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Heterosis in watermelon for earliness, growth, fruit yield and quality parameters

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ABSTRACT

Hybrids in watermelon are popular due to earliness, high yield, improved quality, disease resistance and transport ability. Small and marginal farmers demand seed of promising public sector hybrids to reduce the expenditure on seed. Therefore, forty F_1 hybrids developed by crossing eight lines and four testers were evaluated in Punjab state for 16 traits. Significant mid-parent heterosis (MPH) in desirable direction was recorded for all traits except titratable acidity. Significant standard heterosis (SH) over 'Jannat' in desirable direction was recorded for all traits except node number of first female flower, seed number per fruit, titratable acidity and lycopene. The highest SH was observed for ascorbic acid (47.5%) followed by fruit number (34.3%) and 100-seed weight (-33.3%). The maximum MPH was noted for dry matter (49.1%), succeeded by seed number (-37.5%), 100-seed weight (-35.8%), vine length (-35.3%), fruit number (33.6%), and marketable yield (31.3%). The number of hybrids exhibiting significant and desirable SH was highest for ascorbic acid (20), followed by vine length (16), 100-seed weight (15), internode length (10) and fruit number (8). The number of hybrids manifesting significant and desirable MPH was maximum for vine length (24) followed by node number of first female flower (12), internode length (10), seed number per fruit (8), total soluble solids (8) and dry matter (8). Three promising hybrids (PWM-1 × PWM-3, PWM-14 × PWM-3, and PWM-30 × PWM-63-32) exhibiting heterosis for multiple traits are recommended for multi-location testing across the state to identify superior hybrid for a particular zone or stable across diverse zones.

Key words: Lycopene, hybrid vigour, internode length, seed number, total soluble solids.

INTRODUCTION

Watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai var. *lanatus*], a cucurbitaceous dessert crop, was cultivated over 1.26 lakh hectares in India in 2023 with an average productivity of 28.8 tonnes per hectare. India ranks third in watermelon production globally, following China and Turkiye (Anonymous, 3). Although the Punjab state ranks 14th in watermelon production, its cultivation is picking up in the state. In Punjab, the area under the crop has increased from 907 hectares in 2011-12 to 2,700 hectares in 2021-22. However, the crop productivity in Punjab (18.2 tonnes per hectare) is two-third of the national average (Anonymous, 2) which can be enhanced by the cultivation of F_1 hybrids. Heterosis breeding is generally used in watermelon to combine cytoplasmic traits of the female parent with dominant traits of the pollen parent (Wehner, 15). Production of hybrid seed in watermelon by hand pollination is comparatively easy due to its monoecious sex form, considerable seed count per fruit, and low seed rate per unit area (Choudhary *et al*., 4). An outstanding watermelon hybrid (Asahi Yamato × Miyako), which was superior due to earliness, high yield, disease resistance and transport ability, was initially developed by Yanagisawa and Hosono (16). Thereafter, although many studies have highlighted the presence of heterosis in watermelon (Patel *et al*., 8; Nyurura and Maphosa, 7; Singh *et al*., 11), only a few hybrids have been released by public sector in India and private sector is leading in this regard. However, the high seed cost of private sector hybrids is a major economic burden on small and marginal farmers who demand promising and low-cost public sector hybrids having earliness, high yield, and improved quality fruits to reduce the expenditure on seed.

Hence, this study aimed to evaluate 40 newly developed watermelon F_1 hybrids for 16 traits, to estimate the heterosis exhibited by them over their mid-parent and a commercial private sector hybrid for various traits, and to identify promising hybrids which can be considered for multi-location testing across diverse agro-climatic zones of the state.

MATERIALS AND METHODS

The current investigation was carried out at Jodhpur Romana Farm of the Punjab Agricultural University-Regional Research Station, Bathinda, Punjab, India, during spring-summer seasons of 2022 and 2023. The farm is located at 30°17' North latitude, 74°58' East longitude and 211 m altitude. The location belongs to South-Western part of Punjab and falls under the semi-arid agro-climatic region with an average annual precipitation of 400-450 mm. In this experiment, eight

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round fruited watermelon lines (PWM-1, PWM-14, PWM-20, PWM-112, PWM-54-19, Sugar Baby, Arka Manik and PWM-30) were crossed with five elliptical or oblong fruited testers (PWM-3, PWM-63-32, PWM-7-10, V-15, and V-3) in a line × tester mating design in summer 2022. During spring-summer 2023, all 40 hybrids, 13 parental lines, along with a commercial check hybrid 'Jannat' [Known You Seed (India) Pvt. Ltd., Pune] were grown in a randomized block design (RBD) with three replications. The seedlings were transplanted on both sides of the raised beds having 3.0 m width. Plant-to-plant distance in a row was kept at 60 cm. Eight plants per entry per replication were maintained in a net plot size of 3.0 m × 2.4 m.

The observations were recorded for 16 traits including node number of first female flower, days taken to first fruit harvest, internode length (cm), vine length (m), number of primary branches, number of fruits per plant, fruit weight (kg), marketable yield (t/ha), rind thickness (mm), number of seeds per fruit, 100-seed weight (g), lycopene (mg/100 g fresh weight), total soluble solids (TSS) (^{o}brix), titratable acidity (%), ascorbic acid (mg/100 ml juice), and dry matter (%). The replicated data were analysed for analysis of variance (ANOVA) procedure for RBD to estimate genotypic differences and LSD values for genotypes at 5% level of significance. Thereafter, heterosis was estimated over mid-parent (average or mid-parent heterosis, MPH) and standard check (standard heterosis, SH) in microsoft excel worksheet using the formula given below and tested for significance using standard methods (Srinivasulu *et al.*, 14).

$$MPH (\%) = [(F_1 – MP) × 100] /MP$$

$$SH (\%) = [(F_1 – SC) × 100] /SC$$

where, F_1 = mean value of the F_1 hybrid

MP = average of the mean values of both parents of the F_1 hybrid

SC = mean value of the standard check viz., Jannat

RESULTS AND DISCUSSION

Earliness, expressed by node number of first female flower and days taken to first fruit harvest, is a desirable trait in watermelon hybrids as early harvest fetches high premium in the market. The extent of heterosis was higher for node number of first female flower (-25.7 to 4.0% for MPH and -9.7 to 23.3% for SH) compared with days taken to first fruit harvest (-7.8 to 8.0% for MPH and -4.7 to 7.4% for SH) (Table 1). Twelve and five hybrids exhibited significant negative MPH for node number of first

Table 1: Range of heterosis (%) and number of hybrids showing significant positive and negative heterosis for 16 traits in watermelon.

Trait	Standard heterosis (SH)			Mid-Parent heterosis (MPH)		
	Range (%)	No. of heterotic hybrids in positive direction	No. of heterotic hybrids in negative direction	Range (%)	No. of heterotic hybrids in positive direction	No. of heterotic hybrids in negative direction
Node number of first female flower	-9.7 to 23.2	3	0	-25.7 to 4.0	0	12
Days taken to first fruit harvest	-4.7 to 7.4	11	1	-7.8 to 8.0	8	5
Internode length (cm)	-19.9 to 8.2	0	10	-26.6 to 6.8	0	10
Vine length (m)	-24.8 to 22.1	2	15	-35.3 to 20.4	2	24
Number of primary branches	-30.9 to 25.9	2	8	-30.5 to 29.7	5	13
Number of fruits per plant	-35.4 to 34.3	8	6	-30.6 to 33.6	7	13
Fruit weight (kg)	-38.1 to 15.0	1	26	-42.0 to 23.2	6	17
Marketable yield (t/ha)	-46.0 to 8.8	5	27	-58.9 to 31.3	6	22
Rind thickness (mm)	-19.2 to 18.9	3	2	-26.5 to 18.1	1	5
Number of seeds per fruit	-0.9 to 202.9	39	0	-37.5 to 68.3	22	8
100-seed weight (g)	-33.3 to 82.8	15	5	-35.8 to 89.9	9	7
Lycopene (mg/100g fresh weight)	-20.5 to 3.8	0	8	-9.1 to 17.7	6	0
Total soluble solids (^{0}brix)	-11.9 to 16.7	2	0	-5.8 to 22.0	8	0
Titratable acidity (%)	-9.7 to 64.8	7	0	-23.4 to 46.6	2	0
Ascorbic acid (mg/100ml juice)	-7.5 to 47.5	20	0	-19.9 to 18.8	3	2
Dry matter (%)	-15.3 to 18.8	2	0	-12.5 to 49.1	8	0

female flower and days taken to first fruit harvest, respectively, while in respect of SH, the number of such hybrids was one for days taken to first fruit harvest (Table 1). The cross-combination viz., PWM-1 × V-3 manifested significant negative MPH for both these traits (Table 2). In watermelon, Patel *et al*. (8)

Table 2: Promising watermelon hybrids exhibiting significant and desirable mid-parent heterosis (MPH) and standard heterosis (SH) along with their mean values for earliness, plant growth and fruit yield.

Trait	Cross-combination	Mean value	MPH (%)	SH (%)
Node no. of first female flower	PWM-112 × PWM-63-32	7.1	-21.0*	-9.7
	Sugar Baby × PWM-3	7.3	-19.9*	-8.0
	PWM-54-19 × PWM-3	7.3	-19.8*	-7.3
	PWM-20 × PWM-63-32	7.4	-16.2*	-6.3
	Sugar Baby × PWM-63-32	7.5	-22.4*	-5.1
	PWM-1 × PWM-63-32	7.7	-14.7*	-2.1
	Sugar Baby × V-3	7.9	-25.7*	-0.4
	PWM-112 × V-15	8.0	-13.4*	1.3
	PWM-30 × PWM-63-32	8.1	-15.3*	3.0
	PWM-1 × V-3	8.3	-17.3*	4.6
	PWM-112 × V-3	8.6	-13.6*	8.9
	Sugar Baby × V-15	8.7	-12.2*	9.7
Days taken to first fruit harvest	PWM-14 × PWM-3	95.0	-4.2*	-4.7*
	Arka Manik × PWM-3	96.7	-7.8*	-3.0
	PWM-112 × PWM-3	97.7	-7.4*	-2.0
	PWM-1 × V-3	98.0	-5.5*	-1.7
	PWM-30 × V-3	100.0	-6.3*	0.3
Internode length (cm)	Sugar Baby × PWM-3	6.4	-13.6*	-19.9*
	PWM-30 × PWM-7-10	6.5	-26.6*	-19.1*
	PWM-112 × V-15	6.5	-16.7*	-18.6*
	Sugar Baby × V-15	6.6	-11.3	-17.9*
	PWM-112 × PWM-3	6.8	-12.8*	-14.7*
	PWM-20 × V-15	6.8	-11.0	-14.4*
	Arka Manik × V-3	6.9	-13.7*	-13.7*
	PWM-54-19 × V-3	6.9	-19.0*	-13.4*
	PWM-30 × PWM-63-32	6.9	-18.7*	-13.1*
	Arka Manik × V-15	6.9	-11.0	-13.0*
	PWM-20 × PWM-7-10	7.0	-13.7*	-12.3
	PWM-54-19 × PWM-3	7.2	-14.3*	-10.2
	PWM-30 × V-15	7.3	-12.2*	-8.1
Vine length (m)	Sugar Baby × PWM-7-10	3.3	12.1*	22.1*
	Sugar Baby × V-3	3.2	20.4*	18.8*
No. of primary branches	PWM-14 × PWM-3	3.4	13.9*	26.0*
	PWM-1 × PWM-3	3.2	9.1	18.5*
	PWM-20 × PWM-63-32	3.1	29.7*	16.1
	Arka Manik × PWM-3	3.1	16.5*	13.6
	PWM-54-19 × PWM-63-32	3.0	20.8*	11.1
	PWM-20 × PWM-3	2.8	18.3*	3.7

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Table 2 contd...

Trait	Cross-combination	Mean value	MPH (%)	SH (%)
No. of fruits per plant	PWM-54-19 × PWM-63-32	2.3	12.0*	34.3*
	PWM-112 × PWM-63-32	2.3	33.6*	34.2*
	PWM-20 × PWM-63-32	2.3	12.8*	29.3*
	PWM-20 × PWM-3	2.2	17.6*	27.0*
	PWM-30 × V-3	2.1	7.1	22.2*
	PWM-30 × PWM-63-32	2.1	-4.9	19.7*
	Arka Manik × PWM-7-10	2.0	-0.2	15.0*
	Arka Manik × V-3	2.0	6.3	12.5*
	PWM-112 × PWM-3	2.0	19.1*	11.8
	PWM-112 × PWM-7-10	1.9	12.4*	10.2
	PWM-1 × V-3	1.8	15.9*	5.0
Fruit weight (kg)	PWM-1 × PWM-7-10	3.3	11.0*	15.0*
	Arka Manik × PWM-3	3.1	10.3*	5.2
	PWM-1 × PWM-3	3.0	17.9*	3.0
	PWM-1 × PWM-63-32	2.9	17.3*	1.3
	PWM-1 × V-3	2.8	13.0*	-5.0
	PWM-14 × PWM-63-32	2.7	23.5*	-6.3
Marketable yield (t/ha)	Sugar Baby × PWM-7-10	55.2	1.3	8.8*
	PWM-30 × PWM-3	54.9	-14.2*	8.2*
	PWM-1 × PWM-7-10	54.8	3.6	8.1*
	PWM-54-19 × PWM-63-32	54.5	4.1	7.5*
	PWM-20 × PWM-63-32	54.1	24.6*	6.6*
	PWM-1 × PWM-63-32	53.0	19.9*	4.5
	PWM-1 × V-3	50.2	31.3*	-1.0
	PWM-1 × PWM-3	48.6	15.8*	-4.2
	PWM-20 × PWM-3	48.2	17.2*	-4.9
	PWM-14 × PWM-3	43.9	14.2*	-13.4

*Significant at P = 0.05

have also observed MPH and SH ranging from -35.2 to 32.5% and -23.4 to 30.2% for node number of first female flower, and -4.6 to 2.4% and -7.3 to 0.1% for days taken to first fruit harvest, respectively.

Internode length, vine length and number of primary branches are the main plant growth parameters of watermelon. Shorter internodes along with longer vines and high number of primary branches are considered advantageous as such plants are likely to bear more female flowers and fruits. Heterosis was the widest for number of primary branches (-30.5 to 29.7% for MPH and -30.9 to 25.9% for SH) followed by vine length (-35.3 to 20.4% for MPH and -24.8 to 22.1% for SH), and internode length (-26.6 to 6.8% for MPH and -19.9 to 8.2% for SH) (Table 1). Although negative heterosis was more frequently observed than positive for these three traits, two and five hybrids manifested significant positive MPH for vine length and number of primary branches, respectively (Table 1). Singh *et al.* (11) have observed SH of -5.4 to 22.3% for internode length in watermelon. The MPH ranging from -31.7 to 32.4% (Ndukauba *et al.,* 6) and SH varying from -24.0 to 27.8% (Singh *et al.,* 11) had also been observed for vine length in watermelon. Patel *et al.* (8) have also reported MPH of -22.3 to 28.2% and SH from -27.7 to 14.5% in watermelon for number of primary branches.

Positive heterosis is considered desirable for fruit number/plant, fruit weight and marketable yield as fruit number and fruit weight directly contribute to yield. The magnitude of MPH was the widest for marketable yield (-58.9 to 31.3%) followed by fruit weight (-42.0 to 23.2%) and fruit number (-30.6 to 33.6%). On the contrary, the widest magnitude of SH was observed for fruit number (-35.4 to 34.3%) followed by marketable yield (-46.0 to 8.8%) and fruit weight (-38.1 to 15.0%) (Table 1). Although negative heterosis was more frequent than positive heterosis for these three traits, the number of hybrids manifesting significant positive MPH and SH was 7 and 8 for fruit number, 6 and 1 for fruit weight, and 6 and 5 for marketable yield, respectively (Table 1). Seven promising hybrids exhibiting significant heterosis for these three traits were PWM-54-19 × PWM-63-32, PWM-20 × PWM-63-32, PWM-20 × PWM-3, PWM-1 × V-3, PWM-1 × PWM-7-10, PWM-1 × PWM-3, and PWM-1 × PWM-63-32 (Table 2). However, the cross-combination viz., PWM-1 × V-3 manifested significant positive MPH for these three traits (Table 2). The MPH ranging from -53.6 to 22.8% for fruit number (Nascimento *et al.,* 5), -31.1 to 30.5% for fruit weight (Nascimento *et al.,* 5) and -4.1 to 25.0% for yield (Ahmed *et al.,* 1) had previously been reported in watermelon. The SH varying from -33.3 to 46.7% for fruit number (Singh *et al.,* 12), -16.9 to 28.1% for fruit weight (Patel *et al.*, 8) and -40.4 to 43.4% for yield (Singh *et al.,* 11) had earlier been observed in watermelon.

High rind thickness in watermelon is desirable as it improves fruit shelf-life and distant transportation and reduces fruit fly infestation. Besides, watermelon rind is considered useful in preparation of probiotic jam (Setlhoka *et al*., 10). On the contrary, low number of seeds per fruit and small seed size are considered desirable to improve flesh quality and to enhance consumer acceptability. The magnitude of MPH was the widest for 100-seed weight (-35.8 to 89.9%) followed by seed number (-37.5 to 68.3%) and rind thickness (-26.5 to 18.1%). On the contrary, the highest SH was observed for seed number per fruit (-0.9 to 202.9%) followed by 100-seed weight (-33.3 to 82.8%) and rind thickness (-19.2 to 18.9%) (Table 3). Positive heterosis was more frequent than negative for seed number per fruit and 100-seed weight, and there was no hybrid manifesting significant negative SH for seed number per fruit. However, five hybrids exhibited significant negative SH for 100-seed weight. Significant negative MPH was exhibited by 7 hybrids for 100-seed weight, and 8 for seed number per fruit, whereas for rind thickness, 1 and 3 hybrids expressed significant positive MPH and SH, respectively (Table 3). The cross-combination viz., PWM-20 × PWM-3 was promising for rind thickness whereas those found promising for both seed number per fruit and 100-seed weight were Sugar Baby × V-15, PWM-20 × PWM-3, PWM-112 × PWM-63-32, and PWM-112 × PWM-3 (Table 3). The MPH ranging from -17.1 to 18.9% for rind thickness (Ahmed *et al*., 1), -25.9 to 52.4% for seed number

Table 3: Promising watermelon hybrids exhibiting significant and desirable mid-parent heterosis (MPH) and standard heterosis (SH) along with their mean values for fruit quality traits.

Trait	Cross-combination	Mean value	MPH (%)	SH (%)
Rind thickness (mm)	PWM-30 × PWM-3	12.4	3.9	18.9*
	PWM-20 × PWM-3	12.1	18.1*	15.9*
	PWM-1 × PWM-3	11.9	9.8	14.9*
Number of seeds per fruit	Sugar Baby × V-15	246.0	-37.5*	-0.9
	PWM-20 × V-15	300.0	-13.7*	20.9*
	PWM-14 × V-15	333.5	-15.5*	34.4*
	PWM-112 × V-15	333.8	-28.4*	34.5*
	PWM-20 × PWM-3	359.0	-14.6*	44.7*
	PWM-112 × PWM-63-32	414.3	-23.9*	67.0*
	PWM-30 × V-15	434.7	-24.6*	75.2*
	PWM-112 × PWM-3	438.1	-18.7*	76.6*
100-seed weight (g)	PWM-20 × PWM-7-10	3.1	-29.3*	-33.3*
	Sugar Baby × V-3	3.5	-11.4*	-24.9*
	PWM-30 × PWM-63-32	3.6	-6.6	-22.6*
	PWM-54-19 × PWM-7-10	3.8	-17.4*	-19.7*
	Sugar Baby × PWM-63-32	3.8	0.9	-19.2*

Contd...

Table 3 contd...

Trait	Cross-combination	Mean value	MPH (%)	SH (%)
	PWM-20 × V-3	3.8	-6.1	-19.1*
	PWM-20 × PWM-3	3.8	-6.3	-18.6*
	PWM-30 × PWM-3	3.9	-6.9	-17.8*
	Sugar Baby × PWM-3	3.9	-3.8	-17.6*
	Sugar Baby × V-15	3.9	-13.8	-16.1*
	PWM-14 × PWM-7-10	4.0	-11.5*	-16.0*
	PWM-112 × PWM-63-32	4.0	8.0	-14.6*
	PWM-54-19 × PWM-63-32	4.0	1.3	-14.6*
	Arka Manik × PWM-7-10	4.1	-9.0	-13.8*
	PWM-112 × PWM-3	4.1	3.8	-12.3*
	PWM-1 × PWM-7-10	4.5	-35.8*	-4.7
	PWM-1 × PWM-63-32	4.9	-23.6*	3.7
	PWM-1 × V-15	5.5	-24.1*	16.0*
Lycopene (mg/100g fresh weight)	PWM-112 × PWM-7-10	10.3	13.6*	3.8
	PWM-30 × PWM-3	9.8	13.9*	-0.9
	Arka Manik × PWM-7-10	9.8	17.7*	-1.6
	Sugar Baby × PWM-3	9.7	12.2*	-2.5
	Sugar Baby × V-15	9.3	13.0*	-6.6
	Arka Manik × V-15	9.2	15.4*	-7.7
Total soluble solids (^{0}brix)	PWM-1 × PWM-3	11.4	12.1*	16.7*
	PWM-14 × PWM-3	11.4	19.4*	16.3*
	Arka Manik × PWM-7-10	10.8	19.6*	10.2
	PWM-30 × PWM-3	10.6	20.0*	8.2
	PWM-30 × V-3	10.4	19.9*	5.8
	PWM-14 × PWM-63-32	10.4	14.6*	5.8
	PWM-30 × PWM-63-32	10.2	22.0*	3.7
	PWM-30 × PWM-7-10	10.2	19.1*	3.7
Ascorbic acid (mg/100ml juice)	PWM-112 × PWM-3	11.2	13.5	47.5*
	PWM-1 × PWM-3	11.1	18.8*	46.2*
	PWM-14 × PWM-3	10.9	8.6	42.5*
	PWM-54-19 × PWM-3	10.8	2.8	41.8*
	PWM-112 × PWM-63-32	10.8	9.2	41.2*
	Sugar Baby × PWM-3	10.5	16.3*	38.1*
	Sugar Baby × PWM-63-32	10.5	16.7*	37.8*
	Arka Manik × PWM-3	10.3	12.8	35.0*
	PWM-1 × PWM-63-32	10.1	8.7	33.1*
	PWM-54-19 × PWM-63-32	9.9	-5.3	30.0*
	PWM-112 × PWM-7-10	9.9	1.5	29.4*
	Arka Manik × PWM-63-32	9.7	6.6	26.9*
	PWM-30 × PWM-3	9.6	-8.4	26.2*
	PWM-1 × PWM-7-10	9.6	4.4	25.9*

Contd...

Table 3 contd...

Trait	Cross-combination	Mean value	MPH (%)	SH (%)
	PWM-54-19 × PWM-7-10	9.5	-7.8	25.0*
	PWM-30 × PWM-7-10	9.5	-7.9	24.7*
	PWM-1 × V-15	9.5	13.9	24.3*
	PWM-30 × PWM-63-32	9.4	-9.8	23.7*
	PWM-14 × V-15	9.3	4.4	22.5*
	PWM-20 × PWM-3	9.3	4.0	22.5*
Dry matter (%)	PWM-1 × PWM-3	12.1	18.5*	18.8*
	PWM-112 × PWM-7-10	12.1	20.8*	18.8*
	PWM-30 × PWM-3	11.9	37.2*	17.4
	PWM-30 × PWM-63-32	11.6	49.1*	14.2
	Arka Manik × PWM-7-10	11.5	19.9*	13.5
	PWM-30 × V-3	11.1	29.9*	9.5
	PWM-30 × PWM-7-10	10.8	27.5*	6.9
	PWM-30 × V-15	9.7	23.1*	-3.0

*Significant at P = 0.05

per fruit (Ndukauba *et al.,* 6), and -63.9 to 67.0% for seed weight (Ndukauba *et al.,* 6) had earlier been reported in watermelon. The SH varying from 18.8 to 280.8% for seed number per fruit (Singh *et al.,* 12) and -22.8 to 90.2% for seed weight (Singh *et al.,* 11) had previously been observed in watermelon.

Low titratable acidity along with high lycopene, TSS, ascorbic acid and dry matter are highly desirable in watermelon as they make the flesh sweet and nutritive thereby increasing their fruit quality, consumer acceptability and marketability. The magnitude of MPH and SH was the widest for titratable acidity followed by dry matter, ascorbic acid, TSS and lycopene (Table 1). Positive heterosis was more frequent than negative for all fruit quality traits. However, significant negative SH for titratable acidity and positive SH for lycopene was not recorded. The number of hybrids manifesting significant positive MPH and SH was 3 and 20 for ascorbic acid, 8 and 2 for TSS, 8 and 2 for dry matter, respectively, whereas six hybrids exhibited significant positive MPH for lycopene (Table 1). The promising cross-combinations for all fruit quality traits included PWM-112 × PWM-7-10, Arka Manik × PWM-7-10, Sugar Baby × PWM-3, PWM-1 × PWM-3, PWM-14 × PWM-3, PWM-30 × PWM-3, PWM-30 × V-3, PWM-30 × PWM-63-32, and PWM-30 × PWM-7-10. The MPH varying from -44.8 to 22.6% for lycopene (Singh *et al.*, 12), -12.8 to 24.3% for TSS (Souza *et al.,* 13), and -33.6 to 28.8% for ascorbic acid (Rajendran and Thamburaj, 9) had earlier been observed in watermelon. The SH ranging from -18.1 to 13.3% for TSS (Singh *et al.,* 12), -11.5 to 27.9% for ascorbic acid (Singh *et al.,* 11) and -57.4 to 2.7% for dry matter (Singh *et al.,* 11) had previously been reported in watermelon.

The promising cross-combinations exhibiting significant and desirable heterosis for multiple traits have been identified (Fig. 1). Those manifesting MPH for 5 to 6 traits included PWM-1 × PWM-3, PWM-1 × V-3, PWM-14 × PWM-3, PWM-20 × PWM-3, PWM-20 × PWM-63-32, and PWM-30 × PWM-63-32. Hybrids exhibiting SH for 5 traits included PWM-1 × PWM-3, PWM-14 × PWM-3, PWM-30 × PWM-63-32, and PWM-30 × PWM-3. Three outstanding F_1 hybrids have been shortlisted viz., PWM-1 × PWM-3, PWM-14 × PWM-3, and PWM-30 × PWM-63-32. The climate of the Punjab state is diverse comprising semi-arid, sub-humid and humid zones. Before a variety or

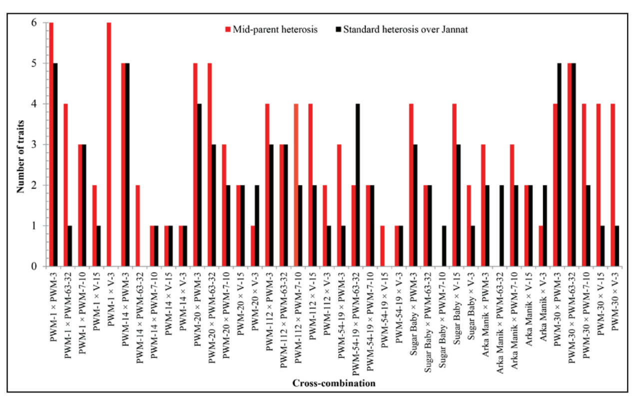

Fig. 1. No. of traits for which significant and desirable mid-parent (MPH) and standard heterosis (SH) was exhibited by 40 watermelon hybrids.

hybrid is recommended for general cultivation in the state, it must be evaluated in all zones of the state to identify its adaptation for a particular zone or stability across the state. Therefore, the three promising hybrids identified here are recommended for multi-location testing across the state before being considered for commercial release.

AUTHORS' CONTRIBUTION

Conceptualization of research (NG); Designing of the experiments (NG); Contribution of experimental materials (NG); Execution of field/lab experiments and data collection (KS, NG, MM); Analysis of data and interpretation (KS, NG); Preparation of the manuscript (NG, KS).

DECLARATION

The authors declare that they do not have any conflict of interest.

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