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Evaluation of heterosis and important traits in new hybrids of *Iris germanica* in F1

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ABSTRACT

Purpose: The purposes of this research were to assess important traits and heterosis and to introduce superior hybrids of *Iris germanica*. **Research method:** 28 hybrids and seven parents of *Iris* rhizomatous were evaluated. The experiment was carried out in a randomized complete block design (RCBD) with three replications at the Ornamental Plants Research Center (OPRC) from 2014 to 2018. **Findings:** Hybrid of oprc37 (cross of V5×V4) had a higher positive of heterosis in flower size, leaf width, and hybrid of oprc25 (V8×V6) in the inner tepal length and outer tepal width in superior parents compared to their parents. The highest heterosis was observed for the traits of peduncle length, peduncle diameter and crown diameter, respectively, in some hybrids of oprc20 (V2×V4) and oprc16 (V2×V5). Hybrids of oprc42 and oprc43 of the cross between *I. spuria* and *I. germanica* (V7×V2) in the most traits in superior parents and self-parents had higher positive of heterosis. It can be expected that these selected F1 (oprc37, oprc25, oprc20 and oprc16) to able introduced as a variety of commercial, developed on the market ornamental plants. **Limitations:** No limitations were found. **Originality/Value:** Inter-varietal hybridization is an effective way to contribute to the phenotypic variation of Iris flowers, to produce new plant materials for breeding purposes and to release new cultivars.

INTRODUCTION

Iris spp. has been considered as an ornamental and medicinal plant from a long time ago, but nowadays its ornamental aspect draws more human attention. Iris is native to Iran belongs to monocotyledonous class and has wildlife in the different parts of the country. There are about 300 wild species of iris in the world (Wendelbo, 1977), of which 20 species and their sub-species are found in Iran (Ghanadi, 1991; Azimi et al., 2011). Iris is one of the most valuable flowers, and Iran is one of its primary origins. German iris (*Iris germanica* L.), belongs to the Iridaceae family, which is one of the most important types of bearded iris and classified as early hybrids, rhizomatous, tall, and arilless seeds (Ibrahim et al., 2012). Most Iris species in Iran are categorized into rhizomatous, bulbous, and tuberous groups (Azimi et al., 2012). The general characteristics of German iris include the colorful flowers, propagated by the rhizome, flat leaves, triplet components of the flower, orchid-like flowers, resistance to salinity stress (Sarvandi et al., 2020), the calcareous soils, and the adverse environmental conditions, and have low water requirements (Azimi et al., 2018a).

Considering these features, the German iris has become the most favorite flower for the landscape designers so that it can be found in the rocky gardens of most countries (Ghanadi, 1991; Alam et al., 2004; Azimi et al., 2018b). Hundreds of valuable varieties of this species are extended through the world and it has been grown as a perennial ornamental plant. In addition to its ornamental importance, the rhizomes of some varieties of *I. germanica* contain essential oils (Burke et al., 1998). These aromatic compounds along with ketones are majorly used in the perfumery industry (Claire, 2005). The plant breeders classify the cultivars and varieties to discover the genetic distances among them and use of their existent diversity in the crossing programs and it is believed that the heterosis, the superiority of the hybrids over the average performance of their parents, is related to the genetic distance (Joshi et al., 2001). The half-siblings are produced with different strategies. Four types of crossing systems (free pollination, polycross, top cross, and diallel crosses) have been introduced (Kasperbauer, 1990). The diallel crosses are used less frequently in the applied plant breeding as only a few parents can be studied. In the progenies derived from the free pollination technique, the seeds are also harvested from the maternal parent, but the paternal parent is not entirely clear; while in the progenies of both polycross and top cross strategies, the pollens from the paternal parents are considered as the homogeneous pollen populations of all parental genotypes. In these methods, after crossing, the seeds of the genotypes with a common parent are semi-sib relatives (Kasperbauer, 1990). In the polycross technique, clones of an individual plant are located among the clones of other plants in a way which allows the random crossing among genotypes. The bulbous iris is the cross incompatible with the rhizomatous iris and it is impossible to hybridize these two categories. Inter-specific hybridization is a commonly used method in different close related species for producing progenies with new traits. This method has been widely utilized in different *Iris* species (Zhen et al., 1997; Burke et al., 1998; Shimizu et al., 1999; Yuval et al., 2002; Zhen et al., 2003; Arnold et al., 2010).

Intervarietal hybridization is another common way of transferring desirable attributes between different cultivars (Zamani et al., 2010; Yang et al., 2015). These attempts have resulted in the reports in *Alstroemeria* (Bridgen et al., 1989), *Gladiolus* (Ohri & Khoshoo, 1983a; b), *Lilium* (Lim & Van Tuyl, 2006), *Narcissus* (Brandham, 1986; Wylie, 1952), Tulip (Van Eijk et al., 1991) and *Zantedeschia* (Snijder, 2004). Studies have been conducted on morphological attributes and breeding of native bulbous plants of Iran including daffodils (Chehrazi et al., 2007); *Iris germanica* (Firouzi et al., 2018; Azimi et al., 2012; 2018); *Gladiolus* (Azimi 2020a; 2020b; 2020c; 2020d); *Cyclamen* (Naderi et al., 2016); and *Fritillaria* (Momenei et al., 2013). In a study, eight dwarf cultivars of *I. germanica* were obtained from five crosses carried out among five dwarf and standard-height cultivars, and the traits of plant height and flower color were different in the first generation, indicating that their parents were heterozygous in nature. In this study, the heredity of plant height in a number of progenies was different from that of parents, in the way that they had a lower height and were not superior to their parents in this trait (Huang et al., 2003). Moreover, Yuval et al. (2002) studied morphological attributes of *Oncocyclus* irises and suggested that natural selection had an important role in the population differentiations. Shimizu et al. (1999) produced somatic hybrids of *I. ensata* and *I. germanica* through protoplast fusion. The results of intra- and interspecies hybridization in genus *Iris* showed the seedlings derived from the cross failed to survive after 6-8 weeks due to low compatibility among species. There was high compatibility in three interspecies crosses so that the first-generation seedlings seemed to be grown well. The flower color trait in the seedlings of the first-generated of *Iris tectorum* × *I. tectoroum F. alba* and *I. Tectorum F.alba* × *I. Tectorum* was shown to be under a single gene control while that of *I. germanica LP* × *I. germanica PP* was controlled by several genes. In the study, a wide variety of colors was produced in seven new cultivars, generally a combination of purple (Zhen et al., 1997). In another study, Zhen et al. (2003) have found that bush height had high variation among progenies, while mean values of progenies were lower than their parents. They confirmed that it was possible to obtain dwarf German iris through back cross with dwarf parents.

The high diversity in color and shape in the market will be a motive for introducing new cultivars. The diversity and innovation of the flower industry are desirable for all so that hundreds of new colors and varieties are annually introduced to the world. Due to the ornamental and economical importance of the German iris, this study was conducted to hybridize different cultivars to achieve a new hybrid with important economical traits.

MATERIALS AND METHODS

In this study, seven varieties of German iris (*I. germanica*) and a wild species called *I. spuria* were used. It should be noted that all attempts considered breaking the seed dormancy, investigating the germination time, and optimizing the seed germination and seedling growth conditions. At the beginning of flowering, the crosses were made among seven lines of iris. The research was based on a randomized complete block design with three replications at the ornamental plant research center (Mahhallat) during the years 2014-2018. The parents were hybridized by the partial diallel method, but nine hybrids were successfully obtained. The hybridization steps including the emasculation (anther removal), bagging, pollination and seed production are performed. The successful crosses are shown in Table 1. The seeds of successful crosses were carefully collected and cleaned in the late summer and stored until the planting time (December) as there is a need to vernalize them to germinate, they had been mixed with wet peat and put in a transparent and opaque plastic pot for 45 days under a temperature condition of 4°C (Firouzi et al., 2018). After the dormancy breaking and observing the germination of seeds, they were cultivated under greenhouse conditions. The nursery bed was comprised of the equal mixture of the compost, composted manure, clay, and soft sand in each pot. Seeds from each offspring were sown in clay pots containing composted manure, sand, clay and leaf mould (1:1:1:1) under greenhouse conditions. At the stage of 4-5 leaves (April), seedlings were planted in 30 × 30 cm^2 spacing in the field. 28 hybrids derived from crosses of seven parents were studied.

At the beginning of flowering, the traits had been separately measured in both hybrids and parents as leaf width, peduncle length, flower size, fall petal width, standard length (from the base of floret to the tip), standard width, plant height (from the crown on the surface of the soil to the tip of the stem), flowering stem diameter, and crown diameter (UPOV, 2000). The SAS 9.1 software program had been used to analyze the descriptive statistic, variance analysis, and mean comparisons by the Duncan multiple range tests. Moreover, the quantification of the heterosis influence (percentage) had been estimated according to the Hellauer et al. (1998) method and using below equations, as heterosis (superiority of the F1 hybrid over its parental mean) and heterobeltiosis (superiority of the F1 hybrid over its better parent). Relative heterosis compared to the mean of parents according to formula (1) (Hellauer et al., 1998); and relative heterosis compared to the superior parent by formula (2) (Hellauer et al., 1998):

$$\text{Hmp or MPH} = (\text{Mean Hybrid value - Mean parent value / Mean parent value}) \times 100 \quad (1)$$

$$\text{Hsp or HPH} = (\text{Mean Hybrid value – High parent value / High parent value}) \times 100 \quad (2)$$

RESULTS AND DISCUSSION

Flower size

Based on the mean comparison results, the largest flower (90.00 mm) and the smallest flower (6.03 mm) were observed in parent v4 and v7, respectively. In the hybrids, the largest flower (139.00 mm) in the hybrid oprc37 and the smallest flower (87.33 mm) in the hybrid oprc38 had been observed, both of which were derived from the cross v4×v5 (Table 2). The hybrids were shown superiority in the flower size compared to their parents. There was found higher positive heterosis (Hsp= 54.44%) over the parents and to their superior parent (Hmp=51.04%) (Parent v4 with a flower size of 90.00 mm). The results of this study were consistent with (Azimi et al., 2018a; Azimi et al., 2018b) in the *Iris germanica*. The smallest flower among all hybrids was observed in the oprc38 (Table 2) which also exhibited the more negative heterosis (MPH=-5.11%) comparing to the parents and smallest flower among all studied hybrids (oprc28 hybrids). Also, in some research, significant negative heterosis observed in ornamental plants (Yang et al., 2015; Azimi et al., 2018a). These hybrids could be considered for the production of the miniature flower in the breeding programs. Moreover, a larger flower in the iris exerts an influence on the marketing of flowers in the domestic and global markets due to more beauty and attractiveness, leading to the remarkable increase in the economic incomes (Jozghasemi et al., 2015). The hybrid oprc37 can be considered in breeding programs as it has higher positive heterosis in the flower size and the ability of iris to or vegetative propagation (rhizome dividing), as well. Therefore, it could be expected that this selected hybrid could be successful as a commercial cultivar in the flower industry. It is clear that the introduction of commercial cultivars could provide the economic prosperity of domestic flower marketing by enhanced diversity.

Table 1. Cross combinations for the production of *Iris*

Genotype codes	Parents (parental code)	
	♀	♂
oprc16 and oprc17	*Iris germanica* brown color (v2)	*Iris germanica* blue color (v5)
oprc18-oprc21	*Iris germanica* brown color (v2)	*Iris germanica* jasmine color (v4)
oprc22 and oprc23	*Iris germanica* jasmine color (v4)	*Iris germanica* dark violet color (v8)
oprc24 and oprc25	*Iris germanica* bright purple color (v6)	*Iris germanica* dark violet color (v8)
oprc26-oprc33	*Iris germanica* white color (v1)	*Iris germanica* dark violet color (v8)
oprc34-oprc41	*Iris germanica* jasmine color (v4)	*Iris germanica* blue color (v5)
oprc42 and oprc43	*Iris germanica* brown color (v2)	*Iris spuria* blue color (v7)

Table 2. Mean of each characteristic and their heterosis in the parents as well as their progenies of oprc (16-21, 42 and 43)

Code	Crown diameter (mm)	Diameter of flowering branch (mm)	Bush height (cm)	Inner tepal width (mm)	Inner tepal length (mm)	Outer tepal width (mm)	Flower size (mm)	Peduncle thickness (mm)	Peduncle length (mm)	Leaf width (mm)
V2	16.28bc†	11.12 b	68.30i-n	39.21 o-p	55.50 lm	36.22 q-r	36.22m	9.23e-h	16.52r	24.01q
V5	15.8bc	12.30b	73.16g-i	42.10m-l	51.43mn	35.2g-r	35.2m	8.75fgh	18.20g- r	25.10q
Oprc16	15bc	5.00cb	81.00def	53.00b-e	75.00d-g	45.00j-m	103.33ghi	11.00c-f	22.00nop	53.00c
Hmp	-6.48	-50.30	14.52	30.36	40.28	46.53	10.48	22.36	26.73	115.84
Hsp	-5.06	-59.34	10.72	25.89	45.83	27.84	9.86	25.71	20.88	111.15
Oprc17	13bc	4.66de	81.66def	54.00bcd	75.00d-g	45.00j-m	126.00def	9.00e-h	41.33a-d	53.00c
Hmp	-18.95	-60.20	15.45	32.82	40.28	46.53	34.71	0.11	138.08	115.84
Hsp	-17.72	-62.11	11.62	28.27	45.83	27.84	33.96	2.88	127.09	111.15
V2	16.28bc	11.12b	68.30i-n	39.21o-p	55.50l- m	36.22g-r	36.22m	9.33e-h	16.52r	24.01q
V4	18.40ab	8.23c	73.00g-j	59.70a	79.13e	55.03a	90.00l	9.10e-h	14.10r-s	30.2o-p
Oprc18	4i	4.00d-f	77.00d-h	40.00l-p	70.00g-j	41.00mno	118.00d	14.00bc	24.00m-p	37.00k-n
Hmp	-76.93	-58.66	8.99	-19.12	3.99	-10.14	28.96	52.75	56.76	36.15
Hsp	-78.26	-51.40	5.48	-32.99	-11.54	-25.49	31.11	53.85	70.21	22.52
Oprc19	13be	4.23de	88.00c	37.00o-r	81.33bc	38.00opg	105.00ghi	8.00fgh	31.00h-k	35.00mn
Hmp	-25.03	-56.28	-88.68	-25.18	20.82	-16.71	14.75	-12.71	102.48	29.13
Hsp	-29.35	-48.60	-89.04	.38/02	2.78	-30.95	16.67	-12.09	119.86	15.89
Oprc20	12/00bcd	4.00d-f	74.00g-j	34.00r	76.00c-g	40.00nop	112.00edf	6.00hi	46.00a	38.00k-n
Hmp	-30.80	-58.66	4.74	-31.25	12.90	-12.33	22.40	-34.53	200.46	40.19
Hsp	-34.79	-51.40	1.37	-43.05	-3.95	-27.31	24.44	-34.07	226.24	25.83
Oprc21	11cde	6.00c	79.00d-g	48.00f-i	82.00bc	32.00r	134.00a	8.00fgh	36.00f-h	37.00k-n
Hmp	-36.56	-37.98	11.82	-2.49	21.81	-29.86	46.45	-12.71	134.14	36.51
Hsp	-40.22	-27.10	8.22	-19.60	3.63	-41.85	48.89	-12.09	155.32	22.52
V2	16.28bc	11.12b	68.30i-n	39.21o-p	55.50l-m	36.22q-r	36.22m	9.23e-h	16.52r	24.01q
V7	7.2h	5.23d	107.10a	24.06d	51.50mn	6.03t	6.03n	6.10h-i	28.4m-n	22.30r-s
Oprc42	10.00c-h	4.00d-f	68.00i-n	52.00b-f	74.00e-h	44.00k-n	121.00cd	12.00b-e	38.00c-g	48.00c-f
Hmp	-14.82	-51.07	-22.46	64.37	38.32	108.28	38.21	56.56	69.19	107.30
Hsp	-38.57	-64.03	-0.44	32.62	33.33	21.48	30.11	30.01	130.02	99.92
Oprc43	8.00e-h	3.00def	72.00h-k	50.00d-g	82.00bc	35.00qr	135.00a	12.00b-e	34.00f-i	41.00g-l
Hmp	-31.86	-63.30	-17.90	58.05	53.27	65.68	54.20	56.56	51.38	77.07
Hsp	-50.86	-73.02	5.42	27.52	47.75	-3.37	45.16	30.01	105.81	70.76

Table 2. (Continued) OPRC (34-41)

Code	Crown diameter (mm)	Diameter of flowering branch	Bush height (cm)	Inner tepal width (mm)	Inner tepal length (mm)	Outer tepal width (mm)	Flower size (mm)	Peduncle thickness (mm)	Peduncle length (mm)	Leaf width (mm)
V4	18.40ab†	8.23bc	73.00g-j	59.70a	79.13e	55.03a	90.00l	9.10e-h	14.10r-s	30.2o-p
V5	15.8bc	12.30b	73.16g-j	42.10kn	51.43mn	35.2q-r	35.2m	8.75fgh	18.20q-r	25.10q
Oprc34	11.00cde	6.00c	81.00def	45.00h-l	86.00a	48.33fk	100.00ij	12.00b-e	21.00op	47.00def
Hmp	-35.67	-41.55	10.84	-11.59	31.74	7.13	8.66	34.45	30.03	69.98
Hsp	-40.22	-27.10	10.96	-24.62	8.68	-12.17	11.11	31.87	48.94	55.63
Oprc35	10.00c-g	5.00cd	66.00k-n	44.00i-l	65.00jkl	48.00g-k	108.00e-g	8.00fgh	20.00p	40.00h-m
Hmp	-41.52	-51.29	-9.69	-13.56	-0.43	6.39	17.35	-10.36	23.84	44.66
Hsp	-45.65	-39.25	-9.59	-26.30	-17.86	-12.77	20.00	-12.09	41.84	32.45
Oprc36	7.00h	6.00c	84.33cd	39.00m-q	65.00j-l	40.00nop	101.00hij	6.00hi	39.00b-f	48.00c-f
Hmp	-59.06	-41.55	-15.39	-23.38	-0.42	-11.34	9.75	-32.77	141.49	73.60
Hsp	-61.96	-27.10	15.52	-34.67	-17.86	-27.31	12.22	-34.07	176.59	58.94
Oprc37	10.00c-g	5.00cd	91.00b	55.00bc	77.00c-f	51.00d-h	139.00a	12.00b-e	34.66f-i	64.00a
Hmp	-41.52	-51.29	-24.52	8.05	17.95	13.04	51.04	34.45	114.61	131.46
Hsp	-45.65	-39.25	24.66	-7.87	-2.69	-7.32	54.44	31.87	145.82	111.92
Oprc38	9.00d-h	4.00d-f	75.00f-i	47.00g-j	77.00c-f	50.00e-i	87.33k	12.33b-e	25.00m-p	61.33ab
Hmp	-47.37	-61.3	2.63	-7.66	17.95	10.83	-5.11	38.15	54.80	121.81
Hsp	-51.09	-51.39	2.74	-21.27	-2.69	-9.14	-2.97	35.49	77.30	103.08
Oprc39	7.00h	3.00def	67.00k-n	42.00k-n	75.00d-h	50.00e-i	107.00f-i	12.00b-e	31.00h-k	36.00lmn
Hmp	-59.06	-70.77	-8.32	-17.48	14.89	10.83	16.27	34.45	91.95	30.20
Hsp	-61.96	-63.55	-8.22	-29.65	-5.22	-9.14	18.89	31.87	119.86	19.20
Oprc40	8.00e-h	3.00def	69.00i-m	50.00d-h	76.00c-g	50.00e-i	1320.00ab	15.00a	38.00c-g	43.00f-i
Hmp	-53.22	-70.77	-5.58	-1.77	16.42	10.83	43.43	68.07	135.29	55.51
Hsp	-56.52	-63.55	-5.48	-16.25	-3.95	-9.14	46.67	64.83	169.50	42.38
Oprc41	9.00d-h	4.00d-f	70.00il	48.00f-i	71.00f-i	47.00h-k	121.33cd	8.00fgh	39.00b-f	46.00d-g
Hmp	-47.37	-61.03	-4.21	-5.70	8.76	4.18	31.84	-10.36	141.49	66.36
Hsp	-51.09	-51.40	-4.11	-19.60	-10.27	-14.59	34.81	-12.09	176. 60	52.32

† Means with the same letter in each column are not significantly different.
Hmp: Heterosis than mean parents; Hsp: Heterosis than the superior parent. Values for heterosis is expressed in percentage.

Table 2. (Continued) OPRC (22-25)

Code	Crown diameter (mm)	Diameter of flowering branch (mm)	Bush height (cm)	Inner tepal width (mm)	Inner tepal length (mm)	Outer tepal width (mm)	Flower size (mm)	Peduncle thickness (mm)	Peduncle length (mm)	Leaf width (mm)
V4	18.40ab†	8.23c	73.00g-j	59.70a	79.13e	55.03a	90.00l	9.10e-h	14.10r-s	30.2mn
V8	14.8c	11.23b	70.66i-l	38.93o-p	49.00n	36.00q-r	36.00m	8.43fgh	28.66j-m	35.33mn
Oprc22	10.66c-f	5.00c-d	94.00r	40.00l-p	76.00c-g	42.00l-o	115.00ed	14.00bc	24.00m-p	39.00i-m
Hmp	-35.78	-48.61	30.86	-18.89	18.63	-7.72	28.18	59.82	12.25	19.03
Hsp	-42.06	-39.25	28.77	-32.99	-3.95	-23.68	27.78	53.85	70.21	29.14
Oprc23	12bcd	6.00c	90.00abc	41.00l-p	84.00b	44.66j-m	132.00cde	11.00c-f	42.33a-d	47.00def
Hmp	-27.71	-38.33	25.30	-16.86	-31.12	-1.88	47.13	25.57	1968.90	43.45
Hsp	-34.78	-27.10	23.29	-31.32	6.15	-18.84	46.67	20.88	3037.09	55.63
V6	14.26c	11.20b	70.00i-l	39.6o-p	49.00n	35.06q-r	35.06m	8.75fgh	18.06q-r	25.10q
V8	14.8c	11.23b	70.66i-l	38.93o-p	49.00n	36.00q-r	36.00m	8.43fgh	28.66j-m	35.33mn
Oprc24	7.00h	2.00f	58.00pq	43.00j-m	68.00h-k	50.00e-i	135.00a	10.00d-g	21.33op	51.00cd
Hmp	-51.82	-82.17	-17.53	9.51	38.77	63.77	54.79	16.41	-8.69	68.79
Hsp	-52.70	-82.19	-17.92	10.45	38.77	92.31	50.96	18.62	-25.57	44.35
Oprc25	11.00cde	3.00def	60.00opq	50.00d-g	86.00ab	54.00b-e	135.00a	11.00c-f	31.33h-k	44.00f-i
Hmp	-24.29	-73.25	-14.69	27.34	75.51	76.87	54.79	28.08	34.12	45.62
Hsp	-25.68	-73.29	-15.09	28.44	75.51	107.69	50.96	30.49	9.32	24.54

Table 2. (Continued) OPRC (26-33)

Code	Crown diameter (mm)	Diameter of flowering branch (mm)	Bush height (cm)	Inner tepal width (mm)	Inner tepal length (mm)	Outer tepal width (mm)	Flower size (mm)	Peduncle thickness (mm)	Peduncle length (mm)	Leaf width (mm)
V1	20.23a†	16.10a	81.22def	57.14ab	76.11c-g	50.21b	50.21l	9.12e-h	29.18j-i	38.14k-l
V8	14.8c	11.23b	70.66i-l	38.93o-p	49.00n	36.00q-r	36.00m	8.43fgh	28.66j-m	35.3mn
Oprc26	14.00c	6.00c	82.00def	65.00a	80.00b-e	50.00e-i	110.00efg	11.00c-f	25.00l-p	58.00b
Hmp	-20.07	-56.09	7.98	35.32	27.89	15.99	10.28	25.36	-13.55	57.89
Hsp	-30.79	-62.73	0.96	13.76	5.11	-0.42	-0.06	20.61	-14.32	52.07
Oprc27	9.00d-h	6.00c	95.00a	48.00f-i	75.00d-g	50.00e-i	120.00cd	13.00bcd	30.00i-l	58.00b
Hmp	-48.61	-56.09	25.10	-0.07	19.89	15.99	20.30	48.15	3.73	57.89
Hsp	-55.51	-62.73	16.97	-15.99	-1.46	-0.42	20.61	42.54	2.81	52.07
Oprc28	11.33de	4.00d-f	81.00def	50.00d-g	65.33j-l	50.00e-i	106.00ghi	11.00c-f	28.00j-m	50.00cde
Hmp	-35.31	-70.73	6.66	4.09	4.44	15.09	6.27	25.36	-3.18	36.11
Hsp	-43.99	-75.15	-0.27	-12.49	-14.16	-0.42	-3.70	20.61	-4.04	31.10
Oprc29	10.00c-g	5.00cd	62.00nop	56.00b	72.00f-i	50.00e-i	109.00efg	10.00d-g	20.00p	33.00no
Hmp	-42.91	-63.41	-18.36	16.58	15.10	15.99	9.27	13.96	-30.84	-10.17
Hsp	-50.57	-68.94	-23.66	-1.99	-5.40	-0.42	-0.97	9.65	-31.46	-13.48
Oprc30	7.00h	3.00def	68.00j-n	44.00i-l	67.00ijk	48.00g-k	96.00j	7.00ghi	23.00m-p	45.00e-i
Hmp	-60.03	-78.05	-10.46	-8.40	7.11	11.36	-3.76	-20.23	-20.47	22.50
Hsp	-65.40	-81.37	-16.28	-22.99	-11.97	-4.40	-12.78	-23.25	-21.18	17.99
Oprc31	7.00h	3.00def	70.00i-l	41.00k-o	71.00f-j	54.00b-e	136.00a	4.00i	28.00j-m	51.00cd
Hmp	-60.03	-78.05	-7.82	-14.65	13.50	25.27	36.34	-54.42	-3.18	38.83
Hsp	-65.40	-81.37	-13.81	-28.25	-6.71	7.55	23.56	-56.14	-4.04	33.72
Oprc32	6.00h	5.00cd	63.00m-p	38.00m-r	74.00e-i	46.00f-j	119.00cd	7.00ghi	31.00h-l	35.00mn
Hmp	-65.74	-63.41	-17.04	-20.89	18.30	6.72	19.29	-20.23	7.19	-4.72
Hsp	-70.34	-68.94	-22.43	-33.50	-2.77	-8.38	8.11	-23.25	6.23	-8.23
Oprc33	7.00h	4.00d-f	65.33c-o	40.00l-p	62.00kl	46.00i-l	119.33cd	4.00i	27.00k-n	37.00k-n
Hmp	-60.03	-70.73	-13.97	-16.73	-0.89	6.72	19.63	-54.42	-6.64	0.72
Hsp	-65.40	-75.15	-19.56	-29.99	-18.54	-8.38	8.41	-56.14	-7.47	-2.99

† Means with the same letter in each column are not significantly different.
Hmp: Heterosis than mean parents; Hsp: Heterosis than the superior parent. Values for heterosis is expressed in percentage.

Inner tepal length and width

According to the results of the mean comparison, it was observed that the highest inner tepal length and width were found in v1 and v4 and the lowest inner tepal length and width were shown in the v7, which belonged to *I. spuria* (Table 2). In hybrids, the highest inner tepal length (86.00 mm) was observed in the hybrids oprc25 and oprc34 and the highest inner tepal width (65.00 mm) was found in the hybrids oprc26, while the lowest inner tepal length and width were obtained in hybrid oprc33 and oprc20, respectively (Table 2). Hybrid oprc25 (cross v8×v6) and hybrid oprc34 (cross v4×v5) showed the superiority (Hmp=75.51% and Hmp=31.74%) heterosis, respectively over their parents in the length of the inner tepal and even they indicated higher positive heterosis compared to the superior parent (Table 2). This population could be used since the width of fall petal and the inner tepal was important in the iris breeding programs (Jozghasemi et al., 2015; Azimi et al., 2011), the results of this study were consistent with the researches of (Arnold et al., 2010; Burke et al., 1998; Huang et al., 2003) in the Iris. In the crosses of *I. pseudacorus* with *I. laevigata* and *I. revsicolor*, hybrids were appeared to have superiority in most traits (Austin, 2005).

Outer tepal width

The maximum width of the outer tepal width was observed in parent v4 and the minimum width of the outer tepal in the parent v7, which belonged to *I. spuria*. Based on the results of the mean comparison of the progeny population (Table 2), the greatest and the lowest outer tepal were observed in the hybrids of oprc25 (54 mm) and oprc21 (32 mm). Hybrid of oprc25 had been derived from cross v8×v6, in which these two parents had a moderate outer tepal width (Table 2). However, hybrid 25 (Hmp=76.87%) from the cross of genotypes v6 and v8 was found to be a superior in the outer tepal width compared to other hybrids and even had higher positive heterosis compared to the superior parent in the outer tepal width (Table 2), as this trait suggested being an important economic trait in Iris should be considered more in comparison to other evaluated factors, the results of this finding were in agreement with those of (Arnold et al., 2010) in the iris. Azimi et al. (2012) and Jozghasemi et al. (2015) investigated 14 species of the Iranian native iris, respectively, and suggested that the outer tepal width was the main part of the flower, which considered as an important economic trait in the iris breeding.

Flowering stem diameter and plant height

The highest diameter of the flowering stem was observed in parent v1 (16.10 mm) and the lowest one was found in parent v7 (5.23mm) in which the highest plant height (107.10 cm) was shown, this parent belonged to *I. spuria* (Table 2). On the other hand, the lowest plant height was observed in parent v2 up to 68.30 cm. Based on the results of the mean comparison of hybrids, the diameter of the flowering stem was significantly decreased in all hybrids compared to parents and the lowest diameter of the flowering stem was observed in the hybrid oprc24 (Hmp=-82.17%). The negative heterosis in the hybrids may be due to the accumulation and appearance of the recessive genes in hybrids (Alam et al., 2004), or it may be due to the non-additive effects of genes controlling the quantitative traits of the flowering stem diameter in the iris (Rahimi et al., 2009). Also, a significant negative heterosis was reported in *Chrysanthemum* (Yang et al., 2015). The highest plant height was obtained in the hybrid oprc27 at 95.00 cm and the lowest plant height was observed in hybrid oprc19 (Table 2). The hybrids of oprc23 and oprc21, which were derived from cross v4×v8 and v4×v2, respectively, had the highest diameter of the flowering stem among the progeny, but had the negative heterosis compared to parents. However, they showed the highest diameter of the flowering stem compared to the other investigated hybrids. Therefore, according to the obtained results of the heterosis percentage of the hybrids, it was suggested that the hybridization of the studied hybrids had no significant effect on the superiority of the flowering stem diameter in comparison with the parents. The hybrid oprc27 with a height of 95.00 cm, which was derived from the cross of parents v1 and v8, had higher positive heterosis compared to parents (Hmp=25.10%) and a superior parent (Parent v8).

Plant height was superior in the hybrids compared to the parents; this was consistent with the results of Huang et al. (2003) that obtained eight species of dwarf German iris from five crosses and stated that the plant height was different in the first generation. The plant height in cut flowers is found to be a very important trait since it is applied in flower sorting according to size. Therefore, this finding proposed that the higher the plant height, the larger the dimensions of the leaf and the reproductive parts, and the populations possessed higher height could provide a basis for the production of high quality flowers. The length and the diameter of the flowering stem were considered as the valuable features of the iris appearance. Consequently, it was suggested that the hybrid of oprc27, which has higher positive heterosis, could be used to improve the quality of iris cut flowers in the breeding programs leading to the enhanced economic profit in the flower market. In accordance with our results, heterosis and a wider range of height in the F1 were reported in the progeny of other Irises.

Leaf width

Higher leaf width was observed in parent v1 and v3 with 41.2 and 38.12 mm, respectively, and the lowest leaf width was found in parent v7 with about 22.3 mm, which belonged to *I. spuria*. Based on the results of the mean comparison of hybrids a higher leaf width was shown in oprc37 and oprc38 which was 64.00 and 61.33 mm, respectively, and the lowest leaf width was observed in oprc29 (Table 2). The oprc37 and oprc38 that were derived from the cross of parents v4 and v5 showed a significant difference with the others and had the widest leaf width in the studied hybrids. Moreover, they had a high superiority compared with parents (Hmp=131.46% and Hmp=121.81%) and the high positive heterosis in comparison with their superior parent (parent v4), the results of this finding were found to be relevant to (Azimi et al., 2018a; Azimi et al., 2018b) in the *Iris germanica*. The Increased leaf area would enhance the amount of photosynthesis, resulting in more carbohydrate accumulation (Arnold et al., 2010), which would lead to the increased flower life which would provide the possibility of transport to far distant places in the flower export industry. Therefore, hybrids of oprc37 and oprc38 could be used in the Iris breeding program and might be introduced as a commercial cultivar in the flower market to increase the competitive ability.

Length and diameter of the peduncle

The maximum length of the peduncle in parent v1, v7, and v8 were 29.18, 28.48 and 28.66 (mm), respectively. The lowest length of the peduncle was observed in parent v4 with 14.1 (mm). The higher diameter of the peduncle in parent v1 and v2 were 9.12 and 9.23 (mm), respectively. The lowest peduncle diameter of the genotype v7, which is *I. spuria*, was 6.1 (mm). Based on the results of the mean comparison of progenies, the maximum length of the peduncle was observed in the hybrid of oprc20 with 46.00 mm, and the lowest length was found in hybrids of oprc29 and oprc35 (Table 2). The maximum diameter of the peduncle in the hybrid of oprc40 was 15.00 mm and the minimum peduncle diameter was observed in the hybrids of oprc33 and oprc31 with 4.00 mm. oprc20 obtained from the cross of genotypes v2 and v4 had a significant difference in the length of the peduncle compared to other populations and also possess high positive heterosis in comparison with its superior parent (cross v2×v4) (Table 2). The oprc40 derived from the cross v4×v5 had higher positive heterosis than those of its parents and superior parent (parent v4) and showed a significant difference in the peduncle thickness compared to other populations. Peduncle diameter influences the stability of the iris flower on the stalk, the higher the peduncle thickness, the more stable the flower on the stem will be. The results of this finding were in agreement with the research performed by Huang et al. (2003) and Azimi et al. (2018a) in the iris. It should be considered that the larger diameter of the peduncle had a significant effect on stem connection to the flower and it could be used in the breeding programs of iris.

Crown diameter

The maximum and minimum crown diameter was observed in the parent v1 (20.23 mm) and the genotype v7 (7.2 mm) belonged to *I. spuria*. According to the results of the mean comparison of the hybrids (Table 2), it was found that the highest and the lowest crown diameter belonged to the hybrids of oprc16 and oprc18. The oprc16 derived from the cross v2 × v5, which had shown a significant difference compared to other studied populations, was found to have negative heterosis (Hsp=-5.06%) (Table 2). Considering the results, it could be stated that the oprc16 had shown a significant difference in the increased crown diameter compared to the other evaluated hybrids (28 hybrids). The results of this finding were consistent with the studies of (Azimi et al., 2018a; Azimi et al., 2018b; Arnold et al., 2010; Burke et al., 1998; Huang et al., 2003) in the iris. Alam et al. (2004); Nuruzzaman et al. (2002) observed the negative heterosis in the height and diameter of the rice and stated that the hybrid could be utilized to produce the dwarf cultivars in the breeding programs, so hybrid of oprc16 could be applied in the breeding programs of the iris to result in the production of the dwarf and potted cultivars (because parents had the capability of the cultivation in open field).

Cross of *I. germanica* and *I. spuria*

This cross had been conducted as a reciprocal cross which ultimately led to the production of two progeny populations with the color variation in flowers, in which the color of flowers, mostly in the range of purple, was inherited from the paternal parent (*I. spuria*). The hybrid of oprc42 was found to have higher positive heterosis than parents and the superior parent in most traits except for the plant height, the diameter of flowering stem and crown diameter and the hybrid of oprc43 had higher positive heterosis than parents and the superior parent in most traits, except for the width of fall petal, the diameter of the flowering stem, and crown diameter (Table 2). German iris with a chromosome number of 2n=44-48 was known as a rhizomatous, tall, arilless seeds and bearded and belonged to genus *Iris* based on the systematic relations (Anonymous, 2002), *I. spuria* with a chromosome number of 2n=44-48 was tall, rhizomatous, bearded, and wetland specific (Azimi et al., 2010), and according to systematic relations was found to be the species of subgenus Xyridion (Anonymous, 2008). The results of Azimi et al. (2010; 2011), categorized *I. germanica* and *I. spuria* in a group by the evaluation of genetic diversity of Iranian iris, which was genetically closely related to each other and could be used to select traits in the breeding programs. Many cultivars of the ornamental geophytes (bulbous flowers) have originated from the complex crosses of species, which has led to the production of a wide range of the different shapes and colors in flowers (Benschop et al., 2010). Progenies of interspecies hybridization of *I. fulva* with other species of Louisiana *Iris* species showed that there are the compatible genes among *I. fulva*, *I. brevicaulis*, and *I. hexagona* (Arnold et al., 2010). Heterosis is known to be a multigenic complex trait and can be extrapolated as a total of many physiological and phenotypic characteristics (Kumar Baranwal et al., 2012).

CONCLUSION

Inter-varietal hybridization, in which satisfactory attributes or genes are transferred from one variety into another, is a promising strategy for improving plant traits (Yang et al., 2015). The results had generally shown that the highest percentage of heterosis compared to the parents and superior parent was suggested in the hybrid oprc37 (cross v4×v5) for the flower size and leaf width, hybrid oprc25 (cross v6 × v8) for the standard length and the width of the fall petal and the oprc20 (cross v2×v4) for the peduncle length, and oprc16 (cross v2×v5) for the crown diameter. Given the fact that higher flower diameter, fall petal width, standard width and peduncle length of the iris had remarkably influenced on increasing the economic income in the domestic and global markets due to the beauty and attractiveness. Therefore, the hybrids of oprc37, oprc25, oprc20, and oprc16 could be used to produce the superior cultivars in the breeding programs of the iris. It should be noted that this research had been conducted for the first time in Iran and could provide a new platform for planning to hybridize the wild and commercial cultivars in the future.

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Conflict of interest

The author declares that there is no conflict of interest.

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