of head weight. Machikowa *et al*. (2011) found that additive gene action is more important in inheritance of achene yield. Kandalkar (1997) reported that both additive and non-additive gene action govern seed yield. There are reports that indicate non-additive gene action predominantly govern achene yield (Putt, 1966; Singh *et al.,* 1999; Devi *et al.*, 2005; Ghaffari *et al.,* 2011). However, studies about the nature of gene action for head inclination are limited.

There are four types of head inclination in sunflower which can be identified following pollination and fertilization and would be stable by physiological maturity (Skoric *et al.*, 2012). Kovacik and Skaloud (1980) reported that head angle of sunflower is controlled by four major genes (H_{ba}, H_{bb}, H_{bc} *and* H_{bd}), each have three different alleles, and totally 12 alleles with additive action. They estimated that each allele makes about 15° changes in head angle, however, other environmental factors may also influence this characteristic.

Currently several parental lines including cytoplasmic male sterile and fertility restoration inbred lines with desirable characteristics as early maturity, and lower plant height have been improved in sunflower breeding program at Seed and Plant Improvement Institute, Karaj, Iran. Due to the importance of head inclination on sun damage on florets and achene setting on sunflower capitulum as well as on bird damage to achenes (Knowles, 1978), this study was conducted to provide information about genetic control of head inclination in sunflower. This information is valuable in selection of suitable parental lines for development of hybrids with desirable architectures in sunflower breeding programs.

MATERIALS AND METHODS

The experiment was carried out in growing season 2018 at Seed and Plant Improvement Institute (SPII), Karaj, Iran. Twelve sunflower single cross hybrids and seven parents of inbred lines; four cytoplasmic male sterile lines as the Lines (L) and three restorer lines as testers (T) (Table1) with different head inclination, obtained from Oilseed Crops Research Department, Seed and Plant Improvement Institute (SPII) (Ghaffari *et al.*, 2017), were evaluatedusing randomized block design with three replications in a line × tester (L ×T) mating design.

Each experimental plot consisted of four rows of four meters length and 60 × 25 cm between and within row spacing. Fertilizers were applied at the rate of 100:75:100 kg ha^{-1} N: P: K, respectively. Plant characteristics including head diameter and weight, plant and head height, achene yield, inclined length and head inclination were measured at the time of physiological maturity as is shown in Fig. 1.

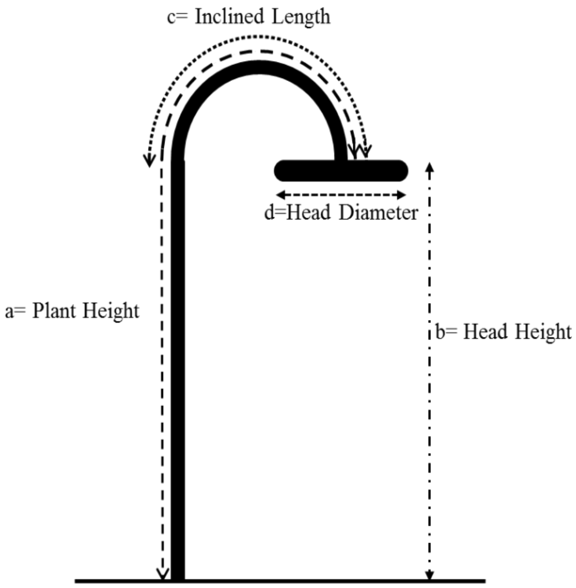

Fig.1. A schematical sunflower plant displays the measurements related to head inclination.

Inclined length considered from turning point of stem to head. Head inclination calculated using equation.

$$\text{Head Inclination} = \frac{\text{Plant Height-Head height}}{\text{Plant height}} \times 100 \quad (1)$$

Head weight included the weight of whole head and all the filled achenes on it. Achene yield was estimated based on plot yield after excluding margins.

To estimate genetic components for the measured characteristics, the collected data was subjected to the line × tester analysis (Kemptorne, 1977 and Singh and Chaudhary, 1997) using the following equations.

$$\sigma^2 A = 2(MSL+MST-2MSLT)/(rl+rt) \quad (2)$$

$$\sigma^2 D = (MSLT-MSe)/r \quad (3)$$

Where σ^2A and σ^2D represent additive and dominant variance; MSL, MST, MSLT and MSe represent mean square for lines, testers, line ×tester interaction and experimental error, respectively. r, l and t represent number of replication, lines and testers, respectively.

$$h_B^2 = \frac{\sigma_G^2}{\sigma_G^2 + \sigma_e^2} \quad (4)$$

$$h_N^2 = \frac{\sigma_A^2}{\sigma_A^2 + \sigma_D^2 + \sigma_e^2} \quad (5)$$

$$\bar{A} = \sqrt{\frac{2\sigma_D^2}{\sigma_A^2}} \quad (6)$$

Where σ^2_G is genetic variance, h2B, and h^2_N are broad sense and narrow sense heritability, respectively.

Data were analyzed using SPSS (Ver. 24).

Table 1. The list of single cross hybrids and their parental lines of sunflower

No.	Hybrid	No.	Hybrid
1	RGK33 × AGK344	7	RGK25 ×AGK344
2	RGK15 × AGK354	8	RGK111 × AGK2
3	RGK15×AGK370	9	RGK21 ×AGK376
4	RGK21×AGK110	10	RGK33 × AGK354
5	RGK15 × AGK356	11	RGK25 × AGK376
6	RGK21 × AGK356	12	RGK21 × AGK38
No.	Parental line	No.	Tester line
1	AGK46	1	RGK15
2	AGK110	2	RGK21
3	AGK356	3	RGK33
4	AGK370		

RESULTS AND DISCUSSION

Analysis of variance revealed significant differences among the sunflower genotypes for head inclination and all the related traits (Table 2) indicating considerable variation among the hybrids, parental and tester lines. This variation made further examination possible by using L × T analysis. Significant differences were observed among the parents and hybrids for the measured traits except for inclined length in hybrids. There were also significant differences among the restorers and CMS lines for head inclination and most of the related traits. Significant differences between restorers and CMS lines indicated higher variation in female and male parental inbred lines for all of the studied traits. There were also significant differences among the lines for head diameter, head weight and plant height and among the testers for all studied traits except inclined length, which confirmed the additive gene action in inheritance of these traits.

Table 2. Analysis of variance for some components of head inclination in sunflower hybrids and parental lines

S.O.V.	df	Head diameter	Head weight	Plant height	Head height	Achene yield	Inclined length	Head inclination
Replication	2	20.3**	21.9*	337.6**	662.2**	60.7*	255.2*	132.1**
Genotype	18	36.0**	319.1**	2226.7**	1994.6**	593.3**	501.3**	314.5**
Parent (P)	6	14.3**	56.2**	957.9**	2719.1**	249.1**	856.6**	851.8**
Restorer (R)	2	0.8	18.0	196.3**	379.0**	0.8	610.3**	316.3**
CMS	3	7.4**	5.6	573.6**	370.0**	212.9**	110.3	76.1*
R vs. CMS	1	62.0**	284.4**	3634.3**	14446.3**	854.1**	3588.9**	4250.9**
Hybrid (H)	11	10.1**	40.1**	426.5**	458.2**	57.0**	111.3	48.8*
Line (L)	3	5.7*	104.0**	141.7**	97.1	38.3	98.5	17.1
Tester (T)	2	34.8**	58.1**	1141.0**	1776.0**	132.1**	133.0	146.3**
L × T	6	4.0*	12.0	330.7**	199.5*	42.3*	98.5	32.2
P vs H	1	451.6**	4966.8**	29640.7**	14547.9**	8558.8**	2657.4**	11.4
Error	36	1.6	6.0	26.6	67.1	17.1	56.3	19.4
C. V. (%)		7.2	9.1	3.5	7.8	12.2	18.1	15.3

*and **: Significant at the 5% and 1% probability levels, respectively.

Significant L × T interaction effects on head diameter, plant and head height, and achene yield indicated that non-additive actions, in addition to additive action, in inheritance of these traits. Memon *et al.* (2015) and Rameeh and Andarkhor (2017) also estimated the degree of dominance more than one for seed and oil yield components of sunflower which confirms the importance of non-additive gene action for these traits. These results indicated that hybrid breeding will be more effective for improving of these traits. There were significant differences between the parents and hybrids for all of the studied traits except head inclination which implies the expression of considerable heterotic for these attributes.

Proportional partitioning of sum of squares for different traits showed that the lines contributed more than other sources in observed variation for head weight (62.4%) in hybrids while contribution of the testers was greater for head diameter (62.8%), plant height (48.6%), head height (70.5%), achene yield (41.7%) and head inclination (54.5%) (Fig. 2). The relative contribution of the L × T interaction was the highest for inclined length (63.9%). These results illustrated the important role of testers on head inclination than lines and L × T interactions.

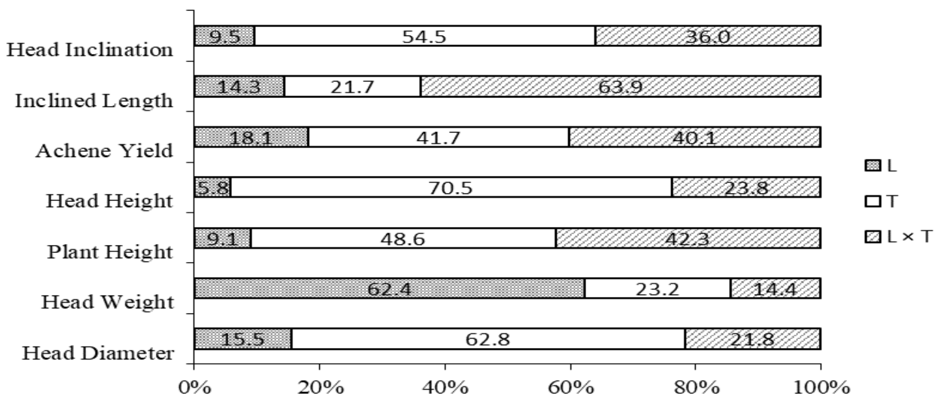

Fig. 2. Contribution of lines and testers to variation of head inclination and related traits in sunflower hybrids and their parental lines

Mean comparison for hybrids showed that RGK33 × AGK370 (23.7%) and RGK33 × AGK356 (24.0%) had the lowest head inclination, respectively (Table 3). Unlike the parental lines, all hybrids had head inclination in desired range (15-36%) which is suitable for minimizing sun and bird damage to florets and seed set of sunflower (Knowles, 1978). Except

RGK33 and AGK356 which had suitable head inclination (25-35%), head inclination of the rest of parental lines were lower (5-9%) in RGK15 and while AGK46, and higher (41-46%) in AGK110 and AGK370. These results indicated that crossing the lines with unsuitable head inclination may lead to the production of hybrids with suitable head inclination.

Table 3. Mean comparison of head inclination and the related components for sunflower hybrids and parental lines

Hybrid/Parent	Head diameter (cm)	Head weight (g)	Plant height (cm)	Head height (cm)	Achene yield (g.head^{-1})	Inclined length (cm)	Head inclination (%)
RGK15×AGK46	19.7	36.0	154.0	105.7	41.5	48.3	31.3
RGK15×AGK110	19.0	32.0	152.0	111.0	44.9	41.0	27.0
RGK15×AGK356	20.3	29.7	138.3	90.3	39.7	48.0	35.0
RGK15×AGK370	21.3	35.7	167.3	107.0	48.6	60.3	36.0
RGK21×AGK46	15.0	38.7	165.7	118.3	46.7	47.3	28.3
RGK21×AGK110	17.8	34.3	173.7	129.3	35.7	44.3	25.3
RGK21×AGK356	17.3	29.3	179.0	123.7	37.1	55.3	31.0
RGK21×AGK370	16.7	37.0	165.3	122.7	39.2	42.7	26.0
RGK33×AGK46	18.0	41.3	177.7	130.3	46.5	47.3	26.7
RGK33×AGK110	16.0	36.3	157.7	114.7	47.1	43.0	27.7
RGK33×AGK356	18.7	34.0	164.3	124.7	44.9	39.7	24.0
RGK33×AGK370	19.3	39.0	174.0	132.3	46.6	41.7	23.7
RGK15	10.3	9.3	128.7	113.0	10.2	15.7	9.0
RGK21	13.7	11.6	108.3	65.3	10.1	43.0	5.3
RGK33	11.0	14.2	120.7	99.3	11.0	21.3	24.7
AGK46	12.3	18.2	120.0	78.3	17.3	41.7	41.7
AGK110	11.7	21.0	109.3	77.7	22.8	31.7	45.7
AGK356	13.7	18.0	132.7	100.7	17.8	32.0	34.7
AGK370	14.3	19.3	98.0	56.3	35.4	41.7	45.0
LSD 5%	2.1	4.1	8.5	13.6	6.8	12.4	7.3
LSD 1%	2.8	5.4	11.5	18.2	9.2	16.7	9.8

The highest head inclination observed in RGK33 × AGK370 that also had the highest achene yield (48.6 g head^{-1}) which implied considerable effect of achene yield on head inclination. This was also true for parental inbred lines that two inbred lines; AGK110 (22.8 g head^{-1}) and AGK370 (35.4 g head^{-1}) with higher achene yield, respectively, had the highest head inclination percentage (45.7 and 45%, respectively). It implied that there are relationships between plant characteristics and head inclination. To examine this, a correlation analysis was performed, and the results were contrary to expectations. Although there were significant correlation between inclined length with head diameter, head weight, head height and achene yield, there was no significant correlation between head inclination and the measured traits (Table 4.). It was interpreted that factors other than agronomic traits such as stem tissue or genetic play important role in head inclination that should be taken into account in future studies.

Table 4. Correlation coefficients between head inclination and the related traits in sunflower hybrids and parent lines

	Head diameter	Head weight	Plantheight	Head height	Achene yield	Inclined length
Head diameter	0.692**					
Head weight	0.453	0.920**				
Plant height	0.798**	0.849**	0.681**			
Achene yield	0.836**	0.734**	0.532*	0.938**		
Inclined length	0.769**	0.521*	0.145	0.665**	0.703**	
Head inclination	0.091	-0.159	-0.313	0.145	0.236	0.287

* and **: Significant at the 5% and 1% probability levels, respectively.

Partitioning of genetic variance to its component demonstrated that additive gene action had significant effect on inheritance of head inclination and its components (Table 5). Except for inclined length, estimated additive variances were significant for all of the other related traits. Non-additive gene action was also significant for head diameter, plant height, head height and achene yield which indicated both additive and non-additive gene action for inheritance of these traits. Additive gen action for expression of head diameter is reported by Machikowa *et al*. (2011) and Tabrizi *et al.* (2012). This means that appropriate selection of lines during inbreeding process could result in plants with desired head diameter.

The optimum head size in sunflower hybrids is between 20-30 cm and beyond this range lead to a decrease in achene yield mainly due to increase of empty seeds (Skoric, 2012). Although Fick and Miller (1992) reported that inheritance of this trait is influenced less by genetic factors than agronomic traits, however higher heritability estimates for head characteristics (Table 5) in this study suggest that in addition to environmental factors, genetic factors and their interaction could affect expression of this attribute in sunflower.

Table 5. Genetic variance components of head inclination and related traits in sunflower hybrids

	Head diameter	Head weight	Plant height	Head height	Achene yield	Inclined length	Head inclination
V (A)	3.09^{**}	13.15^{**}	59.17^{**}	140.38^{**}	8.35^{**}	3.29^{ns}	9.43^{**}
SE 5%	1.04	3.24	35.11	52.59	4.19	5.51	4.43
SE 1%	1.38	4.31	46.70	69.94	5.57	7.33	5.89
V (D)	0.80^{*}	2.01^{ns}	101.35^{**}	44.13^{**}	8.42^{*}	14.08^{ns}	4.25^{ns}
SE 5%	0.79	2.38	63.69	38.85	8.29	19.60	6.43
SE 1%	1.05	3.16	84.70	51.67	11.02	26.07	8.55
Dominance	0.72	0.55	1.85	0.79	1.39	2.93	0.95
h^2_B	0.71	0.72	0.86	0.73	0.49	0.24	0.41
h^2_N	0.56	0.62	0.32	0.56	0.24	0.04	0.28

V (A): Additive variance, V (D): Dominance variance, h^2_B and h^2_N indicate broad and narrow sense heritability, respectively.

Plant height as an important characteristics of plant architecture and yield formation of sunflower (Skoric *et al.*, 2012) was under control of both types of gene action (Table 5). Gvozdenovic *et al.* (2005), Farrokhi *et al.* (2008) and Dhillon and Tyagi (2016) reported that non-additive component played the main role in inheritance of plant height. The value of dominance for this trait was more than one (1.85) which implies that heterosis breeding, in addition to selection, can be effective in improvement of plant height in sunflower. Taller plants may lodge particularly when heads are of larger size and heavier (Fick and Miller, 1997).

Considering the positive correlation of plant height with achene yield (Chikkadevaiah *et al.*, 2002; Mijic *et al.*, 2009; Ghaffari *et al.*, 2012) defining optimum plant height is one of the main challenging issues in sunflower breeding. Achene yield as the final economic product constitutes the major part of head weight and can affect head bending in sunflower. In addition, both additive and non-additive gene action, higher value of dominance (1.39) was observed for this trait which is in agreement with the findings of Kandalkar (1997). There are reports that confirm the importance of non-additive than additive gene action in inheritance of achene yield of sunflower (Devi *et al*., 2005; Ghaffari *et al.*, 2011).

There was significant additive gene action for inheritance of head inclination that is in accordance with Kovacik and Skaloud (1980) who reported that head angle of sunflower is under control of four major genes that act additively. This indicates the importance of selection of inbred lines for development of new hybrids with appropriate head inclination (15-35%) (Knowles, 1978).

There was partial dominance involved in inheritance of head inclination and lower heritability effects indicated environmental effects on inheritance of this trait. These results complicate selection for head inclination during inbreeding process of parental inbred lines. Therefore, efficient morphological markers highly correlated with head inclination in parental lines are required to guarantee desired expression of this trait in hybrids. Decision in this concept requires information about relationship of related components with head inclination.

As most of the traits are highly related to the achene yield as the ultimate goal in sunflower breeding, it is important to consider ideo-type development based on selection for each characteristic during inbreeding process. Some of the ideal measures for these traits have been defined, as for head diameter (20-30 cm) (Skoric 2012), but there is lack of information for other components as head weight or head thickness, which can affect head inclination in sunflower. Considering the higher heritability estimates for head weight, it can be a potential morphological criterion for selection during inbreeding process. This trait is under control of additive gene action and selection of parental inbred lines with optimum head weight can result in suitable head inclination. Other attributes such as head thickness or stem tissue can also have significant effects on head weight and head inclination in sunflower, therefore, further studies on this trait is required.

Broad sense heritability was higher for plant height (0.86), head weight (0.72), head height (0.73) and head diameter (0.71) (Table 5) which showed considerable effect of genetic factors on inheritance of these characteristics. In contrast, heritability estimates for head inclination was relatively low (0.41 and 0.28 for broad and narrow sense heritability, respectively), indicated likely effects of other factors on inheritance of this trait. It is well established that the higher the heritability of a trait the higher success in selection for that trait in earlier generations under field conditions (Mijic *et al.*, 2009).

CONCLUSIONS

The results of the present study revealed significant differences among the sunflower genotypes for head inclination and all related traits. These variation among the genotypes facilitated further analysis by using L × T analysis. Among hybrids, RGK33 × AGK370 (23.7%) and RGK33×AGK356 (24.0%) had the lowest head inclination, respectively. Unlike the parent lines, all hybrids had head inclination in suitable range (15-36%) considering sun and bird damages to florets and to seed set on capitulum.

Among the parent lines, RGK33 and AGK356 had suitable head inclination, RGK15 and RGK21 had lower (5-9%) while AGK46, AGK110 and AGK370 had higher (41-46%) head inclination. This indicated that it is possible to develop hybrids with suitable head inclination through crossing parental lines with undesirable head inclination. There was no significant correlation between head inclination and other traits suggesting that factors other than agronomic traits may affect head inclination.

The results showed that head inclination is controlled mainly by additive gene action which implies the important role of selection for improvement of parental lines with desirable head inclination. Both additive and non-additive gene actions were significant for head diameter, plant height, head height and achene yield. There was over dominance gene action for plant height, achene yield and inclined length, and partial dominance for head diameter, head weight, head height and head inclination. Broad sense heritability estimates were higher for plant height (0.86), head weight (0.72), head height (0.73) and head diameter (0.71). However, lower heritability estimates for inclined length, achene yield and head inclination indicated environmental effects on inheritance of these traits. All developed hybrids by crossing of restorer lines RGK21 and RGK33 with maternal lines had suitable head inclination as compared with the progenies of RGK15.

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