A DISSERTATION FOR THE DEGREE OF MASTER OF SCIENCE

Variation in Harvest Fruit Quality Related to Cane-based Fruiting Positions in 'Sweet Gold' Kiwifruit Vines

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Submitted in partial fulfillment of the requirements for the degree of

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CONTENTS

CONTENTS i

LIST OF TABLES ii

LIST OF FIGURES iii

ABSTRACT iv

INTRODUCTION 1

MATERIALS AND METHODS 3

Plant Materials 3

Classification of Cane-based Fruiting Position 3

Evaluation of Fruit Quality 5

Analysis of Non-structural Carbohydrates 5

Statistical Analysis 6

RESULTS AND DISCUSSION 7

Variation in Fruit Quality Related to Cane-based Fruiting Positions 7

Variation of Starch and Soluble Sugar Contents Related to Cane-based Fruiting Positions 16

LITERATURE CITED 20

ABSTRACT IN KOREAN 24

ACKNOWLEDGEMENTS 25

LIST OF TABLES

Table 1. Soluble sugar contents (mg·g^{-1} DW) of kiwifruits at harvest in different cane-based fruiting positions in 2020 …………………………........…………………...................….. 18

Table 2. Total starch, amylose, and amylopectin contents (mg·g^{-1} DW) of kiwifruits at harvest in different cane-based fruiting positions in 2020 ..………………….........…….. 19

LIST OF FIGURES

Fig. 1. Diagram illustrating the classification of cane-based fruiting positions 4

Fig. 2. Changes in fruit weight (g) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C) 10

Fig. 3. Changes in dry matter (DM, %) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C) 11

Fig. 4. Changes in soluble solid content (SSC, °Brix) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C) 12

Fig. 5. Changes in titratable acidity (%) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C) 13

Fig. 6. Changes of firmness (kgf) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C) 14

Fig. 7. Changes of flesh coloration (hue, °*h*) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C) 15

ABSTRACT

This study investigated the effects of cane-based fruiting position on fruit quality at harvest in a golden-flesh kiwifruit variety, ‘Sweet Gold’ (*Actinidia chinensis* var. *chinensis*). The vines were grown on a pergola-trained system under a protected plastic film house in Jeju, Korea. The fruits were classified according to 6 cane-based fruiting positions (3 positions from the trunk to the tip of the leader × 2 positions from the leader to the apex of the cane). Fruits that developed at fruiting positions far away from the trunk (fruiting positions 6 and 5) had higher fruit weights, whereas fruits that developed at positions close to the trunk (positions 1 and 3) exhibited a higher dry matter percentage and soluble solid contents. The variation in titratable acidity was very low, and the values were not significantly different between different fruiting positions. Fruits that developed far away from the trunk and leader (position 6) exhibited the highest firmness and flesh coloration. Fruits that developed far away from the trunk and leader (position 6) and close to the trunk and distal to the leader (position 4) had the highest starch levels and lowest soluble sugar contents. These results indicated that there were small variations in fruit quality parameters at harvest in fruits at different fruiting positions within vines. These differences were not consistent over the two years of the study period and there were no distinct correlations among these fruit quality parameters.

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INTRODUCTION

The kiwifruit is a woody plant belonging to the *Actinidia* genus of Actinidiaceae family within Ericales (Ferguson, 1984). The *Actinidia* genus contains more than 76 species and 125 taxa. The kiwifruit is a deciduous and dioecious vine that originated in temperate forests in the mountains and hills of south-western China. In Jeju, Korea, the kiwifruit is mostly cultivated with pergolas (including trellis frames) in a monocropping system. Pistillate cultivars are planted in a protected plastic house, and require intensive artificial pollination for successful fruit set and a high fruit quality (Oh et al., 2021).

The kiwifruit has strong antioxidant properties due to its high content of vitamin C, carotenoids, and flavonoids. Kiwifruits also contain sugars, organic acids, amino acids, proteins, and minerals, which are beneficial for human health (Xu and Zhang, 2003). These properties have led to an increase in the consumption of kiwifruit and the expansion of its agricultural production (Poudel, 2019). In 2019, China accounted for half the global production of kiwifruit (50.5%), followed by New Zealand (12.8%). However, Korea only accounted for approximately 0.13% of the global production of kiwifruit in 2019 (FAO, 2021).

There are major three types of kiwifruits, including the green-fleshed (*A. chinensis* var. *deliciosa*), golden-fleshed, and red-fleshed (*A. chinensis* var. *chinensis*) varieties. Of these, green-fleshed and golden-fleshed kiwifruits are most common commercially cultivated varieties in the world (Ferguson and Huang, 2007; Montefiori et al., 2011). The golden-fleshed kiwifruit is more tasteful and aromatic compared to the green-fleshed variety (Testolin and Ferguson, 2009), and in recent years, its cultivation has increased in Korea as well as in other countries.

'Sweet Gold' is a new promising kiwifruit cultivar with high sweetness (Kim et al., 2018), and has replaced existing golden-fleshed and green-fleshed varieties. However, despite its high sweetness, this variety exhibits a broad range of fruit quality, especially in flesh coloration. In ‘Hayward’ kiwifruit, fruits close to the leader on canes that emerge far away from the trunk show higher soluble solid content (SSC) compared to those of other fruits (Hopkirk et al., 1986). Moreover, fruits set on canes and spurs at the ends of the leader have higher SSC than those on the middle part of the vine at harvest (Pyke et al., 1996). The fruit size and SSC of ‘Hayward’ kiwifruits are also affected by fruit position, the shoot, and the size of the shoot (Kulczewski , 2003; Sagredo et al., 2014). However, to date, there are no studies reporting the range of variation in fruit quality of golden-fleshed kiwifruits. The maintenance of high fruit quality within a vine is essential for ensuring success in the highly competitive fruit market. Several factors including canopy density, cane thickness, fruiting shoot type, and the number of fruits may affect a range of parameters related to fruit quality, and the responses to these factors may differ between plant genotypes.

In this study, I evaluated a range of fruit quality parameters and their association with different cane-based fruiting positions at harvest within vines of the golden-fleshed ‘Sweet Gold’ kiwifruit.

MATERIALS AND METHODS

Plant Materials

The golden-fleshed ‘Sweet Gold’ (*A. chinensis* var. *chinensis*) variety was grafted on a plant of the ‘Hayward’ (*A. chinensis* var. *deliciosa*) variety for use in this study. The vines were planted at a spacing of 6 × 4 m and trained with the pergola system in a plastic house located at Jeju-si, Korea. Five vines with similar canopy and shoot growth were randomly selected as biological replicates. General cultural management including artificial pollination, flower and fruit thinning, summer pruning, nutrition management, and pest control was conducted according to conventional practices.

Classification of Cane-based Fruiting Position

The vine canopy was horizontally divided into four quadrants. Each quadrant was classified into six cane-based fruit positions (1–6). Positions 1–3 indicated fruits in the proximal part of the canes from the trunk to the leader, and positions 4–6 indicated fruits in the distal part of the canes from the trunk to the leader (Fig. 1). The size of each quadrant was approximately 3 × 2.4 m^2, and each cane-based fruiting position consisted of 3–4 canes.

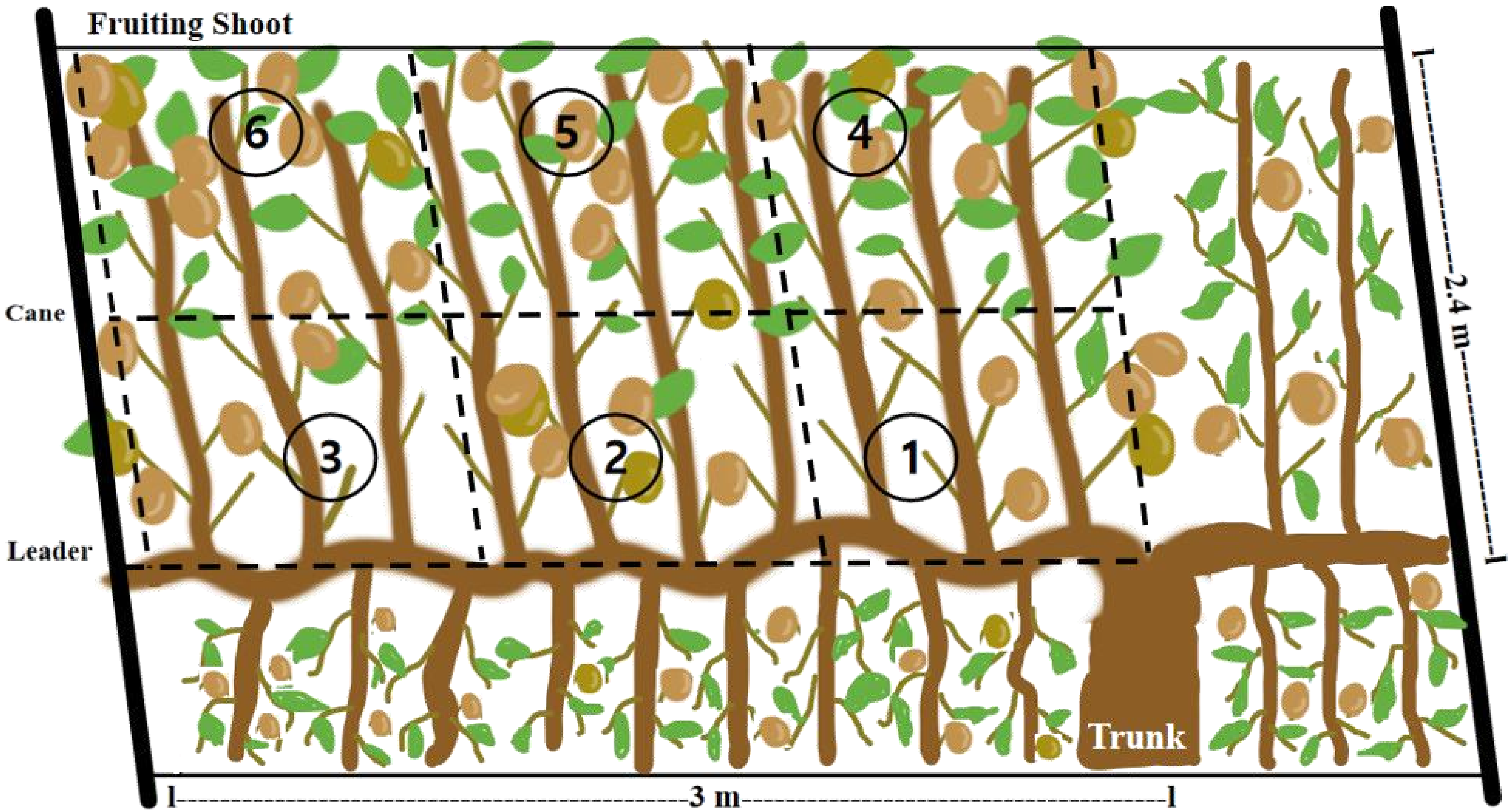

Fig. 1. Diagram illustrating the classification of cane-based fruiting positions.

Evaluation of Fruit Quality

The fruit quality parameters including fruit weight, percent of dry matter (DM), SSC, titratable acidity, firmness, and flesh color were evaluated at harvest. Twenty fruits and six fruits were collected from each cane-based fruiting position of a vine in 2019 and 2020, respectively. Fruit weight was measured using a digital balance (EL2000S, USA). The DM was determined using a 2–3 mm thick slice obtained from the middle part of the fruit. The slice was dried at 65 °C for 24 hours, and DM was measured according to the method described by Burdon et al. (2016). TSS and titratable acidity were measured using a Brix acidity meter (GMK-707R, G-won Hitech, Korea). Fruit firmness was measured using a fruit hardness tester (capacity: 5 kg; FHM-5, Takemura, Japan) equipped with a plunger (diameter: 5 mm). Flesh color was determined using a chroma meter (CR-400, Konica Minota, Japan).

Analysis of Non-structural Carbohydrates

Starch and soluble sugar contents were measured according to the methods described by Wichaya et al. (2015). The fruits were freeze-dried at -70 °C, homogenized using a blender, and stored at -70 °C in powdered form before analysis. One gram of the powder was mixed with 10 mL of 80% ethanol for 30 min at room temperature and then centrifuged at 10,000 rpm for 10 min at 4 °C. The supernatant was filtered through a filter paper (F1002, Chmlap, Spain). The residue was dried at 60 °C for 24 hrs, and 0.2 g of the dried residue was mixed with 4 mL of 18% HCl. The mixture was incubated at room temperature for 30 min, diluted with 36 mL of double-distilled water (DDW), and centrifuged at 10,000 rpm for 10 min at 4 °C. Next, 500 μL of Lugol's solution (0.25 g I_2, 0.5 g KI) was added to 500 μL of the supernatant, and the starch content was measured using the colorimetric method described by Magel (1991). The previously filtered supernatant was evaporated using a rotary evaporator (Laborota 4000, Heidolph, Germany), re-suspended with DDW, and then filtered through a

C_{18} Sep-Pak cartridge (Sep-Pak, Waters, USA) and a 0.2 μm syringe filter. Soluble sugar contents were measured using a high-performance liquid chromatography (HPLC) instrument equipped with the an RID10A detector (Shimadzu, Japan) and a Shim-pak GIS NH_2 column (5 μm, 250 × 4.6 mm, Shimadzu, Japan). The mobile phase was an 80% (v/v) acetonitrile/DDW solution with a flow rate of 1.5 $mL \cdot min^{-1}$, and the column temperature was set to 35 °C.

Statistical Analysis

Our experimental design was completely randomized, and statistical analysis was performed at the 95% confidence level using the SPSS software (version 22.0; SPSS, Armonk, NY). Significant differences among group means were analyzed with Duncan's multiple range test.

RESULTS AND DISCUSSION

Variation in Fruit Quality Related to Cane-based Fruiting Positions

I evaluated the range of variations in fruit quality in the different cane-based fruiting positions of ‘Sweet Gold’ kiwifruit vines during crop seasons in 2019 and 2020. The fruit quality parameters included fruit weight, DM, SSC, titratable acidity, firmness, and flesh color. There were no significant differences in fruit weight among the different cane-based positions at harvest in 2019 and 2020 (Fig. 2). However, fruit weights at different cane-based fruiting positions differed slightly between 2019 and 2020, and these values differed from the mean values of 2019 and 2020. Fruits at positions 6 and 3 were generally heavier (position 6: 94.2 g; position 6: 92.1 g), and consisted of fruits on canes positioned far away from the trunk (Fig. 2C). There were no significant differences in DM among the different cane-based positions at harvest in 2019 and 2020 (Fig. 3). However, as in fruit weight, the DM of fruits at different cane-based fruiting positions was slightly different between 2019 and 2020. Fruits with the highest DM were consistently obtained at position 1 in 2019 (DM: 17.5%) and 2020 (DM: 15.3%). The mean DM for the two years indicated that kiwifruits on canes closer to the trunk had higher DM than those on canes distal to the trunk, although there was no consistent pattern between DM and distance from the leader. Fruits with the highest SSC occurred at position 1 in 2019 (7.4 °Brix) and at position 4 in 2020 (8.9 °Brix) (Fig. 4). Similar to the patterns observed in DM, the mean SSC during the two years was higher in fruits on canes that were proximal to the trunk. However, the SSC and DM showed different overall tendencies of variation among cane-based fruiting positions. Among the six fruit quality parameters measured, the titratable acidity of kiwifruits at different cane-based fruiting positions showed the smallest variation (Fig. 5), and did not show any appreciable pattern of differences. The firmness of kiwifruits showed a wide range of variation between cane-based fruiting positions (Fig. 6). There were no significant differences in 2019.

However, fruit firmness was the only fruit quality parameter with significant differences in 2020, and fruits at position 6 showed consistently high firmness. Flesh color was not significantly different among the cane-based positions in either year (Fig. 7). In 2019, the lowest flesh color value was obtained in fruits at position 4, followed by those at position 1. In 2020, the lowest flesh color value was obtained in fruits at position 5, followed by those at position 1. Accordingly, the mean flesh coloration value for the two years was lowest in fruits at positions 4 and 1.

Shoot vigor and fruiting position on the shoot are known to affect fruit quality parameters (Kulezewski, 2003; Sagredo et al., 2014; Nardozza et al., 2015). Because sampling was limited to fruits at basal positions on shoots with similar growth patterns, these factors were excluded in this study. Richardson et al. (2001) reported that flowers on canes near the tip of a leader tended to open earlier than those on canes near the trunk, and that flowers at the apex of a cane tended to open earlier than those at the base of the cane. Moreover, fruits that develop from early-opening flowers are heavier and have a higher maturity index with higher SSC and lower acidity than those that develop from late-opening flowers (Richardson et al., 2019). Boyd et al. (2008) reported small differences in fruit quality parameters between fruits at different fruiting positions within a vine, and the differences were inconsistent across three crop seasons. However, the researchers found high fruit weight in fruits at positions far away from the trunk and leader (Boyd et al., 2008). This was similar to the findings in this study, where fruits at position 6 exhibited high fruit weight. Moreover, fruits at positions close to the trunk and leader had high DM, which was similar to the high DM in fruits at position 1 in this study. The patterns of variation in other fruit quality parameters reported by Boyd et al. (2008) were different from those observed in this study. In a study that accounted to canopy density, Hopkirk et al. (1986) reported differences in patterns of maturity indices based on fruiting positions within 'Hayward' kiwifruit vines. Fruit quality is positively associated with photosynthetic activation by an increased in leaf area and negatively associated with photosynthetic inhibition due to shading (Snelgar et al., 1998; Remorini et al., 2007); therefore, canopy density may have a negative impact on fruit quality. Several factors including the cultivar (Richardson et al., 2019), training system (Smith et al., 1997), cane vigor (such as cane length and thickness) (Richardson et al., 2019), and mineral and carbohydrate supply (Thorp et al., 2003; Lievre et al., 2021) can also affect the quality parameters of fruits at different fruiting positions within a vine. Therefore, further studies are required to determine the typical spatial patterns of fruit quality parameters at different fruiting positions within a vine in ‘Sweet Gold’ kiwifruits.

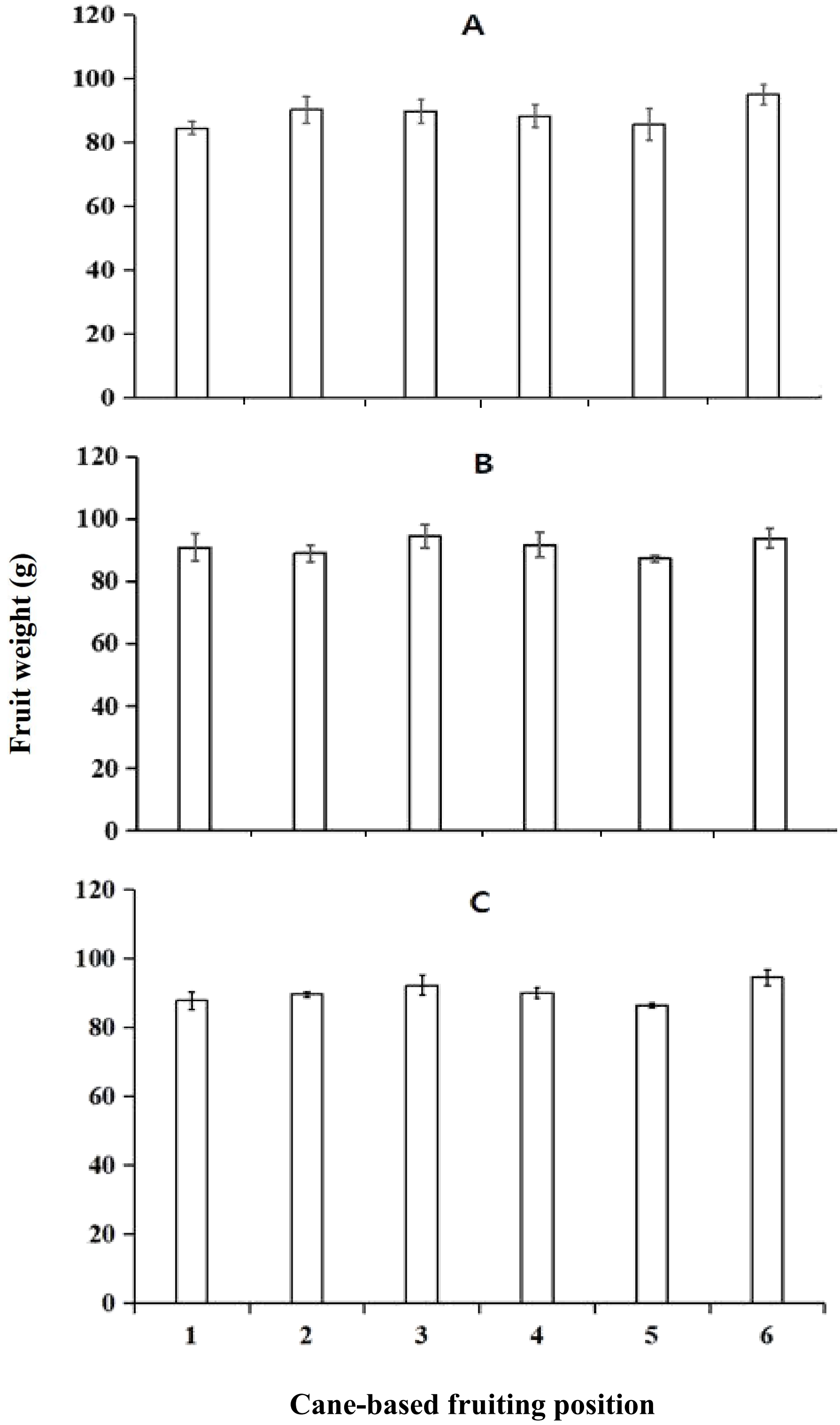

Fig. 2. Changes in fruit weight (g) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C). Vertical bars indicate ± SE (n = 3 for 2019 and n = 5 for 2020).

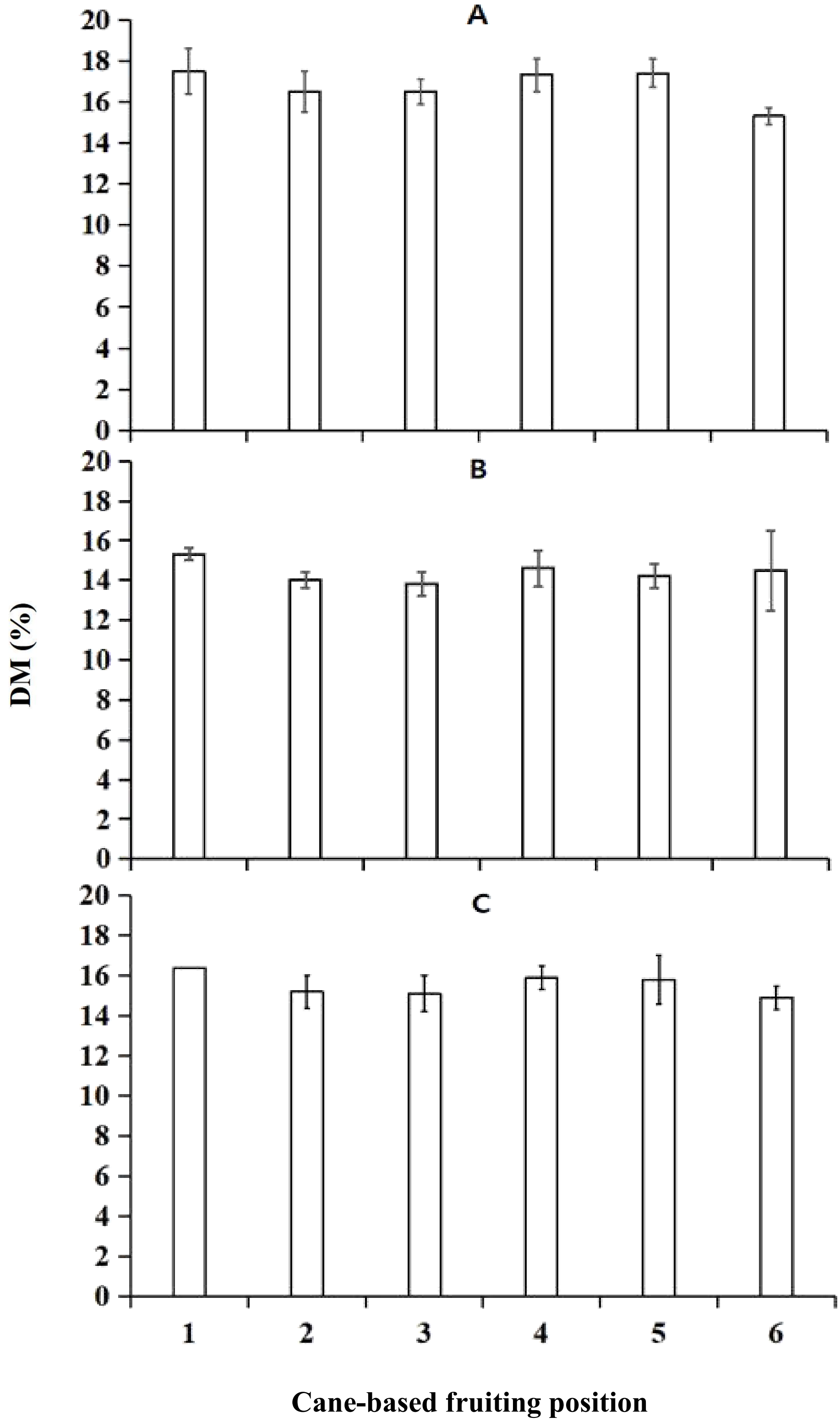

Fig. 3. Changes in dry matter (DM, %) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C). Vertical bars indicate ± SE (n = 3 for 2019 and n = 5 for 2020).

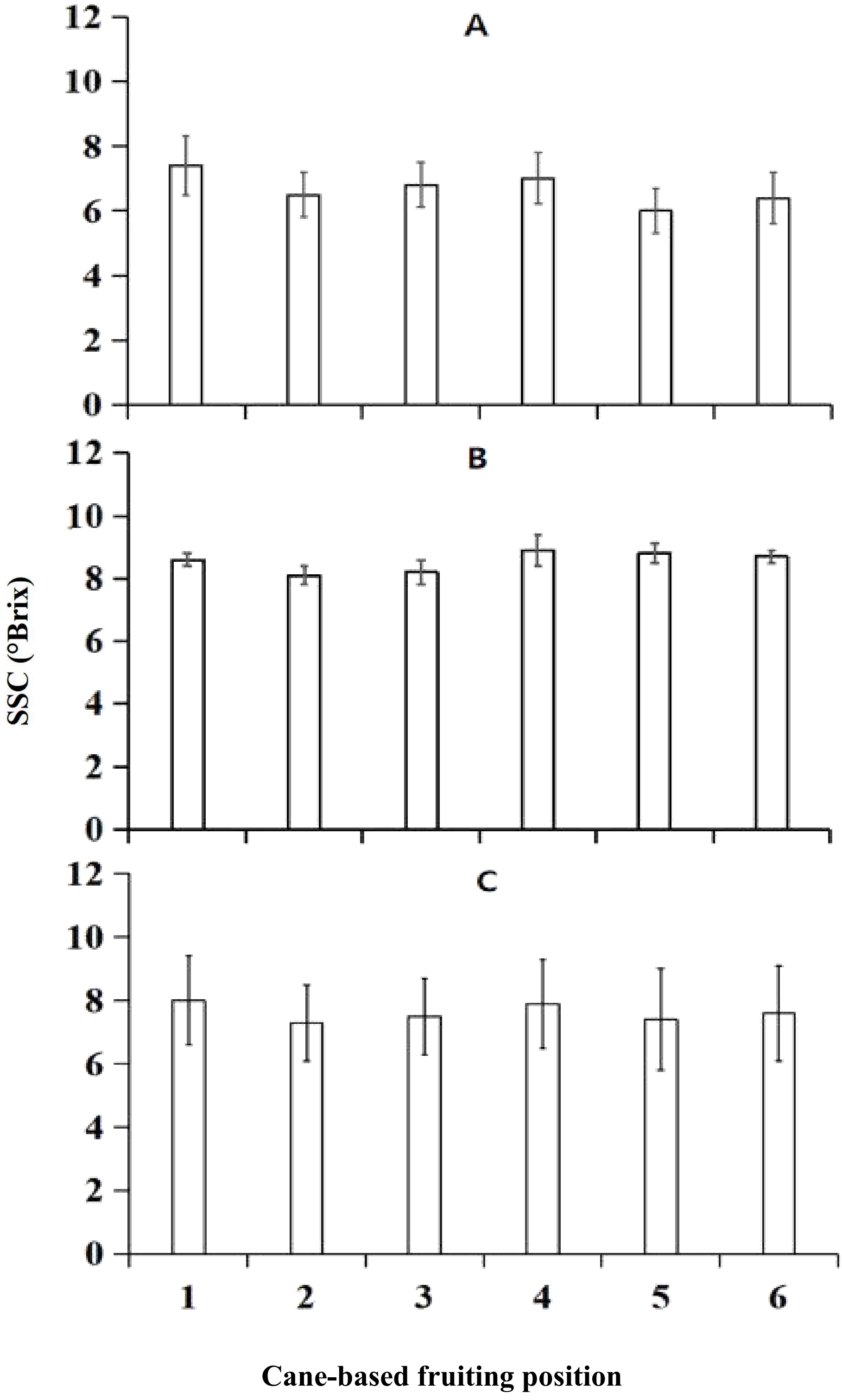

Fig. 4. Changes in soluble solid content (SSC, °Brix) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C). Vertical bars indicate ± SE (n = 3 for 2019 and n = 5 for 2020).

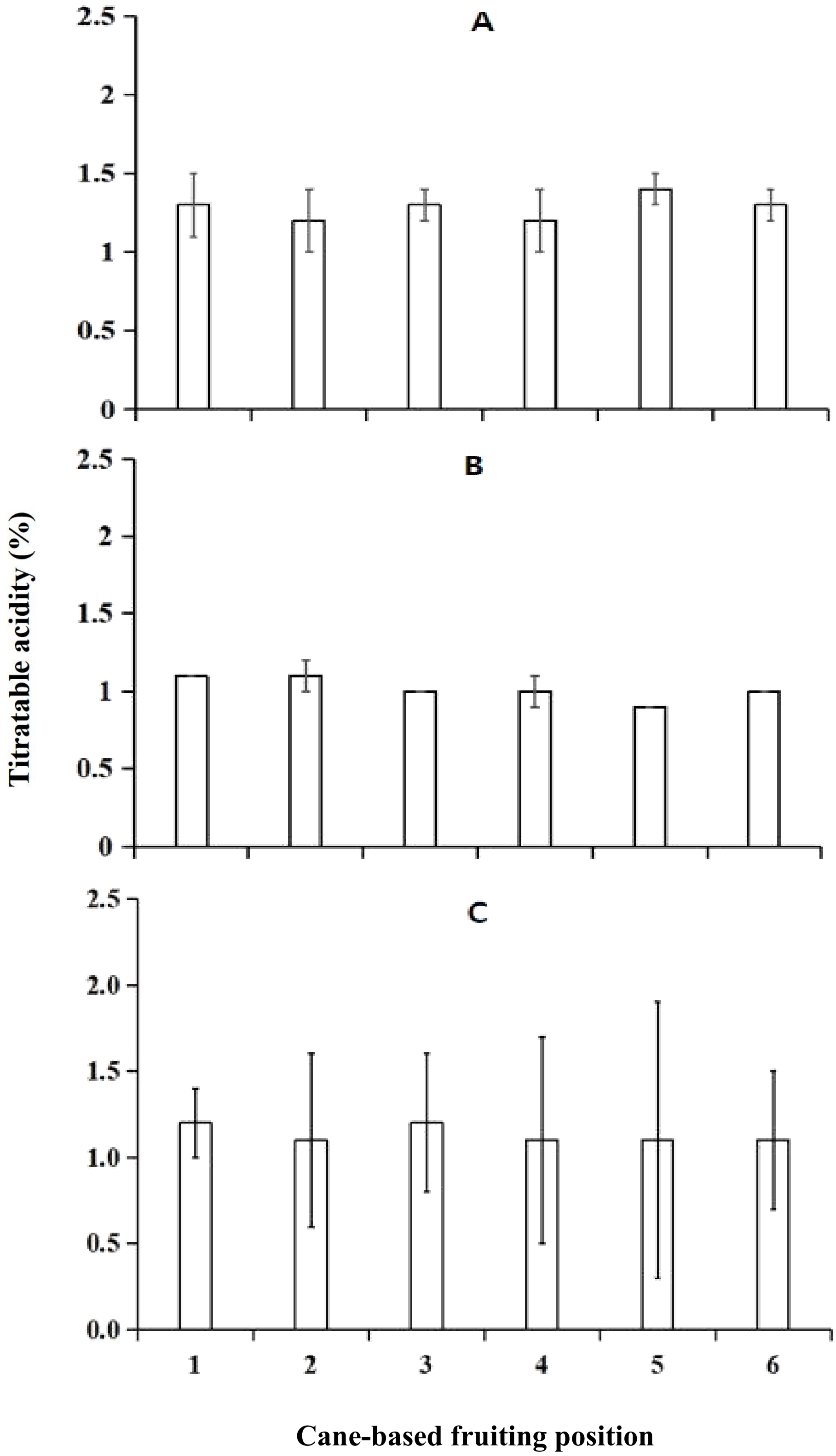

Fig. 5. Changes in titratable acidity (%) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C). Vertical bars indicate ± SE (n = 3 for 2019 and n = 5 for 2020).

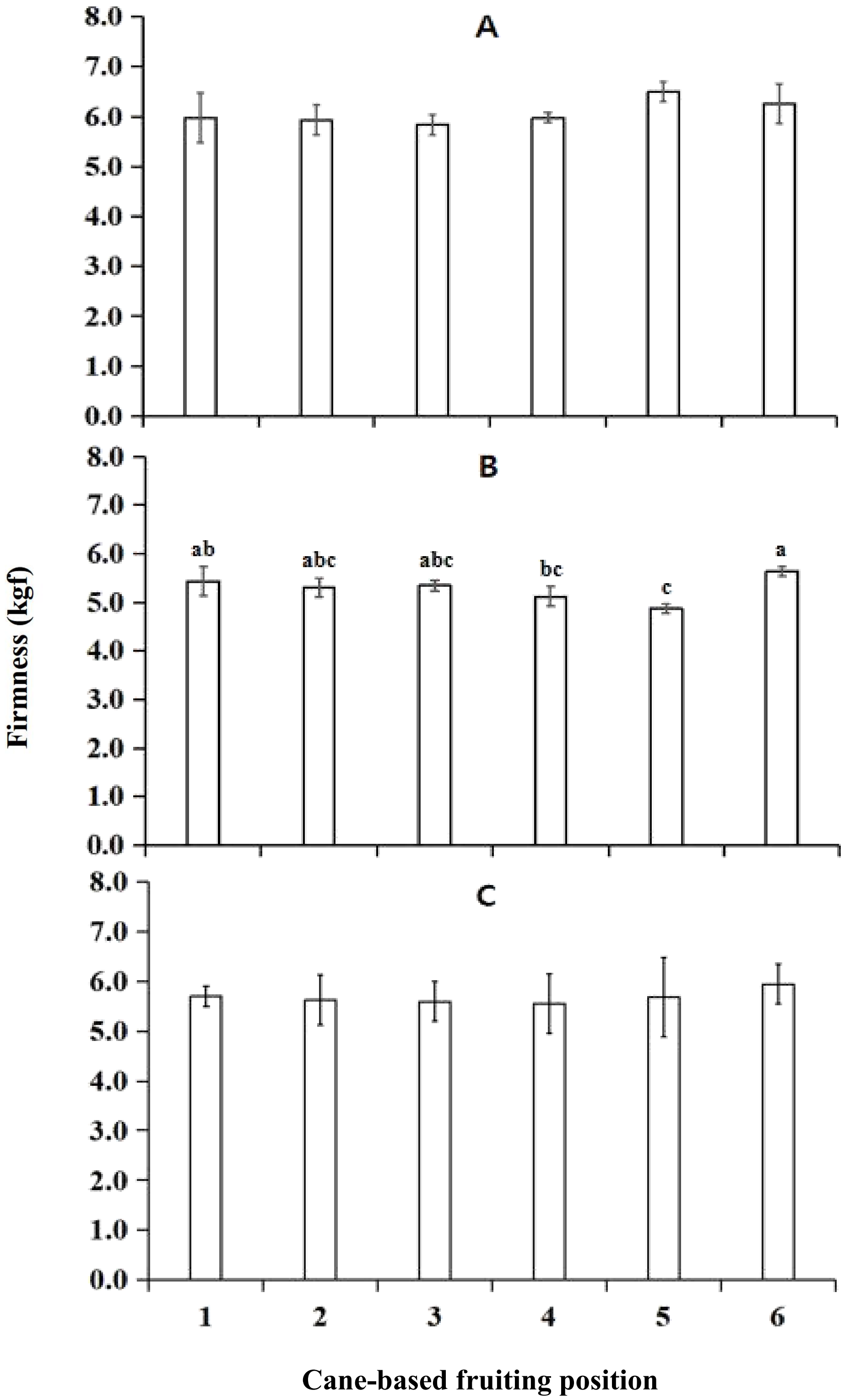

Fig. 6. Changes in the firmness (kgf) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C). Vertical bars indicate ± SE (n = 3 for 2019 and n = 5 for 2020).

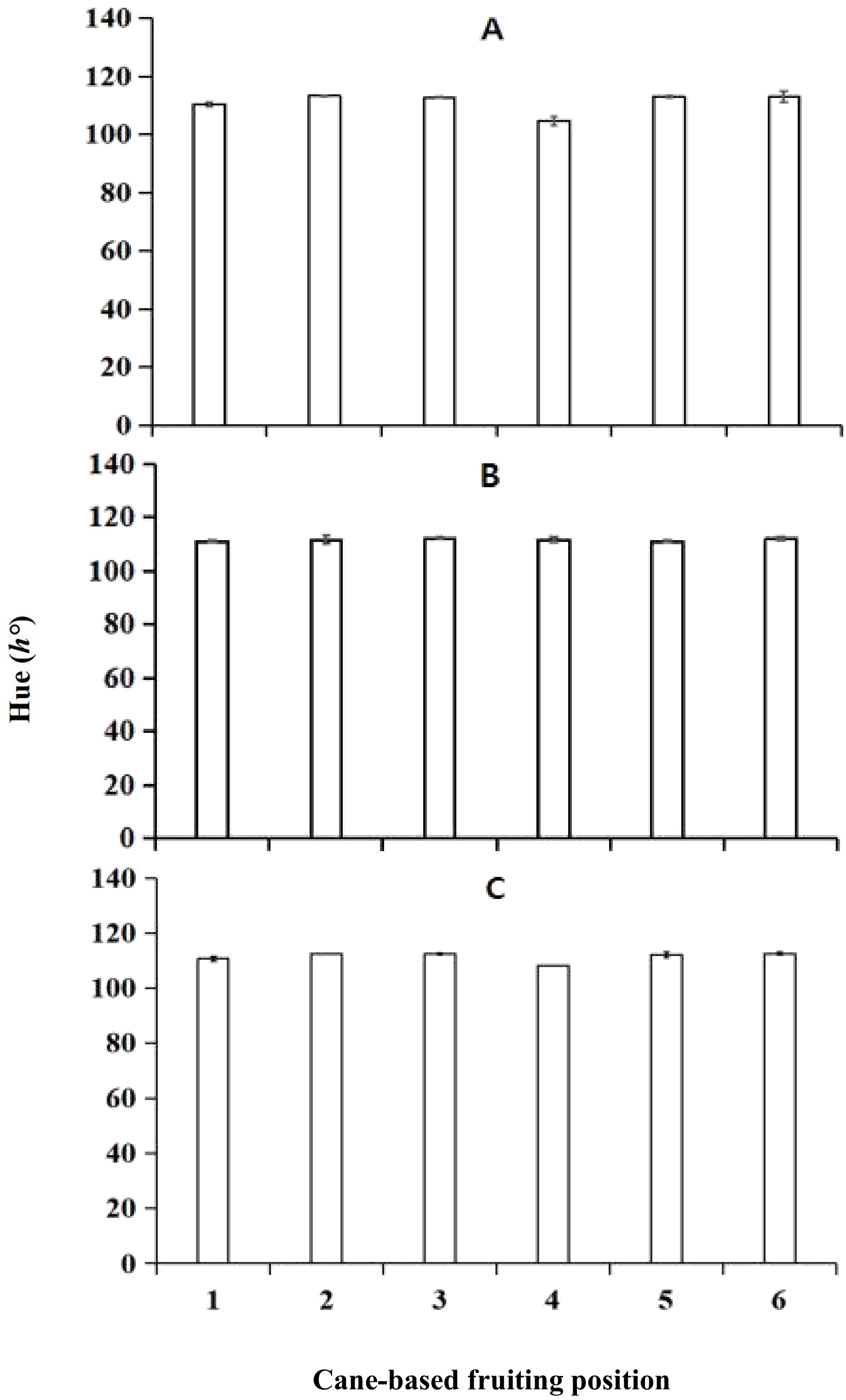

Fig. 7. Changes in flesh coloration (hue, °*h*) at harvest for different cane-based fruiting positions in 'Sweet Gold' kiwifruits for 2019 (A), 2020 (B), and the means of the two years (C). Vertical bars indicate ± SE (n = 3 for 2019 and n = 5 for 2020).

Variation in Starch and Soluble Sugar Contents Related to Cane-based Fruiting Positions

The total starch, amylose, and amylopectin contents of kiwifruits showed some variation between the different cane-based fruiting positions; however, the differences were not statistically significant (Table 2). The starch consisted primarily of amylopectin (74.2–78.5%), and fruits at position 6 exhibited the highest total starch content. The in soluble sugar content of fruits at different cane-based fruiting positions are listed in Table 3. Unlike the starch contents, the soluble sugar contents were significantly different between fruits at different fruiting positions. Fruits at positions 1, 5, and 6 exhibited high soluble sugar contents, and those at positions 2, 3, and 4 exhibited low soluble sugar contents. This pattern of variation in soluble sugar contents was different from starch contents.

Kang et al. (2021) reported that the starch content of 'Sweet Gold' kiwifruits decreased rapidly from 170 days after anthesis. However, the soluble sugar contents increased from 120 days after anthesis, and this was accompanied by an increase in the levels of fructose and glucose. These contrasting patterns of changes in starch content and soluble sugar contents may also differ depending on the temperature and the species and cultivar of *Actinidia* spp. (Beever and Hopkirk, 1990; Sawanobori and Shimura, 1990; Costa et al., 1997; Boldingh et al., 2000; Kang et al., 2021; Li et al., 2021). The starch content and SSC of fruits have been used as harvest indices, in that fruits with high starch content and low SSC are not considered harvestable. In this study, the starch content of fruits was not distinctly related to the total SSC among cane-based fruiting positions. Fruits at position 6 had the highest starch content, the heaviest fruit weight (Fig. 2) and the highest firmness (Fig. 6). In contrast, fruits at position 1 exhibited the highest DM (Fig. 3) and SSC (Fig. 4). However, the overall trend of variation in these parameters across fruiting positions was inconsistent between parameters and across years. Therefore, future studies incorporating consecutive evaluation combined with the assessment of other factors such as genotypes, canopy density, cane and shoot vigor, and cultural environment are needed to determine the effect of fruiting positions on fruit quality in kiwifruits.

Table 1. Soluble sugar contents (mg·g^{-1} DW) of kiwifruits at harvest in different cane-based fruiting positions in 2020.

Fruiting position	Total	Fructose	Glucose	Sucrose	Myo-inositol
1	495.7±45.2^{z}a^{y}	198.7±2.8a	193.5±2.9a	94.8±6.0a	8.8±0.6
2	345.7±32.2ab	142.7±31.5ab	134.9±30.1b	60.9±19.9abc	7.2±0.8
3	348.8±35.2ab	147.7±5.7ab	145.2±5.8ab	48.5±2.5c	7.3±0.7
4	332.9±31.9b	137.1±10.1b	135.3±11.0b	52.4±8.8bc	8.1±1.3
5	454.1±41.7ab	182.7±22.7ab	178.8±21.8ab	83.5±17.2abc	9.2±0.6
6	443.3±40.0ab	172.8±6.7ab	171.2±7.5ab	90.0±5.2ab	9.3±0.4
Significance	*	*	*	*	**ns**

^{Z} Mean ± SE (n = 3)

^{Y} Mean separation within columns by Duncan's multiple range test at *P* = 0.05

Table 2. Total starch, amylose, and amylopectin contents ($mg \cdot g^{-1}$ DW) of kiwifruits at harvest in different cane–based fruiting positions in 2020.

Fruiting position	Total	Amylose	Amylopectin
1	117.0±3.1^{z}ab^{y}	11.3±0.64	88.7±0.60
2	113.7±2.5ab	10.8±0.83	89.2±0.83
3	117.0±2.3ab	11.5±0.62	88.5±0.62
4	114.6±2.9b	11.0±0.54	89.0±0.54
5	117.6±2.2a	11.3±0.70	88.7±0.70
6	119.3±2.1a	11.5±0.45	88.5±0.45
Significance	*	**ns**	**ns**

^{Z} Mean ± SE (n = 3)

^{Y} Mean separation within columns by Duncan's multiple range test at $P = 0.05$

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ABSTRACT IN KOREAN

본 연구는 제주지역 무가온 플라스틱 하우스에서 덕식으로 재배되고 있는 '스위트골드'(*Actinidia chinensis* var. *chinensis*)의 수확 시 가지 착과 부위별 과실 품질에 미치는 영향을 알아보고자 수행하였다. 가지 착과 부위는 가지 6개 구역(주간에서부터 주지의 끝의 거리에 따라 3개의 구역 × 가지 끝에서 주지까지 거리에 따라 2개의 구역)으로 구분하였다. 주간에서 멀리 위치한 부위(6구역, 5구역)에서 생육한 과실들은 과중이 높게 나타났고, 반면 주간에서 가까운 부위(1구역, 3구역)에서 생육한 과실들은 건물중(DM)과 가용성 고형물(SSC)의 함량이 높게 나타났다. 가지 착과 부위에 따른 산 함량의 변화는 작았으며 유의적 차이가 없었다. 주간과 주지에서 멀리 위치한 6구역에서 생육한 과실들은 경도와 착색도가 높게 나타났다. 주간과 주지에서 멀리 위치한 부위(6구역)와 주간에서 가깝고 주지에서 멀리 위치한 부위(4구역)에서 생육한 과실들은 높은 전분 함량과 낮은 가용성 당 함량을 나타냈다. 본 연구 결과는 수체 내 착과 부위별 수확기 과실 품질 특성에는 큰 차이가 없음을 나타내었다. 이들 차이는 2년간 동일한 양상으로 나타나지는 않았으며 과실 품질 특성에도 명확한 관계는 나타나지 않았다.

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