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Heterosis and combining ability for bushy and butternut traits in pumpkin (*Cucurbita moschata*)

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ABSTRACT

The improvement of pumpkin(*Cucurbita moschata* Duch ex Poir.) for intensive cultivation necessitates genetic studies, wherein, heterosis and combing ability were studied in half di-allel fashion involving bushy plants and butternut fruits. The genotypes, P-3621 was best general combiner for short vine, internode, equatorial diameter and high fruit shape index, P-6242 for pulp thickness, P-2211 for number of primary branches, P-10224 for polar diameter as well as vegetative growth and P-1343 for petiole length. However, high specific combining ability (SCA) in P-10224 × P-6242, PS × P-6242, P-41212 × P-2211, PS × P-364, P-41212 × P-6242, P-10224 × P-2211 revealed the occurrence of both additive and non-additive gene effects with the predominance of non-additive effects (σ2SCA/ σ2GCA >1) in the inheritance of bushy and butternut traits, which can be exploited through heterosis breeding and recurrent selection in pumpkin. The hybrids, P-3621 × P-2211, P-6711 × P-2211 and P-6711 × P-6242 had high pulp thickness as well as comparable yield potential with the check hybrids and could be exploited for commercial cultivation.

Key words: Bushy vines, Butternut fruit, Combing ability, Heterosis, Pumpkin

Pumpkin (*Cucurbita moschata* Duch ex Poir., 2n=40) is known as *Halwa kaddu*, *Sita Phal*, *Misti kumra* or *Misti lau* or *Misti kadu*, in India. Among 27 species of genus *Cucurbita*, it is acknowledged for long vines and big summer hardy fruits conspicuously with large seed cavity and long storage life (Pandey *et al.* 2003). The vigorous growth habit, occupying more space, leads to less number of plants per unit area. The second practical problem is large fruit that face problem during marketing as one piece. It makes this nutraceutical rich vegetable an uneconomical and unhygienic. Therefore, to counter these issues, dwarf plants bearing small fruits are required.

The butternut group of pumpkin has dwarf vines and thick-fleshed fruits. Bushy nature in pumpkin is controlled by a dominant gene (Li *et al.* 2007, Wu *et al.* 2007) and is worth to exploit through heterosis breeding. Therefore, assessment of combining ability (GCA and SCA) is prerequisite, which not only provides certain cross combinations with relatively better performance than expected average, but also unveils the occurrence of additive and non-additive genetic variances. Although, information is available on genetic variability, combining ability and heterosis breeding in pumpkin (Pandey *et al.* 2003 , 2010), but attempt has not been made to explore bushy nature, butternut shape and smaller sized fruits of pumpkin in the country. Therefore, combining ability and economic heterosis studies involving the bush and butternut type genotypes were planned to understand the genetic behaviour of these traits in pumpkin.

MATERIALS AND METHODS

The experimental material consisted of nine parents. The passport information of all the parents is given in Table 1. During first season (Feb-June 2015), parental lines were grown in crossing block and all possible crosses were made following di-allel mating design with exclusion of reciprocals [n (n-1/2)], along with selfing of individual parents for their maintenance. Seeds of different crosses were harvested separately and stored for next season planting. In second season (February 2016), all F1 hybrids and their parents were grown in randomized block design with three replications as suggested by Snedecor and Cochran (1967). The bush type parents and their crosses were transplanted at 1.5 × 0.45 m (row × plant) spacing on both sides of the beds, while vine parents and their crosses were raised at 3 × 0.60 m (row × plant) spacing on both side of beds, accommodating 10 plants per replication. The observations such as short vine, number of primary branches, internodal length, leaf length, leaf width, petiole length, polar diameter, equatorial diameter and pulp thickness were recorded on five randomly selected plants.

The analysis of variance for randomized block design as well as combining ability was done for all the characters as

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Table 1 Description of parents on basis of growth habit and fruit traits

Parents	Code	Vines	Fruits shape	Fruit size
Punjab Samrat	PS	Medium long and vigorous	Flat round	Medium
BUMOV-41212-3-1	P-41212	Medium	Oval	Medium
BN-364	P-364	Bush type	Butternut	Small
P-1343-17-5-3	P-1343	Medium long and vigorous	Flat round	Medium
MVSR 6711-14-2	P-6711	Bush type	Flat round	Small
MSBN-3621-9-3-1	P-3621	Bush type	Butternut	Small
B-10-224-3	P-10224	Long and vigorous	Flat round	Very big
MBN-6242-3-1	P-6242	Long and vigorous	Butternut	Medium
CFR-2211-2	P-2211	Bush type	Flat round	Small to medium

per the method given by Griffin (1956). The data pertaining to bush and butternut traits was compiled and subjected to BMM software developed by Singh (1993) for testing the significance of differences for general combing ability (GCA) and specific combining ability (GCA) among parents and F1 hybrids, respectively. The economical heterosis was calculated over cultivated hybrids (PPH-1 and PPH-2) as checks and expressed as percentage increase or decrease in the mean performance of hybrids.

RESULTS AND DISCUSSION

Analysis of variance for the experimental design for various bushy and butternut traits highlighted the outcome of highly significant genotypic coefficient of variance for all the traits under exploration. Analysis of variance for combining ability revealed highly significant mean square values for GCA and SCA, where σ^2SCA/ σ^2GCA was >1 (Table 2). Highly significant genotypic coefficient of variance confirmed the substantial amount of variation for bushy growth and butternut fruit traits in the inbred lines selected for the present exploration. Highly significant mean square values for GCA and SCA indicated the involvement of both additive and non-additive gene effects in the inheritance of the traits under scrutinization. The greater ratio of σ^2SCA/ σ^2GCA (>1) also suggested that the inheritance of most of the traits were controlled under preponderance of non-additive gene effects. These results were substantiated with the findings in sponge gourd (Ram *et al.* 2007, Naliyadhara *et al.* 2010).

GCA effects of parents

The GCA effects of various bushy and butternut traits were presented in Table 3. P-3621 being bushy and butternut parent was best general combiner for short vine length (-47.83), internodal length (-0.80), petiole length (-1.84) and equatorial diameter (-2.29) as well as good general combiner for number of primary branches (0.07) and polar diameter (0.43). Bushy and flat round parent P-2211 was best combiner for number of primary branches (0.14) and polar diameter (1.75) as well as good general combiners for short vine (-22.85), leaf length (0.39) and pulp thickness (0.21). Bushy and round fruited, P-6711, was good general combiners for short vine (-9.05), petiole length (-1.41), number of primary branches (0.09) and pulp thickness (0.05). Butternut and vine parent, P-6242 was the best combiner for pulp thickness (0.44) as well as good general combiner for leaf length (0.71), leaf width (0.99) and polar diameter (0.19). Bushy and butternut parent P-364 was good general combiner for leaf dimensions (0.44 and 0.56, respectively) and equatorial diameter (-0.98). Medium vine and flat round fruited, P-1343, was good general combiner for short vine (-43.80), internodal length (-0.50), petiole length (-2.48) number of primary branches (0.13) and equatorial diameter (-2.02).

Table 2 Analysis of variance for experimental design and combining ability of different bushy growth and butternut fruit traits

Observation	GCA	SCA	Error	Components of genetic variance			GCV	PCV
				σ2GCA	σ2SCA	σ2SCA/ σ2GCA		
Short vine (cm)	12358.4**	4903.19**	62.73	5.06	41.66	8.23	72.46	73.55
Internodal length (cm)	1.90**	2.64**	0.05	0.004	0.035	8.75	47.80	49.36
Leaf length (cm)	6.76**	2.28**	0.18	0.01	0.11	11	11.71	12.75
Leaf width (cm)	12.29**	3.70**	0.01	0.03	0.25	8.33	10.66	11.86
Petiole length (cm)	39.22**	9.22**	0.84	0.06	0.55	9.16	14.38	15.64
No. of primary branches	0.25**	0.18**	0.08	0.001	0.008	8	12.63	13.96
Polar diameter (cm)	35.17**	26.78**	0.009	0.0007	0.006	8.57	33.85	33.86
Equatorial diameter (cm)	28.62**	15.44**	0.008	0.0006	0.005	8.33	28.47	28.49
Pulp thickness (cm)	0.98**	0.31**	0.003	0.0002	0.002	10	25.51	25.80

*, ** Significant at 5% and 1% levels, respectively.

Table 3 General combining ability effects of the parents for bushy growth and butternut fruit traits

Genotypes	VL (cm)	IL (cm)	LL (cm)	LW (cm)	PL (cm)	NPB	PD (cm)	ED (cm)	PT (cm)
PS	22.30**	0.33**	-0.30*	-0.30	-1.38**	-0.29**	-0.02	-0.50**	-0.07
P-41212	38.52**	0.39**	0.45**	0.46**	1.12**	0.02	-1.06	1.12	0.23**
P-364	-3.21	-0.02	0.44**	0.56**	2.17**	-0.04	-0.63	-0.98**	-0.22
P-1343	-43.80**	-0.50**	-1.33**	-1.94**	-2.48**	0.13**	-1.50	-2.02**	-0.40
P-6711	-9.05**	0.10	-0.87**	-0.91**	-1.41**	0.09**	-2.60	0.41	0.05**
P-3621	-47.83**	-0.80**	-0.48**	-0.47**	-1.84**	0.07*	0.43**	-2.29**	-0.40
P-10224	35.45**	0.44**	0.97**	1.56**	2.06**	0.04	3.43**	1.50	0.16**
P-6242	30.47**	-0.01	0.71**	0.99**	2.15**	-0.19**	0.19**	2.54	0.44**
P-2211	-22.85**	0.06	0.39**	0.04	-0.39	0.14**	1.75**	0.20	0.21**
CD (P = 0.05)	4.47	0.13	0.23	0.35	0.51	0.06	0.05	0.05	0.03
CD (P = 0.01)	5.86	0.17	0.31	0.45	0.68	0.08	0.07	0.06	0.04

*, ** Significant at 5% and 1% levels, respectively.

GCA effects of parents for short vine, reduced internodal length, more leaf length and width with short petiole and more number of primary branches were desirable to initiate breeding programme for bushy vines in pumpkin. However, for the development of inbreds with butternut fruit type on bushy vines in pumpkin, GCA effects of parents for high polar diameter and pulp thickness, while reduced equatorial diameter were desirable. The higher general combining ability (GCA) of particular parent in a series of hybrid combinations suggested the greater concentration of predominantly additive genes that lead to high frequency gene flow from one to further generations for better selections. Therefore, P-3621 had potential for generating breeding populations for bushy growth and butternut fruit shape due to its higher estimates of GCA for short vine, internodal length, petiole length, and equatorial diameter and for more number of primary branches, polar diameter, and fruit shape index. However, P-2211 (bushy and round fruited) has prospectively high additive gene effects for the improvement of short vine, leaf growth, less petiole length, number of primary branches, polar diameter and more pulp thickness. The genotype, P-6242 (vine and butternut parent) has great potential for improving vegetative growth, polar diameter and pulp thickness. These parents with high GCA for above mentioned traits can also be used in suitable combinations for developing highly heterotic hybrids for bushy growth and butternut fruit type. High estimates of GCA were earlier presented for long vines and big round fruits in pumpkin (Nisha and Veeraragavathatham 2014, Hussien and Hamed 2015, Tamil Selvi *et al.* 2015), luffa (Tyagi *et al.* 2010), bottle gourd (Janaranjani *et al.* 2016) and watermelon (Bahari *et al.* 2012), but this study concentrated on bushy growth and butternut fruit type in pumpkin with the emphasis on economical fruit size under intensive cultivation. The results for more leafy growth can be substantiated with the findings of El-Tahawey *et al.* (2015) in pumpkin.

SCA effects of F_1 hybrids

Among the F_1 hybrids involving bushy and butternut parent (Table 4), P-10224× P-6242 was best specific combiner for polar diameter (15.41) and equatorial diameter (-6.98) as well as good specific combiner for short vine (-68.01), internodal length (-1.47), petiole length (-2.72) and number of primary branches (0.28). PS × P-6242 was good specific combiner for most of the traits such as short vine (-39.44), internodal length (-0.74), leaf length (0.98) and width (2.29), petiole length (-2.66), polar diameter (9.26) and equatorial diameter (-4.51) related to bushy growth habit and butternut fruit shape except number of primary branches and pulp thickness. P-41212 × P-2211 was good specific combiner for short vine (-60.65), internodal length (-1.05), leaf width (1.05), polar diameter (1.14) and equatorial diameter (-3.96) as well as average specific combiner for leaf length (0.33) and petiole length (-0.75). PS × P-364 was best specific combiner for petiole length (-5.51) as well as good specific combiner short vine (-85.00), internodal length (-1.57), number of primary branches (0.16) and equatorial diameter (-2.31). P-41212 × P-6242 was best specific combiner for short vine (-111.72) as well as good specific combiner internodal length (-1.12), petiole length (-2.65), number of primary branches (0.40) and pulp thickness (0.83). P-10224× P-2211 was good specific combiner for most of the bushy and BN traits such as short vine (-72.14), internodal length (-1.11), petiole length (-2.03), polar diameter (1.56) and equatorial diameter (-4.23).

In present investigation, highly significant SCA effects for short vine and other bushy traits and butternut fruit were observed in P-10224× P-6242, PS × P-6242, P-41212 × P-2211, PS × P-364, P-41212 × P-6242 and P-10224× P-2211. The involvement of both poor combiners for short vine, petiole length, and equatorial diameter in P-10224× P-6242, for short vine in PS × P-6242, for internodal length and equatorial diameter in P-41212 × P-2211, for number of primary branches in PS × P-364, for short vine and petiole

Table 4 Specific combining ability effects of F1 hybrids for bushy growth and butternut fruit traits

F1 hybrids	VL (cm)	IL (cm)	LL (cm)	LW (cm)	PL (cm)	NPB	PD (cm)	ED (cm)	PT (cm)
PS × P-364	-85.00**	-1.57**	-1.19**	-0.45	-5.51**	0.16	-5.99	-2.31**	-0.28
PS × P-6242	-39.44**	-0.74**	0.98**	2.29**	-2.66**	-1.23**	9.26**	-4.51**	-0.69
P-41212 × P-3621	79.89**	0.56**	0.69*	1.68**	4.60**	-0.05	2.11**	3.84	0.28**
P-41212 × P-6242	-111.72**	-1.12**	-1.24**	-1.55**	-2.65**	0.40**	-2.88	0.24	0.83**
P-41212 × P-2211	-60.65**	-1.05**	0.33	1.05*	-0.75	-0.06	1.14**	-3.96**	-0.82
P-364× P-6711	-25.92**	-0.93**	1.85**	1.80**	0.67	-0.41**	-0.23	0.22	0.18**
P-364× P-3621	-18.58**	0.21	0.77*	0.64	4.87**	0.18	1.02**	-1.16**	-0.25
P-364× P-2211	35.99**	1.06**	0.36	0.39	-0.90	-0.12	3.07**	2.14	0.34**
P-6711× P-3621	2.24	0.51**	0.187	-1.30*	-1.18	-0.53**	1.69**	-1.78**	0.01
P-6711× P-6242	31.51**	0.73**	-1.03**	-0.84	2.38**	0.50**	2.62**	-0.49**	-0.70
P-6711× P-2211	31.39**	0.16	0.72*	1.10*	1.92*	0.06	1.90**	4.56	1.04**
P-3621 × P-6242	-55.03**	-0.56**	-1.45**	-1.62**	0.09	0.10	-6.33	-1.44**	0.03
P-3621 × P-2211	-50.94**	-0.60**	-2.03**	-2.76**	-2.49**	0.16	-8.12	-0.77**	-0.11
P-10224× P-6242	-68.01**	-1.47**	-1.42**	-1.17*	-2.72**	0.28**	15.41**	-6.98**	-0.87
P-10224× P-2211	-72.14**	-1.11**	-0.45	-0.02	-2.03**	-0.06	1.56**	-4.23**	-0.17
CD (P = 0.05)	12.72	0.37	0.68	0.99	1.47	0.18	0.15	0.14	0.09
CD (P = 0.01)	16.69	0.49	0.89	1.30	1.93	0.24	0.20	0.18	0.12

*, ** Significant at 5% and 1% levels, respectively. (Only data of best 15 hybrids is presented)

length in P-41212 × P-6242 and for internodal length and equatorial diameter in P-10224× P-2211 unconcealed high SCA due to the predominance of non-additive gene effects for the inheritance of these traits in mentioned crosses and suggested its exploitation through heterosis breeding for these traits related to bushy and butternut traits in pumpkin. Similar results of higher SCA with non-additive gene effects for long vines, number of primary branches, fruit length and diameter, pulp thickness were earlier presented in pumpkin (Nisha and Veraragavathatham 2014, Hussien and Hamed 2015, Tamil Selvi *et al.* 2015), luffa (Tyagi *et al.* 2010), and watermelon (Bahari *et al.* 2012), but this study was concentrated on bushy growth of pumpkin for promoting intensive cultivation. The connection of one good or average and one poor combiner for fruit shape index, internodal length and number of primary branches in P-10224× P-6242, for internodal length, leaf length and width, petiole length, polar diameter and equatorial diameter in PS × P-6242, for short vine, leaf width, polar diameter, and petiole length in P-41212 × P-2211, for short vine, petiole length, internodal length in PS × P-364, for internodal length and number of primary branches in P-41212 × P-6242, for short vine and petiole length in P-10224× P-2211 disclosed the preponderance of both additive and non-additive gene effects for the inheritance of these traits in mentioned crosses and suggested the exploitation of these gene effects through heterosis breeding and recurrent selection for high SCA especially in these crosses for improvement in bushy and butternut traits in pumpkin. Similar findings for both types of gene effects were earlier reported in bottle gourd (Janaranjani *et al.* 2016). The union of both good combiners for polar diameter in P-10224× P-6242, for leaf length and leaf width in P-41212 × P-2211, for pulp thickness in P-41212 × P-6242 and for polar diameter in P-10224× P-2211 revealed the prevalence of additive and additive × additive gene effects for the inheritance of these traits in discussed crosses and recommended the utilization of these gene effects through hybridization followed by selection for the improvement of bushy and butternut traits in pumpkin. High additive genetic variance for leaf area, fruit dimensions and pulp thickness has been earlier reported in pumpkin (Hussien and Hamed 2015, El-Tahawey *et al.* 2015)

Economic heterosis (%)

Among 36 crosses, the magnitude of economic heterosis for short vines, internodal length, leaf length, leaf width, petiole length and number of primary branches over PPH-1 and PPH-2 ranged from -62.42 to 342.62%, -46.28 to 248.71%, -13.13 to 57.69%, -8.37 to 56.06%, -7.02 to 69.75%, and -20.75 to 67.84%, respectively (Table 5). Emphasizing the objective of present investigation, the maximum economic heterosis over both checks for short vines was observed in P-364× P-6711 (-62.42 and -51.54%, respectively), followed by P-364× P-2211 (-60.82 and -49.48%, respectively) and P-6711× P-3621 (-54.05 and -40.76%, respectively), P-41212 × P-3621 (-53.38 and -39.89 respectively), P-6711× P-2211 (-51.79 and -37.84 respectively), P-364× P-3621(-51.79 and -37.84, respectively), P-6711× P-6242 (-50.73 and -36.47, respectively) and P-3621 × P-2211(-47.28 and -32.02,

Table 5 Economic heterosis (%) of F1 hybrids for traits related to bushy growth habit and butternut fruit type

F1 Hybrids	VL (cm)		IL (cm)		LL (cm)		LW (cm)		PL (cm)		NPB		PD (cm)		ED (cm)		PT(cm)	
	PPH-1	PPH-2	PPH-1	PPH-2	PPH-1	PPH-2	PPH-1	PPH-2	PPH-1	PPH-2	PPH-1	PPH-2	PPH-1	PPH-2	PPH-1	PPH-2	PPH-1	PPH-2
PS × P-364	-7.44	19.34	16.23	-3.88**	6.45**	22.75**	14.50**	29.36**	25.54	14.74	-14.5	20.84**	-0.22	19.81**	-15.57**	0.89	-33.55	-0.48
PS × P-6242	114.19	176.19	46.58	21.20	11.81**	28.93**	20.24**	35.86**	50.53	37.58	-14.5	20.84**	29.03**	54.95**	19.11	42.35	-12.37	31.21**
P-41212 × P-3621	-53.38**	-39.89**	14.10	-5.65**	12.39**	29.61**	15.25**	30.21**	57.15	43.64	-10.5	26.5**	24.00**	48.91**	-29.31**	-15.52**	-44.62	-17.07
P-41212 × P-6242	112.74	174.31	58.97	31.44	28.83**	48.56**	38.13**	56.06**	66.05	51.77	-20.75	12.01**	30.53**	56.75**	-3.87**	14.87	0.97**	51.21**
P-41212 × P-2211	-15.81	8.55	3.41	-14.48**	17.46**	35.44**	19.06**	34.52**	38.08	26.21	-25	6.00**	-8.70	9.63**	-1.42**	17.80	-15.3	26.82**
P-364 × P-6711	-62.42**	-51.54**	-12.82**	-27.91*	-8.87	5.07**	0.32	13.34**	1.77	-6.98**	-25	6.00**	-21.75	-6.03	-2.84**	-14.83**	-26.71	9.75**
P-364 × P-3621	-51.79**	-37.84**	-23.07**	-36.39**	3.00**	18.78**	4.51**	18.08**	14.11	4.29	-12.5	23.67**	45.01**	74.14**	-37.89**	-25.77**	-44.29	-16.58
P-364 × P-2211	-60.82**	-49.48**	-35.04**	-46.28**	3.15**	18.95**	6.39**	20.20**	9.10	-0.27	-25	6.00**	-23.70	-8.37	-13.53**	3.33	-26.71	9.75**
P-6711 × P-3621	-54.05**	-40.76*	-15.38**	-30.03**	-2.56	12.35**	5.37**	19.05**	1.71	-7.02**	-8.25	29.68**	36.75**	64.23**	-20.88**	-5.44**	-34.85	-2.43
P-6711 × P-6242	-50.73**	-36.47**	0.00	-17.31**	-0.07	15.22**	8.37**	22.45**	32.42	21.03	-10.5	26.5**	-0.45	19.54**	-14.35**	2.35	-22.47	16.09**
P-6711 × P-2211	-51.79**	-37.84**	-20.51**	-34.27**	-6.23	8.12**	-0.80	12.07**	19.77	9.47	-14.5	20.84**	-38.25	-25.85	-2.65**	16.34	-18.56	21.95**
P-3621 × P-6242	-36.39**	-17.98	-1.28**	-18.37**	6.60**	22.92**	13.64**	28.39**	25.49	14.70	-4.25	35.33**	171.79**	226.39**	-35.03**	-22.35**	-31.92	1.95**
P-3621 × P-2211	-47.28**	-32.02**	-5.12**	-21.55**	11.81**	28.93**	16.64**	31.79**	29.48	18.35	-18.75	14.84**	45.01**	74.14**	-9.18**	8.53	0	49.75**
P-10224 × P-6242	132.66	200.00	62.39	34.27	26.11**	45.43**	27.87**	44.47**	52.70	39.57	-25	6.00**	37.80**	65.49**	-25.03**	49.43	-12.05	31.7**
P-10224 × P-2211	120.84	184.75	72.22	42.40	23.40**	42.30**	25.61**	41.92**	51.18	38.18	-25	6.00**	13.27**	36.03**	46.39	74.95	10.09**	64.87**
CD (P = 0.05)	22.17		0.63		1.18		1.72		2.57		0.31		0.27		0.21		0.15	
CD (P = 0.01)	29.45		0.84		1.57		2.28		3.41		0.42		0.36		0.28		0.21	

*, ** Significant at 5% and 1% levels, respectively. (Only data of best 15 hybrids is presented)

respectively). All these hybrids had significant economic heterosis over both checks for internodal length except P-41212 × P-3621, for leaf length and width except P-364× P-6711, P-6711× P-2211 and P-6711× P-3621 having heterosis over PPH-2. However, only two bushy hybrids, i.e. P-6711× P-3621 (-7.02) and P-364× P-6711 (-6.98) had significant economic heterosis over PPH-2 for petiole length. All these hybrids also exhibited significant economic heterosis over PPH-2 for number of primary branches. One hybrid P-6711× P-10224 involving bushy and vine parent had significant heterosis for short vine, internodal length (over PPH-2), leaf dimensions, and pulp thickness.

Among 36 crosses, the range of economic heterosis over both checks for polar diameter, equatorial diameter and pulp thickness over PPH-1 and PPH-2 varied between -38.25 and 226.39%, -37.89% and 90.32%, -36.26% and 321.11% and -44.62 and 101.46%, respectively (Table 5). Among ten best bushy hybrids, only five hybrids P-6711× P-3621, P-41212 × P-3621, P-364× P-3621, P-3621 × P-6242 and P-3621 × P-2211 had significant and desirable heterosis over both the check hybrids for polar diameter, equatorial diameter and fruit shape index, while four hybrids viz; P-364× P-6711, P-364× P-2211, P-3621 × P-6242 and P-3621 × P-2211 exhibited significant heterosis for pulp thickness over PPH-2 only.

From the *per se* performance of best ten bushy hybrids (Table 6), five hybrids viz; P-6711× P-3621, P-41212 × P-3621, P-364× P-3621, P-3621 × P-6242 and P-3621 × P-2211 had butternut fruits; two hybrids, P-364× P-6711 and P-6711× P-6242, had round fruits and three hybrids P-364× P-2211, P-6711× P-2211, P-6711× P-10224 had flat round fruits. Among butternut, round and flat round hybrids, P-3621 × P-2211, P-6711× P-2211 and P-6711× P-6242 having high pulp thickness (3.07, 2.5 and 2.38 cm, respectively) were the best bushy hybrids with comparable yield potential, respectively.

The present investigation emphasized on high heterosis for traits associated with bushy growth habit and butternut fruit bearing. Most of the researchers in earlier studies in pumpkin, cucumber and ridge gourd worked in the direction of increased vine length (Nisha and Veeraragavathatham 2014, Hussien and Hamed 2015, Davoodi *et al.* 2016, Hanchinamani and patil 2009, Narasannavar *et al.* 2014), but our study was concentrated on bushy growth habit of the pumpkin. Heterosis for leaf length and leaf width provided a scope for development of hybrids with more vegetative growth that was also reported by El-Tahawey *et al.* (2015) in pumpkin. High heterosis for petiole length (negative) provided a possibility for improvement of hybrids with concentrated leaf bearing on bushy vines and for number of primary branches (positive) was the indicator of prolific vegetative growth in bushy and butternut hybrids. The results of heterosis for more number of primary branches were substantiated with the findings of Hussien and Hamed (2015) in pumpkin, Narasannavar *et al.* (2014) in ridge gourd and Janaranjani *et al.* (2016) in bottle gourd. High heterosis for fruit length has been reported in many cucurbits such as bitter gourd by Thangamani and Pugalendhi (2013), pumpkin by Hussien and Hamed (2015) and ridge gourd by Narasannavar *et al.* (2014). For the development of butternut hybrids high heterosis in negative direction in equatorial diameter is desirable, but literature reports are available on greater diameter in pumpkin, bitter gourd and ridge gourd (Hussien and Hamed 2015, Thangamani and

Table 6 Per se performance of best hybrids on the basis of growth habit

F1 Hybrid	Short vine (cm)					Per se performance								
	Mean	GCA	SCA	Heterosis		YPH (tonnes/ha)	IL (cm)	LL (cm)	LW (cm)	PL (cm)	NPB	PD (cm)	ED (cm)	PT (cm)
				PPH-1	PPH-2									
P-364× P-6711	31.44	A×G	-25.92**	-62.42**	-51.54**	25.91	2.04	12.42	18.68	20.12	3.00	10.43	10.52	2.25
P-364× P-2211	32.78	A×G	35.99**	-60.82**	-49.48**	23.93	1.52	14.06	19.81	21.57	3.00	10.17	12.71	2.25
P-6711× P-3621	38.44	G×G	2.24	-54.05**	-40.76*	30.81	1.98	13.28	19.62	20.11	3.67	18.23	11.63	2.00
P-41212× P-3621	39.00	P×G	79.89**	-53.38**	-39.89**	30.41	2.67	15.32	21.46	31.07	3.58	16.53	10.39	1.70
P-364× P-3621	40.33	A×G	-18.58**	-51.79**	-37.84**	32.07	1.80	14.04	19.46	22.56	3.50	19.33	9.13	1.71
P-6711× P-2211	40.33	G×G	31.39**	-51.79**	-37.84**	39.74	1.86	12.78	18.47	23.68	3.42	8.23	14.31	2.50
P-6711× P-6242	41.22	G×P	31.51**	-50.73**	-36.47**	29.86	2.34	13.62	20.18	26.18	3.58	13.27	12.59	2.38
P-3621 × P-2211	44.11	G×G	-50.94**	-47.28**	-32.02**	33.02	2.22	15.24	21.72	25.60	3.25	19.33	13.35	3.07
P-6711× P-10224	45.56	G×P	171.60**	-45.54**	-29.78**	35.71	2.70	14.70	20.46	23.50	4.75	10.27	17.17	2.70
P-3621 × P-6242	53.22	G×P	-55.03**	-36.39**	-17.98	34.76	2.31	14.53	21.16	24.81	3.83	36.23	9.55	2.09
PPH-1 (check)	83.67					38.94	2.34	13.63	18.62	19.77	4.00	13.33	14.70	3.07
PPH-2 (check)	64.89					31.36	2.83	11.82	16.48	21.63	2.83	11.10	12.30	2.05
CD (P = 0.05)	22.24		12.72	22.17		5.27	0.65	1.19	1.74	2.58	0.32	0.27	0.25	0.16
CD (P = 0.01)	29.17		16.69	29.45		6.92	0.85	1.56	2.28	3.39	0.42	0.35	0.33	0.21

*, ** Significant at 5% and 1% levels, respectively.

Pugalendhi 2013, Narasannavar *et al.* 2014). All the hybrids involving bushy and butternut parents, i.e. P-6711× P-3621, P-41212 × P-3621, P-364× P-3621, P-3621 × P-6242 and P-3621 × P-2211 had butternut fruit shape and highlighted the possibility for exploiting heterosis with more polar diameter and less equatorial diameter for the same. All the hybrids also had high heterosis for fruit shape index. Among bushy hybrids, P-3621 × P-2211, P-6711× P-10224 and P-6711× P-6242 after hybridization can be further used for the selection of transgressive segregates with bushy growth habit and thick pulp butternut fruits. The results of high heterosis for thick fruit pulp were substantiated with the findings of Narasannavar *et al.* (2014) in ridge gourd, Nisha and Veeraragavathatham (2014) and Tamil Selvi and Jansirani (2016) in pumpkin and Janaranjani *et al.* (2016) in bottle gourd.

Conclusion

The genotypes, P-3621 and P-2211 being best combiner for bushy growth habit and butternut fruit traits, while P-6242 for leafy growth and pulp thickness, provided good scope for the improvement of these traits in future breeding programmes. Very high SCA estimates in P-10224× P-6242, PS × P-6242, P-41212 × P-2211, PS × P-364, P-41212 × P-6242, P-10224× P-2211 for most of the bushy and butternut traits revealed the occurrence of both additive and non-additive gene effects with the predominance of non-additive effects for the inheritance of these traits. Both types of gene effects can further be utilized through heterosis breeding and recurrent selection for high SCA especially in these crosses for the development of bushy and butternut traits in pumpkin. Among bushy hybrids, P-3621 × P-2211 (butternut), P-6711× P-2211 (round) and P-6711× P-6242 (flat round) had more pulp thickness (3.07, 2.5 and 2.38 cm, respectively) and comparable yield potential with the check hybrids. These hybrids can be exploited for commercial cultivation after testing in multi-environments.

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