J. Hortic. Sci.
Vol. 20(1), 2025

https://doi.org/10.24154/jhs.v20i1.3052

Original Research Paper

Inheritance pattern of leaf and fruit traits in watermelon [*Citrullus lanatus* (Thunb) Mansf.]

Choudhary B.R.[1*], Ram H.[1], Rane J.[1] and Pandey S.[2]
[1]ICAR-Central Institute for Arid Horticulture, Bikaner - 334 006, Rajasthan, India
[2]Indian Council of Agricultural Research, New Delhi, India
[*]Corresponding author Email: choudharybr71@gmail.com

ABSTRACT

Rare traits can significantly contribute to the development of trait-specific genotypes and may also be effectively used as morphological markers in breeding. Most of the watermelon cultivars or genotypes are having lobbed leaves but YF 5-2-7 exhibiting non-lobed leaves along with yellow fleshed round fruits. The study was conducted during 3 seasons to develop F_1, F_2 and their evaluation along with parental lines. The breeding line AHW/BR-22 was used as a female parent and crossed with unique yellow fleshed watermelon genotype YF 5-2-7 to produce F_1 and F_2 generation to study the inheritance of leaf shape, fruit shape and flesh colour. Based on the segregation pattern of progeny, it is concluded that leaf shape and fruit shape did not follow monogenic inheritance, while, monogenic control was observed in flesh colour. This study provides valuable insights into the genetic basis of leaf shape, fruit shape and flesh colour in watermelon, which can have practical applications in breeding programmes, facilitating the development of improved watermelon varieties with desirable and unique traits.

Keywords: Inheritance, qualitative, watermelon

INTRODUCTION

Watermelon [*Citrullus lanatus* (Thunb.) Mansf.] is an important fruit vegetable crop belonging to the family *Cucurbitaceae*. It is one of the most extensively grown crops worldwide (Huh et al., 2008) and is widely grown in the tropics and Mediterranean (Tindall, 1983). In 2023, global watermelon production reached a record high of 104.93 million tons, marking a 1.83% increase from the previous year. China remained the leading producer. The total cultivation area also expanded, reaching 3,042.9 thousand hectares. India produced about 3.62 million tons of watermelon from 126-thousand hectare area (FAO, 2023).

Watermelon is used as refreshing fruit cherished for its juicy sweetness, especially during hot weather. Watermelon is rich source of minerals, vitamins, citrulline, carotenoids and antioxidants (Choudhary & Singh, 2011; Choudhary et al., 2015; Choudhary, 2019). Predominantly, it has monoecious sex form but andromonoecious sex form which is rarely observed has also been reported (Choudhary et al., 2021). It exhibits good amount of diversity in fruit size, shape, rind pattern and flesh color (Choudhary et al., 2016).

For the quality perspective, flesh colour is a vital trait of watermelon. King et al. (2009) classified eight flesh colour for watermelon: white, salmon yellow, orange, crimson red, scarlet red, pale yellow, canary yellow, and green. According to Zhao et al. (2013) and Lv et al. (2015), there is an abundance of lycopene, β-carotene, and xanthophyll in the flesh color red, orange, and yellow, respectively. Watermelons with yellow flesh have higher levels of the antioxidant β-carotene, which may offer protection against eye disorders and cancer. It is not easy to breed watermelon cultivars with specific rind colour, fruit shape, and flesh color to draw the attention of consumers. One of the main goals of breeding watermelon fruit has been to improve its rind colour, fruit shape, and flesh colour (Gusmini & Wehner, 2006; Wang et al., 2019). As some genes are frequently distorted throughout inheritance, breeding for a particular flesh color may be very challenging. When populations segregating for red and salmon yellow flesh, abnormal phenotypes are frequently observed (Wang et al., 2019).

In India, the commercially available public sector varieties have red flesh. However, now the people are

Fig. 1 : Phenotype of parental lines, AHW/BR-22 fruit (a), leaf (b), YF 5-2-7 fruit (c) and leaf (d)

more conscious towards health issues and therefore, yellow fleshed varieties attract the consumers. The introgression of yellow flesh trait from the available germplasm to elite cultivars through breeding programs requires systematic sourcing to avoid genetic complications. Therefore, comprehending the inheritance pattern of qualitative traits is crucial for retaining fruit quality while transferring the genes. The objective of this investigation was to study the inheritance of different qualitative traits such as leaf shape, fruit shape and flesh colour, and development of desirable segregants having long fruit shape with dark green rind and yellow flesh.

MATERIALS AND METHODS

The study was conducted at Research Farm of ICAR-Central Institute for Arid Horticulture (ICAR-CIAH), Bikaner, Rajasthan, India located at 28° N latitude, 73° 18' E longitude at an altitude of 234.84 m above sea level, during 2022 and 2023. In summer season, 2022, two inbred lines with polymorphic traits developed by ICAR-CIAH were used to develop crosses. The selection of parents has been done based on polymorphic traits with respect to leaf shape, fruit shape and flesh colour. The reciprocal crosses were made between AHW/BR-22 and YF 5-2-7 through hand pollination to develop F_1 hybrids. The parent (AHW/BR-22) is characterized by lobed leaves (Penta lobate), 21.9-24.4 cm long fruits and red flesh while the parent (YF 5-2-7) with lobed leaves (entire), round fruit shape and yellow flesh (Fig. 1). The characterization of parental lines was also done for flowering, fruiting and morphological traits.

During rainy season, 2022, raised the seed of both F_1 hybrids *viz*., YF 5-2-7 × AHW/BR-22 and AHW/BR-22 × YF 5-2-7 and maintained 100 plant population of each hybrid. Characterization of the resultant F_1 hybrids was done for different horticultural and qualitative traits (leaf shape, fruit shape and flesh colour). One F_1 plant of the cross combination AHW/BR-22 × YF 5-2-7 was selfed using pollen from male flower of the same plant to obtain fruits containing F_2 seeds to study inheritance pattern.

Raised the single plant population of AHW/BR-22 × YF 5-2-7 F_2 during summer season of 2023 and maintained 267 plants to study gene action of leaf shape, fruit shape and flesh colour. The observations were recorded on leaf shape, fruit shape and flesh colour and combination of there off from all F_2 population individually. A test for goodness of fit was performed using chi-square analysis of the expected segregation of classical Mendelian ratios (Panse & Sukhatme 1985) as $\chi^2 = \Sigma$ [(Observed number - Expected number)^2/Expected number]. All χ^2 tests were performed with a 95% confidence level.

RESULTS AND DISCUSSION

An examination of the data from the parental lines and the reciprocal crosses (Table 1) revealed that all plants of the parental line AHW/BR-22 produced lobed leaves and long-shaped fruits with red flesh. In contrast, line YF-5-2-7 exhibited non-lobed leaves, round-shaped fruits, and yellow flesh. In the F_1 generations of both crosses (AHW/BR-22 × YF 5-2-7 and YF 5-2-7 × AHW/BR-22), all plants displayed lobed leaves, round fruit shape, and red flesh. This indicates that lobed leaves, round fruit shape, and red flesh are dominant traits. The phonotype of parental lines and F_1 hybrids is presented in Fig. 2 & 3.

Table 1 : Characteristics of parental lines and F_1 hybrids

Trait	AHW/BR-22	YF 5-2-7	YF 5-2-7 × AHW/BR-22	AHW/BR-22 × YF 5-2-7
Days taken to produce 50% female flowering	45-47	47-50	45-51	46-48
Node number at which first female flower appeared	13-16	12-15	14-17	16-18
Days to first fruit harvesting	75-80	77-81	74-80	71-73
Fruit weight (kg)	2.6-2.9	2.0-3.1	2.4-3.0	2.6-2.8
Fruit length (cm)	21.9-24.4	16.6-17.4	19.0-22.4	19.8-21.4
Fruit diameter (cm)	14.8-15.3	16.2-16.7	15.1-17.2	14.4-16.8
Rind thickness (cm)	1.2-1.3	0.9-1.5	1.1-1.3	0.9-1.2
Number of fruits/plant	2-3	2-4	3-4	3-4
Marketable fruit yield/plant (kg)	6.2-8	5.6-8.3	6.5-8.4	6-8.2
Total soluble solids (%)	11.8-12.2	7.6-9.8	10.2-11.0	9.7-10.1
Leaf shape	Lobed (pentalobate)	Non-lobed (entire leaf)	Lobed (entire leaf)	Lobed (entire leaf)
Fruit shape	Long	Round	Round	Round
Flesh colour	Red (Red Group 40A)	Yellow (Yellow Group 21C)	Red (Red Group 40A)	Red (Red Group 40A)

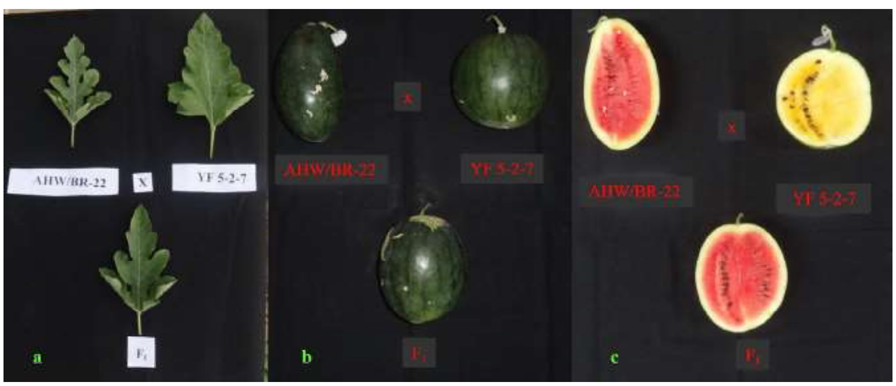

Fig. 2 : Phenotype of parents (AHW/BR-22, YF 5-2-7) and their F_1: leaf (a), fruit shape (b) and flesh colour (c)

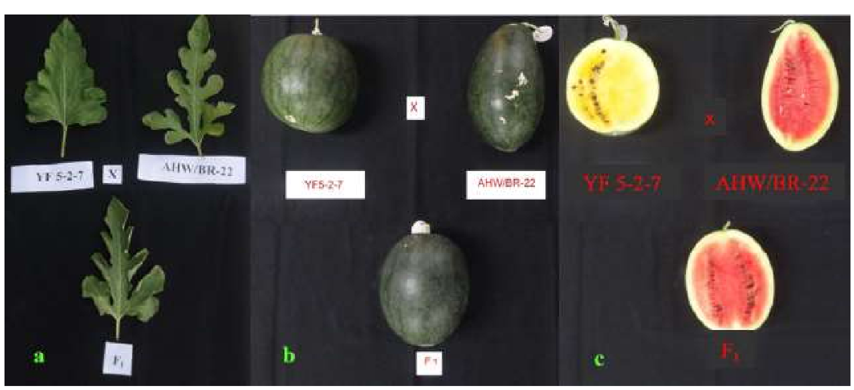

Fig. 3 : Phenotype of parents (YF 5-2-7 and AHW/BR-22) and their F_1: leaf (a), fruit shape (b) and flesh colour (c)

Table 2 : Inheritance pattern of leaf shape in watermelon

Parent & generation	No. of plants	Observed frequency		Observed ratio	Expected ratio	χ^2 value (cal.)*	P** value (d.f.=1)
		Lobed (L)	Non-lobed (NL)	L:NL			
AHW/BR-22	50						
YF-5-2-7	50	-	50				
YF-5-2-7 × AHW/BR-22 F_1	100	100	-				
AHW/BR-22 × YF-5-2-7 F_1	100	100	-				
AHW/BR-22 × YF-5-2-7 F_2	267	216	51	4.24:1	3:1	4.9	0.03

*tabulated value for P=0.05 significance level is 3.84; **figures in parentheses are exact probability values

Inheritance of leaf shape

In F_2 population derived from AHW/BR-22 x YF-5-2-7, out of 267 plants, 216 plants were exhibiting lobbing in leaves, while, 51 plants produced non-lobed leaves (Table 2). The segregation ratio of F_2 plants not fitted well in the expected ratio of 3:1 as lobed and non-lobed leaves, respectively (χ^2 value=4.9 > p-value=0.03).

Inheritance of fruit shape

With respect to fruit shape, all F_1 plants had long shaped fruits while F_2 population segregated with round (233) and long (34) shaped fruits (Table 3). The segregation ratio of F_2 plants not fitted well in the expected ratio of 3:1 as round and long fruits, respectively [χ^2 value (21.4) >p-value (0.00)]. Maragal et al. (2019) also reported a deviation from the Mendelian pattern of inheritance for fruit shape in watermelon (BIL 53 × IIHR-140-152), with the F_1 generation exhibiting an intermediate form between flat and oblong shape. However, Chauhan et al. (2023) reported monogenic inheritance of fruit shape and observed that spherical fruit shape was dominant to oval fruit shape. Several researchers (Tanaka et al., 1995; Dou et al., 2018) reported single gene inheritance pattern with co-dominant gene action for fruit shape in watermelon.

Inheritance of flesh colour

The flesh colour had also been studied for its inheritance pattern (Table 4). All the F_1 plants were red fleshed fruits, while, F_2 population segregated as 206:61 (red: yellow), with goodness of fit for 3:1 (χ^2 = 0.65 > p-value = 0.42). Gusmini & Wehner (2006) also investigated the genetics of flesh colour in watermelon by recording colour variations across different fruit regions separately. Similarly, Maragal et al. (2019) observed intermediate flesh colour in segregating populations derived from various cross combinations, such as white × red and salmon yellow × red. They also observed different colour combinations in different regions of the flesh *viz*., at the centre, at the margin near rind, around the seeds and at carpellar region in some segregants.

Table 3 : Inheritance pattern of fruit shape in watermelon

Parent & generation	No. of plants	Observed frequency		Observed ratio	Expected ratio	χ^2 value (cal.)*	P** value (d.f.=1)
		Round (R)	Long (L)	R:L			
AHW/BR-22	50						
YF-5-2-7	50	50	-				
YF-5-2-7 × AHW/BR-22 F_1	100	100	-				
AHW/BR-22 × YF-5-2-7 F_1	100	100	-				
AHW/BR-22 × YF-5-2-7 F_2	267	233	34	6.85:1	3:1	21.4	0.00

*tabulated value for P=0.05 significance level is 3.84; **figures in parentheses are exact probability values

Table 4 : Inheritance pattern of flesh colour in watermelon

Parent & generation	No. of plants	Observed frequency		Observed ratio	Expected ratio	χ^2 value (cal.)*	P** value (d.f.=1)
		Red (L)	Yellow (NL)	R:L			
AHW/BR-22	50						
YF-5-2-7	50	-	50				
YF-5-2-7 × AHW/BR-22 F_1	100	100	-				
AHW/BR-22 × YF-5-2-7 F_1	100	100	-				
AHW/BR-22 × YF-5-2-7 F_2	267	206	61	3.37:1	3:1	0.65	0.42

*tabulated value for P=0.05 significance level is 3.84; **figures in parentheses are exact probability values

Several researchers have investigated the inheritance of flesh color in watermelon and identified specific loci associated with this trait (Henderson et al., 1998; Gusmini & Wehner, 2006; Bang et al., 2007; Bang et al., 2010). According to Henderson (1989), the Y locus, which contains three alleles, controls the red, orange, and salmon yellow flesh. Y (red flesh) is dominant over both y° (orange flesh) and y (salmon yellow flesh), while y° (orange flesh) is dominant over y (salmon yellow flesh). Henderson et al. (1998) proposed that the homozygous recessive i locus, which produced red flesh independent of the presence of C alleles, can suppress the canary yellow flesh (C), which is dominant over the red flesh (c).

Inheritance of leaf shape, fruit shape and flesh colour

The phenotype of segregating population derived from F_2 generation of AHW/BR-22 × YF 5-2-7 indicated clear difference in fruit shape and flesh colour (Fig. 4). Eight types of combinations were found in segregating population of F_2 generation. When the all 267 F_2 plants interpreted for leaf shape, fruit shape and flesh colour (Table 5), 144 produced lobed leaves with round shaped-red fleshed fruits, 47 with lobed leaves and round shaped-yellow fleshed fruits, 32 with non-lobed leaves and round shaped-red fleshed fruits, 22 with lobed leaves and long shaped-red fleshed fruits, 10 with having non-lobed leaves and round shaped-yellow fleshed fruits, 8 with non-lobed leaves and long shaped-red fleshed fruits, 03 with lobed leaves and long shaped-yellow fleshed fruits, and only one plant had non-lobed leaves with long shaped-yellow fleshed fruits. The segregation ratio of F_2 plants not fitted well in the expected ratio of 27:9:9:9:3:3:3:1 as lobed leaf-round fruits-red flesh colour (LRR); lobed leaf-round fruits-yellow flesh colour (LRY); non-lobed-round fruits-red flesh colour (NLRR); lobed leaf-long fruits-red flesh colour (LLR); non-lobed-round fruits-yellow flesh colour (NLRY); non-lobed-long fruits-red flesh colour (NLLR); lobed leaf-long fruits-yellow flesh colour (LLY) and non-lobed-long fruits-yellow flesh colour (NLLY) respectively, which is evident from the χ^2 test (χ^2 value= 30.2 > p-value = 0.00). It suggests that all the three traits studies may not be independent to each other and there might be inter-allelic interaction like linkage, polygenic effect, pleiotropism, epistasis, etc. which needs to be studied to open the pathway for trait targeted watermelon breeding.

Fig. 4 : Phenotype of segregating population of AHW/BR-22 x YF 5-2-7 in F_2 generation

LRR: lobed leaf, round fruits, red flesh colour; LRY: lobed leaf, round fruits, yellow flesh colour; NLRR: non-lobed, round fruits, red flesh colour; LLR: lobed leaf, long fruits, red flesh colour; NLRY: non-lobed, round fruits, yellow flesh colour; NLLR: non-lobed, long fruits, red flesh colour; LLY: lobed leaf, long fruits, yellow flesh colour; NLLY: non-lobed, long fruits, yellow flesh colour

Table 5 : Inheritance pattern of leaf shape, fruit shape and flesh colour in watermelon

Parent & generation	No. of plants	Observed frequency								Observed ratio	Expected ratio	χ^2 value (cal.)*	P** value (d.f.=7)
		LRR	LRY	NLRR	LLR	NLRY	NLLR	LLY	NLLY	LRR:LRY:NLRR:LLR: LRY:NLLR:LLY:NLLY			
AHW/BR-22	50	50	-	-	-	-	-	-	-				
YF-5-2-7	50	-	-	-	-	50	-	-	-				
YF-5-2-7 × AHW/BR-22 F_1	100	100	-	-	-	-	-	-	-				
AHW/BR-22 × YF-5-2-7 F_1	100	100	-	-	-	-	-	-	-				
AHW/BR-22 × YF-5-2-7 F_2	267	144	47	32	22	10	08	03	01	144:47:32: 22:10:8:3:1	27:9:9:9: 3:3:3:1	30.2	0.00

*tabulated value for P=0.05 significance level is 14.07; **figures in parentheses are exact probability values

CONCLUSION

The investigation conducted has proven to be invaluable in assessing the understanding the inheritance pattern of different morphological traits in watermelon breeding. By exploring deeper insight into the inheritance mechanism and employing the marker-assisted selection approach would be very effective to fasten the breeding of desired cultivars of watermelon. Further, YF 5-2-7 may be useful as male parent for plant breeders interested in development of yellow fleshed cultivars rich in β-carotene having morphological marker (non-lobed leaves) to distinguish the cultivar at seedling stage.

REFERENCES

Bang, H., Davis, A., Kim, S., Leskovar, D., & King, S. (2010). Flesh color inheritance and gene interactions among canary yellow, pale yellow, and red watermelon. *Journal of the American Society for Horticultural Science*, *135*, 362-368. https://doi.org/10.21273/JASHS.135.4.362

Bang, H., Kim, S., Leskovar, D., & King, S. (2007). Development of a codominant CAPS marker for allelic selection between canary yellow and red watermelon based on SNP in lycopene b-cyclase (LCYB) gene. *Molecular Breeding*, *20*, 63-72. https://doi.org/10.1007/s11032-006- 9076-4

Chauhan, S. S. A., Choudhary, H., Yadav, R. K., Basavaraj, Y. B., Ellur, R. K., & Gupta, N. C. (2023). Genetic study of fruit quality traits in watermelon (*Citrullus lanatus*) prebred line derived from *Citrullus lanatus* var. *citroid*. *Indian Journal of Agricultural Sciences*, *93*(12), 1303–1307. https://doi.org/10.56093/ijas.v93i12.141804

Choudhary, B. R. (2019). Watermelon. In: Handbook of Horticulture Volume I. Edited by Dr. K.L. Chadha. ISBN: 978-81-7164-187-1. ICAR, New Delhi, pp. 636-640.

Choudhary, B. R., & Singh, P. K. (2011). Watermelon. In: Biodiversity in Horticultural Crops Vol. III. Edited by Dr. K.V. Peter. ISBN: 978-7035-672-1. Daya Publishing House, New Delhi, pp. 24-42.

Choudhary, B. R., Haldhar, S. M., & Saroj, P. L. (2021). AHW/BR-5 (IC0627526) (IC0627526; INGR19079), a watermelon (*Citrullus lanatus*) germplasm with stable andromonoecious sex form. *Indian Journal of Plant Genetic Resources*, *34*(1), 140.

Choudhary, B. R., Haldhar, S. M., Maheshwari, S. K., Bhargava, R., & Sharma, S. K. (2015). Phytochemicals and antioxidants in watermelon (*Citrullus lanatus*) genotypes under hot arid region. *Indian Journal of Agricultural Sciences*, *85*(3), 414–417. https://doi.org/10.56093/ijas.v85i3.47179

Choudhary, B. R., Pandey, S., Rao, E. S., Singh, D., & Sharma, B. D. (2016). Characterization of variability in watermelon for DUS testing. *Current Horticulture*, *4*(2), 30-34.

Dou, J., Zhao, S., Lu, X., He, N., Zhang, L., Ali, A., Kuang, H., & Liu, W. (2018). Genetic mapping reveals a candidate gene (ClFS1) for fruit shape in watermelon (*Citrullus lanatus* L.). *Theoretical and Applied Genetics*, *131*, 947-958. https://doi.org/10.1007/s00122-018-3050-5

FAO (2023). Food and Agricultural Organization, Rome, Italy. https://www.fao.org/faostat/en/#data

Gusmini, G., & Wehner, T. C. (2006). Qualitative inheritance of rind pattern and flesh color in watermelon. *Journal of Heredity*, *97*(2), 177-185. https://doi.org/10.1093/jhered/esj023

Henderson, W. (1989). Inheritance of orange flesh color in watermelon. *Cucurbit Genetics Cooperative Report*, *12*, 59-63.

Henderson, W., Scott, G., & Wehner, T. (1998). Interaction of flesh color genes in watermelon. *Journal of Heredity*, *89*, 50-53. https://doi.org/10.1093/jhered/89.1.50

Huh, Y.C., Solmaz, I., & Sari, N. (2008). Morphological characterization of Korean and Turkish watermelon germplasm. 1st Cucurbitaceae 2008. In: M. Pitrat (ed.), Proceedings of the IXth EUCARPIA meeting on genetics and breeding of Cucurbitaceae INRA, Avignon (France), May 21st-24th.

King, S. R., Davis, A. R., & Bang, H. (2009). New flesh colors in watermelon? *HortScience*, *44*, 576. https://doi.org/10.4236/as.2013.47A003

Lv, P., Li, N., Liu, H., Gu, H., & Zhao, W. E. (2015). Changes in carotenoid profiles and in the expression pattern of the genes in carotenoid metabolisms during fruit development and ripening in four watermelon cultivars. *Food Chemistry*, *174*, 52-59. https://doi.org/10.1016/j.foodchem.2014.11.022

Maragal, S., Rao, E. S., & Lakshmana Reddy, D. C. (2019). Genetic analysis of fruit quality traits in prebred lines of watermelon derived from a wild accession of *Citrullus amarus*. *Euphytica*, *215*(12), 1-15. https://doi.org/10.1007/s10681-019-2527-x

Panse, V. G., & Sukhatme, R. V. (1985). *Statistical Methods for Agricultural Workers*. 4th Edn. New Delhi, India.

Tanaka, T., Wimol, S., & Mizutani, T. (1995). Inheritance of fruit shape and seed size of watermelon. *Journal of Japanese Society for Horticultural Science*, *64*(3), 543–548. https://doi.org/10.2503/JJSHS.64.543

Tindall, H. D. (1983). *Vegetables in the Tropics*. The Macmillan Press Limited, London, pp. 150-152.

Wang, C., Qiao, A., Fang, X., Sun, L., Gao, P., Davis, A.R., Liu, S., & Luan, F. (2019). Fine mapping of lycopene content and flesh color related gene and development of molecular marker-assisted selection for flesh color in watermelon (*Citrullus lanatus*). *Frontiers in Plant Science*, *10*, 1-16. https://doi.org/10.3389/fpls.2019.01240

Zhao, W., Lv, P., & Gu, H. (2013). Studies on carotenoids in watermelon flesh. *Agricultural Science*, *04*, 13-20. https://doi.org/10.4236/as.2013.47A003

(Received : 13.6.2024; Revised : 23.5.2025; Accepted : 27.5.2025)