1	ACCEPTED ARTICLE
2 3 4 5	The citrulline content of watermelon lines differs in their fruit flesh and rind parts Veysel ARAS [*]
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9 10	Abstract
11	Citrulline is a natural antioxidant and an amino acid. The watermelon is a fruit that is generally
12	eaten for its fruit flesh. In this study, citrulline content was determined in different parts of the
13	fruit flesh and rind of four watermelon lines with varying skin colors. The fruits were divided
14	into six parts, and samples were taken from the rind and fruit pulp for the citrulline in each part.
15	The results showed that the highest value of citrulline was obtained for the genotype with a very
16	light green ground skin color (3.37 g/kg), while the lowest value was obtained from the
17	genotype with a very dark green ground skin color (2.0 g/kg). Regarding the fruit parts, the
18	highest value was taken from the 3rd part (3.72 g/kg), while the lowest value came from the
19	2nd part (2.00 g/kg). Higher citrulline values were found in the fruit flesh (3.10 g/kg) than in
20	the fruit rind (2.40 g/kg).
21	Keywords: watermelon, fruit, citrulline, ground skin color, different parts of the flesh fruit.
22 23	1. Introduction
24	Watermelons are economically important worldwide, with a global production of 101.6
25	million tons. China (60.1 million tons) is the largest producer country, followed by Türkiye (3.5
26	million tons), India (3.3 million tons), Brazil (2.1 million tons), Algeria (2.1 million tons), and
27	several other countries (29.8 million tons) (FAO 2021).
28	The watermelon (Citrullus lanatus (Thunb.) Matsum. & Nakai (2n = 22)) is one of the
29	significant horticultural crops in the Cucurbitaceae family. It is typically consumed in fruit
30	salads, desserts, or drinks. A wide range of phenotypic characteristics, including fruit size,
31	flesh color, rind pattern, and also disease resistance and flesh sweetness, are observed

32 between cultivars (Chikh-Rouhou et al. 2019). Each growing region has a unique set of

33 cultivars that are widely grown and are suited for cultivation in the local environment

34 (Wehner, 2008; Chikh-Rouhou and Garcés-Claver. 2021). Numerous nutrients and

bioactive substances, such as vitamins, lycopene, citrulline, and phenolic compounds, are found
in watermelon (Romdhane et al. 2017). It is a natural source of citrulline, an amino acid,
phenolic compounds, and carotenoid components, including lycopene, which has antioxidant
properties (Rimando and Perkins-Veazie 2005; Aguilo-Aguayo et al. 2010; Sun et al. 2010;
Joshi et al. 2019). Watermelon is freshly consumed by many worldwide, partly due to its lowcalorie content and the fact that it is highly nutritious and thirst-quenching (Watt and Merrill
1975; Sari et al. 2021).

Our body converts citrulline into arginine, an essential amino acid. This critical amino acid plays a significant role in the immunological, gastrointestinal, respiratory, pulmonary, renal, and hepatic systems, as well as aiding in the healing of wounds (Wu et al. 2000; Flynn et al. 2002; Collins et al. 2007). In addition, citrulline has a potential role in vasodilation and cardiovascular functions, as arginine is a conditionally essential amino acid related to the NO system (Levine et al. 2012; Hong et al. 2015). Mandel et al. (2005) and Collins et al. (2007) indicated that watermelon is a potent source of both arginine and citrulline.

49 Recent studies have shown that citrulline and arginine profiles are important in combatting 50 cancer (Fekkes et al. 2007; Yoon et al. 2007; Bowles et al. 2008; Lam et al. 2009; Schnader et 51 al. 2009; Di et al. 2022), heart disease (Tang et al. 2009; Hong et al. 2015), acute hydrocephalus 52 (Perez-Neri et al. 2007), minor intestine diseases, blood poisoning, trauma, and pulmonary 53 hypertension (Papaida et al. 2007; Beyer et al. 2008; Santarpia et al. 2008) shows that it is useful 54 in the healing of various diseases.

The watermelon is the richest known source of citrulline, and this amino acid plays a vital role 55 in drought tolerance (Yokota et al. 2002; Rimando et al. 2005). Citrulline functions as a 56 hydroxyl radical scavenger and may shield plants from oxidative stress brought on by dryness 57 (Akashi et al. 2001). However, neither the effects of production conditions nor the differences 58 between cultivars have been sufficiently investigated (Davis et al. 2011). According to Fish and 59 Bruton (2010), one cultivar produced in two locations showed no change in the amount of L-60 citrulline in the flesh. Tarazona-Díaz et al. (2011) observed a mean citrulline concentration of 61 2.33 mg/g in watermelon flesh based on five lines (four of which were triploid seedless 62 cultivars) grown in a single location. The authors also demonstrated that the seeded cultivar had 63 64 the lowest L-citrulline content in flesh tissue. An earlier study found that 14 watermelon cultivars ranged from 0.5 to 3.6 mg/g in terms of the fresh weight of citrulline, with an average 65 concentration of 2.4 mg/g (Rimando and Perkins-Veazie 2005). The authors claimed that red-66 67 fleshed fruit contained less L-citrulline than yellow or orange fruit. Still, since only a small 68 sample size (three fruits for each variety) was used, it would have been difficult to determine

69 the influence of genotype and environment on the L-citrulline concentration in those fruits. 70 According to Liu et al. (2010), nine induced autotriploid hybrid watermelons produced in 71 greenhouses showed greater L-citrulline levels than their diploid and induced autotetraploid 72 parents. In Fish and Bruton's (2010) and Liu et al.'s (2010) studies, L-citrulline levels peaked 73 at peak maturity.

Previous studies found a higher amount of citrulline in the watermelon rind. (Rimando et al. 74 2005; Jayaprakasha et al. 2011; Tarazona-Díaz et al. 2011; Akashi et al. 2016; Dubey 2021). 75 Rimando et al. (2005) and Kumar et al. (2012) stated that the rinds make up about 30% of the 76 77 watermelon's total weight, while the flesh accounts for about 70% of total weight; conversely, Chakrabarty et al. (2020) and Zamuz et al. (2021) indicated that the rinds and seeds constitute 78 79 approximately 40% of the total fruit weight and the flesh makes up approximately 60% of the fruit. However, the rind is not typically consumed. Although watermelon rind and skin are 80 81 typically discarded as by-products, they have a similar or higher total phenolic and citrulline content than the flesh, indicating that they have excellent antioxidant properties (Tarazona-Díaz 82 83 et al. 2011; Din et al. 2022).

Thus, numerous studies have been conducted on citrulline's therapeutic properties in watermelon (Bahri et al. 2013; Rashid et al. 2020). However, little is known about the citrulline contents of various ground skin colors and fruit parts. Our study investigated the determination of citrulline in different parts of watermelon cultivars with different ground skin colors, both in the flesh of the fruit and the rind.

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2. Materials and methods

91 2.1. Materials

Watermelon pure lines with different ground colors (yellow, stripe, very light green, and very
dark green) (Figure 1) in the Alata Horticultural Research Institute gene pool were used.





Figure 1. Watermelon pure lines of different ground colors used in the experiment.

These pure lines, which can be commercially parented to hybrids, are diploid and self at least 96 six times (Table 1). Apart from skin-ground characteristics, they do not have many different 97 characteristics from the other pure lines in the gene pool. 98

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Table 1. Lines selected for trial and their features.								
Fruit weight Fruit length Fruit diameter Skin thickness (g) (cm) (cm) (cm) Brix								
Very light green	6,890	21.50	20.50	0.90	9.6			
Stripe	9,210	26.80	22.70	1.40	10.6			
Very dark green	8,350	26.00	21.20	1.10	9.9			
Yellow	4,310	18.50	17.10	0.70	8.0			

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2.2. Method 104

The study was carried out at the Alata Horticultural Research Institute, part of the Ministry of 105 Agriculture and Forestry, in an open field at 36°38'08.3' N and 34°21'00.5" E (Erdemli, 106 107 Mersin, Türkiye). Seed sowing started on March 4, 2017, land preparation began on April 6, 2017, and planting in the field was carried out on April 11, 2017. The climate values of the field 108 when the research was conducted are given in Table 2. 109

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 Table 2. Climatic data of the trial area

Tuble 2. Children data of the trial area.							
Climate parameters	March	April	May	June	July		
Max. temperature (°C)	23.5	28.2	30.0	34.2	40.5		
Min. temperature (°C)	2.6	6.1	2.0	14.7	19.3		
Average temperature (°C)	13.4	16.8	20.0	24.6	28.8		
Max. humidity (%)	90.5	88.8	84.0	81.3	80.4		
Min. humidity (%)	39.6	41.4	59.0	61.5	43.5		
Average humidity (%)	69.9	67.2	75.8	75.0	71.4		
Precipitation (mm = kg \div m ²)	211.6	76.4	12.8	0.2	0.0		

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The planting was carried out in an open area on banks with a width of 70 cm and a height of 113 40 cm, covered with black mulch, in a single row at 40-cm intervals, 9 cm from each pure line. 114 The soil pH value of the parcel where the study was carried out was 7.71, and it had a loamy 115 texture. Soil analysis results are given in Table 3. 116

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Table 3. Results of the p	oarcel's soil analysis w	where the study was	conducted
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Analysis	Limit values	Analysis results (0–30 cm)
Texture (100 g/mL)	30–50	48.00 (loamy)
Total calcitic (CaCO ₃ %)	5–15	40 (high calcareous)
Salinity E.C. ds/m (25 °C)	0-0.8	0.32 (slightly salty)
Organic matter (%)	3–4	2.20 (deficient)
pH 1: 2.5	6.0–7.0	7.71 (slightly alkali)
Available potassium (mg/kg)	244-300	70.60 (very low)

	Receivable phosphorus (mg/kg	g) 20–40		21.30 (optimum	n)
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120	According to the findings of	of the soil study, pure	e fertilizers in the a	mounts of 140)–160 kg N/ha,
121	80–100 kg P ₂ O ₅ /ha, and 60–	-80 kg K ₂ O/ha were u	ısed (Güçdemir 20)	12). Drip irrig	ation was used
122	to apply the fertilizers. A	ll phosphorus was	given during soil	preparation.	Nitrogen and
123	potassium were divided into	three parts accordin	g to the three grow	th stages of th	e watermelon.
124	The planting stage is the first	st stage; the period w	hen the first female	e flower opens	s is the second,
125	and the third is when the fru	its reach the size of	an apple (Table 4).		

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Table 4. Application times and fertilizers amounts used throughout the trial.

Application time	Applied fertilizers and their amounts
During soil preparation	90 kg P ₂ O ₅ /ha
During planting (Stage 1)	50 kg N/ha and 35 kg K ₂ O/ha
Stage when the female flower is seen (Stage 2)	50 kg N/ha and 35 kg K_2O /ha
When the fruits reach the size of an apple (Stage 3)	50 kg N/ha and 35 kg K_2O /ha

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Regular pesticide application for diseases and pests was carried out, along with mechanical weeding and trimming. Mechanical and manual methods were used for weed control. When the tendrils and auricles of the fruits were dry, they were harvested on 4 July 2017 and brought to cold storage. Citrulline analysis was then performed by taking the fruits (three replications per pure line and three fruits per replication) from cold air storage at 4 °C and 90–95% relative humidity.

The fruit samples of the pure lines with different ground colors (yellow, stripe, very light green, and very dark green) were brought to the laboratory, and six different parts of each fruit were taken for citrulline analysis. In addition, samples were taken from the part close to the rind and flesh of the six parts. The order in which fruit samples were taken is given in Figure 2.



Figure 2. Locations of samples taken from different parts of the fruit (left); section 1 (rind) and
 section 2 (flesh) samples were taken for citrulline analysis.

142 **2.3.** Citrulline analysis

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143 Citrulline determination was done according to Jayaprakasha et al. (2011) and Tarazona-Díaz 144 et al.'s (2011) methods, which were modified by Aras et al. (2021). In brief, 5 g of watermelon 145 sample was kept in 4 mL of 0.2 M acetic acid for one night and centrifuged at $5000 \times g$ for 1 146 minute. The sample was filtered and vialed with a 0.45-µ filter and analyzed at 207 nm in a 147 0.3mM o-phosphoric acid mobile phase with a flow rate of 0.7 mL min-1 in HPLC (Shimadzu 148 LC-20AD, Japan).

149 2.4. Statistical analysis

Three replications of the experiment were set up using a randomized plot design in the field. 150 151 In each replication, three fruits were used. JMP statistical software (JMP, Version 7, SAS Institute Inc., Cary, NC, 1989-2007, NC 27513-2414, USA) was used to analyze the data 152 153 statistically. Significant differences among groups were determined using the Student's t-test for pairwise comparison and the Tukey test for multiple comparisons ($p \le 0.05$). The numbers 154 155 used in the table are values without logarithmic transformation. As a result of statistical analysis, the coefficient of variation (CV) was 25.98. Due to the high CV, logarithmic 156 157 transformation was applied to the numbers, and statistical analysis was performed again. These 158 letterings were also used in the groupings obtained.

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160 **3.** Result and discussion

The highest citrulline value in watermelon lines was obtained from those with very light green 161 ground skin colors (3.37 g/kg), while the lowest value was obtained from very dark green 162 ground skin colors (2.0 g/kg). For the fruit parts, the highest value was taken from the 3rd part 163 164 (3.72 g/kg), while the lowest value came from the 2nd (2.00 g/kg). When the fruit flesh and rind were compared, higher citrulline values were found in the flesh (3.10) than in the rind (2.40 165 166 g/kg) (Table 3). Akashi et al. (2016) and Dubey (2021) detected higher citrulline levels in the skin than in the flesh. Our findings show a higher concentration of citrulline in the fruit flesh. 167 L-citrulline levels in three distinct kinds of watermelon juice and rinds were measured by 168 169 Jayaprakasha et al. (2011). Compared to watermelon juice, which only contained 11.25–16.73 170 mg/g dry weight of L-citrulline, rinds had 13.95–28.46 mg/g dry weight. According to previous 171 studies, each liter of unpasteurized watermelon juice contains 2.33 g of citrulline (Tarazona-172 Díaz et al. 2013; Bailey et al. 2016). Ridwan (2018) examined the L-citrulline content of watermelons (flesh and rind) grown and consumed in Malaysia and found that it was higher in 173 the rind of red watermelon juice extract (45.02 mg/g) than in the flesh (43.81 mg/g). Similar 174 trends were also observed in yellow crimson watermelon juice extract (16.61 mg/g in the rind 175 176 and 15.77 mg/g in the flesh) of the same fruit. Casacchia et al. (2020) investigated bioactive

compounds obtained from watermelon pulp and rind using nine distinct watermelon cultivars 177 of various origins. The concentration of L-citrulline in fresh rind was substantially higher than 178 that of fresh pulp, except for watermelons from Santana, Romania and Latina, Italy, which 179 contained 2.6 mg/g of L-citrulline in their fresh rind. In our research, we obtained findings 180 ranging from 0.80 to 4.95. The broad range of ground colors in our study can be attributed to 181 the distinct portions of different watermelons. L-citrulline concentration can vary depending on 182 several environmental (such as exposure to drought stress and high light intensity) and 183 physiological factors (e.g., cultivar, genotype, flesh color, and fruit anatomy) (Hartman et al. 184 185 2019). According to the data obtained in our study, this conclusion has also been reached; still, there is no clear information about the relationship between the ground color of the shell and 186 187 watermelon content. For this reason, this lack of relevant data needs to be investigated with more varieties. 188

189 Lines \times parts \times sections interaction was found to be statistically significant. The highest value was obtained from the fruit flesh (4.95) of the 3rd part of the fruit at the striped line of the 190 191 ground colors of the skin, while the lowest value was taken from the fruit rind (0.80) of the 1st part of the fruit at the striped line of the ground colors of the rind. In terms of the lines \times parts 192 interaction, the highest value was obtained from the 3rd part of the fruit flesh (4.74) of the very 193 light green of the ground colors of the skin, while the lowest values were taken from the 5th 194 part (1.51) and 2nd part (1.58) of the fruit of the very dark green line of the ground colors of 195 the skin. Based on the lines \times sections interaction, the highest value was obtained from the rind 196 (3.42) of the very light green of the ground colors of the skin, while the lowest value was taken 197 198 from the rind (1.45) of the fruit of the black line ground colors of the skin (Table 5).

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			Grou	nd skin colors			
Parts of the fruit	Section	Yellow	Very dark green	Very light green	Stripe	Average (section)	Average (part of fruit)
1	1	2.25 e-i	1.20 g-i	4.40 a-e	0.80 i		2.76 D
1	2	2.51 c-i	3.64 a-g	4.40 a-e	2.90 a-i	-	2.76 B
2	1	1.83 e-i	1.46 f-i	2.04 e-i	1.64 f-i	Rind	2.00.0
2	2	2.20 e-i	1.69 f-i	2.04 e-i	3.07 a-i	2.40 B	2.00 C
2	1	2.93 a-i	1.47 f-i	4.69 a-d	4.33 а-е	-	2.52.4
3	2	4.85 ab	1.89 e-i	4.79 a-c	4.95 a	-	3.72 A
4	1	3.14 a-h	1.67 f-i	4.08 a-e	2.60 b-i		2 01 D
4	2	3.14 a-h	2.73 a-i	2.90 a-i	3.05 a-i	-	2.91 B
5	1	4.11 a-h	1.54 f-i	2.38 d-i	2.13 e-i	Fruit	2.59 DC
5	2	3.86 a-f	1.47 f-i	3.06 a-i	2.07 e-i	3.10 A	2.38 BC
(1	0.99 hi	1.36 f-i	2.93 a-i	1.70 f-i	-	2.51 DC
0	2	3.03 a-i	3.90 a-i	2.78 a-i	3.41 a-g	-	2.51 BC
Average (grou of the skin)	nd colors	2.89 B	2.00 C	3.37 A	2.72 B		

Table 5. Amount of citrulline (g/kg) in the rind and flesh of six different parts of watermelonswith different ground skin colors.

Line × Part	(interactio	on)					
1		2.38 d-h	2.42 d-h	4.40 abc	c 1.85 gh		
2		2.01 fgh	1.58 h	2.04 fgh	n 2.36 d-h		
3		3.84 a-d	1.68 gh	4.74 a	4.64 ab		
4		3.14 b-g	2.20 e-h	3.49 a-f	2.82 c-h		
5		3.98 a-e	1.51 h	2.72 d-h	n 2.10 e-h		
6		2.01 fgh	2.63 c-h	2.86 c-h	n 2.55 d-h		
Line × Section	on (intera	ction)					
	1	2.52 cd	1.45 e	3.42 a	2.20 d		
	2	3.26 abc	2.55 bcd	3.33 ab	3.24 abc		
	Lines	Parts	Sections	$Lines \times Parts$	$Lines \times Sections$	Parts × Sections	$Lines \times Parts \times Sections$
Prob > f	<.0001	<.0001	<.0001	<.0001	0.0024	0.0042	0.0272
CV (%5): 0.0)5						

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The mean values given in different capital letters in the same column and row and the mean values of the interaction in the middle of the table with lower case letters were statistically significant; those without lettering were found to be insignificant (p < 0.05).

According to Koga and Ohtake (1914) and Wada (1930), citrulline was the first derivate in 206 watermelon juice (Nguyen et al. 2018). It was later discovered by Inatomi et al. (1969) in seeds 207 and other watermelon fruit parts. The authors could not determine whether citrulline was 208 produced in the fruit or carried there from other plant parts. Citrulline has been found in 209 watermelon flesh and rind, although reports on the substance were based on colorimetric tests; 210 thus, the results may have been overstated (Rimando and Perkins-Veazie 2005). The citrulline 211 extraction method (filtered or sonication) and the chemicals used for extraction (MeOH or HCl) 212 affect the citrulline yield. Our methods are similar to the acid filtration and extraction used by 213 Rimando and Perkins-Veazie (2005). 214

215 Some studies indicate that watermelon juice is a good source of citrulline (Mandel et al. 2005; Collins et al. 2007). Rimando and Perkins-Veazie (2005) sampled six diploid and eight triploid 216 217 varieties of the 14 different watermelon varieties' mesocarp (flesh) and reported that diploid (seeded) or triploid (seedless) watermelons exhibited a somewhat lower average citrulline 218 content. The citrulline concentration in the seeded and seedless varieties was comparable (16.6 219 220 and 20.3 mg/g dwt, respectively) and ranged from 3.9 to 28.5 mg/g dry weight (dwt). On average, triploid watermelons had slightly more citrulline than diploid watermelons. Due to the 221 higher dry weight of the seedless variety, this difference was more significant than the fresh 222 weight basis. According to a recent study, rind contains a low phenolic concentration and high 223 citrulline content (3.34 and 2.33 g/kg, respectively) (Kumar et al. 2021). In another study, 224 225 although watermelon skin had the largest total phenolic content and a greater antioxidant potential and radical scavenging activity than watermelon flesh, the latter had the highest 226 227 citrulline amount (Gu et al. 2023).

In another study, Aras et al. (2021) developed 55 watermelon hybrids (striped and dark green) 228 to observe their bioactive properties (total carotenoid, lycopene, carotene, ascorbic acid, total 229 phenol, antioxidant activity, citrulline, pectin methylesterase, chitinase, fructose, glucose, 230 sucrose, and total soluble solid) in open field conditions in 2017 and 2018. In 2017, the 187 \times 231 80 (striped) hybrid had the highest citrulline value (6.07 g/kg), while the 138-Y \times 91 (striped) 232 hybrid had the lowest (0.31 g/kg). In 2018, the $138-Y \times 91$ (striped) hybrid had the highest 233 citrulline value (9.68 g/kg), while the 138-Y \times 80 (striped) hybrid had the lowest (0.51 g/kg). 234 As can be seen from this study, different hybrids in terms of citrulline have come to the fore 235 236 over the years, and these results showed that citrulline is affected by environmental conditions. Citrulline synthesis and function in plants are complicated. Numerous investigations on the 237 238 physiological and environmental factors in watermelon indicate possible effects on the abundance of citrulline (Hartman et al. 2019). In response to drought and high light-intensity 239 240 stress, citrulline accumulates dramatically in the leaves of Cucumis melo and several other Citrullus species (Akashi et al. 2001; Kawasaki et al. 2000). This implies that citrulline 241 242 functions in osmotic control, scavenging of reactive oxygen species, and possible application as a biomarker in selecting resilient crop plants. These occurrences are supported by the fact 243 that under abiotic and biotic stress, some genes in watermelons are activated (such as glutamine 244 acyl transferases) while others are downregulated (Guo et al. 2013). When stress, such as a high 245 CO level, was diminished in cucumbers under drought stress, citrulline and proline metabolism 246 were downregulated (Hartman et al. 2019). 247

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4. Conclusion

This study investigated the proportion of citrulline in different parts of watermelons with 250 251 different ground skin colors in the flesh of the fruit and the rind. The highest value of citrulline was obtained for the genotype with a very light green ground skin color (3.37 g/kg), while the 252 253 lowest value was obtained from the genotype with a very dark green ground skin color (2.0 g/kg). Higher citrulline values were found in the fruit flesh (3.10 g/kg) than in the rind (2.40 254 255 g/kg). In many previous studies, the citrulline content in the peel part of the watermelon was shown to be higher than in the pulp; however, in our study, the citrulline content in the fruit 256 257 flesh was higher. Since consumers typically consume the fruit flesh, they can easily get citrulline into their bodies. Different growing conditions can affect the bioactive properties of 258 the fruit. For this reason, studies should be repeated and tested under different growing 259 conditions. 260

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